CANTOGETHER

Crops and ANimals TOGETHER

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Synthesis of advantages and gaps of existing innovative mixed farming practices and systems at the district level

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Abstract

The advent of cheaply available feedstuffs, synthetic chemical and fertiliser inputs and a focus on maximising farm profitability has favoured the growth of specialised farming systems at the expense of mixed crop-livestock systems in Europe. Specialised farming districts are generally characterised as having low diversity, high-input use, low autonomy and low efficiency, and perform poorly when assessed in terms of environmental impact or ecosystem services provision. Well-managed synergies between crop and livestock production occurring either at the farm-scale (between farm enterprises) or at the district scale (between specialised farms) have the potential to limit environmental problems via, for example, nutrient cycle closure and broader crop rotations. However, there is a lack of research using empirical farm data to quantify the actual metabolic and ecological benefits/drawbacks of crop-livestock integration strategies currently employed at the district scale in different European contexts. Therefore, a farming system approach was used to describe, analyse and assess the strategies. The strategies assessed were: (1) Local exchange of materials among farms; (2) Provision of high quality forages through a cooperative dehydration facility; (3) Land sharing between dairy and arable farms; and (4) Animal exchanges between lowland and highland regions. A selection of non-cooperating baseline farms (specialised and, where available, mixed) were compared with specialised cooperating farms in each district using data on farming practices and organisation, input use, feeding strategies, fertilising strategies, land use, nutrient recycling, and agronomic and economic performance. The data were collected via farmer interviews. The results indicate that the potential ecological benefits of cooperation are restricted by farmers choosing to use the resources made available via cooperation to intensify their operations as opposed to diversifying them. An increase in the number of milking cows per hectare on dairy farms and increased cropping intensity on arable farms precluded certain benefits, such as lower external input use and improved district-level nutrient autonomy from being realised. In most cases, cooperating farms exhibited higher input use than specialised farms. Cooperation via improved forage provision or animal exchanges resulted in improved productivity, increased land use diversity and lower N surplus per unit of agricultural output compared to non-cooperating farms. Cooperation via material exchange resulted in increased productivity. The findings suggest that if district-level cooperation between specialised farms is organised with the goal of optimising resource use efficiency as opposed to the goal of increasing production then it has potential as a blueprint for sustainable intensification as it can simultaneously raise yields (and income), increase input use efficiency and reduce the potential for negative environmental impact.

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1 Introduction

Specialisation and intensification of farms and of farming districts, largely due to the availability of cheap external inputs to production, leaves farms dissociated from land and its natural communities and cycles. This specialisation in cropping or animal husbandry limits the benefits that would otherwise be realised as a result of synergies between crop and livestock production such as direct nutrient exchange (manure for fodder or bedding material), broader crop rotations for disease and weed control, and improved soil condition as a result of manure application. Furthermore, specialisation results in a loss of flexibility of the farming system leaving it ill-equipped to cope with the many uncertainties regarding future threats and potentials, such as the increasing frequency of extreme climatic events, the revision of the Common Agricultural Policy (CAP), dramatic price swings for agricultural commodities, new environmental regulations, the demand for energy (and other non-food) crops and availability of production resources (e.g. water, nutrients, fossil fuel etc.) (Darnhofer et al., 2010). In an era of ever-more limited resources and stricter environmental regulations specialised farming systems will no longer be able to afford to buy the services formerly achieved through integration of crops and livestock (Clark, 2004). There is therefore a need for practical strategies that can be deployed in specialised farming districts to help, spatially and functionally, reintegrate crop and livestock components, thereby firstly improving system metabolism (e.g. improving autonomy and resource use efficiency, facilitating the closing of nutrient cycles, reducing the need for external inputs while also reducing environmentally harmful emissions), and secondly, providing ecosystem services (e.g. replacing synthetic inputs with input services like N fixation and natural pest control, biological regulation through temporal and spatial diversity of landscape, improved soil biological fertility through spreading of manure on crops, greater carbon sequestration due to an increase in perennial forages relative to cereals).

Integration of crops and livestock at district level requires coordination through collective organisation between specialised farm types. This type of integration is referred to as among-farm integration and consists of spatially separated, specialised crop and livestock farms that are integrated through the exchange of materials either via contracts or partnerships (Sulc and Tracy, 2007) or via agricultural cooperatives. It allows some of the synergies normally provided by within-farm integration to be obtained, but with much smaller increases in farm workload, complexity of rotations, and skills and infrastructure on individual farms involved, and has the advantage that much more diverse activities and larger banks of resources are accessible compared to those available when integration occurs at farm level. Stallman (2011) noted that collaboration among many farms has greater potential with respect to the provision of ecosystem services because it can overcome the spatial scale-mismatch between ecosystem services and agriculture. On the other hand, the distances between some specialised farms within a district will greatly limit their ability to cooperate and thus the range of synergies (e.g. exchange of slurry for grain) they can achieve compared to individual farms that exchange materials within their system.

Crop-livestock integration strategies currently employed in Europe are many and varied as a result of their having to cater for a large number of interacting variables such as farmers' perceptions, farming system type, pedo-climatic region and policy environment. Bell and Moore (2012) noted that, "the degrees to which a particular farm is diversified and/or integrated is a result of a combination of strategic (or land use) and tactical (or agronomic) decisions that are made by its managers". An improved understanding of these decision-making processes will increase the adoption of integrated crop-livestock systems (Entz et al., 2005; Sulc and Tracy, 2007). However, it should be noted that the feasibility of among-farm integration is highly dependent on the appropriate mix of farm types being present in the region (Bos and Van de Ven, 1999) and the eco-efficiency of transporting high bulk, low cost materials such as slurry (BCPC Forum, 2004). When it comes to the management decision of whether or not to innovate, the farmer’s (or group of farmers in the case of a cooperative) decision to adopt an innovative integration strategy can be motivated by economic (desire to increase income and yields), social (desire to reduce work load) or environmental (duty to comply with regulations) goals. Such a goal orientated approach to innovation can result in many of the benefits or drawbacks of the adopted integration strategy being overlooked when the performance of the innovative system is being compared to that of the conventional system. In some cases farmers may use innovative integration strategies as a vehicle to intensify their operations as opposed to diversifying them, thereby restricting the potential benefits of integration. Therefore, it is important to understand the workings of the different strategies employed to mix crops and livestock at district scale.

As the production resources on which specialised farming systems rely become scarcer and thus less affordable, and environmental regulations become more restrictive, farmers will have to reorientate their production systems to better utilise the natural resource base. This can be done by taking advantage of synergies between farm enterprises or by cooperating with neighbouring farmers for mutual benefit. Research at farm-scale by Villano *et al.,* (2010) has already identified strong synergies from complementarity between crop and livestock enterprises but they argue that there is a dearth of empirical farm data and published information about system linkages that would allow farmers to optimally exploit these complementary synergies. At the district-scale, some farmers have developed their own collaborative material exchange strategies to respond to environmental regulations that limit manure application, but despite the potential of such arrangements to improve nutrient recycling, few research studies have assessed their efficacy (Asai *et al.,* 2014). Questions remain as to whether collaboration among-farms might achieve the same range of synergies as within-farm integration (Russelle et al., 2007). Empirical research is therefore needed to quantify the actual metabolic and ecological benefits/drawbacks of crop-livestock integration strategies currently employed at the district scale in Europe.

The purpose of this report is to describe, analyse and assess the strengths and weaknesses of existing methods that facilitate the recoupling of crop and livestock production at the district scale in Europe. Four existing crop-livestock integration strategies were assessed using empirical farm data from district level case studies in different biogeographical regions of Europe. The strategies assessed were: (1) Local exchange of feed or straw for manure or slurry among farms; (2) Provision of high quality forages through a cooperative dehydration facility; (3) Land sharing between dairy and arable farms; and (4) Animal exchanges between lowland and highland regions. By comparing non-cooperating baseline farms (specialised and mixed) with cooperating farms in each case study district, it was possible to identify the benefits and drawbacks, at both farm and district level, of the different integration strategies, in particular relating to system metabolism and to a lesser extent ecosystem services provision.

2 Materials and methods

2.1 General approach

2.1.1 Case study selection

Case studies were chosen to ensure a diversity of mixed farming systems from different biogeographical regions, and located in different European countries. The five case studies selected for assessment were located in: Ebro River Basin, Aragon, Spain; Cavan, Ireland; Domagné, Ille et Vilaine, France; Winterswijk, Netherlands; and Cantons Thurgau and Grisons, Switzerland. The case studies specific locations in relation to the biogeographical regions of Europe are shown in Figure 1. In Sections 2.2.1 to 2.2.5 the selected case studies are presented in their respective regional and agricultural contexts using descriptors of location, climate, soils, land use, farming system and practices, and pertinent farming regulations.

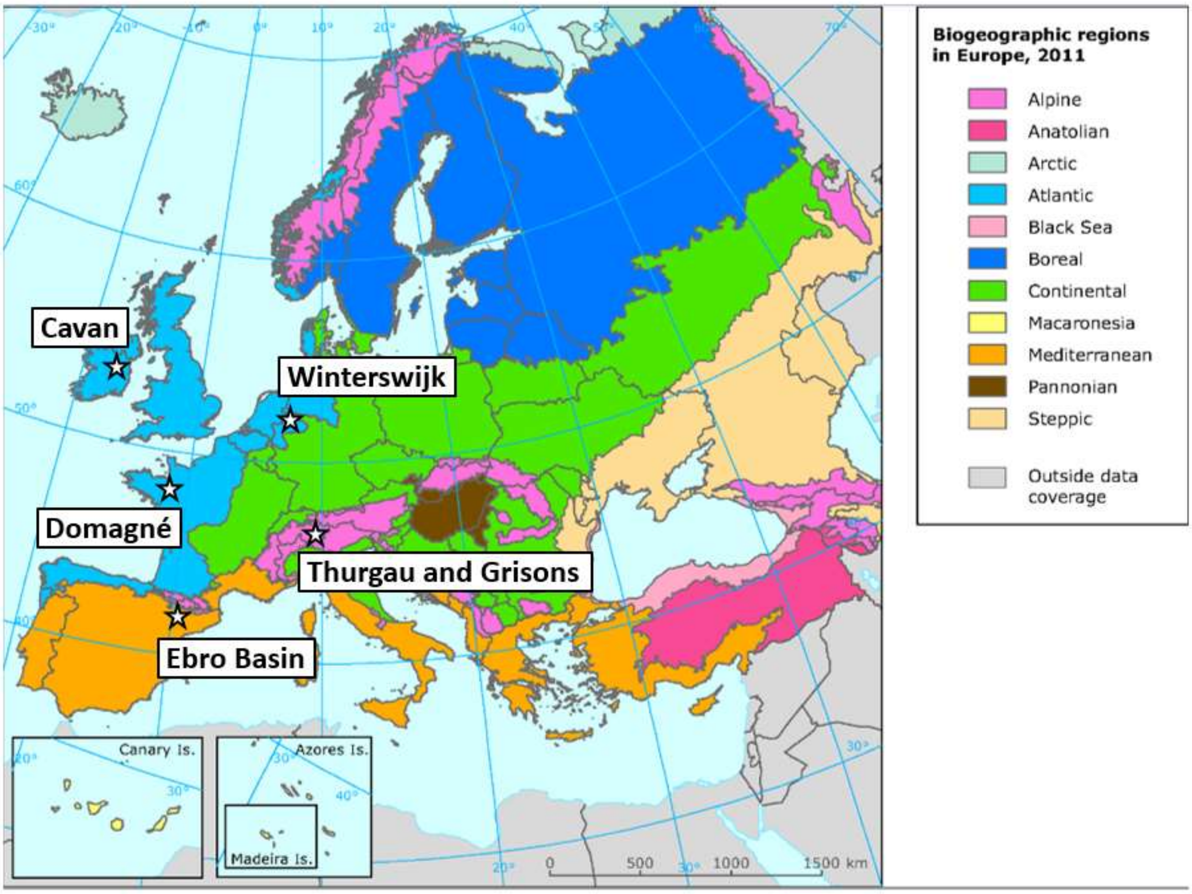

Figure 1. Case study distribution across different biogeographical regions of Europe (Source: European Environment Agency)

2.1.2 Overall study design

2.1.2.1 Research questions

- Which district level crop-livestock integration strategies are the most effective at delivering increased food production, reduced environmental impact and improved ecosystem services provision relative to specialised farming districts?

- What are the knowledge gaps and rules for mixing crop and livestock production at the district scale?
- What are the strengths and weaknesses of the different crop-livestock integration strategies under assessment?

2.1.2.2 Hypotheses to be tested

- The integration of crops and livestock will result in improved ecosystem services provision and better system metabolism relative to specialised farms where integration between crops and livestock is minimal.
- Cooperation between specialised crop and livestock farms in a district will help to close nutrient cycles and should therefore mitigate external inputs such as synthetic fertilisers, forages and concentrates.

2.1.2.3 Research approach employed

In order to respond to the research questions and to test the formulated hypotheses, a farming system approach was employed in the selected case study districts to compare two existing farming systems: non-cooperating specialised and/or mixed farms (i.e. the baseline or reference farms) were compared to cooperating specialised farms. The specialised cooperating farms studied consisted of crop and livestock farms that employed one of four district level crop-livestock integration strategies already defined within the project (Figure 2), those being: (1) Local exchange of feed/straw and manure/slurry among farms; (2) Provision of high quality forages through a cooperative dehydration facility; (3) Land sharing between dairy and arable farms; and (4) Animal exchanges between lowland and highland regions. By describing and analysing these non-cooperating specialised farms, non-cooperating mixed farms (i.e. within-farm mixing) and cooperating specialised farms (i.e. among-farm mixing) in terms of farming practices, nutrient recycling, biodiversity, soil quality, feed consumption, etc., we were able to characterise how the studied innovative crop-livestock integration strategies work and are organised at district scale and also identify the strengths and weaknesses they possess compared to districts in which non-cooperating specialised farms and/or non-cooperating mixed farms predominate. The description and analysis of these systems provided a framework which could be used in conjunction with appropriate indicators of metabolic performance, ecosystem services provision, sustainability, and resilience to conduct a multi-criteria assessment of the different mixed farming systems and mixing options employed at district scale in the various European agricultural settings under study.

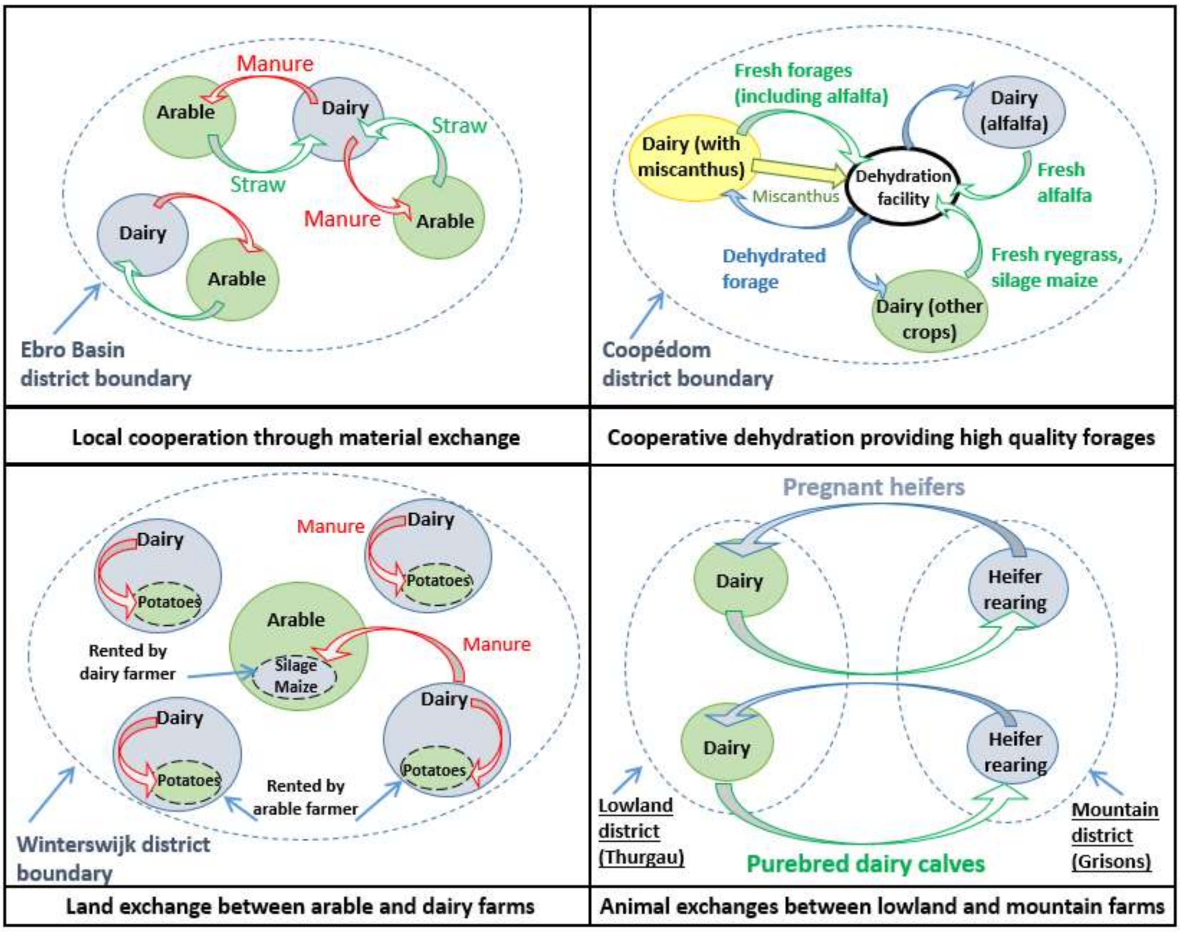

Figure 2. District level crop-livestock integration strategies under study

The general approach applied across the diverse case studies when selecting the farms to be surveyed is outlined in Figure 3. When deemed relevant for a specific case study more than one baseline was defined and assessed. The first baseline considered non-cooperating specialised farms (data collected from farms that do not cooperate) and had a sampling density of 4-7 non-cooperating specialised arable farms and/or 4-7 non-cooperating specialised livestock farms within the district. The second baseline group, which was only relevant or available for some of the case studies, considered non-cooperating mixed farms (farms with interdependent livestock and arable enterprises) and had a sampling density of 4-7 mixed farms within the district. The purpose of this baseline of non-cooperating mixed farms was to allow comparison of the performance of a group of farms that conduct within-farm mixing with that of a group of farms that conducts among-farm mixing. The two baseline groups were compared with 8-10 specialised farms that cooperate for mutual benefit within a district. Drawing on a large body of existing theoretical research on mixed farming systems, general hypotheses were formulated about the expected benefits and drawbacks of integrating crop and livestock production at the district scale. Following this, the general hypotheses were refined while taking into consideration the defining aspects of each integration strategy and the farming district in which it would be assessed. The baseline and cooperating farms selected in each case study using the general approach are outlined in Sections 2.3.1 to 2.3.5

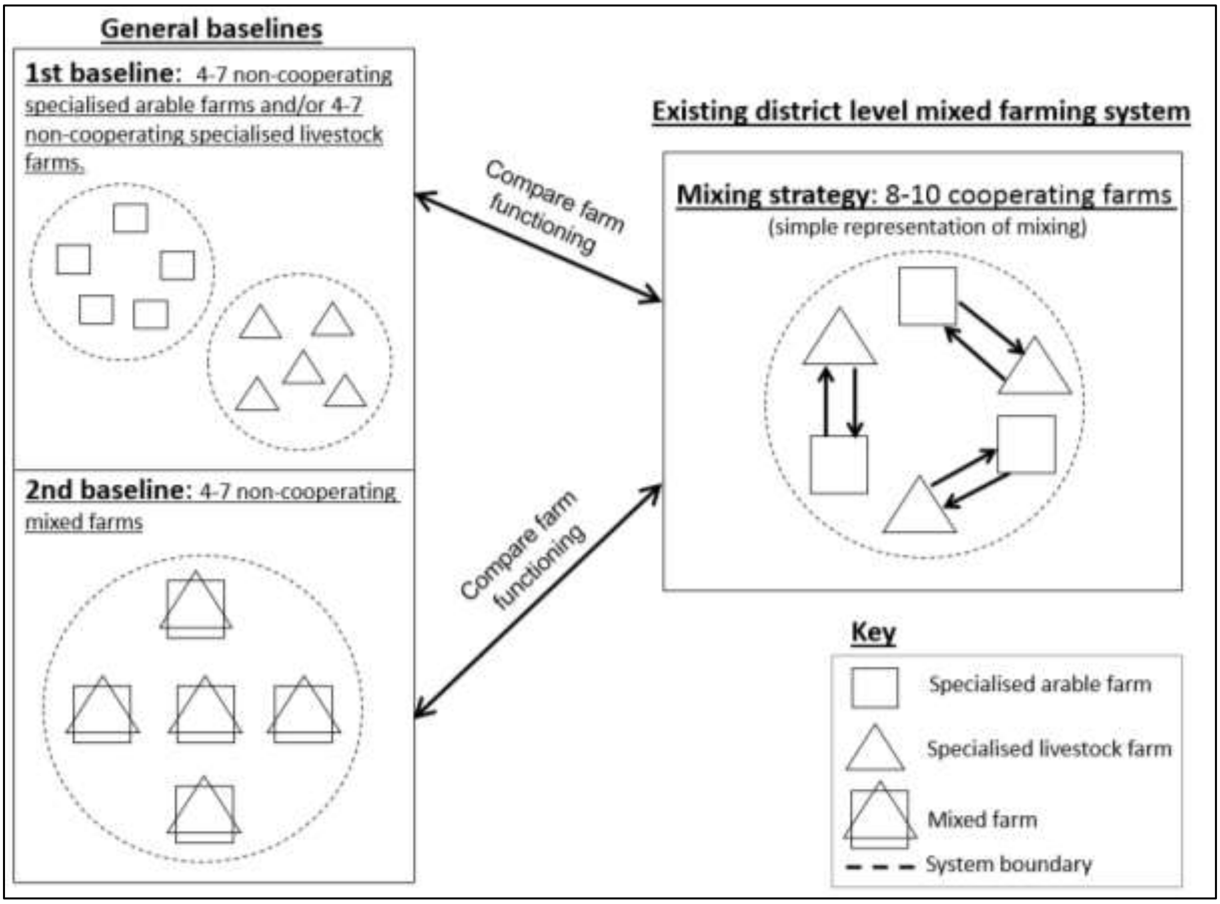

Figure 3. General approach employed to assess performance of cooperating districts relative to baseline districts.

2.2 Case studies presentation and context

2.2.1 Dairy production in the Ebro Basin, Aragon, Spain

The Ebro River Basin of the Aragon community is situated in the northeast of Spain. The climate in the region is Mediterranean semiarid, with precipitation ranging from around 290 to 400 mm/yr. The Ebro Basin is the driest area of Aragon and one of the driest areas of Spain as evidenced by the hydric deficit in the area which ranges from around 250 to around 450 mm. As such, the dairy farming systems in the area are linked to the irrigated valley bottoms of the Ebro River and some of its main tributaries. Land use involves irrigated lands, sown mainly with silage maize, Italian ryegrass and alfalfa. Meat production is prominent throughout the region, while milk production is relevant only in 25 municipalities.

'Market orientated dairy farms' account for only 4% of the total number of farms in the Aragon community, so focus was on 'family orientated dairy farms'. Typical 'family-orientated dairy farms' in the region have 150 cows on average and around 80 ha of utilised agricultural area (UAA) on average. On these farms, crop rotations with legumes (mainly alfalfa) and annual grasses is a relatively common practice. The most common land use is double cropping (two crops grown successively during one year) of Italian ryegrass in winter and silage maize in spring-summer. Grazing is not practiced on dairy farms due to the scattered nature of land parcels. Therefore, the dairy farming system involves permanent housing of cows and zero-grazing with cut irrigated forages fed indoors (Barrantes et al., 2009). High levels of concentrates are used, which usually are not home-grown. In total there are 51 family-orientated dairy farms present in the semi-arid of Aragon. Cattle are fed mainly on maize silage and alfalfa as volume, self-produced or purchased in local cooperatives (cultivated in the neighbourhood). The concentrates consist mainly of locally produced corn and barley and remotely produced soybean meal. In general, straw is used as animal bedding, but it is also used as low quality forage, in particular, for feeding to heifers. As dairy farms in the district don't generally grow cereals, the straw they require for animal bedding and for feeding to heifers as low quality forage is obtained either through purchase from arable farms or through exchange for dairy manure with neighbouring arable farms.

Environmental concerns relating to agriculture in the Ebro River Basin include: 1) lowering of off-site water quality as a result of farming irrigation returns (leading to increases in salinity and nitrate concentrations); and 2) social pressure on water use due to conflicts and competing uses particularly in drier years in semi-arid areas. The majority of municipalities in the Ebro Basin are Nitrate Vulnerable Zones. Increasing nitrate concentrations in stream waters of the Ebro River Basin between 1981 and 2005 were primarily due to agricultural intensification practices of farms in the area (Lassaletta et al., 2009). The authors of the aforementioned study noted that if the trend of increasing nitrate concentrations remained unchanged in the area, by 2015 many of the water bodies assessed would not comply with the EU Water Framework directive requirements.

2.2.2 Pig production in Cavan, Ireland

County Cavan is situated in the Border Region of Ireland, just south of the border with Northern Ireland. The climate is cool temperate oceanic, with precipitation ranging from around 800 to around 1000 mm/yr, and average annual temperature of 10°C. Heavy and poorly drained clay soils cover much of Cavan's land area and are the main reason why crop production is very low in the county compared to grass-based farming systems, which dominate. The Border area is characterised by a large number of pig and poultry farms as well as dairy and beef enterprises. Cavan is one of the leading counties in pig production in Ireland with its farms accounting for approximately 20% of the national pig herd.

In general, pig units in the region are large indoor housing systems, ranging from the low hundreds on small units to between 3,000 and 4,000 on the larger units. These units are essentially industrial farms as they don't have any land, but agreements with neighbouring farmers to provide spread lands for the large volumes of slurry produced by them. Due to the dominance of pasture systems in the county, the majority of pig slurry is spread on land grazed by either dairy or beef cattle. Pig farmers in the Cavan region are often required to spread a significant amount of their slurry on farms located far away from them: in effect they quickly meet the Nitrogen (N) requirement of the grassland farms in their vicinity and must therefore widen their spreading circle. The distance that slurry must be transported is the main constraint limiting the use of slurry on cropland. The distance pig farmers will have to travel to find suitable spread lands will increase towards 2017, as the transition arrangement permitting application of pig manure to land in excess of the prescribed quantity of phosphorus is phased out. By the end of the phasing out period in 2017, it's estimated that pig farmers will have had to double the grassland area they currently spread on, in order to be able to spread the same amount of slurry and remain in compliance with regulations. In contrast, arable land growing cash crops can receive high P application rates due to high P offtake in cereal grains. A shift towards spreading of pig slurry on arable land as opposed to grassland, brought about by collaboration between pig farms and sufficiently close arable farms, in the years up to and after 2017, will help ensure that sufficient spread lands will be accessible in the future. Although the spreading of pig slurry on grasslands already receiving cattle slurry increases the risk of nitrate leaching to groundwater, documented groundwater nitrate concentrations in the area are below 5 mg/L NO_3 (Byrne and Fanning, 2015).

2.2.3 Cooperative dairy production in Domagné, Ille et Villaine, France

Domagné is located in the Department of Ille et Villaine which is situated in the Brittany region of France. The climate in the region is temperate oceanic with mean annual rainfall of 907 mm and an average annual temperature of around 12°C. The soils of Britany are predominantly silty, making them suitable, but not ideal for farming. This soil-climate context has favoured a development of animal production over food crop production in the region, such that Brittany is France's leading region for animal production, with approximately 56%, 20%, and 30% of France's overall production of pigs, dairy cattle and chickens, respectively (Agreste, 2012). Even though 94% of the regions UAA is allocated to animal production (grazing and feed and forage crops), the region is highly dependent on protein crop imports (particularly soybeans). Intensive practices, such as high imported concentrate feed and mineral fertiliser use), are common in livestock systems in Brittany. These intensive practices go a way towards explaining the high average nitrate concentration in Brittany's surface waters, which, between 1991 and 2007, generally exceeded 25 mg/L NO_3.

The Coopédom agricultural cooperative society was created in Domagné in 1969 by 20 farmers as a solution to the lower milk yield observed from cows during the winter months when they were fed on field cured forages. The cooperative adopted the industrial dehydration of forages as an alternative to field curing because rapid de-hydration of forages can produce a high quality winter feed with equivalent nutritional value to that of fresh pasture grazed in summer. Coopédom currently has over 700 members (mostly dairy farmers) within a 30 km radius of its dehydration facility in Domagné. It annually dehydrates approximately 39,000 t of forages, representing 1,600 ha of alfalfa, 1,600 ha of grass, 1,200 ha of maize, 300 ha of fescue and 100 ha of clover produced by its members. The planted alfalfa area that is dehydrated represents 21% of the total area planted with protein crops (legumes) in the Britany region in 2011. The facility to dehydrate alfalfa makes it a viable home-grown protein crop that can reduce dairy farmer's dependency on imported soybean.

The dehydration process uses coal imported from South Africa. In 2009, Coopedom developed an energy self-sufficient fodder drying technique that uses biomass (40% miscanthus and 60% wood from forest or sawmills) as an energy source to fuel dehydration furnaces. This new biomass furnace replaced one of the cooperatives two coal furnaces thereby reducing the CO_2 emissions of the dehydration process by 50%. Coopédom currently harvests approximately 400 ha of miscanthus per annum in order to meet the needs of its biomass furnace. This miscanthus provides 30% of the energy needs of the cooperative and is currently produced by 86 of Coopédom's members located within a 50 km radius of the dehydration plant.

2.2.4 Dairy production in Winterswijk, Netherlands

Winterswijk is located in the Eastern part of the Netherlands in the province of Gelderland. It is part of the province of Gelderland and covers 13,880 ha, of which 8,055 ha is cultivated land. The climate in the region is cool temperate, with average annual rainfall of approximately 780 mm/yr and average annual temperature of 9.5°C. There is significant rainfall throughout the year and the average hydric deficit in the area during the growing season (April to September) is only 30 mm. The majority of soils in the region are sandy, sometimes overlying a clay layer of low permeability. As such, soils vary from quite dry during the summer to having temporary stagnant water at times during the winter period. The soil type together with low rainfall deficit makes the region highly suitable for grass production.

The region is a small-scale landscape with high nature and landscape values, consisting of a mosaic of grasslands, arable fields, hedgerows, woodlots and small brooks with high water quality. Agriculture accounts for 5% of the jobs for the residents of Winterswijk and 61% of the land use (8,450 ha). The region is dominated by agricultural activities (average farm size in the region is 24 ha), with the most important agricultural sector in the region being that of dairy farming (150 farms). Sixty percent of the main production area in the region is used for specialised dairy farming (based primarily on grazed grassland and maize silage as fodder). There are approximately 40 farms with beef cattle in the region and about 10 – 15 arable farms specialised in potato production. The number of pig (~ 40) and poultry (~ 10) farms is decreasing rapidly. Land use in the region is dominated by grass (65%) and maize silage (24%). Other crops are cereals (4%) and potatoes (6%). The stocking rate of dairy cattle is around 2 LU/ha.

2.2.5 Dairy production and heifer rearing in the Cantons of Thurgau and Grisons, Switzerland

The canton of Thurgau (lowland region - 991 km^2) is situated in the northeast of Switzerland in the region known as the Swiss plateau. It is here in the lowlands of the plateau that the majority of Switzerland's productive land is found. The climate in Thurgau is between humid oceanic and continental temperate, with precipitation ranging from around 900 to around 1200 mm/yr, and a mean annual temperature of 9°C. The altitude in Thurgau ranges from about 370 m to 1000 m. In contrast, the canton of Grisons (mountain region - 7105 km^2) is situated in the mountainous Alps region in the southeast of Switzerland. Here, three different altitudinal zones exist: Subalpine (1200 - 1750 m), Alpine (1800 - 2500 m) and glacial (above 2500 m), each having a distinct climate. Agricultural activities in Canton Grisons are generally restricted to subalpine areas where the mean annual temperature is around 5.5°C. These pronounced differences in altitude and climate between the two cantons is the reason for the vast difference in the productivity of their soils, with those of Thurgau being more productive and therefore more suitable for intensive agriculture than the soils of Grisons, of which the majority are more suitable for extensive agriculture. Even though the canton of Thurgau is one of the more intensive agricultural regions in Switzerland, surface water quality, based on nitrate concentrations, is in most cases good (FOEN, 2013). In the Canton of Grisons surface water quality is very good (FOEN, 2013). In the case of groundwater quality, nitrate concentrations in the canton of Thurgau range from good to moderate (FOEN, 2011). Groundwater nitrate levels in the canton of Grisons are predominantly low (FOEN, 2011).

Pasture farming is the dominant farming system in both cantons (and in Switzerland in general), with dairy cattle being the dominant grazing livestock. The average number of cattle per farm in the cantons of Thurgau and Grisons in 2012 was 43.3 and 38.5, respectively. The average size of dairy cattle herds in Thurgau and Grisons in 2012 was 28.5 and 12.5, respectively (Federal Statistical Office, Neuchâtel 2012). Mixed farms are common in Thurgau because of the suitability of the lowlands for crop production (in 2012, 23% of the UAA in the Canton was used to produce cereal and root crops). In contrast, the canton of Grisons is not well suited for crop production (in 2012, 1.6% of the UAA in the Canton was used to produce cereal and root crops) due to climatic conditions and steep slopes, and is therefore dominated by specialised livestock farms. Intensive cattle production (e.g. dairy farming) is less common in Grisons than in Thurgau, but still accounted for 40 % of the cattle numbers in the canton in 2012. Dairy farms in the mountainous canton of Grisons rely on feed imports (concentrates and sometimes even roughage from outside the district) to a greater extent than the canton of Thurgau. In both cantons wheat is the main crop cultivated for food grain, while barley is grown mostly for feed grain.

At present in Switzerland, approximately 50 % of the concentrate feed requirement of livestock is produced in Switzerland, with the remainder imported. The countries feed autonomy could be improved through mutually beneficial collaboration between the cantons of Thurgau and Grisons, whereby, more cattle with lower feed requirements such as heifers or suckler beef from the lowlands are fed on mountain pastures, thus allowing two exploitative options to be pursued by lowland farmers: 1. they may intensify their operations by increasing dairy cow numbers and produce more milk using high quality lowland grass that has higher nutritive value than mountain grass or 2. they may diversify and start to grow crops which may increase the ration of home-grown concentrates fed to cattle.

2.3 Farm selection

2.3.1 Ebro Basin farms

The form of cooperation assessed was the exchange of solid manure produced on family-orientated dairy farms for straw produced on specialised arable farms. The two baseline groups were as follows: the first baseline consisted of non-cooperating specialised dairy farms (ie dairy farms that only have a small area dedicated to crop production relative to their fodder production area, use their manure on their own land, and buy in straw, concentrates and in some cases fodder) and non-cooperating specialised arable farms (ie arable farms that do not use organic fertilisers). It was assessed through surveys of 4 specialised dairy farms and 5 specialised arable farms; the second baseline consisted of mixed farms (ie farms rearing dairy cattle that home produce a significant quantity of the feed and/or straw for livestock and also have a significant fraction of their income coming from the sale of grain). It was assessed through surveys of 4 farms. To assess the district level effects of the innovation – exchange of solid manure for straw, the two baseline groups were compared to 9 cooperating farms (5 family-orientated dairy farms and 4 specialised arable farms that exchange solid manure for straw and/or fodder). A summary of the baseline and cooperating farms assessed is provided in Appendix 1.

2.3.2 Cavan farms

The form of cooperation assessed was the spreading of pig slurry, produced by specialised pig farms, on tillage land as opposed to grassland and the direct purchase from these tillage farms of cereal grains for feeding to pigs. In order to assess the performance of this crop-livestock integration strategy, the cooperating farms were compared to two baseline situations present in the district. The two baselines were as follows: the first baseline consisted of specialised pig farms (ie pig farms that have very little or no land of their own, spread the majority (67-94 %) of their slurry on neighbouring grassland farms and obtain the total amount of their feed requirements either from grain merchants or from compound feed suppliers. It was assessed through data collection surveys of 3 farms. The second baseline consisted of specialised, non-cooperating arable farms (ie arable farms that do not use organic fertiliser as an input and are therefore reliant on synthetic fertiliser to meet crop needs, and do not sell grain directly to pig farmers), thus ruling out arable farms that buy manure or use home produced manure on their crops. It was assessed through surveys of 6 farms. To assess the district level effects of the mixing strategy – spreading of pig slurry produced by specialised pig farms on arable land as opposed to grassland and direct purchase of cereal grains by pig farmers, the two baselines were compared to 3 cooperating pig farms (ie specialised pig farms that spread between 16 and 74 % of the slurry they produce on arable land and that have home-milling systems) and 6 specialised arable farms that were identified as accepting pig slurry from cooperating pig farms and selling them grain. A summary of the baseline and cooperating farms assessed is provided in Appendix 2.

2.3.3 Domagné farms

In the case of the Coopédom cooperative two forms of cooperation/innovation were assessed, these were: 1. coal-fuelled dehydration of forages (since 1969), and 2. coal, miscanthus and wood fuelled dehydration of forages (since 2009), both for feeding to dairy cows. These forms of cooperation affect farm functioning in that they have caused farmers in the district to introduce the protein crop alfalfa in their crop rotations and ensured that high quality forages are available for feeding dairy cattle all year round. The second form of cooperation also allows farms to diversify their production by introducing the biomass crop miscanthus in their cropping system which can reduce farm workload. As much as possible, the farms selected for the baseline and innovations (detailed below) were farms that do not grow cereal or oilseed crops for sale off the farm. If a surveyed farm had only a 'small area' on which it grew cereal or oilseed crops for sale off the farm, then it was included. This 'small area' was defined to be less than 25% of the UAA of the farm. The baseline situation consisted of: 7 dairy farms from outside of the Coopedom district but within the department of Ille et Vilaine.

To assess the district level effect of the first innovation – coal fuelled dehydration of forages, the baseline farms were compared to two innovative groups:

- 6 farms (group 1) growing alfalfa for dehydration and then feeding it to animals. These farms did not grow miscanthus but did have a small area on which they grow perennial ryegrass for dehydration, but the area was less than 20% of the total area used to grow crops for dehydration.
- 6 farms (group 2) growing crops other than alfalfa and miscanthus for dehydration and then feeding them to animals. Care was taken to ensure that the crops grown for subsequent dehydration consisted mainly of silage maize and/or ryegrass. Where possible, the farms selected here were those that also purchase dehydrated alfalfa from Coopédom and feed it to animals.

To assess the district level effects of the innovation – coal, miscanthus and wood fuelled dehydration of forages (Figure 2), the baseline farms were compared to:

- 6 farms that, in addition to having alfalfa, silage maize and ryegrass dehydrated, also introduced miscanthus in place of grass or annual crops, such as wheat or maize.

A summary of the baseline and cooperating farms assessed is provided in Appendix 3.

2.3.4 Winterswijk farms

The form of cooperation assessed was the sharing of land between dairy farms and arable farms specialised in potato production. Dairy farmers leased their fields to an arable farmer for use in potato production. The exchange of fields generally took place when dairy farmers were renewing[1] their grassland, as this allowed arable famers to extend their acreage by planting a potato crop on the dairy farmer's field in spring. The relative small size of these arable farms means that the growing of potatoes on the fields of other farms, such as dairy farms is very important to the arable farmer as it allows him to have long potato-based crop rotations. The dairy farmers use their excess slurry to fertilise the potato crop planted by the arable farmer. After the potatoes are harvested in August/September the field is reseeded with grass.

In order to assess the performance of this crop-livestock integration strategy, it was compared to two baseline situations present in the district, namely specialised dairy farms and mixed dairy farms. There were no specialised arable farms in the district that met the criteria to be classified as non-cooperating and specialised in arable production (in effect the small land area of arable farms in Winterswijk and the economic importance of potato production necessitates that arable farms cooperate with neighbouring dairy farms so as to increase the land area on which they can produce potatoes). Therefore, data from specialised arable farms outside the district was used to construct a third baseline. The baseline groups were as follows: the first baseline consisted of specialised non-cooperating dairy farms (i.e. dairy farms with a grass/maize rotation, using the majority of their manure on their own land, buying in nearly all concentrates for livestock feeding and not exchanging fields with other farmers). It was assessed through surveys of 4 farms; the second baseline consisted of mixed farms (i.e. dairy farms that have a significant fraction of their area under cereals and home produce a significant quantity of the feed and/or straw for livestock). It was assessed through surveys of 3 farms; the third baseline consisted of a sample of 15 specialised arable farms from the Dutch provinces of Gelderland, Overijssel, and Drenthe. To assess the performance and district level effects of the crop-livestock integration strategy - exchange of land between dairy farms and arable farms specialised in potato production, the three baselines were compared to 6 cooperating farms (3 specialised dairy farms that lease fields to 3 specialised arable farms for growing potatoes). A summary of the baseline and cooperating farms assessed is provided in Appendix 4.

2.3.5 Thurgau and Grisons farms

The aim of this case study is to analyse supra-regional collaboration between mountain farmers in the canton of Grisons and lowland farmers in the canton of Thurgau. The form of cooperation assessed was the sale, by lowland farmers, of weaned female pure bred dairy calves to mountain farmers. The mountain farmers raise the heifers and then sell them back to the lowland farmer when they are pregnant and close to calving. The lowland farmer uses the land (and time) that was

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[1] Intensively managed grasslands on the sandy soils in the Winterswijk region are reseeded every 5 years on average (Schils et al., 2002).

previously used for the raising of heifers, to either grow crops, thus increasing the area sown to crops on the farm (these crops may be cash crops or feed crops), or to increase cattle numbers and produce more milk using productive lowland grass. This collaboration is facilitated by a standardised contract, which specifies prices for calves and pregnant heifers.

In order to assess the performance of the crop-livestock integration strategy described above, it was compared to a baseline situation present in each canton. The baseline for Thurgau was as follows: Baseline 1 consisted of specialised, non-cooperating (lowland) dairy farms (ie dairy farms that raise their own heifers, don’t send cattle to graze alpine pastures in summer and have only a small area dedicated to crops). It was assessed through surveys of 4 farms. The baseline for Grisons was as follows: Baseline 2 consisted of specialised, non-cooperating (mountain) dairy farms (ie dairy farms that raise only their own heifers and have only a small area dedicated to crops). It was assessed through surveys of 4 farms. To assess the district level effects of the innovation – sale, by lowland farmers, of weaned female pure bred dairy calves to mountain dairy farmers and growing of crops on lowland dairy farms, Baseline 1 was compared to 4 cooperating (lowland) dairy farms (ie dairy farms that have sold their heifers to mountain farms and are now using the land previously occupied by those heifers to either grow crops or increase cattle numbers and milk production) and Baseline 2 was compared to 4 cooperating mountain farms specialised in rearing of heifers (ie mountain farms that purchased heifers from lowland dairy farms to be raised in the mountains before being sold back to the lowland farmer when pregnant and close to calving). Once specialised in rearing of heifers, mountain farms no longer produce milk. A summary of the baseline and cooperating farms assessed is provided in Appendix 5.

2.4 Data collection

The empirical farm data on which this report is based were collected by case study leaders for a single calendar year via farmer interviews. This included data on local context, integration practices, farming practices, input use, feeding strategies, fertilising strategies, land use, nutrient recycling, and agronomic and economic performance.

3 Results

The results from the five case studies are presented case by case in this section. For each case study the general characteristics of the baseline and cooperating farm groups are first presented and then the results are presented and interpreted using hypotheses specific to each case study.

3.1 Ebro Basin case study results

3.1.1 Characterisation of material exchange

Cooperation through material exchange in the Ebro Basin favours local cooperation between farms (drawing on the natural resource base) over externally supported production which can leave farms exposed to market volatility. When cooperating via the exchange of solid manure for straw the surveyed dairy farms cooperated with 2.7 arable farms on average while arable farms only cooperated with 1 dairy farm. Cooperation is not governed by a contractual agreement and so the risk to farmers is not covered from year to year. The terms of exchange require only that the quantities of, and transport of, exchanged materials are agreed and as such no money changes hands. Even though no contractual agreements are in place the cooperation is quite stable over time. This is evidenced by farms cooperating for 11.2 years on average, with only one incidence of breakdown in cooperation during that period. Cooperation is facilitated by a short average road distance of only 5 km between cooperating farms. The carrying of the economic burden associated with transport of straw/manure and spreading of manure varied from partnership to partnership. Sometimes it was taken on wholly by one or other party and sometimes it was split between the two. The material exchange ratio of manure for straw (by weight) is approximately 5 to 1. The farm survey showed that both farm types are heavily invested in the partnership such that cooperating dairy farms exchange approximately 61% of their total manure production, while arable farms exchange approximately 81% of their total straw production.

3.1.2 General farm characteristics

The mean UAA of the studied farm groups ranged from small in specialised (35 ha) and cooperating (29.6 ha) dairy groups to very large in the mixed (306 ha) dairy group (Table 1). The stocking rate (calculated by dividing the number of livestock units by the on-farm area used for feeding livestock) ranged from medium in the mixed dairy group (2.7 LSU ha^{-1}) to high in the specialised dairy group (3.5 LSU ha^{-1}) to very high in the cooperating dairy group (6.8 LSU ha^{-1}). This range in stocking rates across the different dairy groups was reflected in the milk production per hectare of land used to produce feed for each group. The cooperating dairy group had the highest mean milk production per hectare of feeding area producing 45,503 litres. This value is comparable with very intensive dairy production systems with similar dual maize-Italian ryegrass cultivations assessed by Fangueiro et al. (2008) in Northwest Portugal. The milk yield per cow did not vary with the intensity of the system and was similar across the three groups if slightly lower and more variable in the cooperating dairy group. In terms of tillage system, the specialised arable group is distinctly different from the other groups with only 6 % of its UAA under conventional tillage compared to between 70 and 97 % for the other groups. The practicing of mostly no-till on specialised arable farms precludes them from being as intensive as cooperating arable farms where only 3% of UAA is under no-till. As expected, the cropping regime in the specialised dairy group was strongly orientated towards forage production with forage crops accounting for 94% of UAA. In contrast, the forage production area in the cooperating dairy group only accounts for 75 % of UAA allowing these farms to dedicate 22 % of UAA to cereal and oilseed production for sale off the farm. It is interesting to note that the cropping regime on cooperating arable farms appears to be orientated towards the forage requirement of neighbouring dairy farms as it produces forage crops on 29 % of its UAA compared to the specialised arable farms which only produce forage crops on 9 % of their UAA. This higher forage production on cooperating arable farms may also be a result of easier access to irrigation water (forage crops have higher water demands than cereals and oilseeds) in the areas where cooperating arable farms are located.

Table 1. Characteristics of the studied farm groups; mean values ± standard deviations

Parameter	Specialised Dairy	Specialised Arable	Mixed Dairy	Cooperating Dairy	Cooperating Arable
Utilised agricultural area (ha)	35 ± 7.2	195 ± 85	306 ± 223	29.6 ± 22.8	159 ± 171
Stocking rate (LSU ha^{-1})^{a}	3.5 ± 0.6	-	2.7 ± 1.9	6.8 ± 4.9	-
Milk production per feed area (lit ha^{-}	25235 ± 4252	-	17756 ±	45503 ± 31353	-

^{1})			8582		
Milk production per cow (lit)	10510 ± 1033	-	10508 ± 871	10405 ± 2 484	-
Feed concentrate intake (kg LU^{-1} year^{-1})	3127 ± 274	-	3040 ± 443	2917 ± 793	-
Conventional tillage area (% of UAA)	73 ± 31	6 ± 9	70 ± 22	90 ± 22	97 ± 7
Irrigated area (%)	100 ± 0	26 ± 37	97 ± 6	82 ± 25	85 ± 29
Forage area (%)	94 ± 7	9 ± 12	51 ± 14	75 ± 35	29 ± 12
Cereals and oilseeds area (%)	6 ± 7	75 ± 21	47 ± 11	22 ± 32	70 ± 11

[a] Stocking rate was calculated by dividing the number of livestock units by the on-farm area used for feeding livestock

3.1.3 Hypothesis testing for Ebro Basin

The mean values of N input, N outputs and N surplus in the studied farm groups for the survey year 2013 are reported in Table 2. The average N surplus of the farms in the specialised and cooperating dairy groups was directly linked to their milk production per hectare and stocking rate (Figure 4 and 5).

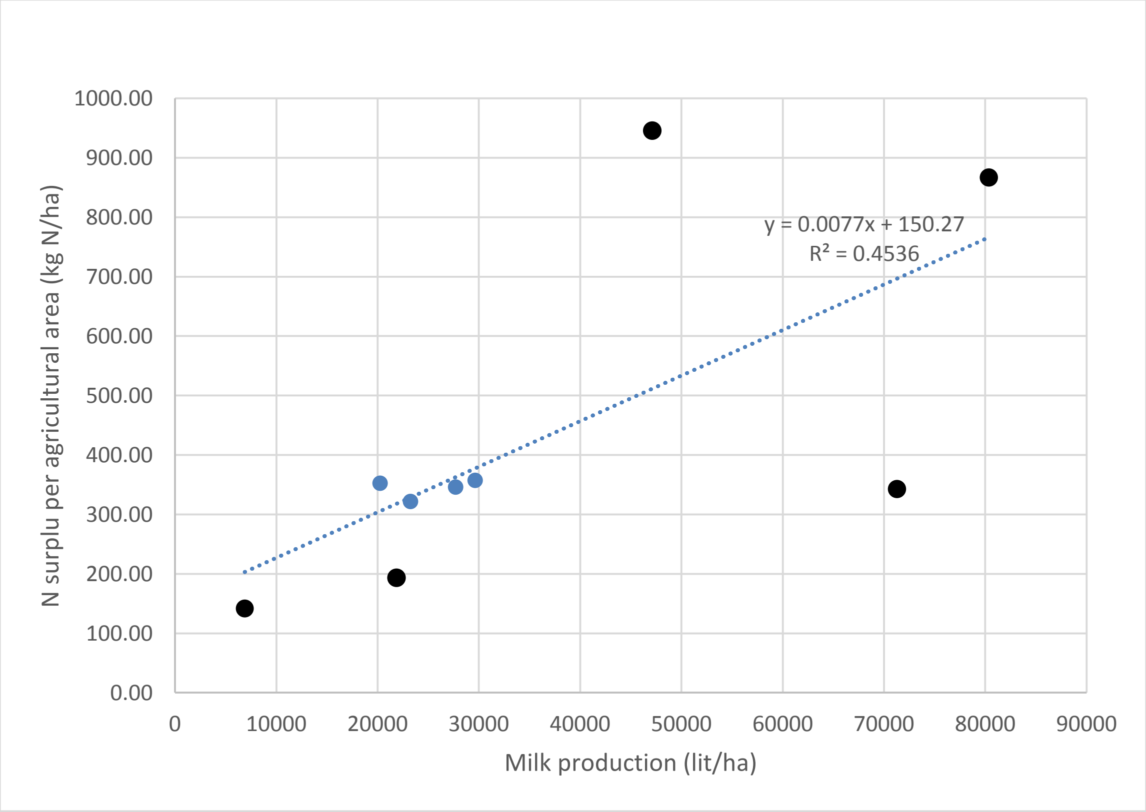

Figure 4. Relationship between N surplus per UAA and milk production per hectare for specialized (blue markers) and cooperating dairy farms (black markers)

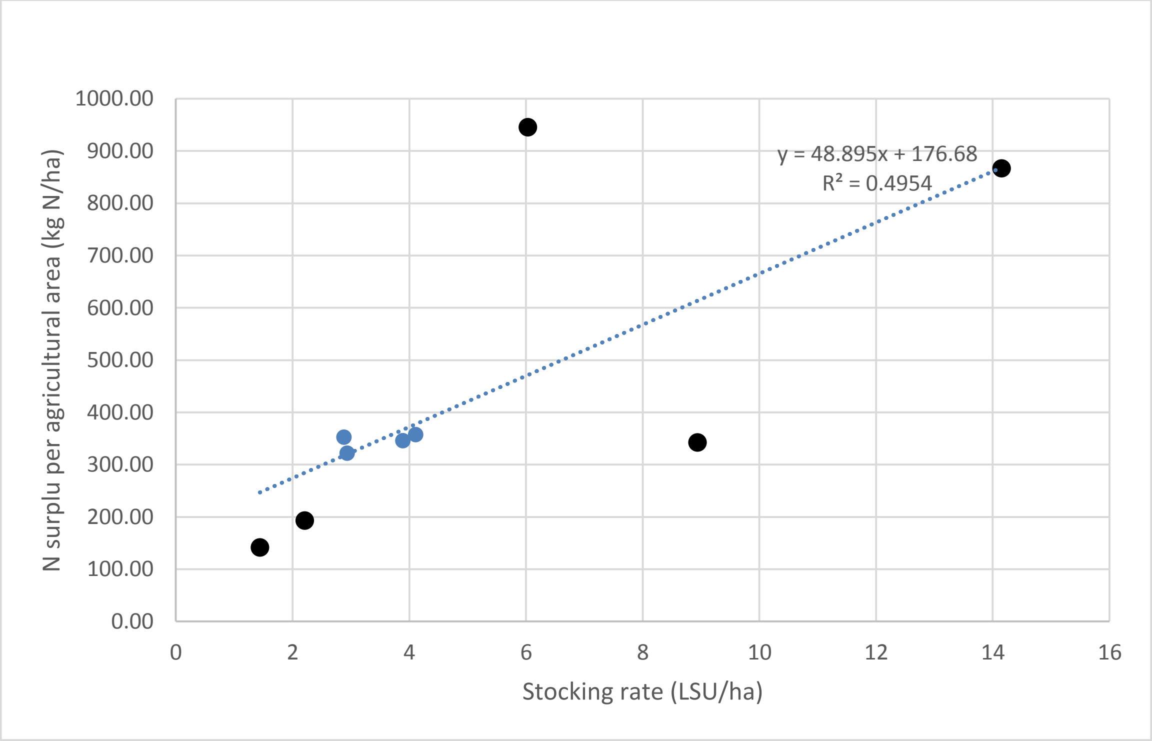

Figure 5. Relationship between N surplus per UAA and stocking rate for specialized (blue markers) and cooperating dairy farms (black markers)

It was hypothesised that cooperation would: 1) reduce mineral fertiliser use on cooperating arable farms relative to their specialised counterparts; and 2) limit over application of manure thus preventing highly positive nutrient budgets on cooperating dairy farms. The first part of the hypothesis was proved false as the mineral N fertiliser input per hectare on cooperating arable farms was more than double that used on specialised arable farms (Table 2). Such results were due to intensive arable farming on cooperating arable farms as revealed by intensive soil tillage and irrigation. The second part of the hypothesis was also proved false in that the N surplus was higher on cooperating dairy farms than on their specialised counterparts (Table 2). This result may be put down to the fact that cooperating dairy farms have a much higher stocking rate which requires them to import higher volumes of concentrate feed and plant products than specialised dairy farms. Expressing the N surplus of specialised and cooperating dairy farms per unit of agricultural output (Table 3) showed them to have similar N surpluses.

Table 2. Components of the N balance (kg N ha^{-1} year^{-1}) in the five groups of farms studied; mean values ± standard deviations

Parameter	Specialised Dairy	Specialised Arable	Mixed Dairy	Cooperating Dairy	Cooperating Arable
Mineral fertilisers	1.6 ± 3.2	66 ± 38	125 ± 31	72 ± 49	163 ± 85
Animals	0 ± 0	0	2.4 ± 4.8	0	0
Organic fertilisers	0 ± 0	0	0	0	30 ± 22
Forage and by-products	58 ± 54	0	4 ± 6.9	420 ± 419	0
Feed concentrates	315 ± 55	0	64 ± 56	537 ± 368	0
Biologically fixed	103 ± 70	19 ± 33	79 ± 51	76 ± 133	65 ± 62
Atmospheric deposition	15	15	15	15	15
Irrigation water	18 ± 13	0.9 ± 1.4	12 ± 11	15 ± 11	8.3 ± 10.1
Total inputs	**510 ± 40**	**100 ± 61**	**302 ± 67**	**1135 ± 857**	**280 ± 90**

Crops	4.9 ± 9.8	77 ± 64	130 ± 81	1.4 ± 3	200 ± 87
Milk	139 ± 23	0	32 ± 24	251 ± 173	0
Animals	14.6 ± 6.6	0	15 ± 25	18.5 ± 16.6	0
Manure	7.3 ± 14.6	0	0	366 ± 403	0
Total output	**166 ± 30**	**77 ± 64**	**178 ± 50**	**637 ± 575**	**200 ± 87**
Surplus	345 ± 16	23 ± 13	124 ± 71	496 ± 382	80 ± 57

It was hypothesised that cooperation helps to increase the fraction of the nutrients entering farm gates that comes from the district (for both arable and dairy farms) thus improving autonomy. To test this hypothesis, the district N autonomy was calculated as N input (via material exchange of straw or manure, biological fixation and deposition)/total N input for each farm group. The hypothesis was proved false for cooperating dairy farms as they exhibited lower district N autonomy (16%) than specialised dairy farms (24%) (Table 3). The significantly higher stocking rate on cooperating dairy farms makes them more dependent on imported forage and feed thus reducing their district N autonomy. The hypothesis was proved true for cooperating arable farms as they had higher N autonomy (41%) than their specialised (38%) counterparts (Table 3). This indicates that the fraction of locally sourced nutrients entering farm-gates is higher for cooperating arable farms than for specialised arable farms.

Table 3. Nitrogen surplus, efficiency and autonomy of the studied farm groups; mean values ± standard deviations

Parameter	Specialised Dairy	Specialised Arable	Mixed Dairy	Cooperating Dairy	Cooperating Arable
N surplus (kg N ha^{-1})	345 ± 16	23 ± 13	124 ± 71	496 ± 382	80 ± 57
N surplus (kg N $ton\text{-}milk^{-1}$)	13.9 ± 2.4	-	24.8 ± 9.7	12.9 ± 7	-
N efficiency (kg N sold in products per kg N input)	0.31 ± 0.02	0.7 ± 0.16	0.6 ± 0.17	0.25 ± 0.07	0.71 ± 0.17
N surplus per unit agricultural output (kg N/kg N sold in products)	2.2 ± 0.26	0.49 ± 0.3	0.78 ± 0.52	2.16 ± 1.15	0.48 ± 0.41
District N autonomy (%)	24 ± 14	38 ± 27	32 ± 17	16 ± 12	41 ± 15

In order to assess the degree to which cooperating farms are more intensive than non-cooperating farms, indicators of farming intensity for the different farm groups were calculated and are presented in Table 4.

Table 4. Indicators of level of intensity of the studied farm groups; mean values ± standard deviations

Parameter	Specialised Dairy	Specialised Arable	Mixed Dairy	Cooperating Dairy	Cooperating Arable
Conventional tillage area (%)	73 ± 31	6 ± 9	70 ± 22	90 ± 22	97 ± 7
Irrigated area (%)	100 ± 0	26 ± 37	97 ± 6	82 ± 25	85 ± 29
Silage maize area (%)	32 ± 13	0	9 ± 8	15 ± 22	0
Imported concentrates fed per LU (kg LU^{-1} $year^{-1}$)	3107 ± 304	-	1746 ± 536	2448 ± 1274	-
Double cropped area (%)	43 ± 33	4 ± 9	36 ± 31	42 ± 53	14 ± 19
Cropping intensity (ratio between irrigated crop area and physical area equipped for irrigation)[a]	0.86 ± 0.65	0.14 ± 0.32	0.73 ± 0.62	0.89 ± 1.03	0.27 ± 0.38
Pesticide applications to barley	1	2.9 ± 0.84	0.5 ± 0.58	0	0.75 ± 0.5
UAA with 0 pesticide applications (%)	42 ± 13	22 ± 22	47 ± 17	90 ± 14	41 ± 6
Total labour (FTE ha^{-1})	0.055 ± 0.017	0.007 ± 0.003	0.022 ± 0.010	0.151 ± 0.159	0.013 ± 0.005

[a] double or triple cropping areas are counted two or three times respectively.

It was hypothesised that cooperation between specialised arable and livestock farms would probably limit the crop species diversification of arable farms compared to mixed farms and may thus result in short, simplified crop rotations. This hypothesis was proved to be true as cooperating arable farms, when compared to mixed farms, exhibited: 1) lower land use diversity as measured by Shannon's Diversity Index; 2) simpler crop rotations with lower species diversity; 3) smaller area alternating spring and winter crops; and 4) greater area with two or more subsequent cereals. When compared to specialised dairy farms, cooperating dairy farms had lower land use diversity, shorter crop rotations and fewer species in the rotation, less area alternating spring and winter crops and greater area with two or more subsequent cereals. These results provide further evidence of the higher intensity of farming taking place on cooperating dairy farms relative to specialised dairy farms.

Table 5. Proxies of resistance and resilience of the studied farm groups; mean values ± standard deviations

Parameter	Specialised Dairy	Specialised Arable	Mixed Dairy	Cooperating Dairy	Cooperating Arable
Shannon's diversity index	1.15 ± 0.35	1.18 ± 0.38	1.6 ± 0.17	0.83 ± 0.59	1.21 ± 0.2
Duration of crop rotation (yr)	6 ± 3.4	5 ± 2.8	6.5 ± 3.0	3.3 ± 3.4	6.5 ± 3.9
No. of crop species per rotation	3.8 ± 1.5	2.5 ± 0.9	4.1 ± 1.5	1.7 ± 0.5	2.9 ± 0.6
Area alternating spring and winter crops (ha)	54 ± 30	60 ± 36	53 ± 25	42 ± 53	25 ± 26
Area with 2 or more subsequent cereals (ha)	6 ± 7	75 ± 21	47 ± 11	22 ± 32	70 ± 11

3.2 Cavan case study results

3.2.1 Characterisation of material exchange

Cooperation in the Cavan case study generally involves large landless pork production units that export pig slurry to neighbouring farms. In the majority of cases the slurry is given at no cost to neighbouring grassland farms as there are only a small number of arable farms in close proximity to the pig units. Some of the pig farms that send slurry to arable farms have a home-milling unit where they formulate their own feed rations. These farms purchase grain from some of the arable farms they cooperate with and also from grain merchants. The grain is then used in the formulation of feed rations. Surveyed cooperating pig farms give slurry to approximately 4 arable farms on average and purchase grain from 1 arable farm on average. They also export slurry to a large number of beef and dairy cattle farms. Surveyed cooperating arable farms generally only cooperate with one pig farm but they may also cooperate with other farm types in order to access organic fertilisers. The stability of cooperation over time is strongly affected by the price of mineral fertiliser and feed grain. In years when cooperation broke down it was generally a result of price variation in these commodities. The economic burden associated with transport and spreading of slurry was generally carried by the pig farmer.

3.2.2 General farm characteristics

The mean UAA of the studied farm groups ranged from very small in specialised (7 ha) and cooperating (5 ha) pig groups to large in the specialised arable group (99 ha) and very large in the cooperating arable group (Table 6). The landless production system used on the specialised and cooperating pig farms makes it difficult to assess their stocking rate. The specialised pig farms stocked more animals per farm than the cooperating farms. There was no difference between the slaughter weight of fattening pigs on specialised and cooperating farms. Cooperating pig farms send a much higher percentage of the slurry they produce to be spread on arable land than do specialised pig farms. The grain purchased by cooperating pig farms from cooperating arable farms represents approximately 35 % of the total feed concentrates imported onto the farm. The crops species grown on specialised arable and cooperating arable farms were similar. There was no clear evidence to suggest that cooperating arable farms had orientated their land use toward neighbouring pig farms feed requirement. Land use diversity was slightly higher on specialised arable farms than on cooperating arable farms as indicated by Shannon’s diversity index.

Table 6. Characteristics of the studied farm groups; mean values ± standard deviations

Parameter	Specialised Pigs	Specialised Arable	Cooperating Pigs	Cooperating Arable
Utilised agricultural area (ha)	7.3 ± 2.5	99 ± 102	5.0 ± 2.0	199 ± 186
Stocking rate (LSU ha^{-1})	1942 ± 1080	-	1634 ± 978	-
Stocking rate (LSU farm^{-1})	14967 ± 12114	-	8927 ± 8420	-
Meat production per ha (ton LW ha^{-1})	4874 ± 4104	-	2985 ± 2905	-
Slaughter weight per pig (kg LW pig^{-1})	107.9 ± 1.8	-	108.0 ± 6.4	-
Feed concentrates (kg LU^{-1} year^{-1})	500 ± 26	-	514 ± 47	-
Total labour (FTE ha^{-1})	3.07 ± 2.88	0.0226 ± 0.014	1.88 ± 1.27	0.0137 ± 0.001
Total labour (FTE LU^{-1})	0.0018 ± 0.0006	-	0.0011 ± 0.0001	-
Slurry production per farm (m^{3})	16461 ± 14984	-	14113 ± 15763	-
Slurry going to tillage land (%)	18.0 ± 14.0	-	44.1 ± 48.4	-
Distance between cooperating farms (km)	27.3 ± 3.8	-	31.2 ± 18.6	32.0 ± 27.2
Total concentrates imported (tons)	7556 ± 6143	-	4696 ± 4553	-
Total grain exchanged (tons)	0 ± 0	-	889 ± 679	772 ± 662
Grain exchanged as % of conc. fed (%)	0 ± 0	-	34.5 ± 45.8	-
Barley (%)	-	49 ± 26	-	43 ± 42
Wheat (%)	-	22 ± 23	-	24 ± 27
Silage Maize (%)	-	1 ± 1	-	12 ± 26
Oats (%)	-	3 ± 4	-	8 ± 9
Ryegrass (%)	-	7 ± 9	-	7 ± 9
Oilseed Rape (%)		9 ± 8		3 ± 8
Shannon’s diversity index	-	1.084 ± 0.490	-	0.928 ± 0.470

3.2.3 Hypothesis testing for Cavan case study

The mean values of N input, N outputs and N surplus in the studied farm groups for the survey year 2013 are reported in Table 7. It was hypothesised that cooperation would reduce mineral fertiliser use on cooperating arable farms relative to their specialised counterparts (slurry spread on cropland instead of grassland will be recognised as a valuable nutrient source to help sustain crop yields in tillage systems). The hypothesis was proved true as the mineral N fertiliser input per hectare on cooperating arable farms was 21 kg N ha^{-1} lower than on specialised arable farms (Table 7). Lowering of mineral N fertiliser input on cooperating farms did not result in a lower total N input on cooperating farms compared to specialised farms. The total N input per hectare was approximately

40 kg higher on cooperating farms which indicates that these farms have not fully accounted for slurry they receive in their nutrient budget. The N surplus per hectare was higher on cooperating arable farms than on their specialised counterparts (Table 7). This result may be put down to the fact that cooperating arable farms are applying more N per hectare than specialised arable farms but are outputting similar N in agricultural product. Even though cooperating arable farms apply more N per hectare than specialised arable farms the overall outcome for the environment may still be positive at the district scale if less pig slurry is spread on grassland cattle farms where the N loading is already high. Unfortunately we lack the data that would allow comparison of N pressure on cooperating arable farms and cooperating dairy farms.

Table 7. Components of the N balance (kg N ha^{-1} year^{-1}) in the five groups of farms studied; mean values ± standard deviations

Parameter	Specialised Pigs	Specialised Arable	Cooperating Pigs	Cooperating Arable
Mineral fertilisers	0 ± 0	145 ± 42	0 ± 0	124 ± 43
Animals	0 ± 0	0	0 ± 0	0 ± 0
Organic fertilisers	0 ± 0	0	0 ± 0	71 ± 60
Feed concentrates	27858 ± 15499	0	24553 ± 15419	0 ± 0
Biologically fixed	0 ± 0	11 ± 17	0 ± 0	0 ± 0
Atmospheric deposition	0 ± 0	7 ± 0	0 ± 0	7 ± 0
Total inputs	27858 ± 15499	163 ± 34	24553 ± 15419	202 ± 93
Crops	0 ± 0	138 ± 14	0 ± 0	148 ± 39
Animals	15024 ± 8612	0	12945 ± 8108	0
Slurry	8510 ± 5064	0	9751 ± 8295	0
Total output	23535 ± 13398	138 ± 14	22696 ± 16083	148 ± 39
Surplus	4323 ± 4635	24 ± 38	1858 ± 5820	54 ± 83

It was hypothesised that cooperation helps to increase the fraction of the nutrients entering farm gates that comes from the district (for both arable and dairy farms) thus improving autonomy at the district scale. To test this hypothesis the district autonomy was calculated as N input (via exchange of pig slurry or grain purchase, biological fixation and deposition)/total N input for each farm group. The hypothesis was proved true for both cooperating farm groups as they both exhibited higher district N autonomy (21 % and 35 %) than their specialised counterparts (0 and 12%) (Table 8). The higher district N autonomy on cooperating arable farms relative to specialised arable farms is of greater importance than the higher district N autonomy on cooperating pig farms relative to specialised pig farms because the replacement of mineral fertiliser with organic fertiliser is a more impacting substitution. This indicates that the fraction of locally sourced nutrients entering farm-gates is higher for cooperating farms than for specialised farms. When assessed in terms of N surplus per unit agricultural product cooperating pig farms outperformed specialised pig farms and specialised arable farms outperformed cooperating arable farms.

Table 8. Nitrogen surplus, efficiency and autonomy of the studied farm groups; mean values ± standard deviations

Parameter	Specialised Pigs	Specialised Arable	Cooperating Pigs	Cooperating Arable
N surplus (kg N ha^{-1})	4323 ± 4635	24 ± 38	1858 ± 5820	54 ± 83
N efficiency (kg N sold in products per kg N input)	0.54 ± 0.03	0.88 ± 0.20	0.55 ± 0.08	0.83 ± 0.32
N surplus per unit agricultural output (kg N/kg	0.25 ± 0.28	0.19 ± 0.29	0.12 ± 0.56	0.41 ± 0.66

N sold in products)				
District N autonomy (%)	0 ± 0	11.9 ± 12.0	21.2 ± 28.5	34.6 ± 12

3.3 Domagné case study results

3.3.1 Characterisation of cooperative forage dehydration

In Domagné, cooperation via the Coopédom cooperative dehydration facility provides high quality feeds for milking cows and improves forage autonomy and protein feed autonomy (if alfalfa is grown). Farmers sign a 5-yr contract with the cooperative in which they agree to either: 1) provide land at the disposition of Coopédom for production of forage (farmers decide what is planted with agreement of Coopédom); or 2) give Coopédom a determined amount of forage for dehydration. The majority of surveyed farms agreed to the former. After dehydration, forages are returned to the same farm on which they were produced. The surveyed farms have been cooperating with Coopédom to produce forage for dehydration for 25 years on average. It is only in the last 5 years that cooperating farms have introduced miscanthus (3 ha on average per farm) displacing the annual crops - silage maize and wheat. Coopedom harvests and transports the forage crops and miscanthus. The average transport distance by road across all cooperating farms is 14.5 km (Table 7). The farm group having only alfalfa dehydrated had only 7 % of UAA growing crops harvested by Coopedom whereas the other cooperating groups had 20% of UAA growing crops harvested by Coopedom. The average costs to the farmer per ton of alfalfa, ryegrass and silage maize harvested, transported and dehydrated were € 156.5, € 175.5, and € 85, respectively, for the surveyed farms. The farmer is paid € 45 - 50 per ton of miscanthus produced.

Table 7. Descriptors of cooperation for the studied groups; mean values ± standard deviations

Parameter	Farms outside Coopédom district	Alfalfa for dehydration	Other crops for dehydration	Miscanthus for biomass furnace
Average road distance between farms and Coopédom (km)	37.5 ± 12.5	15 ± 7	14.8 ± 10	13.8 ± 7
Forage area to be dehydrated (ha)	0	6.2 ± 3	12.5 ± 2.8	18.6 ± 12.4
Forages dehydrated (tons)	0	64 ± 41	75.7 ± 66.8	153 ± 81
Agricultural area growing crops harvested by Coopedom for dehydration or burning (%)	0	7.2 ± 4.2	20.1 ± 4.6	19.7 ± 8.8
Miscanthus area (ha)	0	0	0	3.0 ± 1.4

3.3.2 General farm characteristics

The bovine stocking rate and number of milking cows per hectare was significantly higher in 2 of the cooperating farm groups than in the baseline group (Table 8). In the third cooperating group (miscanthus), these indicators were still higher than the baseline group but to a lesser extent. The higher numbers of milking cows per hectare on cooperating farms was reflected in their milk production which was higher per hectare than in the baseline group. The farm group having only alfalfa dehydrated had the highest mean milk production per hectare producing 6,886 litres. Feed concentrates fed per livestock unit per year were lowest in the baseline group which is in part explained by the fact that this group also has by far the highest % of UAA under permanent grassland (Table 8). The lower animal productivity per hectare in the baseline group may be related to the fact that these farms feed the lowest amount of concentrates per livestock unit. The farm groups that cooperate with Coopedom have only between 21 and 33% of their UAA under permanent grassland

and as such have more of their UAA under silage maize, wheat, alfalfa or miscanthus than the baseline farm group.

Table 8. Average characteristics of the studied farm groups; mean values ± standard deviations

Parameter	Baseline Dairy (2 farms pigs, 1 poultry)	Alfalfa for dehydration (1 farm pigs)	Other crops for dehydration (1 farm pigs)	Miscanthus for biomass furnace
Agricultural Area (ha)	76 ± 19	95 ± 47	64 ± 14	110 ± 41
Bovine stocking rate (LSU ha^{-1})	1.57 ± 0.30	1.81 ± 0.29	1.75 ± 0.38	1.66 ± 0.55
Milking cows (mc ha^{-1})	0.99 ± 0.21	1.26 ± 0.29	1.22 ± 0.18	1.05 ± 0.22
Milk production (lit ha^{-1})	5508 ± 1352	6886 ± 1196	6636 ± 1498	6082 ± 1142
Feed concentrate intake (kg LU^{-1} year^{-1})	680 ± 216	809 ± 199	962 ± 430	920 ± 463
Permanent grassland (%)	47 ± 4	25 ± 10	21 ± 18	33 ± 6
Silage Maize (%)	28 ± 5	32 ± 7	41 ± 14	31 ± 5
Wheat (%)	21 ± 5	27 ± 3	23 ± 10	22 ± 5
Alfalfa (%)	1 ± 2	6 ± 5	0	6 ± 4
Miscanthus (%)	0	0	0	3 ± 2

3.3.3 Hypothesis testing for Coopédom

It was hypothesised that cooperation through dehydration of forages would: 1) help to increase milk yield and forage autonomy on cooperating dairy farms relative to their specialised counterparts; and 2) improve the ratio of grass/alfalfa to silage maize, thus lowering input use. The first part of the hypothesis was proved true: milk yield per cow was higher in the farm groups that cooperated with Coopédom than in the baseline farm group (Table 9). The availability of high quality forages through Coopédom in part explains the higher milk yield in the cooperating farm groups compared to the baseline group. Higher concentrate feed use per livestock unit on cooperating farms compared to the baseline farms may also explain the higher milk yield observed. This may be related to higher intensification in cooperating farms (eg, related to higher animal renewal rate, more frequent use of medicines, etc). In terms of forage autonomy all farm groups were 100% autonomous and this precluded any improvement in forage autonomy as a result of cooperation. The second part of the hypothesis was proved false in that the farm groups growing forage for dehydration did not have a higher ratio of grass/alfalfa to silage maize compared to the baseline group (Table 9). Contrary to the second part of this hypothesis, cooperation did not have the effect of lowering input use: no. of pesticide applications on silage maize, mineral N fertiliser use per hectare and diesel use per hectare (excluding miscathus group) were all higher in cooperating farm groups relative to the baseline group. This result may be due to: 1) the baseline group having a much higher % of its UAA under permanent grassland than the cooperating farm groups and 2) more intensive operations in cooperating farms.

Table 9. Milk production, forage autonomy and input use in the groups of farms studied; mean values ± standard deviations

Parameter	Baseline Dairy	Alfalfa for dehydration	Other crops for dehydration	Miscanthus for biomass furnace
Milk production (lit cow^{-1})	7191 ± 1442	8275 ± 1847	7362 ± 1159	8057 ± 622
Farm forage autonomy (%)	100	100	100	100
Ratio of grass/alfalfa area to silage maize area	1.8 ± 0.5	1.3 ± 0.5	0.9 ± 0.4	1.3 ± 0.3
Pesticide applications to silage maize	3.7 ± 1.0	4.5 ± 1.5	4.0 ± 1.5	4.8 ± 1.9

Mineral fertilisers (kg N ha^{-1} year^{-1})	47 ± 16	71 ± 32	54 ± 12	69 ± 21
Diesel use (lit ha^{-1})	117 ± 24	120 ± 29	122 ± 38	97 ± 28

It was hypothesised that the introduction of alfalfa in crop rotations would: 1) help to reduce the need for external feed inputs such as soybean imported from abroad; and 2) reduce farm workload. The first part of the hypothesis was proved false: the highest amounts of imported concentrates fed per bovine LU were observed in farm groups that fed dehydrated alfalfa to livestock (Table 10). Similarly, higher amounts of soybean were fed per bovine LU on cooperating farms that fed alfalfa than on baseline farms that did not. Contrary to expectations, the baseline farm group had the highest concentrate feed autonomy of all farm groups (Table 10). These results illustrate the higher intensity of farming practiced on cooperating farms relative to the baseline non-cooperating farm group. The second part of the hypothesis was also proved false: total labour per hectare and per LU was found to be higher in all three cooperating farm groups than in the baseline group. This finding was unexpected given that Coopédom harvests 20 % of the UAA of two of the cooperating farm groups. It would appear that the expected decreases in external input use and labour input on cooperating dairy farms were not realised because of higher numbers of milking cows per hectare in two of the cooperating farm groups.

Table 10. Level of intensity of the studied farm groups; mean values ± standard deviations

Parameter	Baseline Dairy	Alfalfa for dehydration	Other crops for dehydration	Miscanthus for biomass furnace
Imported conc. fed per bovine LU (kg LU^{-1})	599 ± 222	809 ± 269	782 ± 227	869 ± 394
Soybean fed per bovine LU (ton LU^{-1})	270 ± 203	400 ± 218	351 ± 258	307 ± 210
Concentrate feed autonomy (%)[a]	17 ± 13	6 ± 10	15 ± 21	9 ± 12
Total labour (FTE ha^{-1})	0.022 ± 0.008	0.026 ± 0.011	0.028 ± 0.008	0.028 ± 0.006
Total labour (FTE LU^{-1})	0.018 ± 0.009	0.021 ± 0.008	0.023 ± 0.007	0.025 ± 0.005
UAA harvested by Coopédom (%)	0	6.6 ± 5	20 ± 4.5	19.7 ± 8.8
Milking cows (mc ha^{-1})	0.99 ± 0.21	1.26 ± 0.29	1.22 ± 0.18	1.05 ± 0.22

[a] Concentrate feed autonomy in terms of dry matter

It was hypothesised that the increase in area growing alfalfa in some cooperating groups would: 1) help to improve land use diversity; and 2) increase the potential for carbon sequestration. The first part of this hypothesis was proved true in that land use diversity as estimated by Shannon's Diversity Index was shown to be higher for cooperating farm groups that introduced alfalfa or alfalfa and miscanthus than for the baseline farm group (Table 11). The second part of this hypothesis was proved false: the potential to sequester carbon in soil (estimated using the % UAA under perennials as a proxy) was not higher in cooperating farm groups relative to the baseline group. The higher % UAA under arable-arable rotation in the cooperating farm groups is further evidence of the lower potential in these groups for carbon sequestration compared to the baseline group (Table 11).

Table 11. Land use diversity and perennial area of the studied farm groups; mean values ± standard deviations

Parameter	Baseline Dairy	Alfalfa for dehydration	Other crops for dehydration	Miscanthus for biomass furnace

Alfalfa (%)	1 ± 2	6 ± 5	0	6 ± 4
Miscanthus (%)	0	0	0	3 ± 2
Shannon's diversity index	1.312 ± 0.178	1.479 ± 0.149	1.225 ± 0.203	1.587 ± 0.143
UAA under perennials (%)	48 ± 5	37 ± 4	30 ± 10	43 ± 7
UAA under arable-arable rotation (%)	17 ± 17	40 ± 11	52 ± 8	37 ± 11

The N surplus can serve as an indicator of the risk to the environment of N loss from agricultural land. The N surplus for each farm group was calculated (Table 12) in order to assess the potential environmental impact of the cooperating farm groups relative to the baseline farm group. When expressed on a per hectare basis the N surplus did not vary significantly across the different farm groups indicating that cooperating with Coopédom did not affect the potential for N loss on an area basis. However, when N surplus is expressed per unit of agricultural product the cooperating farm groups growing either alfalfa or other crops for dehydration by Coopédom had a lower N surplus than the baseline farm group. This implies a lower risk of N loss per unit of agricultural product from these farm groups. It is not clear why the N surplus per unit of agricultural product is highest for the farm group growing miscanthus, but it may be related to this group having the fewest milking cows per hectare while importing the most concentrate feed per bovine livestock unit.

Table 12. N surplus and N use efficiency of the studied farm groups; mean values ± standard deviations

Parameter	Baseline Dairy	Alfalfa for dehydration	Other crops for dehydration	Miscanthus for biomass furnace
N surplus (kg N ha^{-1})	106 ± 38	107 ± 36	105 ± 26	111 ± 26
N surplus per unit agricultural output (kg N/kg N sold in products)	1.5 ± 0.55	1.09 ± 0.28	1.36 ± 0.49	1.55 ± 0.34
N use efficiency (kg N sold in products per kg N input)	0.42 ± 0.10	0.47 ± 0.06	0.43 ± 0.08	0.40 ± 0.06

3.4 Winterswijk case study results

3.4.1 Characterisation of cooperation via land sharing

Cooperation through land sharing is generally not covered by a contractual agreement. Land is generally leased on a yearly basis: dairy farmers lease grassland at the time of renewal to arable farmers for potato production. In some cases the dairy farmer may rent some land back from the arable farmer to grow silage maize, thereby replacing the fodder area lost as a result of leasing. Some less common variations of the arrangement may have dairy farmers leasing land that was previously sown with silage maize to arable farmers for potato production or arable farmers may rent land from dairy farmers to grow silage maize which they then sell to the dairy farmer. In many cases the arrangement may also allow the dairy farmer to bring his excess slurry to fertilise the land where the potatoes or silage maize are grown. The average price paid for renting land on a dairy farm was approximately 750 €/ha and the average price paid for renting land on an arable farm was approximately 1100-1200 €/ha. Surveyed dairy farms cooperated with 1 arable farm on average leasing them about 6 hectares of land on a yearly basis for potato production whereas surveyed arable farms cooperated with up to 32 dairy farms on average renting about 144 hectares of land for potato and silage maize production (Table 13). The mean UAA shown in Table 13 includes only the land that was farmed during the survey year (i.e. the land a farmer leased was excluded and the land a farmer rented was included).

Table 13. Descriptors of cooperation for the studied groups; mean values ± standard deviations

Parameter	Specialised Dairy	Specialised Arable	Mixed Dairy	Cooperating Dairy	Cooperating Arable
No. of farms cooperated with	0 ± 0	0 ± 0	0 ± 0	1 ± 0	32 ± 22
Utilised agricultural area (ha)	67 ± 23	75 ± 0	52 ± 25	72 ± 42	218 ± 150
Land leased from yr to yr (ha)	-	-	-	6 ± 3	NA
Land rented from yr to yr (ha)	-	-	-	6 ± 8	144 ± 116
Land ownership (ha)	67 ± 23	75 ± 0	52 ± 25	73 ± 36	74 ± 50

3.4.2 General farm characteristics

The mean UAA was similar in the specialised and cooperating dairy groups (Table 14). The bovine stocking rate was slightly higher on cooperating dairy farms than on specialised dairy farms. Milk production per cow was highest in the cooperating dairy group and lowest in the mixed dairy group. Cooperating dairy farms had the highest percentage land area under permanent grassland with 71%, compared to 62% on specialised dairy farms. Specialised dairy farms had higher percentage land area under silage maize and temporary grassland than cooperating dairy farms. The UAA of cooperating arable farms is three times bigger than for specialised arable farms but about 85% of the cooperating arable farms' land area is rented on a temporary or permanent basis. Potato production represents the main land use on both specialised (38%) and cooperating (74%) arable farms. Renting a large area of land on a yearly basis from many neighbouring dairy farmers has allowed cooperating arable farms to enlarge their operation and become highly specialised in potato production as they can have long potato-based crop rotations that would not otherwise be possible. Land use diversity, as estimated using Shannon's Diversity Index, was similar on specialised and cooperating dairy farms but higher on specialised arable farms than on cooperating arable farms due to these farms having essentially specialised in potato production.

Table 14. Characteristics of the studied farm groups; mean values ± standard deviations

Parameter	Specialised Dairy	Specialised Arable	Mixed Dairy	Cooperating Dairy	Cooperating Arable
Utilised agricultural area (ha)	67 ± 23	75 ± 0	52 ± 25	72 ± 42	218 ± 150
Stocking rate (LSU ha^{-1})	2.07 ± 0.37	-	1.40 ± 1.06	1.97 ± 0.41	-
Milk production per cow	7991 ± 1061	-	7072 ± 2103	8833 ± 316	-
Feed concentrate intake (kg LU^{-1} year^{-1})	1555 ± 232	-	1521 ± 175	1746 ± 355	-
Permanent grassland (%)	62 ± 19	0 ± 0	58 ± 23	68 ± 10	0 ± 0
Temporary grassland (%)	11 ± 17	3 ± 0	4 ± 8	2 ± 3	0 ± 0
Silage Maize (%)	25 ± 4	0 ± 0	6 ± 6	23 ± 16	21 ± 13
Potatoes (%)	1 ± 2	38 ± 0	0 ± 0	0 ± 0	74 ± 8
Wheat (%)	0 ± 0	16 ± 0	0 ± 0	0 ± 0	0 ± 0
Barley (%)	2 ± 2	10 ± 0	3 ± 4	6 ± 10	0 ± 0
Sugar beet (%)	0 ± 0	16 ± 0	0 ± 0	0 ± 0	3 ± 5
Forage area (%)	99 ± 2	3 ± 0	70 ± 27	93 ± 9	21 ± 13
Cereals and oilseeds area (%)	2 ± 3	38 ± 0	30 ± 27	7 ± 8	1 ± 2
Other crops (%)	0 ± 0	59 ± 0	0 ± 0	0 ± 0	77 ± 10
Shannon's diversity index (crops/grass)	0.85 ± 0.37	1.04 - 1.24	1.09 ± 0.48	0.98 ± 0.2	0.63 ± 0.14

3.4.1 Hypothesis testing for the Winterswijk case study

It was hypothesised that the renting of land by arable farmers from dairy farmers in order to "extend" their arable crop rotations would result in: 1) longer crop rotations; and 2) lower cropping frequency of potatoes and hence a lower incidence of soil-borne diseases on sensitive crops such as potatoes (as indicated by low fungicide or insecticide use on these crops). The first part of the hypothesis was proved true: cooperating arable farms have longer crop rotations than their specialised counterparts, and cooperating dairy farms that lease land to arable farmers for potato production have much longer crop rotations than specialised arable farms and specialised dairy farms (Table 15). Cooperation allows arable farms to become more specialised in potato production (and hence probably less resilient to price variations). The second part of the hypothesis was also proved true: cooperating arable and cooperating dairy farms have a lower cropping frequency of potatoes than specialised arable farms not involved in land sharing. Cropping frequency of potatoes was calculated by dividing the number of years of potatoes in the crop rotation by the total duration of the rotation. Despite the longer crop rotation duration and lower cropping frequency of potatoes on both cooperating arable and cooperating dairy farms, a reduction in pesticide use on these farms relative to specialised arable farms was not observed (Table 15). It appears that any reduction in the incidence of soil-borne diseases that might occur as a result of the lengthening of crop rotations and lowering of potato cropping frequency have not been accounted for in the pest management plans of cooperating arable farms. However, this finding is tenuous given the poor quality of pesticide use data for the arable baseline group.

Table 15. Crop rotation duration and frequency of pesticide use in the five groups of farms studied; mean values ± standard deviations

Parameter	Specialised Dairy	Specialised Arable	Mixed Dairy	Cooperating Dairy	Cooperating Arable
Duration of crop rotation on own land (yr)	4.3 ± 3.2	3.5 ± 0	2.8 ± 0.8	5.2 ± 2.0	4.2 ± 0.3
Duration of crop rotation (potatoes only) on own land (yr)	-	3.5 ± 0	-	5.8 ± 1.7	4.2 ± 0.3
Cropping frequency of potatoes	-	0.29 ± 0	-	0.19 ± 0.06	0.21 ± 0.01
Herbicide applications on potatoes	-	NA	-	2 ± 0	5 ± 1
Fungicide applications on potatoes	-	NA	-	10 ± 0	6.6 ± 2.5
Insecticide applications on potatoes	-	NA	-	1 ± 0	2.2 ± 1.0
Pesticide applications on potatoes	-	13 ± 0	-	13 ± 0	13.8 ± 3.3

It was hypothesised that the inclusion of crops such as potatoes in the grassland based rotations of cooperating dairy farms would: 1) improve weed control as a result of ploughing at time of potato planting; and 2) reduce fuel use on cooperating dairy farms as ploughing is undertaken by arable farmers. The first part of the hypothesis was proved true: the number of herbicide applications at the time of grassland renewal was lower on cooperating dairy farms than on specialised dairy farms (Table 16). The second part of the hypothesis was also proved true: diesel use per hectare was much lower on cooperating dairy farms than it was on specialised dairy farms (Table 16). The magnitude of the decrease in diesel use suggests that there may be other factors at play that are partly responsible for the lower diesel use on cooperating dairy farms. One such factor is the preference for hiring contractors on cooperating dairy farms which results in higher contractor bills but lower consumption of on-farm diesel.

Table 16. Herbicide and diesel use on the studied farm groups; mean values ± standard deviations

Parameter	Specialised Dairy	Specialised Arable	Mixed Dairy	Cooperating Dairy	Cooperating Arable
Herbicide applications on grass	0.3 ± 0.1	-	0.2 ± 0	0.06 ± 0.12	-

Diesel use per ha (lit ha^{-1})	100 ± 58	153 ± 0	55 ± 40	37 ± 37	175 ± 69

It was hypothesised that the renting of dairy fields by arable farmers for potato growing would: 1) provide dairy farmers with an outlet for excess slurry thereby reducing their N surplus per hectare; and 2) reduce mineral fertiliser use on cooperating arable farms as they can rely instead on slurry applied by dairy farmers and on legacy effect of historical applications of slurry on grasslands (e.g., high SOM and high soil P status on newly ploughed grassland). The first part of the hypothesis was proved false: cooperating dairy farms did not avail of the outlet for excess slurry and in fact had a higher N surplus per hectare compared to specialised dairy farms (Table 17). As opposed to having an excess of slurry on the farm, both specialised and cooperating dairy farms were importing organic slurries. This may be due to the surveyed farms having a derogation under the Nitrates Directive which allows them to put up to 250 kg of organic N from dairy slurry on grassland instead of the 170 kg N which they would otherwise be restricted to. The second part of the hypothesis was proved true: mineral N fertiliser use was lower on cooperating arable farms than on specialised arable farms (Table 17).

Table 17. Nitrogen surplus, efficiency and autonomy of the studied farm groups; mean values ± standard deviations

Parameter	Specialised Dairy	Specialised Arable	Mixed Dairy	Cooperating Dairy	Cooperating Arable
N surplus (kg N ha^{-1})	172 ± 43	99 ± 0	39 ± 62	200 ± 58	11 ± 32
N surplus (kg N ton-milk^{-1})	14.9 ± 4.8	-	12.0 ± 6.4	16.5 ± 2.2	-
Farm-gate N input via organic fertiliser (kg N ha^{-1})	30 ± 25	130 ± 0	14 ± 13	6 ± 6	105 ± 23
Farm-gate N output via organic fertiliser (kg N ha^{-1})	2 ± 4	NA	3 ± 6	5 ± 9	0 ± 0
Stocking rate (LSU ha^{-1})	2.07 ± 0.37	-	1.40 ± 1.06	1.97 ± 0.41	-
Farm-gate N input via mineral fertiliser (kg N ha^{-1})	89 ± 20	70 ± 0	24 ± 42	75 ± 65	50 ± 23
Farm-gate N input via feed concentrates (kg N ha^{-1})	95 ± 20	-	56 ± 76	120 ±67	-
Silage maize area (%)	25 ± 4	0 ± 0	6 ± 6	23 ± 16	21 ± 13
District N autonomy (%)	21 ± 11	? ± ?	66 ± 51	11 ± 2	66 ± 3

3.5 Thurgau and Grisons case study results

3.5.1 Characterisation of cooperation through heifer rearing

Cooperation takes place through a standardised contract: dairy calves are sent away to be reared in the mountains, they are purchased back by the lowland farmers just prior to first calving with the price being determined by age at first calving. The average price paid for pregnant heifers by lowland dairy farmers was 2370 CHF. On average, lowland dairy farmers cooperate with 3 mountain rearing farms whereas mountain rearing farms cooperate with 10 lowland dairy farms. Survey data showed that lowland dairy farms have been cooperating for 24 years with no incidence of breakdown in cooperation. The average transport distance by road between surveyed lowland dairy farms and mountain heifer rearing farms was 125 km. Cooperating lowland farms send 17 calves and buy back 14 pregnant heifers on average. The calves are transported by the heifer rearing farmer and the pregnant heifers are transported by the lowland farmer.

3.5.2 General farm characteristics

The bovine stocking rate was similar in the two lowland dairy groups and higher than in the mountain farm groups (Table 18). Cooperating lowland dairy farms had the smallest land area under permanent grassland with only 42%. In contrast, mountain heifer rearing farms had 89% of their land area under permanent grassland. The two lowland dairy farm groups have roughly the same land area dedicated to cropping activities but the cooperating farms dedicate a greater land area to more profitable root crops (potatoes and sugar beet). Land use diversity, as estimated using Shannon's Diversity Index, was higher on cooperating lowland dairy farms than on non-cooperating lowland dairy farms due to a more equitable distribution of land area among the different crop types of the former.

Table 18. Average characteristics of the studied farm groups; mean values ± standard deviations

Parameter	Lowland Dairy (baseline)	Mountain Dairy (baseline)	Lowland Dairy (no heifers)	Mountain Heifer Rearing
Agricultural Area (ha)	50 ± 19	38 ± 13	40 ± 14	39 ± 11
Bovine stocking rate (LSU ha^{-1})	2.63 ± 0.76	1.66 ± 0.50	2.68 ± 0.57	1.48± 0.24
Permanent grassland (%)	52 ± 23	79 ± 30	42 ± 12	89 ± 17
Temporary grassland (%)	10 ± 12	13 ± 19	22 ± 7	3 ± 3
Silage Maize (%)	10 ± 10	8 ± 11	11 ± 11	4 ± 7
Wheat (%)	9 ± 6	0 ± 0	10 ± 7	2 ± 4
Barley (%)	4 ± 4	0 ± 0	1 ± 3	3 ± 4
Sugar beet (%)	2 ± 4	0 ± 0	6 ± 5	0 ± 0
Potatoes (%)	0 ± 0	0 ± 0	2 ± 4	0 ± 0
Corn maize (%)	4 ± 6	0 ± 0	0 ± 0	0 ± 0
Oilseed rape (%)	1 ± 3	0 ± 0	1 ± 2	0 ± 0
Shannon's diversity index (crops/grass)	1.22 ± 0.36	0.43 ± 0.53	1.38 ± 0.15	0.37 ± 0.54

3.5.3 Hypothesis testing for Swiss case study

Regarding cooperating lowland dairy farms, it was hypothesised that if the freed up land previously occupied by heifers is used for cash cropping then: 1) farm income will increase, or, if the land is used for feed crops; then 2) concentrate feed autonomy will improve; and 3) nutrient cycles may become more closed. Contrary to the hypothesis, it appears that cooperating lowland dairy farms have opted not to increase the area on which they grow crops, but instead have opted to use the land formerly occupied by heifers to increase the number of milking cows on the farm. This is evidenced by an increase in number of milking cows per hectare in the cooperating lowland dairy group relative to the non-cooperating lowland dairy group (Table 19). Therefore, instead of the expected increase in crop production, there is an increase in milk production per hectare on cooperating lowland dairy farms relative to non-cooperating lowland dairy farms. Consequently, net income per hectare is higher on cooperating lowland dairy farms than on non-cooperating lowland dairy farms, but not for the reason originally hypothesised. It is higher for three reasons: 1) increased milk production per hectare; 2) increased production of more lucrative cash crops, such as sugar beet and potatoes; and 3) increased production of apples for sale. The second part of the hypothesis was proved false: concentrate feed autonomy was not higher in the cooperating dairy farm group than in the non-cooperating dairy farm group. This is to be expected given that cooperating dairy farms have increased the land area under cash crops at the expense of crops such as barley and corn maize that could potentially be used as feed crops. It may be that the absence of heifers from cooperating dairy farms has afforded farmers not only the time and land to increase milk production but also the time to grow more labour intensive crops such as sugar beet and potatoes which require many more applications of pesticide than cereal crops. Even though concentrate feed autonomy was lower on cooperating lowland dairy farms compared to specialised lowland dairy farms the amount of imported concentrates fed per milking cow per year was much lower on the cooperating lowland farms. This shows that cooperation has allowed lowland dairy farms to substitute expensive imported concentrates with home-grown roughages thereby increasing their overall feed autonomy. The third part of the hypothesis was proved true, but again not for the reason originally hypothesised: cooperation did result in the closing of nutrient cycles, as is evidenced by a lower N surplus per hectare on cooperating lowland dairy farms than on non-cooperating lowland dairy farms. The probable reasons for the observed lower N surplus on cooperating lowland dairy farms are the lower amount of N imported in concentrate feeds and the higher amount of N exported through cash crop sales. Nitrogen use efficiency was considerably higher on cooperating lowland dairy farms than on specialised dairy farms. This may be a result of specialising in milk production and outsourcing of heifer rearing to mountain farms.

Table 19. Land use, farm income, and input use in the groups of farms studied; mean values ± standard deviations

Parameter	Lowland Dairy (baseline)	Mountain Dairy (baseline)	Lowland Dairy (no heifers)	Mountain Heifer Rearing
Cereals and oilseeds (% UAA)	18 ± 17	0 ± 0	12 ± 8	5 ± 8
Root crops (%)	2 ± 4	0 ± 0	9 ± 8	0 ± 0
Milking cows (mc ha^{-1})	1.86 ± 0.52	0.93 ± 0.37	2.31 ± 0.75	0.05 ± 0.10
Milk production (lit cow^{-1})	8640 ± 805	7702 ± 1097	8627 ± 917	6300 ± 0
Income dairy/beef (CHF/ha)	8806 ± 1828	5490 ± 2578	10145 ± 1518	2757 ± 586
Income arable (CHF/ha)	538 ± 524	0 ± 0	1156 ± 1169	101 ± 172
Net Income (CHF/ha)	2405 ± 976	2435 ± 1168	5700 ± 2361	3881 ± 490
Concentrate feed autonomy (%)	15 ± 14	0 ± 0	9 ± 16	13 ± 25
Imported conc. fed per milking cow (tons mc^{-1} yr^{-1})	1.9 ± 0.4	1.6 ± 0.7	1.3 ± 0.8	1.4 ± 0.0
Mineral N fertilisers (kg N ha^{-1} year^{-1})	44.4 ± 21.1	26.8 ± 49.8	60.1 ± 20.8	0.4 ± 0.7
Imported feed conc. N (kg N ha^{-1} year^{-1})	122 ± 38	49 ± 18	82 ± 34	5 ± 4
Imported Org. N fertilizer (kg N ha^{-1} year^{-1})	27.1 ± 38.2	0 ± 0	0.2 ± 0.4	1.7 ± 3.4
N surplus (kg N ha^{-1})	198 ± 49	107 ± 75	124 ± 45	49 ± 10
N efficiency (kg N sold in products per kg N input)	0.34 ± 0.11	0.29 ± 0.08	0.49 ± 0.11	0.33 ± 0.14
UAA with ≥ to 1 pesticide application (%)	29 ± 19	8 ± 11	50 ± 34	0 ± 0
Diesel use (lit ha^{-1})	179 ± 73	145 ± 72	171 ± 42	121 ± 58

It was hypothesised that a switch from dairying to heifer rearing will reduce workload on mountain farms thus allowing farmers to: 1) increase their off-farm income; 2) optimise the use of home-grown feed resources; and 3) reduce external inputs of concentrated feed. The first part of the hypothesis was proved true: the mountain heifer rearing farms have lower on farm labour per hectare which allows them to take up employment outside the farm as evidenced by higher off-farm labour than on mountain farms specialised in dairy production (Table 20). The mountain heifer rearing farm group are the only farm group that can afford the time to take up work outside the farm. The opposite effect of cooperation was observed on the lowland dairy farms where the move towards specialisation in milk production has resulted in higher labour input per hectare relative to non-cooperating lowland dairy farms. The second part of the hypothesis was proved true: the mountain heifer rearing farms had the highest forage autonomy of the studied farm groups. This is probably due to the number of heifers kept on the heifer rearing farms being well matched to the mountain districts natural capacity to produce forages. It should be noted that the heifers also spend time grazing on summer pasture in the Alps which may also explain the high forage autonomy on these farms. Optimised use of home-grown feed resources on mountain heifer rearing farms is further evidenced by very high district N autonomy in this group compared to all other groups (Table 20). The district N autonomy for each farm group was calculated as N input (via organic fertiliser, biological fixation and deposition)/total N input. The third part of the hypothesis was also proved true: the amount of imported concentrates fed per LU was much lower in the mountain heifer rearing group than in the mountain dairy group. Similarly, the amount of imported concentrate fed per LU on the cooperating lowland dairy group was lower than in the non-cooperating lowland dairy group. At first this result seems counterintuitive given that cooperating lowland dairy farms have higher dairy production intensity compared to non-cooperating lowland dairy farms, but a closer look at the grazing regime and the amount of plant materials consumed per livestock unit helps to better understand this result. Non-cooperating dairy farms have a smaller pasture area available for milking cattle and that area must be shared with heifers, whereas cooperating dairy farmers can dedicate a much larger pasture area to milking cattle only. Milking cattle on cooperating lowland dairy farms also spend longer grazing each day. It is not surprising then that the total plant material fed per bovine livestock unit (including grazed pasture and home-grown and imported plant materials) is higher in the cooperating dairy farm group than in the specialised farm group where it is necessary to feed more concentrates in order to compensate for a smaller grazing area and lower importation of plant materials. This is further evidence of the potential for improved efficiency via among-farm cooperation that allows individual farms to specialise in either dairy production or heifer rearing.

Table 20. Labour, and forage autonomy on the studied farm groups; mean values ± standard deviations

Parameter	Lowland Dairy (baseline)	Mountain Dairy (baseline)	Lowland Dairy (no heifers)	Mountain Heifer Rearing
Labour on own farm (FTE ha^{-1})	0.061 ± 0.017	0.087 ± 0.028	0.080 ± 0.018	0.042 ± 0.015
Labour off-farm (FTE)	0 ± 0	0 ± 0	0 ± 0	0.375 ± 0.480
Forage autonomy grazing excluded (%)	91 ± 9	97 ± 2	89 ± 9	99 ± 2
District N autonomy (%)	36 ± 12	49 ± 11	32 ± 6	81 ± 7
Imported concentrates fed per bovine LU (ton DM LU^{-1})	1.36 ± 0.33	0.90 ± 0.47	1.12 ± 0.77	0.12 ± 0.09
Total plant material fed per bovine LU (ton DM LU^{-1})	5.09 ± 1.06	4.72 ± 1.46	5.72 ± 1.74	3.40 ± 0.84
Pasture for milking cattle (ha)	8.2 ± 4.3	16.4 ± 6.0	18.2 ± 3.7	1.3 ± 2.7
Pasture for calves < 1yr (ha)	9.5 ± 5.2	5.7 ± 9.6	0.2 ± 0.3	11.9 ± 18.1
Pasture for heifers (ha)	11.5 ± 5.1	20.7 ± 14.0	0 ± 0	25.0 ± 22.4
Milking cow grazing time (hr day^{-1})	3.3 ± 1.5	10.8 ± 3.4	4.3 ± 0.6	-
Bovine stocking rate (LSU ha^{-1})	2.63 ± 0.76	1.66 ± 0.50	2.68 ± 0.57	1.48± 0.24
Milking cows (mc ha^{-1})	1.86 ± 0.52	0.93 ± 0.37	2.31 ± 0.75	0.05 ± 0.10

The N surplus for each farm group was calculated (Table 21) in order to assess the risk to the environment of N loss from the cooperating farm groups relative to the non-cooperating baseline farm groups. When expressed on a per hectare basis the N surpluses on both cooperating lowland dairy and cooperating mountain heifer rearing farms were lower that on their respective non-cooperating counterparts. This indicates that the areal risk of N loss to the environment is lower on cooperating farms relative to non-cooperating farms. However, it should be noted that even though lowland dairy farms (baseline group) have a higher N surplus than cooperating lowland dairy farms, they import less mineral fertilizer (Table 19). Furthermore, they import more organic fertilizer (Table 19) than cooperating farms which may have positive implications at the district level by lowering N surpluses on neighbouring farms. It should also be noted that the lower permanent grassland area and higher temporary grassland area on cooperating lowland dairy farms relative to non-cooperating lowland dairy farms (Table 18) may impact negatively on biodiversity levels and increase the risk of N loss through leaching (when grassland is renewed). Recently measured nitrate levels in canton Thurgau indicate that surface water quality in the area is generally good (FOEN, 2013) while groundwater quality ranges from good to moderate (FOEN, 2011). When N surplus is expressed per unit of agricultural product the cooperating lowland dairy group had a much lower N surplus than the non-cooperating lowland dairy group farm group whereas the mountain farm groups had similar N surpluses. This finding is reflected in the N use efficiencies of the farm groups: cooperating lowland dairy farms had higher N use efficiency than non-cooperating lowland dairy farms whereas mountain heifer rearing farms had similar N use efficiencies to non-cooperating mountain dairy farms.

Table 21. N surplus and N use efficiency of the studied farm groups; mean values ± standard deviations

Parameter	Lowland Dairy (baseline)	Mountain Dairy (baseline)	Lowland Dairy (no heifers)	Mountain Heifer Rearing
N surplus (kg N ha^{-1})	198 ± 49	107 ± 75	124 ± 45	49 ± 10
N surplus per unit agricultural output (kg N/kg N sold in products)	2.18 ± 0.89	2.63 ± 0.91	1.12 ± 0.56	2.49 ± 1.35
N efficiency (kg N sold in products per kg N input)	0.34 ± 0.11	0.29 ± 0.08	0.49 ± 0.11	0.33 ± 0.14

4 Discussion

4.1 Ebro Basin – local exchange of materials among farms

In the Ebro Basin, cooperation via the exchange of straw produced on arable farms and farmyard manure produced on intensive dairy farms is a mutually beneficial partnership formed out of necessity and opportunism: the intensity of permanently housed dairy systems necessitates that dairy farmers have access to extra land to spread excess manure, and straw to bed their livestock, while neighbouring arable farms have an opportunity to replace purchased mineral fertilisers with a local source of nutrients while also improving soil organic matter levels. As a result of cooperation, dairy farms have access to a greater land area to spread excess manure. The result is a doubling of the stocking rate on cooperating dairy farms relative to specialised dairy farms as they take advantage of new outlets for manure acquired through material exchange. As this increase in stocking rate is aligned only with the farming systems ability to manage manure and not with its ability to produce livestock feed, higher volumes of plant products and concentrate feed must be imported onto the farm to sustain the system. The exchange arrangement could be improved if manure were to be exchanged for alfalfa and straw, as this would help ensure easy access to sufficient livestock feed (i.e. reducing exposure to price volatility) while also improving the nutrient exchange equality between cooperating farms. Cooperation also results in intensification on arable farms: in order to accommodate manure which must be incorporated into the soil, cooperating arable farms must use conventional tillage, a more intensive practice than that of no-till which predominates on specialised arable farms. The outcome of more intensive tillage is higher cropping intensity on cooperating arable farms relative to specialised arable farms.

The increase in farming intensity on both cooperating dairy farms as indicated by higher stocking rate, and on cooperating arable farms as indicated by the intensity of tillage and cropping has restricted the benefits that these farming systems would otherwise have realised as a result of cooperation, such as lower mineral N fertiliser input per hectare on cooperating arable farms, and lower N surplus and higher district N autonomy on cooperating dairy farms. The higher farming intensity on cooperating farms is accompanied by higher labour input per hectare compared to non-cooperating farms. Cooperating arable farms performed poorly in terms of system resilience when compared to mixed farms: they had 1) lower land use diversity as measured by Shannon's Diversity Index; 2) simpler crop rotations with lower species diversity; 3) smaller area alternating spring and winter crops; and 4) greater area with two or more subsequent cereals. A higher level of plant diversity and a greater land area alternating spring and winter crops, as observed on mixed dairy farms, is evidence of greater potential for natural pest control on these farms.

4.2 Cavan – local exchange of slurry

In the Cavan case study, highly intensive pig production on landless farms necessitates that pig farmers cooperate with many neighbouring farms so that they can effectively manage their massive N excess. Neighbouring dairy farms are generally more willing to accept slurry as they have personal experience with this nutrient source and generally have storage facilities on-farm and access to spreading equipment. Dairy farms in close proximity to the cooperating pig farms quickly reach the amount of slurry they can receive while staying within the environmental regulations. It is therefore necessary to cooperate with arable farms as they can receive higher volumes of slurry due to higher offtake in crop products. For arable farmers, the benefits of using slurry are: 1) a local and cheap source of nutrients that can replace mineral fertilisers and 2) improved district N autonomy relative to specialised arable farms. Unlike manure (as observed in the Ebro Basin study), slurry application does not have the potential to greatly increase soil organic matter. Our results showed that cooperating arable farms partly accounted for the N provided by imported slurry from cooperating pig farms as evidenced by them using less mineral fertiliser than specialised arable farms. However, the higher N surplus on cooperating arable farms indicates that the nutrient input via slurry is not fully accounted for in nutrient budgets. In addition, cooperation helped both pig farmers and arable farmers to improve their autonomy in terms of N sourced at the district scale. However, our results did not show any other effects of the cooperation on pig farmers, except a lower N surplus per unit agricultural output. Unfortunately, the quality of economic data for all the groups made it difficult to determine if the cooperation has any effect on the farm profitability.

4.3 Domagné - provision of high quality forages through the Coopédom cooperative dehydration facility

The Coopédom agricultural cooperative was initially created to close the gap between milk yields in summer, when cows graze fresh pasture, and milk yields in winter, when cows are stall-fed field cured forages. The facility to rapidly dehydrate freshly harvested forage crops ensures that the quality and nutritional value of winter feed matches that of fresh grazed pasture and also makes alfalfa a viable home-grown protein crop that, when introduced on Coopédom farms, can reduce their dependency on imported soybeans. As the rapid dehydration of forages is highly energy consuming, a biomass furnace fuelled by locally produced miscanthus and wood was constructed to reduce the systems dependency on coal imports (Berland and Salaün, 2014). Farms that cooperate with Coopédom are more intensive than specialised baseline farms: they have more milking cows per hectare, higher milk yield per cow and higher soybean use. Dehydration of forages to preserve their quality has also increased the livestock carrying capacity of farmland, thereby presenting farmers with an opportunity to further increase farm profitability by increasing the number of milking cows per hectare of land used for feed production. Farmers have seized this opportunity. As a result, cooperating dairy farm groups appeared to be more intensive than the baseline group: cooperating dairy groups have between 21% and 33% of UAA under permanent grassland compared to 47% for the baseline group. This lower area under permanent grassland on cooperating farms may be a result of Coopedom's effect on the cropping regime: crops dehydrated by Coopédom are generally shorter term crops requiring higher input use.

A higher intensity of farming on cooperating dairy farms as indicated by higher numbers of milking cows and increased arable cropping has prevented cooperating farms from realising some of the expected benefits of having forages dehydrated by Coopédom, such as lower external inputs of protein feeds from abroad and reduced farm workload. Farms that cooperate with Coopédom had higher dependence on imported protein feed such as soybean compared to specialised baseline farms. The results show that farms cooperating with Coopédom through the dehydration of alfalfa or the supply of miscanthus for furnaces had higher land use diversity than specialised dairy farms. However, the potential for increased carbon sequestration as a result of introducing the perennial crops alfalfa and miscanthus on cooperating farms was not evident when perennial crop areas and percentage of the area under arable-arable rotation on cooperating and specialised farms were compared.

The higher input use observed on cooperating farms compared to baseline farms as a result of greater numbers of milking cows per hectare and increased arable cropping could pose an environmental risk if the nutrients imported onto the farm are not used efficiently. The N surplus per hectare and per unit agricultural product was used to assess the potential environmental impact of cooperating with Coopédom. The N surplus per hectare was similar across the baseline and cooperating farm groups indicating that cooperation does little to reduce or increase environmental pressure when assessed on a land area basis. The N surplus per unit agricultural product was lower in two of the three cooperating farm groups compared to the baseline group indicating that cooperation has potential for reducing the environmental pressure per unit of product produced. Farms that cooperate can essentially increase their product output per hectare without increasing their N surplus per hectare of UAA. This is evidence of the potential for cooperation between specialised farms in a district to provide environmental benefits while also increasing farm efficiency, productivity and profitability. In regions such as Brittany, where intensive agricultural is widely practiced and water quality impacted, cooperation such as that taking place via the Coopédom cooperative can potentially increase food production without increasing the risk of water quality deterioration.

4.4 Winterswijk - land sharing between dairy and arable farms

In Winterswijk, land sharing on a yearly basis between dairy farms and arable farms has given cooperating arable farmers access to the land they require to enlarge their operation and become highly specialised in potato production as they can have long potato-based crop rotations that would not be possible if they were restricted to their own land area. Even though cooperating arable farms are highly specialised in potato production, they have a lower potato cropping frequency than non-cooperating arable farms. This is a result of the majority of their potato crop being planted on the cooperating dairy farmers' land at the time of renewing grasslands. Unfortunately, the quality of pesticide use data for the specialised arable baseline group made it difficult to determine if the reduction in cropping frequency of potatoes on cooperating arable farms resulted in a corresponding reduction in pesticide use. Interviews with cooperating arable farmers indicated that pesticide sprayings were done via a fixed preventative scheme against phytophthora, aphids and weeds. Sprayings against nematodes and other diseases connected with a short rotation of potatoes represented only a small proportion of total pesticides used. Cooperating arable farms were less reliant on mineral N fertilisers than specialised arable farms as they were able to rely instead on slurry applied by dairy farmers and on the legacy effect of historical applications of slurry on grasslands (e.g., high SOM and high soil P status on newly ploughed grassland).

For cooperating dairy farms, the planting of potatoes in crop rotations reduced the need for weed control allowing farmers to reduce the no. of pesticide applications made on grassland. Fuel use per hectare was lower on cooperating dairy farms (relative to specialised dairy farms) as ploughing operations for grassland renewing were conducted by cooperating arable farmers. The use of more contract workers on cooperating dairy farms relative to specialised dairy farms may also partly explain the lower diesel use on cooperating dairy farms. It appears that cooperating dairy farms did not avail of the extra land accessed via land sharing in order to dispose of excess slurry.

4.5 Switzerland - animal exchanges between lowland and mountain regions

Supra-regional collaboration between lowland and mountain farms through contract rearing of heifers was expected to afford lowland dairy farmers the time and land to diversify their operations and introduce new crops. Instead, cooperating lowland dairy farmers opted to use the land formerly occupied by heifers to increase the number of milking cows on their farms. As such, some of the expected benefits of cooperation through heifer rearing were not realised on cooperating lowland dairy farms, such as increased concentrate feed autonomy as a result of the growing of feed crops for use on the farm. Even though concentrate feed autonomy on cooperating lowland dairy farms was lower than on specialised lowland dairy farms the amount of imported concentrates fed per milking cow was much lower on the former due to optimised utilisation of home-grown roughages for feeding dairy cows.

Some benefits of cooperation through heifer rearing were realised on lowland dairy farms as a result of increasing the number of milking cows per hectare, such as, greater net income per hectare due to increased milk production per hectare and a lower N surplus per hectare due to increased efficiency in feeding regime and nutrient use as a result of specialising in milk production and outsourcing of heifer rearing. Drawbacks of cooperation for lowland dairy farms were a reduction in the permanent grassland area (replaced by temporary grassland) and an increase in the % UAA receiving one or more pesticide applications. Mountain farms that through cooperation were able to specialise in heifer rearing benefitted from: higher off-farm income; optimised use of home-grown feed resources; and lower external inputs of concentrate feed. The N surplus per hectare and per unit agricultural product was lower for cooperating lowland dairy farms (relative to specialised lowland dairy farms) and heifer rearing farms (relative to mountain dairy farms). This is evidence that while some of the benefits expected from supra-regional collaboration between specialised farms were not observed, this form of cooperation has potential to reduce the environmental pressure of dairy farming while improving farm profitability.

4.6 Benefits and drawbacks of among-farm mixing

The benefits and drawbacks of the different crop-livestock integration strategies assessed are tabulated for the individual case studies in Table 22. In the case of Ebro Basin, local exchange of manure for straw did not result in any benefits for the cooperating farms involved. The drawbacks identified for cooperating dairy farms such as lower district N autonomy and higher N surplus per hectare were mainly a result of having a much higher stocking rate than specialised dairy farms. The drawbacks identified on cooperating arable farms were mainly due to greater land area under conventional tillage compared to specialised arable farms. Unlike in the Ebro Basin case study, cooperation via local exchange of materials in the Cavan case study did result in some benefits for the farms involved but these were limited to higher district N autonomy for both cooperating groups and lower mineral fertiliser use for cooperating arable farms.

In providing high quality forages for feeding to dairy cattle Coopédom has enabled dairy farms to benefit from a higher milk yield per cow compared to farms that don’t cooperate with Coopédom. In some cases cooperation with Coopédom has resulted in higher land use diversity and lower N surplus per unit product. Unfortunately a number of drawbacks to cooperating with Coopédom were also identified such as higher input use and smaller land area under permanent grassland. In Winterswijk, land sharing between dairy and arable farms mostly resulted in benefits, such as longer crop rotations, lower external input use for the cooperating dairy farms relative to their specialised counterparts. On cooperating arable farms, such benefits as lower mineral fertiliser use and lower N surplus per hectare were identified. Animal exchanges between lowland and highland regions in the Swiss case study resulted in many benefits and only a few minor drawbacks for the cooperating farms involved. The benefits identified were mainly a result of optimised use of feed and labour resources within the two regions.

Table 22. Main benefits (+) and drawbacks (-) for cooperating farms compared to specialised farms (unless indicated as mixed)

Ebro Basin	Cooperating dairy farms	Cooperating arable farms
Local exchange of manure for straw	(-) higher labour input per ha (-) lower district N autonomy (-) higher N surplus per hectare	(-) higher mineral fertiliser use (-) higher cropping intensity (-) lower land use diversity (relative to mixed farm)

	(-) higher external input (roughages; concentrates)	(-) simpler crop rotations (relative to mixed farms)
Cavan	**Cooperating pig farms**	**Cooperating arable farms**
Local exchange of grain for slurry	(+) higher district N autonomy	(+) lower mineral fertiliser use (+) higher district N autonomy (-) higher N surplus per hectare/unit product
Coopédom	**Dairy farms that cooperate with Coopédom (A = alfalfa; B = other crops; C = alfalfa/miscanthus)**	
Provision of high quality forages through a cooperative dehydration facility	(+) higher milk yield per cow – groups A, B, and C (+) higher land use diversity – groups A and C (+) lower N surplus per unit product – groups A and B (-) higher input use (pesticide, fertiliser, and soybean) – groups A, B, and C (-) lower concentrate feed autonomy – groups A, B, and C (-) higher labour per hectare and per LU – groups A, B, and C (-) lower area under permanent grassland – groups A, B, and C	
Winterswijk	**Cooperating dairy farms**	**Cooperating arable farms**
Land sharing between dairy and arable farms	(+) longer crop rotations (+) lower herbicide use when renewing grassland (+) lower fuel use (-) higher N surplus per hectare	(+) lower frequency of potato in crop rotation (+) lower mineral fertiliser use (+) lower N surplus per hectare
Switzerland	**Cooperating lowland dairy farms**	**Cooperating mountain heifer rearing farms**
Animal exchanges between lowland and highland regions	(+) higher net income per ha (+) higher feed autonomy (+) lower N surplus per ha/unit product (+) lower external input of concentrate feed (+) lower fuel use (-) higher % UAA receiving 1 or more pesticide applications (-) lower % UAA under permanent grassland	(+) lower on-farm labour (+) higher off-farm income (+) higher forage autonomy (+) higher district N autonomy (+) lower N surplus per hectare (+) lower external input of concentrate feed (+) lower fuel use

5 Conclusions

Cooperation between specialised farms in a district via each of the four crop-livestock integration strategies assessed generally led to increased access to local resources, such as land, labour, feed or nutrients compared to specialised non-cooperating farms in the same district. In the case of the land made accessible as a result of cooperation, it was used to manage excess manure/slurry, increase milk production per hectare or broaden crop rotations. In the case of newly accessed labour, it was utilised to increase cropping intensity and increase income from outside the farm. In the case of newly accessed feed, it was utilised to increase milk production per hectare. Lastly, in the case of newly accessed nutrients, they were utilised to replace mineral fertiliser inputs. The farmer’s decision about how to manage these extra local resources largely determined the resulting benefits of cooperation. In three of the four district-level crop-livestock integration strategies assessed (namely: material exchange in the Ebro Basin, forage dehydration and animal exchange) there was a marked increase in farming intensity on cooperating farms relative to specialised farms, as indicated by farmers opting to increase: 1) the number of milking cows per hectare on dairy farms; and 2) the cropping intensity on arable farms. As a result of farmers opting to use the local resources made available via cooperation to increase farming intensity as opposed to diversifying their operations, some of the expected benefits of recoupling crop and livestock production at the district scale were not realised, such as lower external input use, greater farm diversification and improved district-level nutrient autonomy.

However, intensification that optimises the use of home-grown feed resources and available land and labour resources is more sustainable than intensification that relies primarily on increasing inputs from outside the district. By optimising the use of available resources within a district, cooperation generally resulted in benefits for the farms involved. The level of benefits observed were specific to the crop-livestock integration strategy employed: in the case studies of Domagné (Coopédom) and Switzerland the benefits of cooperation included improved productivity and lower N surplus per unit of agricultural output. Cooperation in these case studies allowed farms to increase production without an increase in N surplus per hectare. In contrast, benefits of cooperation through material exchange in the Ebro Basin case study were restricted to arable farms that exhibited increased productivity. There were no clear benefits observed on dairy farms in the Ebro Basin which appeared to be due to cooperation being strongly orientated towards increasing the outputs of milk and meat (and as a result, manure) from the dairy system without attempting to increase the local feed input to the system. In Cavan, the extra cost of transporting pig slurry to distant arable farms instead of neighbouring cattle farms is a burden the pig farmer must carry without receiving any benefit in return.

As a conclusion, this study provides first empirical evidence that cooperation among specialised farms at the district scale does not necessarily lead to more diversified farming systems, but it can still lead to some environmental benefits by reducing the environmental impact of farming per unit of agricultural product produced. While cooperation generally had the counterintuitive effect of increasing farming intensity this sometimes led to metabolic benefits for the farming systems concerned. The findings suggest that if district-level cooperation between specialised farms is designed with the goal of optimising local resource use efficiency within the district (e.g. Coopédom and Switzerland case studies), as opposed to the goal of increasing production (Ebro Basin case study) then it has potential as a blueprint for sustainable intensification as it can simultaneously raise yields (and income) and increase input use efficiency, without increasing the potential for negative environmental impact. However, it remains unclear if cooperation helped farmers to intensify their system, or if cooperation is required to sustain already intensive systems. These results provide a platform to discuss integration strategies between crop and livestock and to design resource efficient farming systems at different spatial scales.

6 Appendices

Appendix 1. Summary of the baseline and cooperating farm groups studied in the Ebro Basin case study.

Situation	Farm type	No. of farms assessed
Baseline 1: Specialised dairy	Dairy farms with only a small area dedicated to crop production, use their manure on their own land and buy in straw, grains and some fodder.	4 farms
Baseline 2: Specialised arable	Arable farms with no organic fertiliser input	5 farms

Baseline 3: Within-farm mixing	Farms with both dairy animals and cereal crops, on which a significant amount of the feed and/or straw for livestock is home produced and with a significant fraction of income comes from grain sales.	4 farms
Mixing Strategy: Exchange of solid manure for straw	Specialised dairy farms that exchange solid manure for straw with specialised arable farms	5 dairy and 4 arable

Appendix 2. Summary of the baseline and cooperating farm groups studied in the Cavan case study.

Situation	Farm type	No. of farms assessed
Baseline 1: Specialised pig	Pig farms that spread the majority of the slurry they produce on nearby grassland and purchase feed from grain merchants or compound feed suppliers.	3 farms
Baseline 2: Specialised arable	Arable farms that do not use organic fertiliser as an input and sell grains through the market.	6 farms
Mixing Strategy: Exchange of slurry and grain between farms	Specialised pig farms that send a significant fraction of the slurry they produce to arable land and purchase feed grain directly from arable farms.	3 pig and 6 arable

Appendix 3. Summary of the baseline and cooperating farm groups studied in the Coopédom case study.

Situation	Farm type	No. of farms assessed
Baseline: Specialised dairy farms	Dairy farms located outside the Coopédom district	7 farms
Mixing strategy 1a: cooperation through coal fuelled dehydration of forages	Dairy farms that grow some alfalfa for dehydration and feeding to animals	6 farms
Mixing strategy 1b: cooperation through coal fuelled dehydration of forages	Dairy farms that grow some silage maize and/or ryegrass for dehydration and feeding to animals (no alfalfa).	6 farms
Mixing strategy 2: cooperation through coal, miscanthus and wood fuelled dehydration of forages	Dairy farms that, in addition to having alfalfa, silage maize and ryegrass dehydrated, also introduced miscanthus.	6 farms

Appendix 4. Summary of the baseline and cooperating farm groups studied in the Winterwijk case study.

Situation	Farm type	No. of farms assessed
Baseline 1: Specialised dairy	Specialised dairy farms with grass/maize rotations, using the majority of their manure on their own land, buying in concentrates and not exchanging fields	4 farms
Baseline 2: Mixed farms	Mixed farms (i.e. dairy farms	3 farms

	growing cereals on their own land)	
Baseline 3: Specialised arable	Specialised arable farms from outside the district that do not rent land or use organic fertiliser	No farms of this type in the case study area; therefore data of arable farms on sandy soils in eastern part of the Netherlands[a] vwas used (n=15)
Mixing strategy: Land sharing between dairy farms and arable farms	Specialised dairy farms that lease some fields to arable farms specialised in potato production	3 dairy farms and 3 arable farms

[a] Dutch provinces of Gelderland, Overijssel, and Drenthe.

Appendix 5. Summary of the baseline and cooperating farm groups studied in the Swiss case study.

Situation	Farm type	No. of farms assessed
Baseline 1: Specialised, lowland dairy farms in canton Thurgau	Lowland dairy farms that raise their own heifers don't send cattle to graze alpine pastures in summer and have only a small area dedicated to crops	4 farms
Baseline 2: Specialised, mountain dairy farms in Canton Grisons	Mountain dairy farms that raise their own heifers and have only a small area dedicated to crops	4 farms
Mixing strategy: sale, by lowland farmers, of heifers to mountain farmers specialised in heifer rearing	Lowland dairy farmers that sell their weaned female pure bred dairy calves to mountain farmers specialised in heifer rearing, who later sell them back when pregnant and close to calving.	4 lowland dairy farms and 4 heifer rearing mountain farms

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