Exploring the potential of agroforestry integration in arable and dairy farms in The Netherlands

– an ex-ante assessment at field and farm level

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Abstract

Farming systems in temperate regions are dominated by crop monocultures and large reliance on external inputs such as artificial fertilizers and concentrate animal feeds, which result in pressure on ecological processes. Integration of well-designed agroforestry configurations is considered as a promising avenue to maintainfarm productivity, while simultaneously strengthening ecological functioning of agroecosystems. The complexity of farming systems and the lack of knowledge on the performance of these agroecologically sound practices under Dutch economic, climatic and environmental conditions hamper farmers to implement agroforestry.

In this study we performed a model-based ex-ante analysis of the impact of agroforestry implementation on the economic and environmental performance of two existing farms in The Netherlands. At the field level, we show that two out of three of the designed agroforestry configurations (AFCs) outperformed the monoculture crops (triticale and pasture), resulting in higher financial margin and organic matter balance. Furthermore, we show that these configurations could be successfully integrated at the farm level, reducing or eliminating the existing trade-off between ecological and economical objectives.

We suggest that these promising results serve as a starting point for investigating other AFCs, and new cultivation techniques. Further research is needed to develop process-based estimations of technical coefficients of AFCs to further unravel the opportunities for agroforestry in The Netherlands. Additionally, bottlenecks in spatial policy require attention to support implementation of agroforestry in The Netherlands.

1. Introduction

The intensification of agriculture in Europe has led to simplification of landscapes and an increased reliance on external inputs(Bos et al. 2013; Stoate et al. 2001; Stoate et al. 2009). Currently, societal demand and associated policies focus on reversing the trend of decline of biodiversity and ecosystem services (ESs)(Doorn et al. 2016; Emmerson et al. 2016).When the provisioning of ESs is improved, agriculture could be based to a larger extent on ecological processes and internal cycling of resources(Kremen & Miles 2012; Rey Benayas & Bullock 2012; Bommarco et al. 2013). In this context, ecological intensification (Tittonell 2014) in the form of agroforestry practices holds the promise to offer long-term sustainable solutions as it potentially removes the trade-off between economic performance and sustainable production.

After WOII, agriculture in Europe followed the trend ofintensification, characterized byincreased use of external inputs, enhancedlaborefficiency and aggregation of fields. The modernization of agriculture in the Netherlands is a case in point(Meerburg et al. 2009).Silvoarablepractices were considered an obstacle to this modernization (Eichhorn et al. 2006). Boundary trees and shrubs were removed to congregate fields, while scattered trees and shrubs were removed from the landscape to allow mechanized forms of agriculture.To a large extent this process was driven by market forces and Common Agricultural Policy (CAP)(Eichhorn et al. 2006; Herzog 2000)that successfully resulted in a doubling of yields per hectare(Schutter 2011).The intensification also came with hidden environmental and social costs (Bos et al. 2013). Despite the fact that legislation on nitrogen application halvednitrogen surpluses over the period 1992-2014 and environmental standardswere met, nitrate and phosphate still cause undesirable environmental effects in the majority of the surface waters (RIVM 2016). Further improvement of water quality in agricultural landscapes is required(Rozemeijer et al. 2014; Bos et al. 2013)as the average gross nitrogen surplus of The Netherlands is among the highest of Europe (EUROSTAT 2016); Silvis et al. 2013). Functional biodiversity in the Dutch agricultural landscape continues to decrease. This affects the adaptability of farming systems, by cause of an increasing dependence on external resources(Erisman et al. 2014). For example,populations of meadow birds are declining in almost all OECD countries with an even stronger decrease in The Netherlands (Silvis et al. 2013).

Directed by European Common Agricultural Policy (CAP) 2014-2020 (European Commission 2013), The Netherlands is committed to invest in biodiversity, nature, landscape, water quality and vitalization of rural areas to counteract the current problems(Ministerie van Economische Zaken 2014). The most common policy measure aimed at farmers is the dispense of subsidies to compensate the yield losses and increased labour costs that are the result of applying agricultural nature conservation. This is a subsidy-driven system that is expected to collapse the moment granting of the subsidies stops(Erisman et al. 2014).To achieve true sustainability, other forms of nature-inclusive agriculture systems are needed that sustain high production while providing ecosystem services. Agroforestry holds potential to meet these requirements.

Throughout the scientific literature, many definitions of agroforestry exist(Atangana et al. 2014). A commonly used definition originates from Lundgren & Raintree (1983), whodefinedagroforestry systems as '*land-use systems and technologies where woody perennials (trees, shrubs, palms,* *bamboos, etc.) are deliberately used on the same land management unit as agricultural crops and/or animals, either on the same form of spatial arrangement or temporal sequence."*

The main environmental benefits expected fromagroforestry systems in Europe are carbon sequestration (Nair et al. 2009; Nair et al. 2012), biodiversity conservation (Bergmeier et al. 2010; Mosquera-Losada et al. 2012), increased soil fertility (Nair 1993) and improvement of water and air quality (Jose 2009; Palma et al. 2007).The economic benefits are related to improved growing conditions, a decrease of yield losses and a higher land equivalent ratio (Graves et al. 2007).

Agroforestry is a common and well-studied practice in tropical and Mediterranean areas (Rigueiro-Rodríguez et al. 2009). Starting from 1989, experiments were conducted to determine whether agroforestry also improves productivity for farmers in The Netherlands(Oosterbaan & Kuiters 2009; Oosterbaan et al. 2005).

From 2001 until 2005 the SAFE (Silvoarable Agroforestry for Europe) project aimed for reducing uncertainties about the validity of silvoarable systems in Europe (Dupraz et al. 2005). Graves et al. (2007) compared Dutch forestry systems with arable systems and silvoarable systems with the bio-economic modelled Yield-SAFE (van der Werf et al. 2007).

A current international project on agroforestry is the EU-funded AGROFORWARD project (www.agroforward.eu). Seventeen countries are involved in researching agroforestry practices to stimulate rural development. Current research in the Netherlands mainly focusses on integrating fruitand fodder trees in animals systems(Bestman et al. 2014; Eekeren et al. 2014; Bestman 2015; Timmermans & Bestman 2016).

While the attention for agroforestry continues to grow,more information on potentially viable Dutch agroforestry systems comes available. Farmers are open to the idea of agroforestry (Graves et al. 2009), which is reflected by increasing attention of farmers for initiatives as'Van Akker naarBos'(From Field to Forest)and Agroforestry Network Brabant, which connect farmers and policy makersto fast-forward the implementation of agroforestry by exploring revenue models in an attempt to create nature inclusive agriculture.

Several issues complicate this exploration of agroforestry revenue models for existing farms. First, agroforestry demands strategic, long term planning, since some of the returns are only expected after decennia and costs and revenues change over time.Second, experience with and knowledge about the complex agroforestry arrangements of trees, shrubs, crops and animals are limitedfor Dutch economic, climatic and environmentalconditions. In addition, farm systems are complex due to the interactions between the various components, resources and management activities. As a consequence, it is challenging to anticipate the impact of farming strategies that integrate polycultures. For example, the decision to plant fodder trees to obtain animal feed has indirect implications for several aspects, such as animal ration composition, manure quality, soil quality, labourrequirement and income.

Successful implementation of agroforestry thereforeasks for a redesign of farming systems. Different approaches for (re)designing farming systems exist and new methods are continuously being developed. Farm models can be used to overcome the complexities mentioned above and facilitate ex-ante analysis of the impact of adjustments in farm configuration on the performance of farming systems. An extensive range of different models is used for analysis and design of farming systems

(Martin et al. 2013; Le Gal et al. 2011; Robertson et al. 2012).Modelling approaches for farm system analysis are linear programming (for optimization), system dynamics (for process simulation) and agent-based models (for coupled social-ecological simulation) (Feola et al. 2012).

Since farmers balance several environmental and productive objectives while operating in a system with policy constraints, their strategic and operational decisions depend on multiple goals. Here, multi-objective optimization tools are useful to support decisionmaking in providing trade-off and synergy analysis (Groot et al. 2012). FarmDESIGN(Groot et al. 2012) links a farm balance model to a multi-objective Pareto-based Differential Evolution algorithm, allowing to evaluate environmental and economical trade-offs and synergies. For this project of integrating agroforestry practices on existing farms the trade-off analysis is essential to explore options and discuss them with farmers to find the best fit.

FarmDESIGN proofed to be a useful tool for similar farm system analyses and design. Cortez-Arriola et al. (2016) explored management alternatives with the corresponding trade-offs and synergies, for the enhancement of economic farm performance of smallholder dairy farm systems in a municipality in Mexico. Earlier applications of the model include an analysis on the role of farmers' objectives in current farm practices and adaptation preferences (Mandryk et al. 2014) and options to improve family income, labor input and soil organic matter balances by soil management and maize–livestock interactions for specific farms in Mexico (Flores-Sánchez et al. 2014).

The goal of the study wasto explore opportunities to integrate agroforestry practices and explore associated trade-offs.

This study seeks to answer the follow questions:

1. *How do two case study farms perform currently in terms of selected indicators of productive, economic, environmental and social performance?*
2. *What are promising Agroforestry Configurations (AFCs) and how do these AFCs perform in comparison with existing production activities?*
3. *How do the farms perform in terms of the selected indicators after optimized integration of agroforestry practices?*
4. *What are the associated trade-offs and synergies between the various indicators?*

This ex-ante evaluation on the effects of integrating agroforestry aimsto give farmers and policy makers in their decision making by providinginsight in the value of agroforestry in The Netherlands and therefore could contribute to finding agroecological solutions for existing problems in Dutch agriculture.

2. Materials and Methods

2.1 Case study farms

We selected an arable and a dairy farm to explore opportunities for integrating agroforestry practices. The arable farm is certified as biodynamic and is situated between the cities of Arnhem and Nijmegen, The Netherlands. On an area of 15.6 ha, the farmer cultivates a small area of pumpkins and various cereals: the winter cereals spelt (*Triticumspelta*), Sint Jans rye (*Secalecereale*), triticale (*Triticosecale*) and emmer (*Triticumdicoccoides)*, and the summer triticaleheliaro*(Triticumaestivum L.*). Heliaro and pumpkin are directly followed by mustard, which is integrated into the soil as a green manure. All cultivation activities are contracted out to another farmer. The organic fertilizers champost, deep litter manure and slurry are imported.The arable fields are part of a larger system with pastures and forests, footpaths and hedgerows, which are managed by the farmer with the objectives to preserve the landscape and to provide habitat for meadow birds. The farmer receives financial compensation for the provision of these ecosystem services.

The dairy farm is situated on loamy sand in between the cities of Tilburg and ‘s-Hertogenbosch in the south of The Netherlands. The farmer owns 20 ha of permanent pasture and rents ca. 15 ha for pasture and cultivation of silage maize. The herd consists of 63 Holstein-Frisian dairycows with a replacement rate of 0.35 and therefore about 22 heifers and 22 calves. The milk production of the cows is slightly above 7350kg/cow/year. All fields are fertilized with on-farm producedfarmyard manure and slurry, of which in some years a few tonnes of surplus needs to be exported. Both pasture and maize are fertilized with artificial fertilizers. Concentrates and maize silage are imported, as well as the bedding materials barley straw for young cattle and sawdust for the milking cows.

The farmers have been closely involved throughout the study, in particular during parameterization of the company, drafting AFCs and exploring AFC integration.

2.2 Farm model parameterization

The case study farms were modelled in the whole-farm model FarmDESIGN (Groot et al., 2012). In this model, cropping and animal husbandry practices are formalised as production activities, which are defined as the cultivation ofa crop or vegetation and/or management of a herd in aparticular physical environment, completely specified by itsinputs and outputs (Van Ittersum and Rabbinge, 1997).Theinputs and outputs are fully determined by the physicalenvironment, the plant and animal types and the appliedproduction techniques.An overview of all modelparameters with their calculations and sources can be found in the Supplementary Materials 1 and 2. This information was gathered through farmer interviews and literature research.

TheFarmDESIGNmodel was used to explore opportunities to integrate the AFCs and to evaluate farm performance before and after integration of the AFCs. FarmDESIGN is a multi-objective optimization and design tool for farming systems (Groot et al. 2012). It is built around the concept of the DEED-cycle (Giller et al. 2008), that distinguishes the steps Describe, Explain, Explore and Design as phases of an iterative cycle of stakeholder negotiated research and learning. We applied this approach with the farmers. In the ‘Describe’ part of the model the components of the farming system are listed and their characteristics are quantified as parameters. Based on these quantifications, the farming systems performance is reflected in the 'Explain' part of the model, in the form of indicators*inter alia*, an organic matter balance, labour balance, financial balance, feed balance and nutrient cycles.

The graphical user interface of the model contains windows that support data entry and indicator analysis dedicated to each of the steps of the DEED-cycle. Prior to Pareto-based multi-objective optimization of the system the user can setdecision variables in the 'Describe' window, and select indicators that serve as objectives and or are subject to constraints in the 'Explain' window. A parameter is transformed into a decision variable if the model is permitted to adjust the parameter during the optimization process (e.g. crop areas, feed purchase, destination of crop and animal products, and livestock number). Objectives are indicatorsto evaluate the performance of the farming systems (e.g. operating profit, nutrient efficiencies and organic matter balance) and can be minimized or maximized. Constraints are limitations on selected indicators to ensure realistic and desirable outcomes (e.g. farm labour, feed rations and total farm area) within predefined ranges. A complete list of all decision variables, objectives and constraints used in the explorations can be consulted in Supplementary Materials 3-5.

Optimization of the farming system is executed in the 'Explore' windowof the model.ThePareto-based Differential Evolution algorithm is used to generate sets of solutions that contain alternative farming system configurations. After each iteration,FarmDESIGN evaluates every solution for its Pareto rank (see Figure 3 in Groot et al., 2012) and the distance from other solutions in the solution space. Exploration is stopped manually when solutions are stable, resulting in 1000-1500 iterations per optimization without AFC and 1500-2500 iterations for optimization with the AFC. The integration of the Restoration Agriculture configuration in the dairy farm was initially unsuccessful. Therefore, two additional explorations where executed with 5 and 10 hectares of Restoration Agriculture as starting points.

Optimized farming system configurations are plotted in graphs with the optimization objectives on the axes. Non-dominated farm configurations form the trade-off frontier from which optimized farming system configurations can be selected for further study. From here, new farming systems can be designed and fine-tuned (Design) as the start of a new DEED-cycle.

2.3 Calculation of objectives

Optimization of the current farm is executed based on the objectives to maximize the organic matter (OM) balance and operating profit.

The OM balance (O; kg OM/ha) is calculated as:

$$O = \sum_{i=1}^{5} I_i - \sum_{j=1}^{2} D_j \qquad (1)$$

Where:

I_i= OM input by crop residues, green manures, feed losses, residues of own manure and imported manure (kg OM/ha).

D_j= degradation of soil organic matter and losses through erosion (kg OM/ha).

The operating profit (P; Euros) is calculated as:

$$P = \sum_{p=1}^{2} M_p - \sum_{q=1}^{6} C_q \qquad (2)$$

Where:

M_p= gross margin related to crop and animals production (Euros).

C_q = costs for manure costs, assets (e.g. buildings and machinery), regular labour, casual labour, and land and general costs (Euros).

For the arable farm a third objective is added to maximize a group of cereals that are not productive and profitable, but that increase diversity and are of high cultural value. This group of 'desired cereals' consists of spelt, heliaro and rye.

The area of desired cereals or agroforestry is expressed in frequency of occurrence in the rotation (G) and is calculated as:

$$G = \frac{\sum_{c=1}^{n} A_c}{F} \qquad (3)$$

Where:

A_c = area of crop c, for n crops belonging to the group of desired cereals (ha).

F = total farm area (ha).

Other FarmDESIGN calculationshave been described by Groot et al. (2012).

2.4 Designs of the agroforestry configurations

In consultation with the farmers, three agroforestry configurations (AFCs) were designed. For the determination of the AFCs, the farmers'personal preferences for certain perennials and initial expectations about costs and benefits served as initial starting points. Both farmers formulated the preconditions that the AFCs can be managed as natural systems, with low labour requirements for establishment, fertilization and crop protection, being aware that yield is not being maximized. The AFCs are displayed in Figure 1. The biomass flows from fine root turnover were considered in effective organic matter calculations, but not included as a separate crop product.

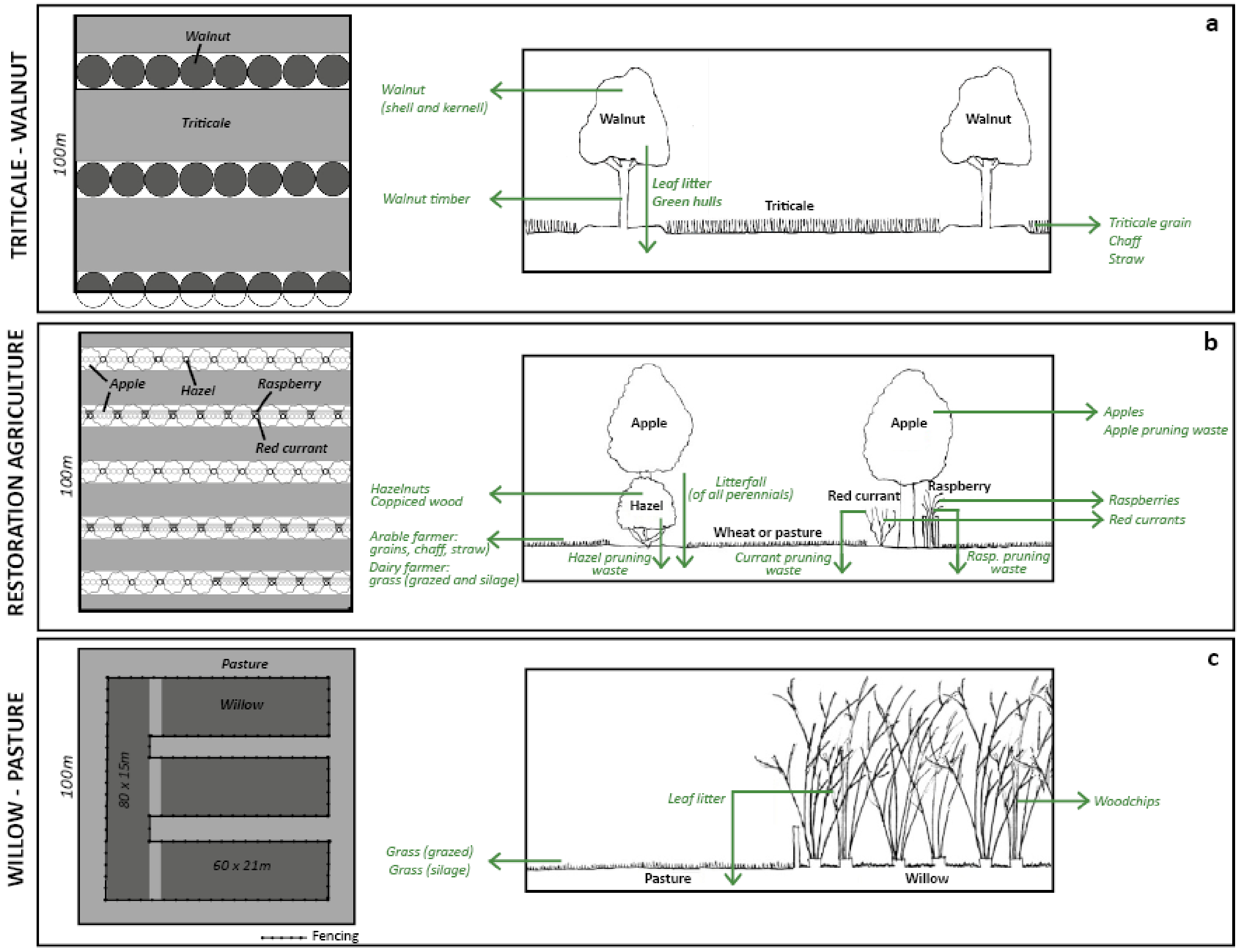

Figure 1: Schematic representation of the AFC triticale-walnut (arable farm; a),Restoration Agriculture (arable and dairy farm; b) and willow-pasture (dairy farm; c). Not true to scale. Left: one hectare of AFC at maturity, displayed from above. Right: a section of the crops (bold) and the flow of crop products (italic). Arrows pointing out of the box represent field outputs. Other biomass flows are circulated in the system. Fine root turnover is considered in EOM calculations.

2.4.1 Triticale and walnuts

The arable farmer wants to introduce walnuts in its triticale fields. Since the canopy width of a solitary walnut is 10-15 m (Oosterbaan 2015) the trees are planted at a distance of 12.5 m within the row (Figure 1a). To assure enough light for triticale production when the trees are mature, the tree rows are planted 40m apart. This allows 20 walnut trees per hectare. The length of the rotation is equal to productive age of the walnut of 50 years (Oosterbaan 2015; Borrell et al. 2005). The trees are planted on beetle banks. The width of the beetle bank increases along with the increasing walnut canopy width from 3m in the first year to 12.5m at the end of the rotation. The average percentage of area available fortriticale cultivation over the entire rotation period is 68.6%.

2.4.2Restoration Agriculture

Both farmers want to explore the opportunities to implement the alley cropping agroforestry configuration as proposed by Shepard (2013). Some adjustments were proposed to the configuration provided by Shepard to tailor the system to the expectations of the farmers. Planting densities are decreased and grapes wereremoved from the system to adapt the system to local weather conditions. Chestnuts wereexcluded to ensure a market for all output products.

Figure 1b displays the Restoration Agriculture configuration with a row of apple trees intercropped with hazel, alternated by a row consisting of apple trees, red currants and raspberries with a row distance of 20m. In the alley winter triticale (arable farmer) or grass (dairy farmer) is cultivated. The alley width decreases in time, since it is kept equal to 20m minus the apple tree canopy width, which expands during the rotation period. This results in a hedgerow width of 2m in the first year and 8m in the final year of the rotation with an average percentage of the area used for pasture or triticale of 69.2%. The rotation period of this configuration is 60 years, which is estimated to be the productive age of the apple tree (van Blitterswijk & Baeten 2006). The commercial life span of hazelnut bushes is at least 30 years and can potentially extend for hundreds of years (Stahl 2007). In this configuration it is assumed that the hazels stay in production for the full rotation and are coppiced every 10 years to rejuvenate the shrub and to collect coppice wood. Red currants produce fruit for 10-15 years (Crawford 2012; Bratsch & Williams 2009) and thus complete four lifecycles in the 60-year-rotation. In the configuration a hedgerow of raspberries is created. Farmers using this technique in the Netherlands manage to have productive plants for at least 7 years. In the natural system under extensive management it is assumed the raspberries complete four lifecycles in the 60-year-rotation. The AFC contains 50 apple trees, 215 hazel shrubs, 165 red currant shrubs, and 415 raspberry plants per ha.

2.4.3 Willow-pasture

The AFC willow-pasture is integrated in the dairy farm to generate woodchips. Different designs with 50% pasture and 50% willow production were proposed and discussed with the farmer. The AFC in Figure 1c offers a satisfactory amount of 'edge' between pasture and willow, to facilitate browsing, and to provide a windbreak effect and shade. Fencing can be removed where the four blocks of willow intersect to allow easy grass cultivation. The AFC has a rotation length of 3 years, which is typical for Short Rotation Coppicing (LantmannenAgroenergi, no date; Caslin, Finnan and McCracken, 2011; Dimitriou and Rutz, 2015).

2.5 Framework for quantifying interactions

Cost, revenues and biomass flows ultimately determine the performance the AFCs. These essential characteristics of the AFCs are input parameters in FarmDESIGN and need to be determined in advance, in the Describe phase.

Yields for the three AFCs could not be derived directly from literature, because of the lack of studies on comparable systems under comparable growing conditions. Therefore, a framework was set up to estimate crop yields. Yields under conventional, monoculture production systems were set as a starting point. Yields for the AFC crop products were changed according to the effect of tree-crop-interactions (TCI's).

TCI's are categorized according to the equation for calculating yield changes in simultaneous agroforestry systems as presented by Rao et al. (1998):

$$I = F + C + M + P + L + A \quad (4)$$

where the total effect of the interactions on the yield of a crop (I) is the sum of the effects of changes in chemical, physical and biological soil fertility (F), competition for water, nutrients and radiation (C), microclimate (M), pests and diseases (P), soil conservation (L) and allelopathy (A). The more a certain resource is available in the environment, the smaller effect changes in the availability of that resource have on the total overall net effect (I) and the more other limiting resources become available, the greater the relative importance of a certain individual limiting resources becomes (Kho 2000). The directions of these rules can be changed. A positive effect can be achieved when trees provide a limiting resource to the crops and a negative effect can be prevented by the suppression of competition for a limiting resource.

Based on this framework, literature research wasconducted quantify the interactions in the individual AFCs of this study. Competition for water and nutrients weretaken into account, but are expected to play a minor role in yield reduction, since both are sufficiently available on the farms used in this study. The main interactions to be considered in the triticale-walnut AFC werecompetition for light, followed by the allelopathic effect of juglone on the growth of triticale (Figure 2). A minor decrease in triticale yield is expected due to nutrient and water competition. Reduced wind speed and increased pest control have a small positive effect on triticale yields. The total influence of the trees after 50 years adds up to a decrease in yield of 35%, as depicted in Figure 2. The relative influence of the tree ontriticale over time is kept equal to the width of the tree over time, as calculated in Supplementary Material 3.

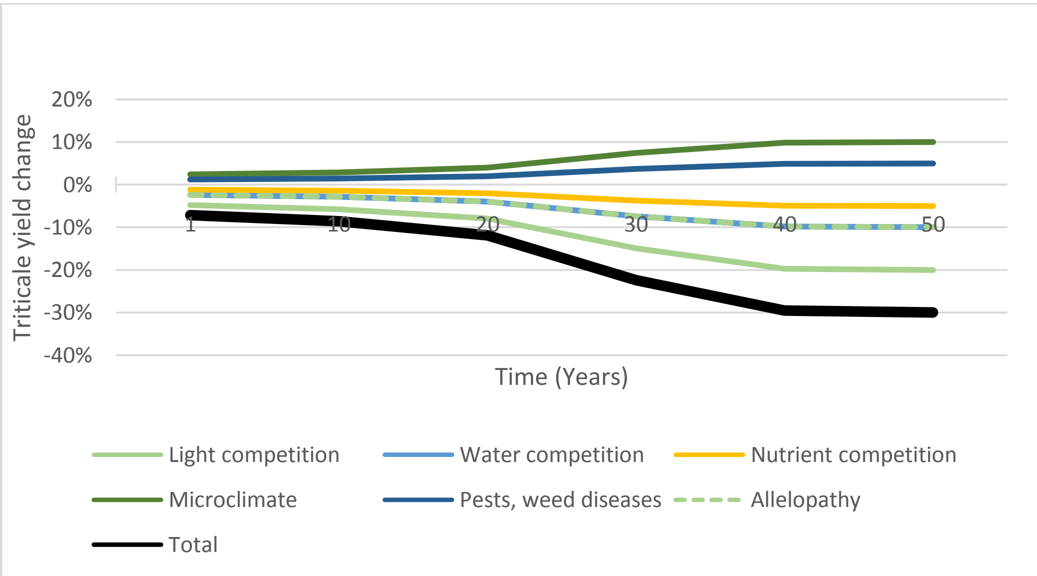

Figure 2: The individual and total influence on tree crop interactions on triticale yield in time.

In Restoration Agriculture the alley is narrower compared to the triticale walnut AFC, resulting in increased light competition. It is assumed the negative effect of this interaction is compensated by the lack of allelopathic chemicals in the Restoration AgricultureAFC. Therefore, the triticale reduction in the Restoration Agriculture AFC is assumed equal to the triticale reduction in the triticale-walnut AFC. For the dairy farmer the grass production in the alleys of both Restoration Agriculture AFC and willow-pasture AFC is expected to decrease and change in quality.

Red currant, raspberry and hazel are naturally part of the understory of the forest, but perform best with full sun exposure. These plants are expected to perform according to the low end of the yield ranges found in literature. The yields for standard apple trees found in literature ranged widely from 45-180 kg/tree (Crawford 2012). The main interaction expecting to decrease apple yields is the provision of habitat by leaf litter to multiple fungal diseases. A full report on the expected interactions is available as Supplementary Material 6.

2.6 Determining AFC parameters

All calculations, sources and considerations for determining AFCs parameters, together with the parameters of the AFCs, can be consulted in the supplementary materials 3-5. The most decisive parameters for the performance of the each AFC are shown in Figure 3.

2.6.1Yields and prices of crop products

Crop experts where consulted to discuss the outcomes of the literature research to determine the final yield per AFC. FarmDESIGNsummarizes outcomes throughout a year, while the yields are affected by dynamic processes that are affected by cultivation area per hectare AFC, interaction between components and yield formation per plant. To bypass this time dimension, the yields for different time periodswere calculated and averaged.Prices of the crop products were kept equal to prices found at Dutch pick-your-own farms, in the literature and from the estimations by crop experts.

2.6.2 Chemical composition of crop products

The majority of parameters on composition of food products were derived from the USDA Food Composition Database (USDA 2015). Chemical constituents on pruning waste were determined by laboratory analyses of the biomass collected from a local pick-your-own farm. Average performing shrubs were selected and pruned by the farmer, weighted and oven dried to determine dry matter, nitrogen, phosphorus, potassium and ash contents. The organic matter was assessed gravimetrically by dry combustion of the organic material in a furnace at 500-550 °C. For N, P and K determination, the samples were digested with a mixture of H_2SO_4–Se and salicylic acid (Novozamsky et al. 1983). The actual digestion wasstarted by H_2O_2 and in this step most of the organic matter is oxidized. After decomposition of the excess H_2O_2 and evaporation of water, the digestion is completed by concentrated H_2SO_4 at elevated temperature (330°C) under the influence of Se as a catalyst. In these digests total N and P measured spectrophotometrically with a segmented-flow system (Auto-analyzer II, Technicon).In the same digests K was measured with aVarian AA240FS fast sequential atomic absorption spectrometer.

2.6.3Costs and labour on field level

To determine the costs per AFC, a list of all cultivation activities and investments was composed for each AFC. These lists included costs associated with the purchase of plants, plant support and fencing and the costs and labour associated with cultivation, such as planting, pruning, harvesting, mowing, shredding of pruning waste, and fertilization. Based on literature and estimations by the farmers and crop experts, labour demand of for all cultivation activities wasestimated. In consultation with the farmer we determined the contribution of the farmerlabour (regular labour in FarmDESIGN), hired employees (casual labour) or contract workers (contract work costs) for the execution of each of the cultivation activities. These costs and labour requirements weresummed for the total rotation period and divided by the years of the rotation to determine cultivation costs, contract work costs, regular labour and casual labour per year. Finally, the costs and labour requirements of the perennials were added to the costs and labour hour of the crop in the alley.

For the willow-pasture AFC it is assumed the willow cuttings areplanted with a machine used for cabbage planting, as suggested by Boosten & Jansen (2013) and De Dobbelaere (2011). In willow cultivation, weed control is very important and most crucial in the first year after planting, as weeds can decrease yields by 95% (Lantmannen Agroenergi n.d.; Dimitriou & Rutz 2015). Labour for weeding was not included in the willow-pasture configuration since the farmer is able to arrange free labour for these kinds of activities. Another crucial activity in willow cultivation is harvesting. It was assumed that the farmer would be able perform this task with a tractor mounted cut-and-chip harvester as presented by Ehlert & Pecenka (2013). Other considerations can be found in the Supplementary Material 4.

Possible obtainable subsidies for the planting of trees or the provision of ecosystem services were ignored in this study.

2.6.4EOM at field level

Effective organic matter (EOM)at the field level was determined by multiplying biomass of shredded pruned materials, fine root turnover and litterfall by their humificationcoefficients, which were approximated based on literature. It was taken into account that the system increases its organic matter production as the system matures, by estimating organic matter production in different time periods. An average of the organic matter production over the entire rotation was used as a field parameter.

TRITICALE - WALNUT

REVENUES

	Max. yield (kgFM/tree/yr)	Avg. yield (kgFM/ha/yr)	Price (€/kg)	Avg. revenue (€/ha/yr)
Triticale grain		3303	0.37	1222
Chaff		1633	0.00	0
Straw		1950	0.12	234
Walnuts	18 (DM)	213	4.00	852
Walnut wood	1 m3 (928 kg)	371.2	0.27	100
			Total Revenue	**2408**

LABOUR and CULTIVATION COSTS

Cultivation costs (€/ha/yr)	30
Contract work costs (€/ha/yr)	1276
Regular Labour (h/ha/yr)	24.9
Casual Labour (h/ha/yr)	0

EFFECTIVE ORGANIC MATTER

	Effective OM (kg/ha/yr)
Walnut Leaf litter	214
Walnut fine roots	120
Triticale	1099
Beetle bank	300
Green hull	21
Total EOM	**1756**

RESTORATION AGRICULTURE

REVENUES

	Max. yield (kg FM/tree/yr)	Avg. yield (kgFM/ha/yr)	Price (€/kg)	Avg. revenue (€/ha/yr)
Apples	40	1708.0	1.00	1708
Hazelnuts	0.9	55.0	3.50	193
Raspberries	0.75	274.0	4.00	1096
Red currants	2	283.9	4.00	1136
Wood (apple)	0.5m3 (375kg)	312.5	0.13	42
Wood (hazel)	16	200.0	0.12	23
			Subtotal Revenue	**4197**

Additional crop products for arable farmer

	Avg. yield (kgFM/ha/yr)	Price (€/kg)	Avg. revenue (€/ha/yr)
Triticale grain	2636	0.37	975
Triticale grain (unsalable)	1419	0.00	0
Triticale straw	1695	0.12	203
Total revenue arable farmer (€/ha/yr)			**5376**

Additional crop products for dairy farmer

	Avg. yield (kgFM/ha/yr)	Price (€/kg)	Avg. revenue (€/ha/yr)
Grass (silage)	5130 (DM)	0.12	616
Gras (grazed)	1710 (DM)	0.12	205
Total revenue dairy farmer (€/ha/yr)			**5018**

LABOUR and CULTIVATION COSTS

	Arable farmer	Dairy farmer
Cultivation costs (€/ha/yr)	308	555
Contract work costs (€/ha/yr)	1093	332
Regular Labour (h/ha/yr)	74.5	72.6
Casual Labour (h/ha/yr)	111.4	111.4

EFFECTIVE ORGANIC MATTER

	Effective OM (kg/ha/yr)
Leaf litter (all perenials)	701
Fine roots (all perenials)	173
Pruning waste (hazel)	37
Pruning waste (red currant)	54
Pruning waste (raspberry)	62
Triticale/pasture + herbicous growth under trees	1400
Total EOM	**2427**

WILLOW-PASTURE

REVENUES

	Max. yield (kg FM/tree/yr)	Avg. yield (kgFM/ha/yr)	Price (€/kg)	Avg. revenue (€/ha/yr)
Willow Wood Chips	40000	13333	0.02	267
Grass (grazed)		1175 (kgDM)	0.12	141
Grasss (silage)		3530 (kgDM)	0.12	424
			Total Revenue	**831**

LABOUR and CULTIVATION COSTS

Cultivation costs (€/ha/yr)	720
Contract work costs (€/ha/yr)	0
Regular Labour (h/ha/yr)	17.3
Casual Labour (h/ha/yr)	0

EFFECTIVE ORGANIC MATTER

	Effective OM (kg/ha/yr)
Willow Leaves	438
Willow Fine roots	873
Pasture	700
Herbicious growth under willow	350
Total EOM	**2361**

Figure 3: Important FarmDESIGN parameters that determine AFC performance as a result of literature research.

3. Results

3.1 Current performance of farms

3.1.1Arable farm

During the reference year 2015 the crop rotation of the arable farm consisted of 2.63 ha pumpkin, 1.95 ha heliaro, 2.89 ha rye, 4.61 ha triticale and 3.67 ha spelt. For fertilization, 8.5 Mg deep litter manure, 6.5 Mg champost and 7.37 Mg slurry was imported. This resulted in an operating profit of €18,111. Annually 1,823 kg OM/ha was added by crop residues and green manure and 2205 kg OM/ha through manure import. Since 2,377kg OM/ha is decomposed annually, the net increase of the OM balance is 1,651 kg OM/ha. Nitrogen use efficiency at farm level was 75%.

3.1.2Dairy farm

In the initialsituation the dairy farm owned 20 ha of pasture andrented fields for pasture (11 ha) and maize silage cultivation (4.6 ha). The total share of grassland was 87%. To supplementthe livestock ration, 44,750 kg DM concentrates and 32,000 kg DM maize silage were purchased annually. Additionally, 10,400 kg sawdust together with small amounts of barley straw were imported and applied as bedding material. On farm produced slurry was used for the fertilization of maize and pasture, together with artificial fertilizers. This farm configuration resulted in an OM balance of 1,426 kg OM/ha. Of the inputs on the organic matter, 75% originated from manure application. The operating profit was €22,704.

3.2 AFC performance at field level

The inputs (requirements), internal flows (nutrients and organic matter) and outputs (revenues) of each field determine field performance, which together determine the overall farm performance. The individual performance of individual production activitiesin terms of economic margin and inputs on the OM balance are shown in Figure 4. For a clear comparison, OM additions by fertilizers were not included in Figure 4. For the arable farmer, the emmer crop stood out in terms of economic performance with a margin of €3,527 per hectare, due to the high price in 2015 (€1.37/kg). Spelt, Rye and Heliaro formed the group of desired cereals, with clearly a low margin and high input to the OM balance. Heliaro outranked all other cereals in input on the OM balance, because it is the only summer cereal which was followed by the green manure mustard, which delivers 972 kg OM/ha. Triticale-walnut outperformed sole triticale. Restoration Agriculture stands out with an input on the OM balance of 2,737 kg/ha and a crop margin of €3,974.

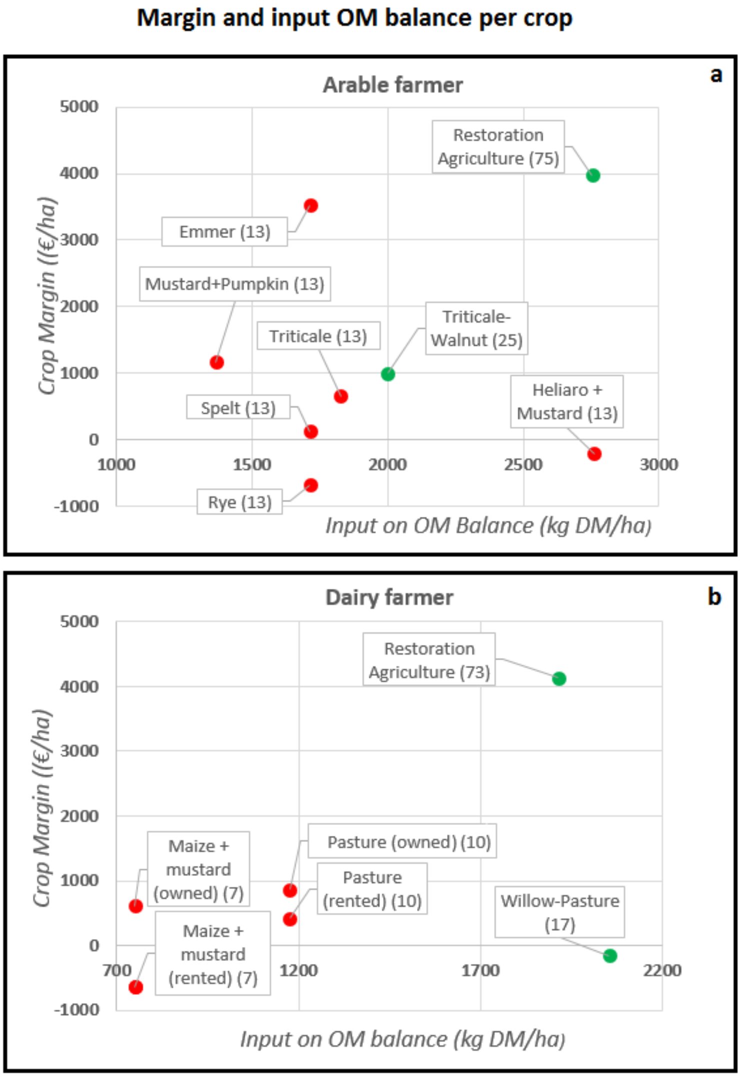

Figure 4: Performance of crop production activities in terms of contribution to soil organic matter and gross margin for current crops (red) and agroforestry fields (green) for the arable (a) and dairy farm (b). Regular labour (hours/ha) is displayed between parentheses, but is not included in the crop margin calculations on field level. The input on OM balance does not include OM inputs by imported manure and fertilizers.

The dairy farmer cultivates his crops both on owned and rented land, resulting in two different economic performances. Agroforestry was only calculated for cultivation on owned fields. Due to high renting costs for the maize fields, maize production resulted in a negative margin for the rented fields. Compared to sole grass (owned pasture), willow-pasture added 75% more OM per year. However, the cultivation of one hectare of willow-pasture had a negative margin. Restoration Agricultureoutperformed sole grass (owned pasture) forboth indicators.

3.3 Explorations at farm level

3.3.1 Arable farmer: Exploration from current situation

Figure 5a shows the exploration results in terms of the window of opportunity for improving thefarm configuration without triticale-walnut for the indicators operating profit and OM balance. A clear trade-off between operating profit and OM balance existed. With only the current crops in the rotation, an operating profit of more than €37,200 could be attained without decreasing the OM balance (Figure 5a, point A). This can be achieved by cultivating 4.5 ha pumpkin, 5 ha emmer, 2.6 ha heliaro and 3 ha triticale. Continuing along the trade-off frontier, the area of pumpkin reduced, heliaro increased and spelt was increased. Point B is the result of 5 ha emmer, 5 ha heliaro, 3.5 triticale and 2 ha spelt. From this point forward only a minor increase in OM was possible, due to the restriction on the maximal area of heliaro. The highest OM balance presented in the figure is point C. The rotation of this farm configuration consisted of 5 ha heliaro, 4.5 ha triticale 3 ha rye, 2 ha emmer and 1 ha spelt. With this configuration the operating profit (€19,800) was slightly higher than the operating profit of the original rotation. The outcomes of points A, B, and C indicate a trade-off between the cultivation area of the desired cereals (heliaro, rye, spelt) and operating profit. This trade-off was confirmed by Figure 5b.

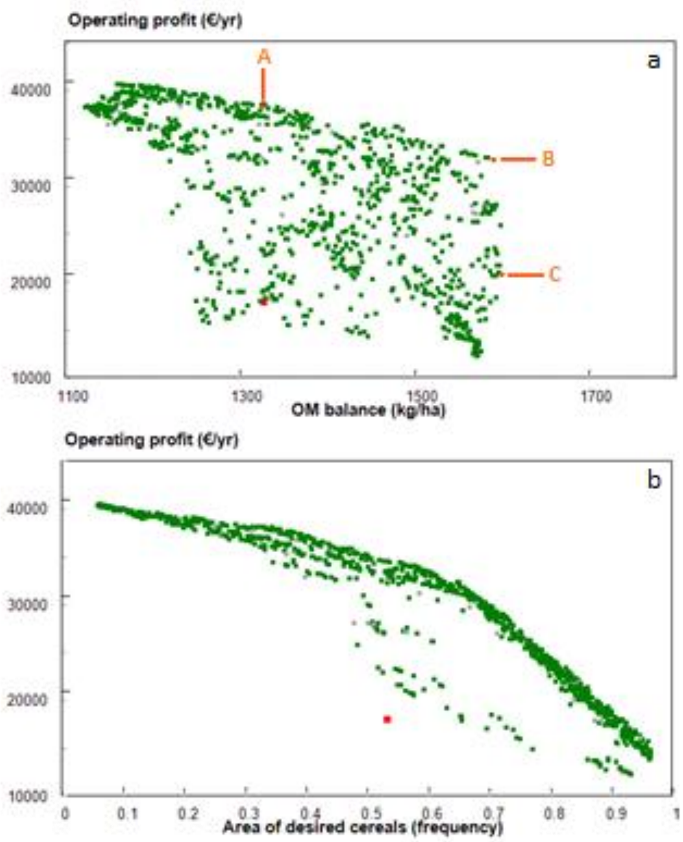

Figure 5: Optimization of the current situation for the arable farmer, with the objectives or operating profit and OM balance (a) and area of desired cereals (b).

3.3.2 Arable farmer: Exploration with triticale-walnut

With the inclusion of the triticale-walnut field, both higher operating profit and organic matter balance can be achieved.The exploration of thecurrent farm (light) and the exploration of the farm with triticale-walnut configuration (dark) are combinedin Figure 6a.

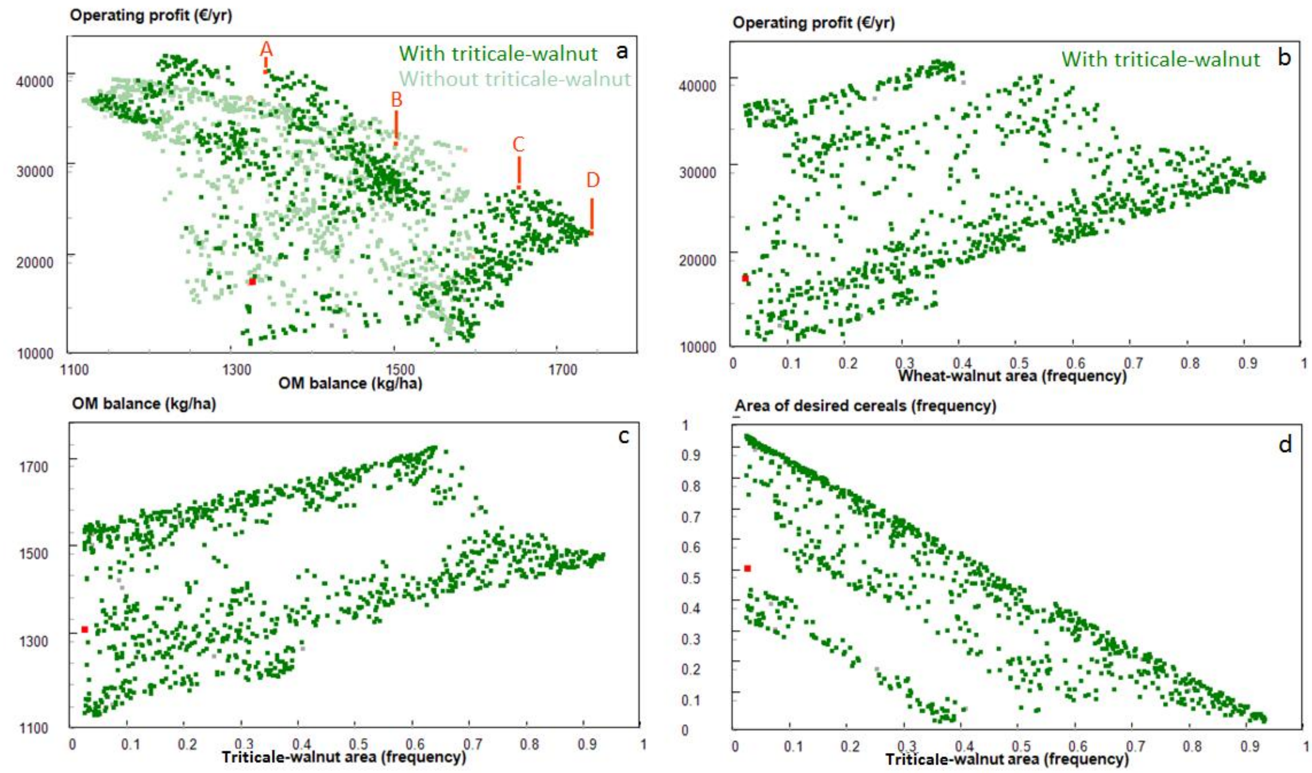

Figure 6:Outcomes of the exploration of the arable farmer with the triticale-walnut configuration along the objectives operating profit, OM balance, area of desired cereals and triticale-walnut area.

Along the trade-off front 4 non-dominated configurations wereselected. Option A shows the best financial performance (€40,100) while still improving the OM balance. This is the result of a rotation with three crops with high margins (8.4 of triticale-walnut, 4.7 ha emmer and 1.7 hectare pumpkin). An higher OM balance could be achieved by option B (11.5 ha of triticale-walnut, 2.2 ha pumpkin and 1.2 ha heliaro) and option C (7.8 ha triticale walnut, 4.5 ha heliaro, 2 ha emmer) at the expense of a decrease in operating profit. Option D is the outcome of 10 ha of triticale-walnut and 5 ha of heliaro. Large areas of triticale-walnut were found in the configuration along the entire trade-off frontier, indicating triticale-walnut contributes to both operating profit and OM balance. The shape of the cloud point of Figure 6b shows a positive relation between operating profit and triticale-walnut cultivation. However, along the trade-off frontier an increase of triticale-walnut results in lower operating profits. This is because very high amounts of agroforestry prevent other well performing crops from being part of the rotation. The same can be observed for the OM balance (Figure 6c). Most generated farm configurations are composed of a high level (up to 95%) of a combination of triticale-walnut and desired cereals (Figure 6d).

3.3.3 Arable farmer: Exploration with Restoration Agriculture

When FarmDESIGNoptimized the farm configuration with the option to integrate Restoration Agriculture, a more pronounced increase in OM balance and operating profit was observed (Figure 7a). Operating profit increasedup to €54,500 for point A. This configuration comprised10 ha of Restoration Agriculture and 5 ha emmer. For point Bin Figure 7a the area of Restoration Agriculture further increased to 12.8 ha at the expense of emmer, resulting in lower operating profit. Point C marks a farm configuration with the maximum area of Restoration Agriculture allowed (15.5 ha), resulting in an OM balance of 2,180 kg/ha.

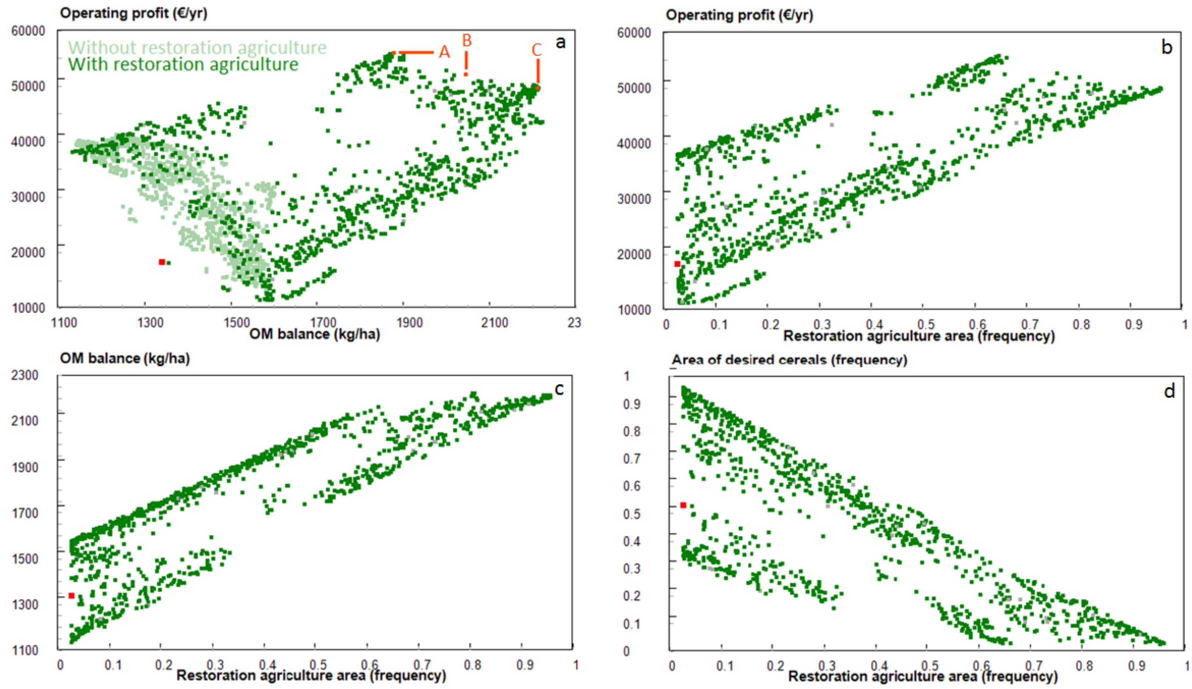

Figure 7: The results of optimizing the arable farm with Restoration Agriculture, with the objectives to maximize operating profit, OM balance and the group of desired cereals.

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Parallel to the triticale-walnut configuration, Restoration Agriculturewas positively related to operating profit (Figure 7b). At the point Restoration Agricultureexceeded 65% operating profit declines, because emmer is forced out of the rotation. Integration of Restoration Agriculture into the farm improves the OM balance (Figure 7c). With 65% of Restoration Agriculture in the rotation, the OM balance barely improves after adding more Restoration Agriculture, since it is at the expense of the area of heliaro. It is possible to increase the current acreage of desired cereals while integrated up to 50% of Restoration Agriculture (Figure 7d). At the trade-off frontier almost all cultivated area consist of Restoration Agriculture and desired cereals. A high ratio of Restoration Agriculture to desired cereals resultedin high operating profits.

3.3.4 Dairy farmer: Exploration with Restoration Agriculture

For the integration of Restoration Agriculture at the dairy farm three explorations are executed, with 0, 5 and 10 haof Restoration Agriculture as starting points (Figure 8a). The first exploration is the optimization of the current situation without the possibility to integrate Restoration Agriculture. For all three highlighted options (A, B and C) the owned fields (20 ha) are used for pasture. Additionally, 9.5 haof pasture and 3 haof maize was rented. The maximal operating profit of €31,800/yr (A) was the result of increasing grass silage and maize import while decreasing purchase of concentrates. To obtain a higher OM balance, more maize silage, concentrates and bedding materials are imported, resulting in a lower financial performance (B and C).

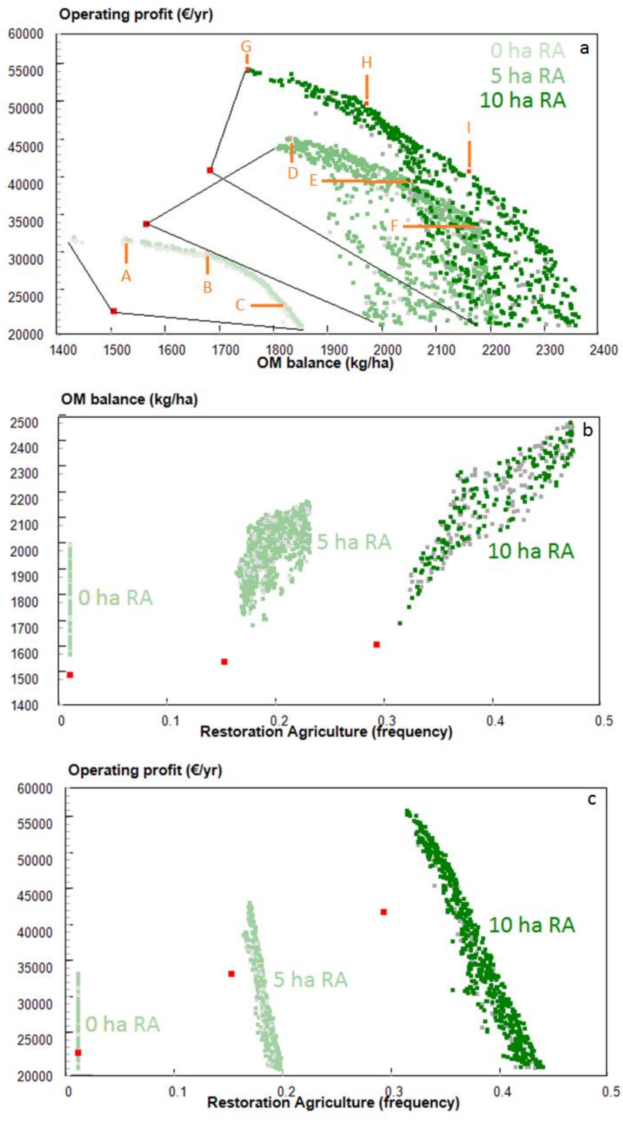

Figure 8:Exploration of integrating Restoration Agriculture (RA) at the dairy farm, with 0, 5 and 10 hectares of RA as starting points.

The implementation of 5 haRestoration AgricultureAFC resulted in options to increase operating profit and OM balance (D, E and F in Figure 8a). The loss of area of grass for options D, E and Fwascompensated by cultivating 2 hectare of maize and almost doubling grass silage imports. Maximal operating profit of €44.400 is obtained by reducing all other inputs. Higher OM balances (E and F) were the result of increasing maize silage imports with factor 1.9 (E) and 2.2 (F) and importing more concentrates. With 10 hectares Restoration Agriculture 7-11 ha of land is rented for pasture and 2.3 hectares for maize production. This results in an operating profit of €53,800 when all purchases are minimized (G). Increasing the import of DM again results in a higher OM balance and smaller operating profit (H and I).

Figure 8b shows that it would be possible to influence the portion of Restoration Agriculture in the rotation. Since the area of Restoration Agriculture is the same for each cloud, the different outcomes on the x-axis werethe result of different whole farm areas. While the area of owned fields was kept constant, the area of rented fields changed. The high returns on the Restoration Agriculture fields would allow the farmer to reduce the area of rented fields. With 10 hectares of Restoration Agriculture only 8.5-11 hectares are rented, compared to 15.6 hectares in the current situation. In this way it is possible to implement Restoration Agriculture on almost half of the fields, resulting in an OM Balance of 2,500 kg/ha. Increasing the portion of Restoration Agriculture by reducing the area of rented fields, causes a trade-off with operating profit (Figure 8c).

3.3.5 Dairy farmer: Exploration with Willow-pasture

As a result of a different stable system, 6 kg DM/cow/day of woodchips are used as bedding, compared to 0.18 kg DM/cow/day of sawdust in the other explorations. Larger amounts of dry matter are added to the manure and consequently to the soil, resulting in a higher initial OM balance. The large amount of woodchips required in this system lead to higher purchase costs. For this reason the initial starting point inFigure 9 differs from the starting point in the other explorations. The trade-off curve of the exploration without willow-pasture (Figure 9a, light points) forms the a shape equal to the exploration without AFC in Figure 8a. However, optimization is this case improves operating profit by only €2,000 by renting less area for maize production, decreasing purchase of maize silage and increasing grass silage purchase (Figure 9, point A).

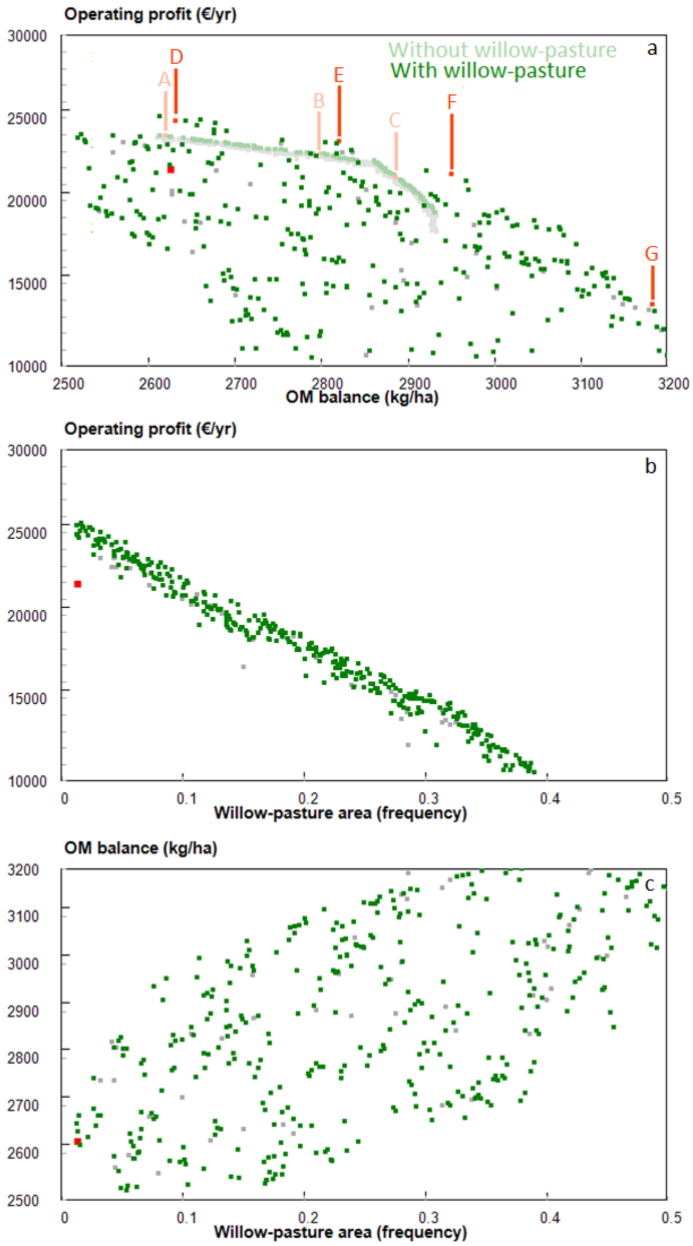

Figure 9: Exploration along the objectives operating profit and OM balance with (dark) and without (light) the willow-pasture AFC (a) and the trade-off between integrating willow-pasture AFC on OM balance (b) and operating profit (c).

From this point, OM balance is increased by increasing silage imports and increasing the application of woodchip compost (B and C). Increasingthe OM balance above 2,950 kg/ha could not be achieved without lowering the operating profit below the current level (C).

When the willow-pasture configuration is integrated, a similar but longer trade-off frontier arises (Figure 9a, dark points). Without giving in on the OM balance the operating profit could further be improved up to €24,300 (D). This is the results of the same changes that are applied under option A. Option E is the result of integrating 1 hectare of willow-pasture. To compensate, more grass silage is bought. The improved OM balance is the result of increasing bedding material with 7%. The highest achievable OM balance without decreasing operating profit below current levels is 2,930 kg/ha (F), with 2.3 hectares of willow pasture. Following the trade-off, OM balance increases at the costs of operating profit (G).

A clear trade-off existedbetween operating profit and willow-pasture area (Figure 9b). Integrating the AFC leads to lower grass yields, that need to be compensated by purchasing feed. The trade-off continues up to 66% of willow pasture, equal to all 20 hectares of owned land, resulting in decreased operating profit.

From Figure 9c a positive trade-off could be observed between OM balance and the integration of willow-pasture. Willow-pasture is integrated at the expense of conventional pasture and adds organic matter in the form of willow leaves and fine root turnover of the trees. The remarkable width of the cloud of generated farm configurations is caused by the flexibility in bedding materials applied.

4. Discussion

In this study we compared farm performance and exploredopportunities for improvement in economic and environmental performance with and without AFCs for two existing farms. We found that 2 out of 3 AFCs outperformed the monoculture crop (sole triticale and sole pasture) in operating profit and OM balance. Special about this study is that we not only focussed on the performance of temperate climate agroforestry at thefield level, but also explored opportunities to integrate the agroforestry fields in existing farms and subsequently evaluated the performances at thefarm level.This model-supported approach allows an ex-ante analysis of impacts that were discussed with farmers managing relatively high productive farms. These farmers want to innovate, but also desire accurate insight in the potential consequences of implementation of new technologies and practices.

Furthermore, this study provideddistinctive insight in the existing trade-off between operating profit and OM balance without agroforestry. Increasing the OM balance in the original farm configurations could be mainly achieved by importing organic matter (in feed, bedding material, or manure) resulting in decreased operating profit. However, the increase in OM due to integration of the AFCs was caused by the intrinsic property of the trees to generate organic matter. A prominent result of this study is the disappearance of the trade-off between these objectives when Restoration Agriculture is introduced to the farming system, since this production activity combines high productivity with large organic matter inputs. As a consequence, the Restoration Agriculture AFC in particular showed exceptionally high performance on economic margin (field level) and operating profit (farm level) for both farmers. In this study the integration of agroforestry practices lead to a higher OM balance. Although the results of this study are difficult to generalize, they proof that well designed multifunctional agriculture systems could offer sustainable solutions for the farmer and the environment.

It should be noted that the number of indicators (objectives) used in this study was limited and did not address potentially positive effects on animal welfare, farm resilience, stability, aboveground and underground biodiversity, landscape and farmers image and self-worth. These effects are discussed with the farmers, but not quantified in this study.

Our study used a case study approach for only two highly contrasting farms, and tested only a small number of AFCs. Subsequent studies could develop tools to generate larger numbers of AFC configurations and their technical input and output coefficients. Small adjustments in planting density or harvesting techniques of each AFC are expected to change tree-crop interactions, cultivation costs and required labour for each AFC, which in their turn influence field performances. We expect other configurations and techniques can be used with higher field performances.

The more detailed assessment would require additional field experiments and modelling tools. Approximating yields in these complex AFC configurations remains challenging, mainly because of the largenumber of variables influencing plant growth and yield, and the lack of process-based insight in the ecological interactions between species in time and space. Models like Yield-SAFE (van der Werf et al. 2007) can be used provide insight in the processes, although many biophysical models still oversimplify biophysical processes that are essential in predicting yields (Jose et al. 2004).

4.1 Parameter approximation

While parameterizing the AFCs of this study, some issues were simplified or not taken into account, which in reality could positively influence the performance of the system. First, this study ignores funding opportunities for the provision of ecosystem services by the perennials. In The Netherlands, subsidies are available for agricultural nature conservation (RVO n.d.) and possibly other grants become available in the future. Second, food produced in a natural, sustainable system such as an agroforestry system can be rewarded with premium prices, exceeding the prices that wereused in this study. Clear communication to the customer is key, either through direct consumer-farmer relations, certification scheme or a collective (local) brand. Additionally, the landscape changes through implementation of agroforestry open up opportunities for alternative incomes through recreation (Oosterbaan et al. 2004). Another indirect form of income that wasignored in the study is the effect of the trees on animal welfare. The trees provide a microclimate that reduce animal stress and potentially increases milk production up to 1 kg/cow/day (Van et al. 2014). It remains unclear what is the exact effect of browsing willow on the overall health of cattle, but it is suggested the inflammatory components and high selenium content have beneficial effects the cows health (Eekeren et al. 2014; Luske & Van Eekeren 2011).
Another simplification that wasmade in parameterizing the AFCs is the discrete delineation between tree canopy and alley of crop production. In reality it would be plausible that the tree canopy and alley partially overlap, making it possible to cultivate triticale and grass underneath the tree canopy or grow additional beneficial or productive crops under the canopy.

Other issues that weresimplified or ignored in this study may result in a more negative performance of the system. The yields in the Restoration Agriculture AFC are kept equal for the arable farm and dairy farm. This might not be realistic since the farmers are dealing with different soil types and water tables. Other uncertainties are the effect of litter fall on the triticale and the difficulty of estimating certain cultivation costs and labour requirements. Requirements for labour and investment for harvesting, storage, cleaning and distribution are hard to estimate and strongly depend on the scale at which agroforestry is implemented. Small areas of agroforestry might benefit from pick-your-own systems, which do provide opportunities for better interaction with the community. Larger areas of agroforestry complicate complete and homogeneous harvest by pick-your-own systems and are expected to benefit from more mechanized harvesting techniques. Hence, the proper cultivation and harvesting method is best decided after determination of the scale of production. In this study cultivation costs and labour requirement are predetermined and therefore not entirely accurate. In the Restoration Agriculture AFC the harvestable yield of raspberry forms an uncertainty. In conventional production the plants are covered from the moment of blooming and crop protection is needed to prevent damage by aphids, trips and spider mites. Applying biological control is often not successful in open air, since the beneficial insects are free to leave the system. However, in home gardens raspberries generally perform well without protection (Strik 2008; Smith et al. 2007; Crawford 2012).

4.2 Model deficiencies and limitations

Estimating organic matter flows remain a challenge. The simple OM calculations of FarmDESIGN's offer a good first impression on the OM balance. However, in reality, EOM input and SOM breakdown are the result of a large number of environmental conditions and complex interactions (Cotrufo et al. 2015; Sollins et al. 1996). In FarmDESIGN, the predefined humification rate for different materials plays a determining role in the OM balance. Humifaction coefficients for biomass flows found throughout literature diverged and are therefore not expected to be accurate.

Another point of attention in interpreting our outcomes is field heterogeneity. OM balances werepresented at field and farm level. Nevertheless, in the AFCs significant field heterogeneity is expected, while more organic matter is added to the soil underneath and close to the canopy, than in the middle of the crop alley. Consequently it is not obvious the entire alley crop benefits from the effect of increased SOM on field level. Likewise, nutrient inputs and outputs are presented atfield level, while alley and hedgerow crops have other nutrient requirements. A detailed fertilization plan is required to provide all the different plants their necessary nutrients.
Additionally, the nutrient flows in time are not part of this study. To fully describe the integration of the agroforestry practices, the consequences on soil characteristics and nutrient balances per field should be analysed for every year and within each year. While tools for annual field analyses exist (Van Der Burgt et al. 2006), this was not part of this study and remains a challenge for further research.

Field and farm performances are averages of the total rotation period. Information on peaks in cultivation costs and yields over time are not provided. It is however expected that the decrease of grass and triticale yield in time runs more or less parallel to the increase in yield of fruits and nuts. Also peaks in cultivation costs are expected to occur in the same season fruits and nuts are harvested and are therefore compensated in the same season.
A last issue that is ignored in this study is the need for headlands. At the end of the field the farmer needs space to turn its equipment. Therefore it is impossible to plant trees up to the end of the field as proposed in the designs. Also possible effects of the trees on neighbouring fields are ignored. These issues needs to be considered when implementing the AFCs.

4.3 Time-related complications

Estimating yield and field requirements for the entire rotation period, required decision making on cultivation activities for 60 years ahead. In reality, the farmers decision making process is expected to be more dynamic. The AFCs for the arable farmer in this study are based on triticale. However, the farmer is able to annually alternate the production of triticale with emmer (to increase profit) or heliaro (to increase OM balance). Likewise, the farmer is able to, from year to year, invest in better cultivation methods for the fruits and nuts that increase in price. This flexibility leads to a more resilient system.

Predetermination of the final AFC is not in line with the philosophy of Restoration

Agriculture(Shepard 2013). In Restoration Agriculture continued observation of the systems elements and interactions provides the farmer with information, on which he decides to intervene or not. This form of adaptive management is commonly used in natural resource management to create sustainable systems (Soil and Water Conservation Society 2009). Examples of observation-based interventions are changes in the pruning and fertilization scheme, application of mechanical harvesting techniques and the removal or introduction of other crops.

The systems proposed in this study could therefore be seen as standard package that can be complexified and customized to local conditions, and farmer insights and needs. Optimal use of temporal and spatial niche differentiation of species can be used to increase photosynthetic, nutrient and water use efficiencies of the system. The triticale-walnut systems could be expanded with buckthorn and hazel (Oosterbaan & Schepers 2015; Verdonckt et al. 2016). The Restoration Agriculture configuration could be complemented with a range of different berries to produce fruit throughout the entire season and the microclimate in the hedgerow is suitable for the production of mushrooms as well as a range of (medicinal) herbs (Crawford 2012). The willow-pasture AFC could potentially be made profitable by adding other functions, like poultry farming (Bestman 2015; Bestman et al. 2014).

4.4. Towards embedded farming systems

Successful management of the currently proposed complexified systems requires knowledge, skills, increased labour and cultivation costs, which the farmer doesn't necessarily wants to invest in, while in Europe access to land is the most import barrier for young farmers to start farming (European Commission 2015). Therefore we suggest further study needs to be conducted on land sharing systems where specialized (starting) farmers manage the hedgerows and consequently embed their farming system into the in existing farming system. The suggested 'embedded farming system' simplifies and decreases the labour demand for the arable or livestock farmer, while the farmer still benefits from the positive tree-crop or tree-animal interactions and is compensated for the direct production losses by renting fees or margins on the tree products.

4.5 Further recommendations

This study indicates how agroforestry could be integrated in existing arable and dairy farms. Despite being the topic of this study, uncertainties on the bio-economic performance of agroforestry aren't the only impediments for its success in The Netherlands. The strong division between the land uses 'nature' and 'agriculture' in national policy and local spatial legislation restricts planting of trees on agricultural landscapes (Luske et al. 2016). We are emphasizing the importance of reintroduction a land use classification that allows farmers to freely plant and remove trees, as suggested by Luske et al. (2016). The present study aimed to invigorate the discussion about the removal of spatial regulations that prevent the application of sustainable land uses like agroforestry.

For further studies we recommend to investigate other promising AFCs, cultivation techniques, and process-based estimations of technical coefficients. In particular on harvesting techniques, little information is available, while harvesting costs and labour largely determine the overall costs. It would be interesting to investigate the trade-off between tree density and field margin and tree density and OM balance over time for the configuration to fine-tune the AFC configurations.

In this study assumption were made on the distribution channels (and associated farm gate prices) for the fruits and nuts. For the farmers in this study these alternative food networks are currently non-existent and require time to set up and maintain (BioForum Vlaanderen 2012; Gliessman 2015). We recommend exploring the role of farmers cooperatives in facilitating marketing, purchasing machinery for harvesting and processing and the sharing knowledge.

Another topic that needs attention because of its potential to improve the system performance, is the application and development of agroforestry adapted crop varieties. In this study information is used on the effect of tree crop interactions for conventional crop varieties. A farmer is highly recommended to use varieties that are adapted to the growing conditions in the alley. In this context, the development of shade adapted species hold great potential in temperate agroforestry. The farmers willing to experiment with agroforestry practices could select their own seeds based on their performance to create varieties that are adapted to the system. The results of this study help to inspire farmers in The Netherlands to start with agroforestry practices that can be continuously improved through practical experience and scientific research.

5. Conclusion

Our study demonstrates the triticale-walnut AFC and the Restoration Agriculture AFC outperform the current monoculture crops triticale and pasture in economical margin and OM balance. These AFCs were successfully integrated on farm level, with a better farm performance as a result. Without the AFCs, OM balance was increased by purchase of additional feed or bedding material, resulting in a lower operating profit. The AFCs improved OM balance by generating organic matter, diminishing this trade-off. For both farms, integration of Restoration Agriculture offered improved farm configurations with the best results. The willow-pasture AFC could not be integrated without a strong decrease in operating profit, making it infeasible to produce all woodchips on farm. Further research is necessary in order to make more solid process-based estimations of technical coefficients of AFCs. For effective adoption of these promising systems, we also face challenges in non-productive related fields, such aspolicy issues and thesetting up of new revenue models.

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