Assessment of the level of sustainable intensification of Dutch front-runner dairy and arable farms compared to the national average

MSc Thesis, Plant Production Systems


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April 2019

WAGENINGEN UNIVERSITY & RESEARCH

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The Data Used in the present work stem from the Dutch FADN system as Collected by Wageningen Economic Research. The Centre of Economic Information (CEI) has provided access to thesis data. Results shown are and remain entirely the responsibility of the author; neither they represent Wageningen Economic Research / CEI views nor constitute official statistics.

Correct citation: Weber, A., 2019, Assessment of the level of sustainable intensification of Dutch front-runner dairy and arable farms compared to the national average, MSc Thesis Wageningen University, 82 p.

Contact office.pp@wur.nl for access to data, models and scripts used for the analysis

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Acknowledgement

I would first like to thank Gerrie van de Ven for her constant support, guidance, and feedback in all of the last seven months, for that, no matter how busy she was, her door was always open, and for caring so much to help me get the most out of this work. I would also like to thank Hubertus Rijk, who stepped in as supervisor at a later stage, and showed great support and enthusiasm in hours of discussions, looking for potential explanations of the results, helping me to better understand the practical side by sharing his hands-on knowledge and taking me to see Dutch farmers.

I would further like to thank Joost van Heerwaarden for his endless help with statistics, showing patience every time I entered his office, asking for only two minutes of his time. Further thanks to Bastiaen Boekelo and Rob van den Beuken for their help whenever I ran into seemingly dead-ends and frustrations with R. As well as to Jouke Oenema, Joao Nunes Vieira da Silva, and Juliana Dias Bernardes Gil for taking the time to help me better understand underlying processes.

Thanks also to the whole group of Plant Production Systems for making me feel very welcome and for making it such an enjoyable time. Especially to the members of the thesis ring, for their stimulating suggestions and constructive comments. Last but not least, I would like to thank Martin van Ittersum for establishing the contact to Gerrie van de Ven for this thesis.

Preface

This thesis is a contribution to the work of the Knowledge Network for Sustainable Intensification (KNSI), an instrument of the Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE JPI). Initially, it was planned to compare the level of sustainable intensification of front-runner farms in the UK, Ireland, Finland, Denmark, and the Netherlands. However, as it proved to be difficult to receive detailed data on sustainable intensification from these other countries, the focus was shifted to a more detailed analysis of the Netherlands.

List of abbreviations

AWU	Annual work unit
ANV	Agrarische Natuur Vereniging
BIN	Business Information Network
CPA	Crop protection agents
CSP	Corporate Social Performance
C&O	Cows & Opportunities
EIP	Environmental impact points
FA	Front-runners arable
FACCE JPI	The Joint Programming Initiative on Agriculture, Food Security and Climate Change
FADN	Farm Accountancy Data Network
GHG	Greenhouse gas
KNSI	Knowledge Network for Sustainable Intensification
NUE	Nitrogen use efficiency
PUE	Phosphate use efficiency
SI	Sustainable intensification
VL	Veldleeuwerik
WEcR	Wageningen Economic Research
WUE	Water use efficiency

Abstract

The growing global demand for food and the changing climate place increased pressure on agricultural production, highlighting the need for it to be sustainable. The concept of sustainable intensification (SI) is at the forefront of many discussions, and is seen as a main solution for ensuring food security in the face of these challenges. The main idea behind SI is to increase agricultural productivity while simultaneously increasing the resource use efficiency and sustainability of the production. In recent years, many EU policies have focussed on enhancing the sustainability of agriculture, however, the actual level of SI of individual farms remains unknown. Therefore, the aim of this thesis is to identify the current state-of-the-art of the level of SI of better-performing arable and dairy farms in the Netherlands in comparison to the national average. The Netherlands is used as an example, as Dutch agriculture is among the most intensive in Europe, with the need for an improved sustainability. Furthermore, for the Netherlands, there is an abundance of case-specific data on both arable and dairy farms available. Farms participating in the projects Veldleeuwerik for arable farms and Cows and Opportunities for dairy farms were selected as being supposedly at the front in the Netherlands in terms of their level of SI. For the national average, a representative sample of farms from the Bedrijveninformatienet (BIN) was used. To assess the level of SI, fifteen indicators related to intensification, as well as environmental and socio-economic sustainability were defined and calculated based on BIN data provided by Wageningen Economic Research, for a time period of five (arable) and six (dairy) years.

The results showed that both front-runner groups are more intensive and have an advantage in their social sustainability compared to the national average. In the two front-runner groups, farmers are more eager to improve, and are more involved in social structures. The arable front-runner group showed to have an advantage in terms of economic sustainability, while for the dairy front-runner group there was no difference. No advantages were observed in terms of environmental sustainability per unit area, but, as a result of higher yields, an increased environmental sustainability per unit product was observed for the front-runner dairy farms. It is expected that the same would be observed for the front-runner arable farms, as a result of higher crop yields. If intensification is valued as more relevant for SI than extensification, the front-runner groups can be considered as more environmentally sustainable than the national average. However, since Dutch agriculture is already at a high level of intensification, it is recommended to focus on decreasing the environmental impact of production, rather than on increasing yields. As it was not possible to assess the complete picture of SI, because of a lack of data on biodiversity and animal welfare in the database, it is advised to Wageningen Economic Research to expand the registration on these indicators.

1 Introduction

The global demand for food is expected to increase significantly in the next thirty years for two reasons (Godfray et al., 2010; Tilman et al., 2011). On the one hand, the world population is expected to increase rapidly to up to 9.8 billion people by 2050 (United Nations, 2017). On the other hand, raising incomes especially in developing countries will lead to a change in diets with increased animal protein intake (Godfray, 2015; Pretty, 2008; Wezel et al., 2015). The increase in demand for food creates a challenge for agricultural production, as increasing competition for land, water, and energy leads to growing pressure on these natural resources. In addition, these problems are further intensified through climate change (Garnett et al., 2013; Godfray, 2015; Godfray et al., 2010; Smith et al., 2017). Through more extreme weather events such as heat waves, droughts and extreme precipitation, there is a larger variability in agricultural production (IPCC, 2014). Therefore, while increases in agricultural productivity are important to meet the growing demand, they are more than ever under pressure through constraints on natural resources (Godfray et al., 2010).

The increased pressure placed on natural resources highlights the need for a sustainable agricultural production (De Olde et al., 2017; Wezel et al., 2015). Current food production has several negative effects on the environment, such as the release of greenhouse gases (GHG), nutrient run-off, soil degradation, water shortages and biodiversity loss (Godfray et al., 2010). Therefore, it is important to focus on reducing the environmental impact of agriculture, in order to ensure food production also for future generations (Godfray et al., 2010; Wezel et al., 2015). The environmental effects of agricultural expansion – bringing more land into agriculture – are especially severe, as it leads to the emission of GHG, and to a reduction of biodiversity and ecosystem services (Godfray & Garnett, 2014; Tilman et al., 2011). Therefore, intensification – producing more food from the same or a smaller area – is considered a more sustainable solution (Godfray et al., 2010; Godfray & Garnett, 2014). As a result, many call for sustainable intensification (SI) of the food production (De Olde et al., 2017; Garnett et al., 2013; Godfray, 2015; Godfray et al., 2010; Pretty, 2008; Tilman et al., 2011; Wezel et al., 2015).

Contributing to the work of the Knowledge Network for Sustainable Intensification (KNSI), this thesis focuses on assessing the level of SI of better-performing farms in Europe, using the Netherlands as an example. The aim is to consequently be able to understand underlying reasons for a possible advantage in performance, and to eventually transfer it to a broader scale. In the next section, an introduction to the concept of SI will be provided, followed by a context-description of SI in Europe and the Netherlands, as well as an introduction to the groups of front-runner farms that will be the centre of the assessment.

1.1 Sustainable intensification

SI is considered a key solution to combat the challenges of growing food demand and increasing pressure on the supply of food (Firbank et al., 2013; Marinus et al., 2016; Pretty, 1997; Smith et al., 2017; Tilman et al., 2011). The term SI was first defined by Pretty (1997) as the "*substantial growth of yields in currently unimproved or degraded areas while at the same time protecting or even regenerating natural resources*". In the last twenty years, the concept of SI has been at the forefront of many discussions and has appeared in increasing numbers of scientific works and policy reports (Berg, 2017; Gunton et al., 2016; Wezel et al., 2015). Despite this increasingly broad use, there is no set and agreed-to definition of it, the most commonly used definitions originating from Pretty (2008), FAO (2011), or The Montpellier Panel (2013) (Berg, 2017; Struik & Kuyper, 2017; Wezel et al., 2015). Three major recurring principles that are described to characterise SI are the following:

1) An increase in productivity in order to feed the growing population (Berg, 2017; Garnett et al., 2013; Gunton et al., 2016; Wezel et al., 2015).
2) An increase in productivity with as little conversion of natural land into agricultural land as possible, hence, through intensification instead of extensification. This implies an overall increase in resource use efficiency (Berg, 2017; Firbank et al., 2013; Garnett et al., 2013; Gunton et al., 2016; Pretty et al., 2011; Wezel et al., 2015).
3) An increase in the sustainability, especially environmental sustainability, of the agricultural production (Berg, 2017; Garnett et al., 2013; Wezel et al., 2015).

That there is no clear definition for SI is related to the fact that practices that lead towards sustainability in agriculture need to be fitted to the specific circumstances, hence SI should be context- and location-specific (Godfray, 2015; Musumba et al., 2017; Pretty, 1997, 2008). Therefore, in order to assess SI, it is necessary to define it in the given context. Furthermore, in order to make SI tangible and measure progress towards it, principles and indicators need to be defined (Marinus et al., 2018; Musumba et al., 2017; Smith et al., 2017).

1.2 Sustainable intensification in Europe

Since the second world war, European agriculture has intensified rapidly (European Environment Agency, 2015). Especially, in North-Western Europe an intensive way of farming has become dominant through a rapid increase in the use of external inputs such as fertilisers and pesticides, an expanding use of agricultural machinery, as well as through a growing scale of operation (Jepsen et al., 2015; Pretty, 2008; Stoate et al., 2001; Verloop, 2013). On the one hand, this has led to high levels of production in European farming, the agricultural production in Western Europe increased by almost 70% in 40 years (Pretty, 2008). On the other hand, it has led to several negative impacts on the environment (Pretty, 2008). As a result, in the last 30 years, awareness of the impacts of modern farming on the environment has grown and sustainability of agricultural production has become an increasingly important issue in Europe (Oenema, 2013; Stoate et al., 2001). Concerns of the negative impacts of intensive agriculture on soil, air, and water quality, as well as on biodiversity have come up (Stoate et al., 2001, 2009; Verloop, 2013).

However, despite a growing awareness in terms of environmental sustainability, negative environmental impacts of agriculture remain (Jepsen et al., 2015). Hence, it is important to further increase the sustainability of European agriculture (Jepsen et al., 2015; Verloop, 2013). Furthermore, even though great increases in agricultural productivity have taken place, it is expected that this development will not continue in the future (Pretty, 2008). Already in the last years, reductions in the increase of productivity can be identified in Europe, potentially because biological yield ceilings are being approached (Godfray, 2015; Tilman et al., 2011). Europe has to tackle the challenges facing agriculture for its own food security and has a responsibility in global terms to set an example for other regions on how to manage SI. If successful practices of SI can be transferred to under-yielding countries, extensification and the related environmental effects may be reduced (Tilman et al., 2011). Therefore, it remains important for Europe to focus on SI (Godfray, 2015; Pretty, 2008).

1.3 Sustainable intensification in European politics

Agricultural sustainability has been and continues to be central to EU politics (European Commission, 2016a). At the beginning of the 1990s, agro-environmental policies were introduced to reduce emissions and since 2010 sustainable development has been mainstreamed into the Europe 2020 strategy, focussing on low carbon emissions and environmental impact, as well as on climate resilience (European Commission, 2016a; Jepsen et al., 2015). In its newest reform, in 2013, the focus of the Common Agricultural Policy (CAP) has shifted further towards sustainable agriculture, with one of its three objectives being to promote the sustainable management of natural resources and to combat climate change (European Commission, 2018b, 2016b, 2016a). EU legislations that promote sustainable agriculture are for example the Water Framework Directive, Groundwater Directive, Nitrate Directive, EU Directive on National Emission Ceilings for Atmospheric Pollutants, and the Birds and Habitats Directive (European Commission, 2016a; Stoate et al., 2001; Verloop, 2013). Further landmarks in the transition towards a more sustainable agriculture in Europe have been the 2030 Agenda for Sustainable Development, the Paris Agreement and the 4 per 1000 initiative (4p1000, 2018; European Commission, 2016a, 2016b; UNFCCC, 2018).

A further measure of the EU for more SI in agriculture is the creation of The Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE JPI). It was started in 2010 and brings together 21 member countries and New Zealand, with the goal of aligning research regarding SI in European agriculture, in order to face the challenges of ensuring food security and climate change together (FACCE JPI, 2016). This thesis will contribute to the work of the Knowledge Network for Sustainable Intensification (KNSI) which is an instrument of the FACCE JPI for improving SI in Europe under increasing constraints of climate and resource availability. In this context, the KNSI has agreed on the following definition for SI: "*Sustainable intensification means simultaneously raising yields, increasing the efficiency with which inputs are used and reducing the negative environmental effects of food production"*. Similarly, the KNSI has agreed to the following five key principles of SI: "yield gap reduction", "total factor productivity", "resource use efficiency", "limited land conversion, and "environmental sustainability".

1.4 Dutch agriculture

While agriculture makes up only about 1.9% of the GDP of 733.3 billion euros in the Netherlands (World Bank, 2019), Dutch exports of agricultural goods have reached a peak of 91.7 billion euros in 2017, most of the exports going to other European countries (CBS, 2018b). Thus, Dutch agriculture is at the centre of European agriculture. In the Netherlands, agriculture covers about 53% of the land area (FAO, 2016). The biggest farming sector is livestock farms, occupying about 50% of the agricultural land, followed by arable farms, with about 20%, and horticulture farms with about 13% (CBS, 2018a). Dutch agriculture is one of the most intensive in Europe, associated with high inputs and considerable effects on the environment (Eurostat, 2019). However, also in the Netherlands, agricultural sustainability has gained in importance over the last years, with increasingly strict policies (Oenema, 2013). Still, significant differences in environmental performance can be observed between different groups of farms, with experimental farms realising remarkably better environmental performances compared to average farms (Oenema, 2013). Examples of supposedly more sustainable groups of pioneer farms in the Netherlands are the Skylark foundation (VL, Dutch: Veldleeuwerik) for arable farms and the Cows & Opportunities project (C&O, Dutch: Koeien & Kansen) for dairy farms. VL and C&O were selected as pioneer groups for this study, as their missions are focussed on SI.

1.4.1 Veldleeuwerik

In 2002, Heineken started a project with ten arable farms, with the aim of finding out "*how, in time, one could have similar or better results with as little input as possible, without further damaging the environment and, preferably, at lower cost"* (Stichting Veldleeuwerik, 2019). Resulting from this, in 2006 the Skylark foundation was started with fifty growers from Flevoland and multiple other partners, such as Suikerunie, McCain, Agrarische Unie, and Heineken. Together these partners defined their mission "*to realise a future-proof and healthy food production, using innovation and knowledge sharing, and centring on stewardship and a responsible approach of nature, soil, air, water, and habitat*" (Stichting Veldleeuwerik, 2019). The vision is to bring together passionate individuals, exchange knowledge through continuous dialogue, and work together to a more sustainable crop production. The number of participating growers has rapidly grown, to up to 400 in 2014 (Stichting Veldleeuwerik, 2019).

As a knowledge platform, VL brings together growers with chain partners, i.e. companies in the food chain, knowledge partners, i.e. companies with a range of expert knowledge in various fields, and advice organisations that support the growers in setting up sustainability plans (Stichting Veldleeuwerik, 2019). To reach their mission and to obtain an integral approach to sustainability, the following ten Skylark indicators were defined:

1) **Product value:** referring to the economic sustainability of the farm, hence to a good yield with the optimal use of resources.
2) **Soil fertility:** hence a good soil structure and quality.
3) **Soil loss**: focussing to the prevention of erosion by leaving organic matter on the soils, and keeping the soil covered with crops for as long as possible.
4) **Nutrients**: through examination of the fertilisation plan and the N, P_2O_5 and K balance.
5) **Crop protection:** reducing the use and environmental impact of crop protection products as much as possible by paying attention to spraying technology, application time, and choice of products.
6) **Water**: focussing on the quality of the surface water, the quality and quantity of water for irrigation, and the quality of the water for the use of plant protection products.
7) **Energy**: fuel savings through improved workability of the soils and alternative energy sources.
8) **Biodiversity**: focussing on both, above- and below ground.
9) **Human capital**: energy of the farmer through relationships, networks, knowledge and inspiration sources.
10) **Local economy**: referring to social involvement and importance of the farm in the regional economy (Stichting Veldleeuwerik, 2019).

According to CLM (Kuneman, 2017), VL farms show four main differences in performance compared to national average arable farms. 1) VL farms are described as accelerators who work as catalysts for the application of sustainable practices. As a result of knowledge exchange through VL, farmers have a deeper knowledge and implement changes faster and more easily than average farmers. Based on a rough estimate, VL farmers take around 15 more sustainability measures than average farmers. 2) Soil management is most important for VL farmers. In order to protect the soil, VL farmers choose to not intensify their crop rotation, and are pioneers in the application of green manures. Second to soil, crop protection receives the greatest attention through the application of e.g. low-drift techniques and enhanced mechanical weeding. 3) VL farms are pioneers in terms of green energy. 4) Social embedding: The proportion of VL farms that are members in agricultural nature associations or receive courses on the farm is much higher compared to the national average (Kuneman, 2017).

1.4.2 Cows & Opportunities

As a group of front-runner dairy farms, C&O originates from a transfer of the insights gained at experimental farm 'De Marke' to commercial farms. De Marke was set up in 1989 with the aim of creating a dairy farm that meets strict environmental standards and at the same time produces milk yields comparable to those of commercial dairy farms. The farm is continuously developed further, and has achieved to drastically reduce the input of nutrients without an effect on milk yields through a "coherent set of simple measures" (Oenema, 2013; Verloop, 2013). The project C&O was initiated in 1998 in order to extrapolate the insights gained at De Marke to pilot farms and to correspondingly transfer environmentally sustainable farming practices to practicing farms (Oenema, 2013). Similar to De Marke, the main goal of the project is to implement expected environmental legislation and to show the environmental, technical, and economic consequences (Koeien & Kansen, 2019). Hence, the aim is to meet strict standards of environmental legislation and at the same time be entrepreneurial, economically strong, and socially accepted (Oenema, 2013). Thus, the project is a model example of SI.

Seventeen farms were selected as pilot farms. On the one hand, selection was based on farms with a high motivation for working on soil management and environmental goals (Doornewaard et al., 2016). On the other hand, farms were selected in a way that they represent the complete range of conditions for dairy farming in the Netherlands, so that almost all Dutch dairy farmers can relate to the approach of the participants (Oenema, 2013). However, the focus was set on sandy soils as these are the most challenging to manage in terms of environmental performance (Oenema, 2013). Especially in recent years, C&O farms have been larger and more intensive than the average Dutch dairy farm, as they have more dairy cows per farm and a higher milk production per cow, resulting in a higher total milk production and intensity (kg milk per ha) (Doornewaard et al., 2016).

The project is based on intensive coaching and frequent interactions as well as knowledge transfer between researchers, extension specialists and farmers (Oenema, 2013). According to the C&O website, this has already resulted in less manure production, a reduced pollution of water and soils, as well as in lower emissions of GHG (Koeien & Kansen, 2019). E.g. in the period 1998 – 2002 average nutrient surpluses decreased by 4% (N) and 25% (P) more for C&O farms compared to Dutch average dairy farms. Furthermore, in 2011, nutrient use efficiencies were 38% (N) and 85% (P) for C&O farms, compared to 30% (N) and 60% (P) for national average farms (Oenema, 2013). Hence, advantages, especially in nutrient management, have been observed for the pilot farms in the past. Strategies to reduce nutrient losses on C&O farms were based on the optimisation of internal nutrient cycling and were described as the following: 1) reducing the use of chemical fertilisers, 2) optimising the use of home-produced organic manure, 3) reducing grazing time, 4) reducing the relative number of young stock, 5) lowering crude protein content in the ration, and 6) applying and managing a catch crop after maize (Oenema, 2013).

1.5 Research objective

While there have been many efforts in EU politics towards more sustainable agriculture, it is not known what the actual performance in terms of SI of individual farms in Europe is. Most studies look at the national level, not at individual farms (Firbank et al., 2013), so they are based on statistics, averages or groups. The aim of this thesis is to identify the current state of SI of better-performing farms in the Netherlands, in order to consequently be able to understand the underlying reasons for a possible advantage in performance, and to eventually transfer it to a broader scale. For this, farms participating in the projects C&O for dairy farms and VL for arable farms are assumed to be at the front in the Netherlands in terms of their level of SI. To benchmark their results, the two front-runner groups are compared to a calculated national average. The Netherlands is selected as an example, as Dutch agriculture has a high level of intensification, with a need for an improved sustainability (Oenema, 2013). Furthermore, for the Netherlands, case-specific data on both arable and dairy farms is available. The focus is set on arable and dairy farms, as the two most important agricultural sectors in the Netherlands in terms of area and number of farms (CBS, 2018a). Since SI is a process, and not a condition at a certain point in time (Firbank et al., 2013), and there may be a high year-to-year variability in agriculture in the level of SI as a result of e.g. weather, a time span of five (arable) and six years (dairy) is considered for arable and dairy farms respectively.

The resulting research objective of this report is to *determine differences in the levels of SI between front-runner arable and dairy farms and the national average, and to consequently identify the underlying reasons for these differences.* The underlying hypothesis for this is that VL and C&O farms are at the top of the Netherlands in their level of SI.

The research questions needed to address this research objective are the following:

1) How do arable and dairy front-runner farms in the Netherlands perform in terms of SI compared to the national average?
    - What are the main differences in the level of SI between front-runner farms and the national average?
    - What can be the underlying reasons for these differences?
2) What are the main differences in the level of SI between the two arable and dairy front-runner farming groups?

It is hypothesised that a higher level of SI is found among the more innovative, namely front-runner farms. To address the research questions, 15 indicators related to intensification, as well as to environmental, and socio-economic sustainability were defined and calculated based on data provided by Wageningen Economic Research.

2 Materials and Methods

The methods of how the research questions were addressed are described in the following six subchapters. First, the area and structure of the assessed farms are described, followed by descriptions of the data collection, the selection and calculation of indicators, the clearing of data, and the statistical analyses that were carried out. For arable farms the years 2013 – 2017 were assessed, for dairy farms 2012 – 2017. For the arable farms, too few VL farms were included in the data for 2012 (explained further later). In figures, VL farms are referred to as front-runners arable (FA).

2.1 Description of the study area and farm structure

The Netherlands has a temperate climate with an average annual precipitation of 810 mm/year (1970 – 2012). Average minimum and maximum temperatures have a minimum in winter of around 0°C and 5°C respectively and a maximum in summer of 12°C and 22°C respectively (KNMI, 2019). The main soil types in the Netherlands are marine, river or boulder clay soils, sandy soils, and peat soils (Rijkswaterstaat, 2014). The VL farms are a group of more than 400 growers which were not specifically selected, but applied for participating in the project themselves. Therefore, they are spread randomly throughout the Netherlands. The farms of C&O were deliberately chosen in such a way that they represent the complete range of conditions for dairy farming in the Netherlands, with a focus on sandy soils (Oenema, 2013). The soil types of the Netherlands and the soil type and location of the individual C&O farms are given in Fig. 1.

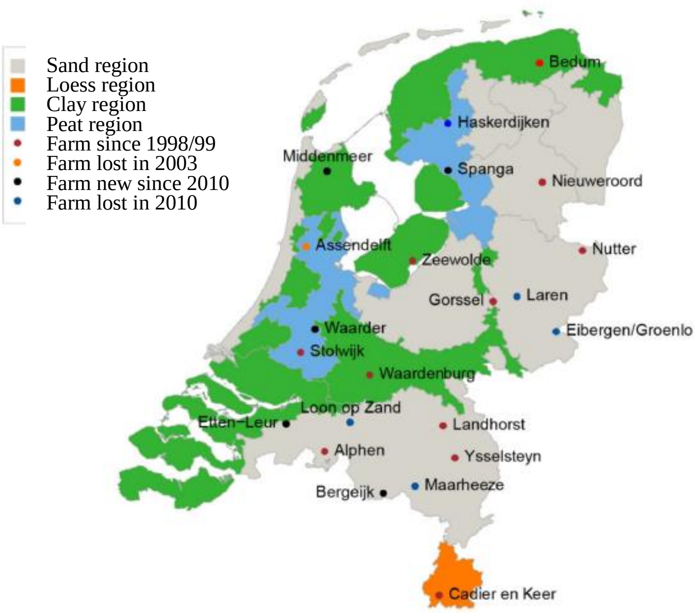


Fig. 1: Soil type and location of Cows & Opportunity farms (taken from Doornewaard et al., 2016).

Table 1 presents the proportion of the front-runner farms in this study with clay, sand, loess and peat soils. The majority of the analysed VL farms had clay soils, whereas for the C&O farms, the majority had sandy soils (Table 1) (source: BIN, 2019).

Table 1: Proportion of farms on different soils for Veldleeuwerik (VL) averaged for 2013 – 2017 and Cows & Opportunities (C&O) averaged for 2012 – 2017 (source: BIN, 2019).

Group	Clay soils (%)	Sandy soils (%)	Loess soils (%)	Peat soils (%)
VL	65	28	7	0
C&O	36	42	6	16

In terms of farm structure, the analysed VL farms had on average a much larger cultivated area than the national average (Table 2). The area of C&O farms was fairly similar to that of the national average with a significantly smaller arable area (Table 2). C&O farms had on average 136 milking cows whereas for the national average farms it was 119 milking cows, which is 2.1 dairy cows/ha cultivated area for C&O and 1.8 cows/ha for national average farms, implying that C&O farms are more intensive than the national average (source: BIN, 2019).

Table 2: Farm structure characteristics per farm for Veldleeuwerik (VL) averaged for 2013 – 2017 and Cows & Opportunities (C&O) averaged for 2012 – 2017, and the corresponding national averages. For arable farms, grass area refers to grass seed, for dairy farms to grassland; Energy area refers to energy crops for arable farms and to fodder crops for dairy farms (source: BIN, 2019).

Group	Size of the farm (ha)	Cultivated area (ha)	Arable area (ha)	Grass area (ha)	Energy/fodder area (ha)
VL	180	163	156	10	0
National average arable	95	85	79	10	10
C&O	71	64	5	52	13
National average dairy	71	66	11	54	14

2.2 Data collection and preparation of data

General statistics, such as from the EU Farm Accountancy Data Network (FADN), were not sufficiently detailed in order to calculate all indicators. Therefore, individual farm data from the more detailed Corporate Social Performance (CSP) variant of the Bedrijveninformatienet (BIN, English: Business Information Network) was provided by Wageningen Economic Research (WEcR) for the period 2012 – 2017. The CSP variant includes a wide range of data collected for EU and national policies. In addition to the mainly economic FADN data, it contains data on supposedly all topics regarded as relevant for the sustainability of farms (Van der Meer et al., 2019; Van der Veen et al., 2012). About 80% of the farms of the BIN sample are included in the CSP variant (Van der Meer et al., 2019). BIN is a stratified random sample of around 1,500 agricultural and horticultural farms in the Netherlands with a standard output above 25,000 euros. It is collected by WEcR in behalf of the Centre for Economic Information (Van der Meer et al., 2019; Van der Veen et al., 2012).

Specialised dairy and specialised arable farms as well as combinations of arable and vegetable farms were assessed. NSO-typology is a way of clustering farms in the Netherlands, calculated based on the share of the standard output (SO) of certain product groups in the total standard output of the farm (Van Everdingen & Wisman, 2016). Hence, the farms with NSO-types “dairy farms”, “arable mainly cereals”, “arable mainly starch”, “arable mainly vegetables”, “arable mainly fodder crops”, “arable other”, “combination of crops”, and “other combinations” were included in the assessment, whereas the farms of NSO-type “vegetable open air” were excluded, as they also comprised a considerable area under greenhouse production.

For the two farming sectors, arable and dairy, two groups of farms were assessed: front-runner farms (VL, C&O) and the national average. In the CBS variant, a representative sample of the farms in the Netherlands is present. This is called “national average” in this study. The front-runner farms were excluded from the national average sample for two reasons, Firstly, in order to allow a fair comparison. Secondly, because the C&O farms were specifically targeted in the data collection, so they represented a larger proportion in the sample than they do in the actual population. In the database, VL and C&O farms were only indicated as front-runner farms starting in 2012, which is why it was not possible to analyse a longer time period.

To be able to calculate all indicators, different data sets were provided, with some farms not covered in all data sheets. These were 17 arable farms and five dairy farms, that were excluded from the analysis. Furthermore, to provide a coherent picture of the front-runner farm groups, only farms of which data was present for at least three years, or farms that entered in 2016, were analysed. As a result, for the VL farms, for each year one farm was excluded, except 2017. For C&O farms, none was excluded.

For the arable farms, the year 2012 was excluded from the analysis based on two reasons. Firstly, for privacy issues, only averages of at least ten farms were allowed to be presented. There were only nine VL farms identified for 2012. Additionally, the group of VL farms identified for 2012 was much smaller than for the other years, hence, it would have not provided a consistent picture of the development over time.

The sample size representing each group is shown in Table 3. The C&O group was represented by all farms of that group, as they have been specifically targeted in the BIN data. In contrast, the VL group was represented by a sample of around 30 of more than 400 farms participating in the project, as they were not specifically targeted in the BIN data but occurred coincidentally.

Table 3: Number of farms representing Veldleeuwerik (VL), Cows & Opportunities (C&O), and the national average (source: BIN, 2019).

Group	2012	2013	2014	2015	2016	2017
VL	-	25	30	33	33	33
C&O	15	15	16	16	16	18
National average arable	-	192	196	191	193	191
National average dairy	347	343	330	344	355	350

In addition to the collection of quantitative data, the former president and potato farmer of the VL project, Adrie Vermeulen, was visited and interviewed on 27 February 2019.

For the other European countries participating in the KNSI, i.e. Finland, Denmark, Ireland, and England, protocols with the required data on arable and dairy farms were set up and requested (Appendix A). Due to various reasons it was not possible to receive this data in the frame of this thesis.

2.3 Selection and calculation of indicators

A first draft of the principles and indicators to address SI was provided by the members of the KNSI and was revised in this thesis after discussions with various experts (J. Dias Bernardes Gil, J. Oenema, G. van de Ven, K. Verloop, J. Nunes Vieira da Silva, personal communication). The final principles and corresponding indicators, as well as units, used in this thesis are presented in Table 4. They were selected on the basis of two reasons 1) for being the most relevant for SI in the given context and 2) that they are easily calculable. There was no strong focus on social sustainability or human wellbeing in this research as SI should be context- and region-specific and the two above-mentioned aspects are not much of an issue anymore in Europe (De Olde et al., 2017; Garnett et al., 2013; Pretty, 2008). Yield and input use were selected to present intensification; nutrient use efficiency, nutrient surplus, water use (efficiency), GHG emissions, feed self-sufficiency, diesel use, as well as biodiversity were selected to represent environmental sustainability; preservation of grazing, income per entrepreneur, income variability, and farmer's age were selected as indicators of socio-economic sustainability. Even if a difference in only one indicator of a principle was observed, this was enough to conclude for a difference in the respective principle.

Table 4: List of indicators and their units for the assessment of SI. The indicators cover the two aspects of SI: sustainability and intensification, and are based on three overarching principles. CPA = crop protection agents, EIP = environmental impact points, GHG = Greenhouse gas, uawu = unpaid annual work unit, # = number.

Aspect SI	Principle	Indicator	Unit arable farms		Unit dairy farms	
			Crop	Farm	Livestock	Farm
Intensi-fication	**Produc-tivity**	Yield	kg/ha	€/ha	kg & €/ha	€/ha
		Fertiliser use	-	kg/ha	-	kg/ha
		CPA use	EIP/ha	EIP/ha	-	-
		Feed costs	-	-	-	€/ha
Sustainability	**Environment**	Nutrient use efficiency	-	kg/kg	-	kg/kg
		Nutrient surplus	-	kg/ha	kg/kg	kg/ha
		Water use (efficiency)	-	m^3/ha	kg/m^3	€/m^3
		GHG emissions	-	-	CO_2eq/kg	CO_2eq/ha
		Diesel use	-	GJ/ha	-	-
		Feed self-sufficiency	-	-	-	%
		Biodiversity	-	#	-	%
	Socio-Econo-mics	Preservation of grazing	-	-	-	#
		Income per entrepreneur	-	€/uawu	-	€/uawu
		Income variability	-	$(€/uawu)^2$	-	$(€/uawu)^2$
		Age farmer	-	years	-	years

The definition of how to calculate the indicators was based mainly on databases, such as the FADN, Eurostat, or WEcR (Eurostat, 2018; FADN, 2018; Wageningen Economic Research, 2018), literature (e.g. Dantsis et al., 2010; Gómez-Limón & Sanchez-Fernandez, 2010; Häni et al., 2003), and own interpretation. All indicators were defined at farm level and selected indicators also at crop and livestock level, depending on relevance and availability of data. Farm level indicators were, if possible, given in a unit that allows comparison between arable and dairy farms, e.g. €/ha for farm level yield (Table 4). For crop level data, the five crops that were cultivated on at least ten VL farms every year, were assessed. These were sugar beet, wheat, onion, ware potato, and seed potato. In the database the data on nutrients was provided in terms of nitrogen and phosphate, so phosphorus was analysed as phosphate.

For dairy farms, in addition to the assessment per unit area, N surplus and GHG emissions were also assessed per kg product, as these were decided to be relevant indicators for intensity. For arable farms, an assessment per kg product was not carried out, as it would have had to be calculated separately for different crops, which would have been too detailed for this assessment.

For most indicators, the boundaries of the assessment were set at farm level, meaning that production and transport processes of the inputs and outputs were not considered. Only for GHG emissions the whole dairy chain was assessed, as this was in the database of WEcR. Fig. 2 presents the farm level boundaries and the related in- and outputs for a) arable farms and b) dairy farms.

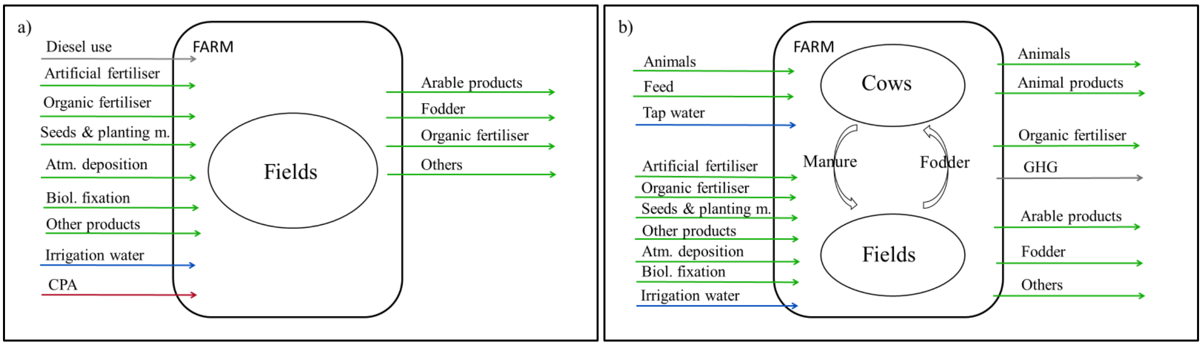


Fig. 2: Farm system boundary and related flows of inputs and outputs for a) arable farms and b) dairy farms. Green flows are evaluated as nutrient inputs and outputs, blue ones as water use, red ones as CPA use and grey ones in terms of energy use or GHG emissions. Seeds & planting m. = Seeds and planting materials, Atm. Deposition = atmospheric deposition of nitrogen, Biol. Fixation = biologic fixation of nitrogen, CPA = crop protection agents, GHG = greenhouse gasses.

In the following, the key reasons for the selection of the indicators and whether they were directly provided as such by WEcR or whether they were calculated in this thesis based on underlying data and if so, how they were calculated, are described.

2.3.1 Yield per area of land

Selection: In the face of the growing population, where food has to be produced more efficiently on the existing area, an increased agricultural productivity is essential (Godfray et al., 2010). As the most commonly used indicator in research for productivity, yield per area is a key indicator of SI, and was therefore selected as a representation for the efficiency in land use (Musumba et al., 2017; Smith et al., 2017).

Calculation: Yield was calculated for both, arable and dairy farms, at farm level (formula (1)) as well as crop and livestock level. For arable farms, the yield at crop level in fresh matter was calculated using formula (2) and for dairy farms, the yield at livestock level was calculated in two different ways (formulas (3) and (4)).

$$Farm\ level\ yield\ (€/ha) = Total\ revenues\ (€)/Area\ of\ cultivated\ land\ (ha)\ (1)$$

$$Crop\ level\ yield\ (kg/ha) = Weight\ of\ crop\ (kg)/Area\ of\ that\ crop\ (ha)\ (2)$$

$$Livestock\ yield\ 1\ (€/ha) = Revenues\ dairy\ cows\ (€)/Area\ feed\ surface\ \ (ha)\ (3)$$

$$Livestock\ yield\ 2\ (kg/ha) = Milk\ production\ (kg)/Area\ feed\ surface\ (ha)\ \ (4)$$

The revenue is defined as the generated income from the sale of goods or services, before costs are subtracted. It is calculated as the price at which goods or services are sold multiplied by the amount sold (Agrimatie, 2019). The 'revenues dairy cows' include the revenues from milk, milk products, and the turn over and growth of cattle. The 'area feed surface' includes the area of grassland and fodder crops.

2.3.2 Use of inputs

Selection: Intensification of agriculture is closely related to the use of inputs, as this has been a major cause for the increase in food production over the last 50 years (Matson et al., 1997). Correspondingly, to assess the level of intensification, it is important to assess whether a certain input is used, and how much of this input is used (Musumba et al., 2017). Hence, the use of inputs was selected as an indicator for intensification. In this thesis, fertiliser, crop protection agents (CPA), and feed were considered as inputs.

2.3.2.1 Fertiliser use

Calculation: Fertiliser use was analysed for arable and dairy farms at farm level in terms of kg P_2O_5 and kg effective N per ha, i.e. the N that is available for the crop within the year of application. The effective N was considered as this indicator was used as a measure of intensity. The values were directly provided by WEcR. Stock changes were not included. Within the fertiliser use, it was distinguished between the 'fertiliser type': fertiliser input via artificial fertiliser, animal manure and other organic manure. No data was available on K, so this was not assessed in this thesis.

2.3.2.2 Crop protection agent use

Calculation: The use of CPA was assessed only for arable farms. Discussions with experts showed that CPA use is not a relevant indicator for dairy farms, as hardly any CPAs are used on these (J. Oenema, K. Verloop, personal communication). For arable farms, this indicator was calculated at farm and crop level as the environmental impact points (EIP) per ha cultivated area. Data on EIP/ha per crop was provided by WEcR. The CPA use at farm level was calculated using formula (5).

$$CPA\ farm\ level\ (EIP/ha) = \frac{\sum_{i=1}^{n} CPA\ use\ crop_i\ (EIP/ha) * area\ crop_i\ (ha)}{\sum_{i=1}^{n} area\ crop_i\ (ha)} \quad (5)$$

Where n represents the total number of crops per farm.

2.3.2.3 Feed costs

Calculation: The purchase of off-farm feeds was calculated for dairy farms at farm level in euros/ha cultivated area. Direct data on feed costs was provided by WEcR. It did not include roughage that was produced on the farm itself. Stock changes were taken into account in the calculation of this indicator by WEcR. It was decided to use this variable instead of the total feed costs (including also the costs of on-farm produced feed), as it was used as an indicator for intensification. It was assumed that if more feed has to be bought, less is produced by the farm, so the farm is more intensive. Furthermore, the assessment boundary was set at farm level which does not include on-farm flows.

2.3.3 Nutrient use efficiency and nutrient surplus

Selection: In order to be environmentally more sustainable, it is essential for European high-input agriculture to increase its resource use efficiency and reduce its losses to the environment (Struik & Kuyper, 2017). Especially, nutrient losses may have severe impacts on the environment such as the pollution of drinking water, eutrophication, soil acidification and a contribution to climate change (Schröder & Neeteson, 2008; Verloop, 2013). Nutrient use efficiency is a measure for the efficiency in the use of nutrients, usually calculated as the nutrient output divided by the nutrient input. Nutrient surplus is the amount of nutrient loss, calculated as the difference of nutrient input and output. Nutrient use efficiencies should always be assessed in relation to productivity levels (nutrient outputs) and the nutrient surplus, as, depending on the productivity level of the farm, a high nutrient use efficiency can imply a high and a low nutrient surplus (Oenema, 2015). Increasing nutrient use efficiencies, and reducing nutrient surpluses are key goals, and were selected as indicators for SI (Musumba et al., 2017; Smith et al., 2017).

Calculation: Nutrient use efficiency and nutrient surplus were calculated in terms of N and P_2O_5. For dairy and arable farms, they were calculated at farm level using formulas (6) and (7). Furthermore, for dairy farms, the nutrient surplus was calculated for N at livestock level, expressed per kg of milk (formula (8)).

$$NUE = kg\ nutrient\ in\ outputs/kg\ nutrient\ in\ inputs \quad (6)$$

$$Nutrient\ surplus\ (kg/ha) = kg\ nutrient\ in\ inputs\ - kg\ nutrient\ in\ outputs \quad (7)$$

$$Nutrient\ surplus\ livestock\ (kg/kg) = \frac{(Nutrient\ surplus)(kg/ha) * area\ (ha)}{kg\ milk\ produced\ by\ farm} \quad (8)$$

Where kg nutrient refers to either kg N or kg P_2O_5, and area to the area of cultivated land. Table 5 shows the nutrient inputs and outputs that were considered in this assessment, separately for arable and dairy farms. Data on the amount of N and P_2O_5 in the different in- and outputs was provided by WEcR. For organic fertilisers, the mineral and organic N applied were included, as it was the aim to look at long-term effects and development. As a consequence, higher efficiencies and lower surpluses can be expected from farms using only mineral fertilisers compared to farms using mineral as well as organic N inputs (Schröder, 2014). Stock changes were considered.

Table 5: Nitrogen and phosphate inputs and outputs in arable and dairy farming that were considered in the SI assessment. Biological fixation and atmospheric deposition only apply for nitrogen. "Other products" and "others" include all purchases or sales of products that do not fall within the above criteria.

Sector	Inputs	Outputs
Arable	○ Artificial fertiliser ○ Organic fertiliser ○ Seeds and planting material ○ Biological fixation (N) ○ Atmospheric deposition (N) ○ Other products	○ Fodder ○ Arable products (excl. roughage) ○ Organic fertiliser ○ Others
Dairy	○ Animals ○ Feed ○ Artificial fertiliser ○ Organic fertiliser ○ Seeds and planting material ○ Biological fixation (N) ○ Atmospheric deposition (N) ○ Other products	○ Animals ○ Animal products ○ Fodder ○ Arable products (excl. roughage) ○ Organic fertiliser ○ Others

2.3.4 Water use

Selection: As a result of the growing population and changing dietary preferences, the global demand for water is rising, hence there is increased competition for water resources (Bouman, 2007). Especially, the water use of agriculture is considerable (Bouman, 2007). Therefore, for agriculture to be more sustainable, it is essential to reduce the amount of irrigation and tap water used which is why this indicator was selected (OECD, 2001; Smith et al., 2017).

Calculation: For arable farms, irrigation water use was assessed at farm level (formula (9)). For dairy farms, water use efficiency (WUE) was assessed at farm and livestock level (formulas (10) and (11)). For arable farms, irrigation water use was examined as an input. For dairy farms, irrigation water use on the fields, as well as tap water use for drinking and cleaning in the stables, were considered. WUE was not calculated for arable farms as irrigation water use was not available at crop level, hence, yield could not be directly linked to water use. Instead, irrigation water use was calculated. This was done assuming that only carrots, winter carrots, chicory, potato (ware, seed, and starch potato) as well as onions and shallots are irrigated. Therefore, for the arable farms, the total irrigation water use per farm was divided equally among the area of these crops. For dairy farms, the WUE was used as an indicator, as milk was assumed to be the main product the water use contributes to.

$$Water\ use\ arable\ farms (m^3/ha) = Water\ use\ irrigation\ (m^3)/crop\ area\ (ha)\ (9)$$

$$WUE\ farm\ level\ dairy\ (€/m^3) = Total\ revenues\ (€)/Total\ water\ use\ (m^3)\ (10)$$

$$WUE\ livestock\ dairy\ (kg/m^3) = Milk\ yield\ (kg)/Total\ water\ use\ (m^3)\ (11)$$

Where crop area refers to the area of carrots, winter carrots, chicory, potato (ware, seed and starch potato), onions, and shallots. Total water use includes irrigation and tap water use.

Overall, data on water use was only available for a very limited number of farms. Furthermore, this indicator has to be treated with great caution because the water use heavily depends on the soil type and weather, and is therefore not necessarily an indicator of good management practice.

2.3.5 Greenhouse gas emissions

Selection: European high-input agriculture is a main emitter of GHG through fertiliser use, ruminants, and land use change, and is thus a major contributor to climate change (Musumba et al., 2017). Therefore, GHG emissions was selected as an indicator for environmental sustainability SI.

Calculation: GHG emissions were assessed only for dairy farms at farm and livestock level, as no data was available for arable farms. The assessment method of WEcR for the GHG emissions is *cradle to factory gate*, meaning that it includes the production of the raw materials used by the dairy industry as input for the cultivation, the transport and processing of the feed, the production of milk, transport of milk to the factory and between production locations, as well as dairy processing and packaging (Agrimatie, 2019).

Three methods for assessing GHG emissions were chosen:

1) For farm level emissions, total CO_2, CH_4 and N_2O emissions were assessed in terms of CO_2 equivalents per ha cultivated area. The emissions in kg were converted to CO_2 equiv. using the conversion factors used by WEcR (1 kg N_2O = 298 CO_2 equiv., 1 kg CH_4= 25 CO_2 equiv.) (Agrimatie, 2019).
2) For the livestock level, the emissions in terms of CO_2 equivalents per kg of milk were analysed. This variable was directly provided by WEcR and included the total emission that is allocated to milk production, i.e. excluding meat, side-breeds and broadening activities. This indicator was calculated only for the years 2013 – 2017, as for 2012 only data for one farm was available.
3) The proportions of the sources of emissions were calculated. They were provided by WEcR. For the national average and C&O, the proportion was averaged over the six years and presented in pie charts. Sources include:
    - Rumen and bowel fermentation (CH_4)
    - Manure (CH_4 and N_2O)
    - Soil (N_2O directly and indirectly)
    - Energy use (CO_2)
    - Contract work and similar (CO_2)

- Purchased feed (CO_2)
- Purchased fertiliser (CO_2 and N_2O)
- Other purchase (CO_2)

Purchased feed, purchased fertiliser and other purchase were identified as off-farm emissions.

2.3.6 Diesel use

Selection: Fossil energy use in agriculture has two main issues regarding sustainability. On the one hand, fossil energy is an exhaustible resource that therefore should be used with particular care. On the other hand, its use leads to the emission of CO_2 (Dalgaard et al., 2001). Agriculture is a major energy consumer, mainly in the form of diesel for on-field activities or transport (Dalgaard et al., 2001). Because no data on GHG emissions was available for arable farms, diesel use was selected as alternative indicator for these farms.

Calculation: Diesel use was analysed as the diesel use (GJ) per ha, a variable directly provided by WEcR. The diesel use by contract work was not included in the calculation of this indicator by WEcR, and no indication about the amount of contract work hired by the farms was available. Therefore, contract work was not considered in this indicator, and farms that hired a lot of contract work, unjustly seem very diesel-use-efficient.

2.3.7 Feed self-sufficiency

Selection: Feed self-sufficiency is defined as the ability of the farm to satisfy the energy demands of the livestock with feed produced on the farm (Ripoll-Bosch et al., 2014). The production of feed concentrate is a major off-farm emission, as it has a very high energy demand as a result of processing and transport and thus is a major contributor to climate change (Guerci et al., 2013). Hence, increasing the feed self-sufficiency leads to reduced off-farm emissions and is considered a potential method to increase the environmental sustainability of dairy farms (Lebacq et al., 2015). Therefore, it was selected as an indicator for environmental sustainability.

Calculation: Feed self-sufficiency was assessed for dairy farms at farm level as the proportion of feed produced on-farm of the total feed consumed by the dairy herd. It was calculated using formula (12).

$$Feed\ self-sufficiency\ (\%) = \frac{Grass\ (kVEM) + Maize(kVEM)}{Total\ feed\ value\ intake\ (kVEM)} * 100\% \quad (12)$$

Where grass and maize refer to the corresponding feed value intake by the dairy herd. It was assumed that all grass and maize fed to the cows was produced on-farm. As this is not the case for all farms, the values of feed self-sufficiency are higher than in reality.

2.3.8 Biodiversity

Selection: Biodiversity is important for the resilience of ecosystems. However, agricultural intensification has negative effects on the biodiversity of farms and may have spill-over effects on the surrounding areas (Loos et al., 2014). At the same time, about half of all species in Europe depend on agricultural habitats. Therefore, agricultural areas in Europe are of great importance for conserving biodiversity and hence, biodiversity was selected as indicator for SI (Stoate et al., 2009).

Calculation: Biodiversity was assessed for arable and dairy farms at farm level. There was no specific data on biodiversity available. Therefore, for arable farms agro-diversity, calculated as the number of crops cultivated per year, was used as an indication of biodiversity. For dairy farms, the cutting percentage of grassland was assessed, a variable that was provided directly by WEcR. It was calculated by WEcR as the share of mowed grassland as a percentage of the total area of grassland. It was assumed that a low agro-diversity and a high cutting percentage result in a low biodiversity, because of a lower species diversity (Van Elsen, 2000). However, this has to be treated with great caution, as it is only the case if the farm has no further biodiversity measures such as flower or buffer strips.

2.3.9 Animal welfare

Animal welfare is an important issue for the European government and its citizens and has gained increasing attention in recent years (Webb et al., 2019). Therefore, it was identified as a relevant socio-economic indicator. Related variables that were provided and considered to be used as an indication of animal welfare were the number of dairy cows per ha of feed area, the costs for animal health, antibiotics use, and days with a minimum of six hours of grazing. It was decided not to use these variables as indicators for animal welfare as, respectively, they were not a viable indicator for animal welfare, their analysis would have been ambiguous, or data for less than ten C&O was available for the individual years. It was therefore decided to exclude this indicator from the analysis, and to assess preservation of grazing instead.

2.3.10 Preservation of grazing

Selection: Grazing has gained increasing importance in the dairy sector of the Netherlands over the last years. It is characteristic for the Dutch countryside, is a Dutch trademark, and contributes to the natural behaviour of the cows (Duurzame Zuivelketen, 2019b). Hence, the grazing covenant was founded in 2012 and the “Duurzame Zuivelketen” (English: Sustainable dairy chain) has formulated the preservation of grazing as one of its four 2020 goals for a future-proof and responsible dairy sector (Duurzame Zuivelketen, 2019a). As a result, preservation of grazing was identified as a relevant socio-economic indicator for this SI assessment.

Calculation: Preservation of grazing was assessed for dairy farms at farm level. It was assessed as the number of grazing days per year, a variable directly provided by WEcR. Data for less than ten C&O farms was available for 2012, hence this year was excluded from the analysis of this indicator.

2.3.11 Age of the farmer

Selection: There are concerns about an increasing age of European, hence also Dutch, farmers (Zagata & Sutherland, 2015). This brings the risk of reduced generational renewal which raises the issue of farming-specific knowledge being lost, and the risk of limited innovations (Bijttebier et al., 2018; Fennell, 1981). Therefore, farmers' age was selected as an indicator.

Calculation: The age of the farmer was evaluated for dairy and arable farms at farm level as the age of the oldest entrepreneur. This variable was provided by WEcR. It would have been interesting to also assess the age of the youngest entrepreneur. Unfortunately, this was not available in the database.

2.3.12 Farm income per entrepreneur

Selection: Profitability is central to the economic side of sustainability and farm income is a key indicator for profitability (Dantsis et al., 2010). A meaningful way to assess farm income is to look at the income per entrepreneur. Hence, this was selected as indicator for socio-economic sustainability of SI.

Calculation: This indicator was assessed for arable and dairy farms at farm level as the net farm income (€) per unpaid annual work unit (AWU), a variable provided by WEcR. The farm income was calculated by WEcR by subtracting the paid costs, depreciation, and the balance of extraordinary income and expenses from the total farm revenue. An AWU corresponded to 2000 hours worked, where one person could be a maximum of one AWU.

2.3.13 Income variability

Selection: Income variability is a key indicator for SI as it is a measure for the stability of the farm income and indicates variability in for example markets or climate (Musumba et al., 2017). This is why it was selected as indicator of SI also in this thesis.

Calculation: Income variability was assessed at farm level for arable and dairy farms. For each farm, the variance in the income per entrepreneur was calculated over the years. Consequently, for the different groups, the mean of the variances of the individual farms was taken (formula (13)).

$$Income\ variability = mean\left(\frac{\sum(x_i - \bar{x})^2}{n-1}\right) \quad (13)$$

- x_i = Income per unpaid AWU of individual farm
- $\bar{x}$ = Mean of income per unpaid AWU over 2013 – 2017 (arable farms) and 2012 – 2017 (dairy farms)
- n = number of observations

A linear regression model was used in order to assess the correlation between the variance and income per entrepreneur. As no significant correlation was identified, it was decided to stick to the variance, and not calculate the coefficient of variation instead (Joost van Heerwaarden, personal communication).

2.4 Determination of outliers

Boxplots were created in order to check for outliers in the data. As it was only possible to show averages of at least ten farms, boxplots cannot be presented and outlier farms were excluded from the assessment. In the following, it will be described which farms were excluded based on this.

Two arable farms and one dairy farm were excluded for the national average from the age calculations because the age figure was above 2000.

Farms of the national average with outliers that were practically impossible were completely excluded from the assessment. For arable farms, these were e.g. farms with an N fertiliser use of above 1000 kg N/ha, negative N or P_2O_5 artificial fertiliser inputs, P_2O_5 use efficiencies above 30, P_2O_5 surpluses above 350 kg/ha, sugar beet yields above 170,000 kg/ha. Furthermore, this included a farm with extremely high farm yields (15 times higher than the median), and a farm with extremely high CPA use (more than ten times higher than the median). For dairy farms, these were e.g. farms with an N fertiliser input of more than 700 kg N/ha, P_2O_5 use efficiencies of 30, as well as a farm with an extremely high feed input (more than 18 times than the median), and a farm with an extremely high farm yield (eight times higher than the median). In total these were 21 arable farms and five dairy farms that were excluded. To be consistent, these farms were excluded from the whole assessment, as wrong values of one indicator may have influenced other indicator values.

For the front-runner farm groups, farms with outliers were only excluded for the specific indicator and year, as these were already small groups of farms and no influence on other indicators were identified. For the VL farms this was one farm for one year with an N fertiliser use of more than 500 kg N/ha and an N surplus of above 400 kg N/ha. For the C&O group, this was one farm with GHG emissions of around 65,000 CO_2 equiv. per ha for two years.

2.5 Data analysis

To calculate the indicators, data analysis was carried out using Excel and R Studio. Indicator values were calculated per year for each individual farm. Yearly averages and standard deviations (Std) were determined for the different groups. ANOVAs were run using R Studio on linear regression models of the averages over the total time period, to determine significant structural differences between the front-runner farms and the national averages. For this, it was assumed that a farm that is a front-runner farm for more than two years or has entered the front-runner project after 2016, is always a front-runner farm. Hence, also farms that left the project after two years were still considered front-runner farms, which may have had a negative effect on the front-runner farm results. To determine significant differences, alpha was set as 0.05. Table 6 shows the levels of significance that were used.

Table 6: Levels of significance based on the p-values. n.s.= not significant.

P-value range	Level of significance
0 < p < 0.001	***
0.001 < p < 0.01	**
0.01 < p < 0.05	*
p > 0.05	n.s.

2.6 Presentation of results

Bar graphs were created to present the results of the indicators. The Std is shown in error bars. For the stacked bar graphs, i.e. fertiliser use and GHG emissions, the Std of the total farmland fertiliser use, and of the total emissions in CO_2 equiv. are presented.

To better visualise the results, radar charts were created. For the radar charts at indicator level, scaling was carried out based on the level of significant difference of the front-runner farms compared to the national average. The national average was defined as reference point and scaled as five. Table 7 shows the score that was attributed to the front-runner farms. For indicators with multiple values, such as crop level indicators and livestock level yield, the level of significance was averaged to create a single value for the radar chart.

Table 7: Scores attributed to front-runner farms based on the level of significance compared to the national average.

Level of significance	If "better"	If "worse"
n.s.	5.00	5.00
*	6.67	3.33
**	8.34	1.66
***	10.00	0.00

For yield per area of land and input use, higher values were defined as more intensive, i.e. "better". Higher values for nutrient use efficiencies, WUE, feed self-sufficiency, and biodiversity, as well as lower values for nutrient surpluses, water use, GHG emissions, and diesel use were defined as environmentally more sustainable and hence "better". Higher values for preservation of grazing, income per entrepreneur and lower values for farmer's age, and income variability were defined as more socio-economically sustainable, i.e. as "better". Respectively, the opposite was defined as "worse".

For the radar charts at principle level, the scores of the indicators attributed to the three principles productivity, environment, and socio-economics (see Table 4) were averaged for each principle. All indicators were weighed equally.

3 Results

In the following, the results of this thesis are presented per indicator, separately for arable and dairy farms. Graphs are presented only for the cases in which significant differences between the national average and front-runner farms were observed. For fertiliser use, the graphs are presented, also if no significant differences were observed, as this was identified as important indicator. Tendencies for development of the indicators over time were identified but not tested statistically. Tables with the yearly averages of the indicators with significant differences, and fertiliser use, can be found in Appendix B. The graphs of the other indicators with non-significant differences can be found in Appendix C; for these, the yearly averages are shown as labels in the graphs.

3.1 Arable farms

For the arable farms, it was tested for significant differences in the averages over 2013 – 2017 between the two groups, i.e. the national average arable and VL farms.

3.1.1 Yield

At farm level, no significant difference in yield in terms of revenues was observed between the national average arable farms and the VL farms ($p = 0.662$). The mean farm yield over the five years was 6,165 €/ha for the national average, for the VL farms it was 311 €/ha lower. The Std was 3,694 €/ha for the national average and 3,936 €/ha for the VL farms.

At crop level, significant differences in yield were observed for sugar beet ($p = 0.015$*), wheat ($p = 0.020$*), ware potato ($p = 0.016$*), and seed potato ($p = 0.044$*). No significant differences in yield were observed for onion ($p = 0.431$). Table 8 shows the average crop yields of the two groups for the main crops, their Std, and level of significance.

*Table 8: Average crop yield and the standard deviation (Std) in kg fresh weight/ha for Veldleeuwerik (VL) and the national average (Nt) over the years 2013 – 2017. P is the level of significance, * indicates p<0.05, n.s. indicates no significant difference.*

Crop	Yield VL	Yield Nt	Std VL	Std Nt	P
Sugar beet	89,761	84,978	12,294	13,354	*
Wheat	9,195	8,563	1,274	1,623	*
Onion	53,135	50,766	13,145	15,132	n.s.
Ware potato	51,596	46,135	7,215	12,331	*
Seed potato	39,693	36,184	5,644	6,744	*

Fig. 3 presents the yearly yield averages for those crops that showed significant yield differences between the national average and the VL farms. For all four crops, every year the average yield of VL was higher than that of the national average. In the development of the yields over time, no trend was identified (Fig. 3).

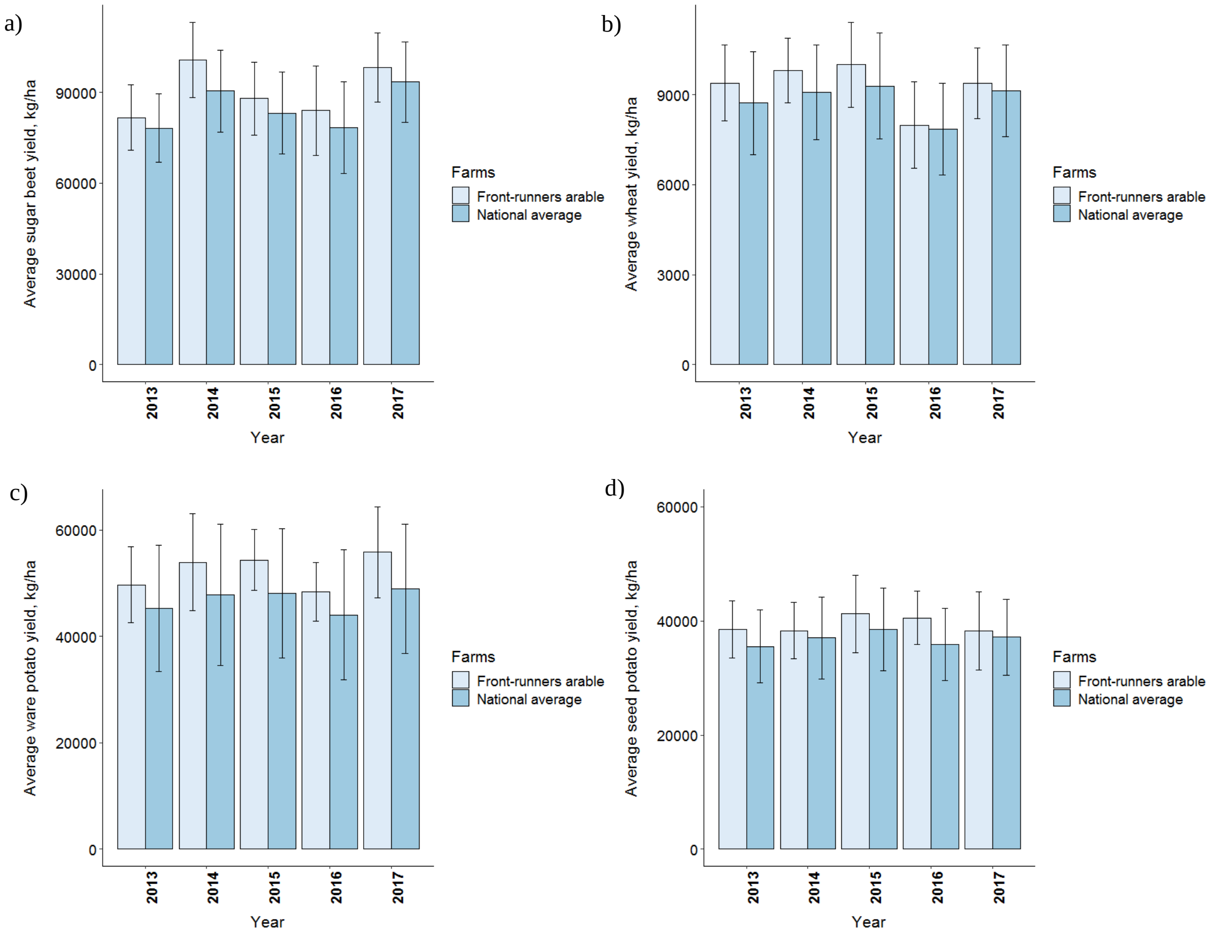


Fig. 3: Average crop yield in kg fresh weight/ha of a) sugar beet, b) wheat, c) ware potato, and d) seed potato for front-runner arable farms and the national average for the years 2013 – 2017. Error bars show the standard deviations of the respective years.

3.1.2 Use of inputs

3.1.2.1 Fertiliser use

No significant differences were observed in the use of nitrogen fertiliser ($p = 0.056$) and phosphate fertiliser ($p = 0.115$). The mean N fertiliser use was 175 kg active N/ha for the national average and 17 kg/ha higher for the VL farms. Respectively, the Std was 52 kg N/ha for the national average and 40 kg N/ha for VL farms. The mean of the P_2O_5 fertiliser use was 59 kg P_2O_5/ha for the national average and 4 kg/ha higher for VL farms. The Std for P_2O_5 fertiliser use was 20 kg/ha for the national average and 17 kg/ha for VL farms. Fig. 4 shows the yearly average fertiliser use for both groups, split up according to the type of fertiliser used. Within the years, the proportion of fertiliser type used to apply N and P_2O_5 was similar for the national average and the VL farms. For both groups, N was mainly applied using artificial fertiliser and P_2O_5 using organic manure. No specific trend was identified for the development of fertiliser use over time (Fig. 4).

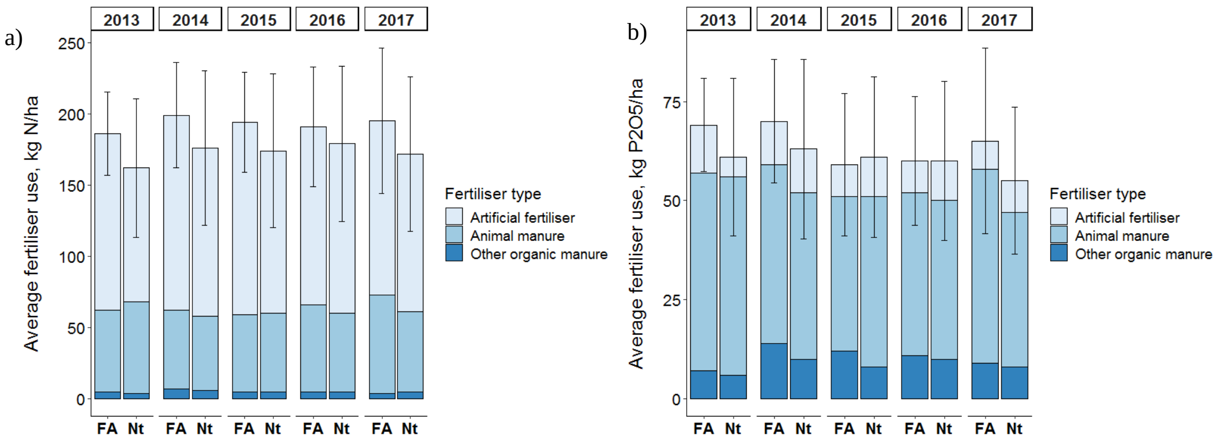


Fig. 4: Average fertiliser use in a) kg active N/ha and b) kg P_2O_5/ha for front-runner arable farms (FA) and the national average (Nt) and the years 2013 – 2017. Error bars show the standard deviations of the total farmland fertiliser use of the respective years.

3.1.2.2 Crop protection agent use

No significant differences were observed for CPA use at farm ($p = 0.924$) and crop level. The mean farm level CPA use of the national average was 1,987 EIP/ha, while that of VL farms was 14 EIP/ha higher. The Std at farm level was 1,026 EIP/ha for the national average and 619 EIP/ha for VL farms. Table 9 shows the average CPA use at crop level for the different crops, the Std as well as the respective level of significance.

Table 9: Average crop protection agent (CPA) use in EIP/ha for Veldleeuwerik (VL) and the national average (Nt) over the years 2013 – 2017. n.s. indicates no significant difference (p<0.05).

Crop	CPA use VL	CPA use Nt	Std VL	Std Nt	P
Sugar beet	1,337	1,467	757	790	n.s. (p=0.36)
Wheat	1,915	2,182	1,043	1,288	n.s. (p=0.17)
Onion	3,446	3,811	1,375	1,802	n.s. (p=0.22)
Ware potato	2,387	2,383	991	1,208	n.s. (p=0.98)
Seed potato	2,263	2,500	1,025	1,252	n.s. (p=0.44)

3.1.3 Nutrient use efficiency

No significant difference was observed in nitrogen use efficiency (NUE) ($p = 0.823$) or phosphate use efficiency (PUE) ($p = 0.583$). For NUE, the mean of the national average was 0.62, whereas that of VL farms was 0.01 less. The Std of the national average was 0.33, that of the VL farms 0.23. The PUE of the national average was 1.29, while that of the VL farms was 0.31 less. The Std of PUE was 1.82 for the national average and 0.51 for the VL farms.

3.1.4 Nutrient surplus

No significant difference was observed for nitrogen surplus ($p = 0.547$) or phosphate surplus ($p = 0.768$). The mean national average N surplus was 105 kg/ha, that of VL farms was 7 kg/ha more, while the Std was 87 kg/ha for the national average and 71 kg/ha for VL farms. The mean national average P_2O_5 surplus was 9 kg/ha, that of VL farms was 1 kg/ha less. The Std of P_2O_5 surplus was 33 kg/ha for the national average and 28 kg/ha for VL farms.

3.1.5 Water use

No significant difference was observed for water use ($p = 0.352$). The mean water use of the national average was 356 m^3/ha, that of VL farms 87 m^3/ha less. The Std of water use was 467 m^3/ha for the national average and 377 m^3/ha for VL farms. The high standard deviation can be explained through differences in soil texture which lead to different water requirements.

3.1.6 Diesel use

No significant difference was observed for diesel use ($p = 0.166$). The mean of the national average was 199 GJ/ha, the mean of the VL farms 30 GJ/ha less. The respective Std was 142 GJ/ha for the national average and 55 GJ/ha for the VL farms.

3.1.7 Biodiversity

No significant difference was observed for biodiversity ($p = 0.303$). The national average farms had on average five crops per year, while the VL farms had on average 0.3 crops more per year. The Std of the national average was 2.08 crops/year and of the VL farms 1.47 crops/year.

3.1.8 Age of farmer

No significant difference was observed for the age of the farmer ($p = 0.334$). The mean age of the national average farmers was 56 years, that of VL farmers two years less. The Std was ten years in both cases.

3.1.9 Farm income per entrepreneur

A strong significant difference was observed for farm income per entrepreneur ($p = 0.00005$***). The mean income per entrepreneur of the national average was 56,107 €, that of VL farms 51,051 € higher. The Std of the national average was 82,020 €, that of VL farms 102,865 €. Fig. 5 shows the yearly averages of farm income per entrepreneur for the two groups. Despite high yearly variations, the income per entrepreneur was considerably higher for the VL farms compared to the national average in every year. No trend was identified for the development of income per entrepreneur over time (Fig. 5).

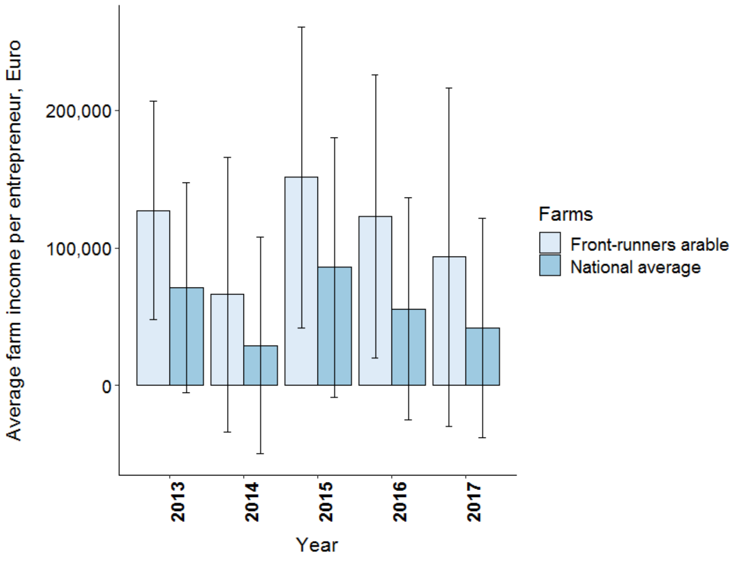


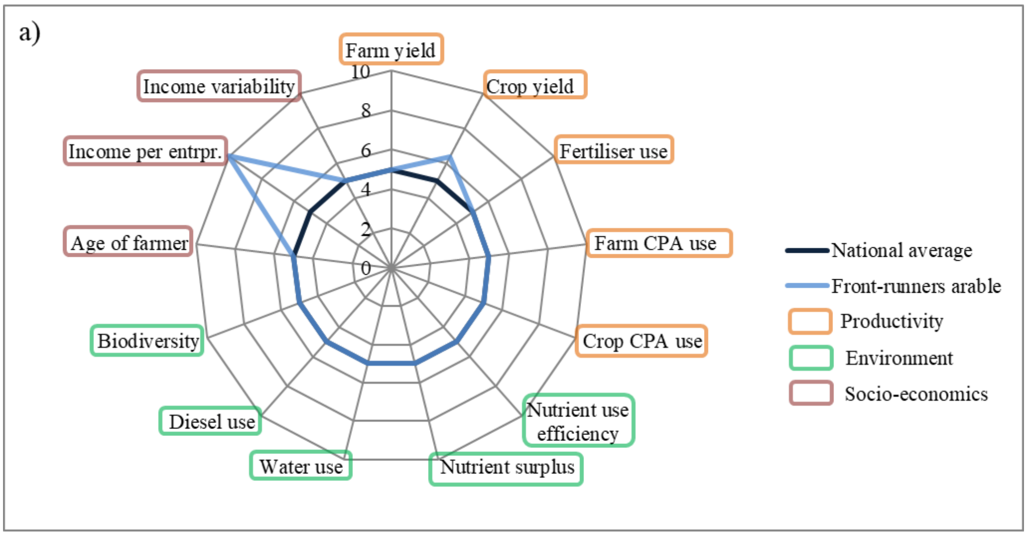
Fig. 5: Average farm income per unpaid work unit for front-runner arable farms and the national average and the years 2013 – 2017. Error bars show the standard deviations of the respective years.

3.1.10 Income variability

No significant difference was observed for income variability ($p = 0.836$). The mean variance of income per entrepreneur of the national average farms was 4,251,784,997 (€/unpaid AWU)^2, that of the VL farms 421,617,745 (€/unpaid AWU)^2 less. These are very high values as a result of the calculation of the variance, which includes squaring the differences to the mean. The Std was 47,309 (€/unpaid AWU)^2 for the national average and 53,474 (€/unpaid AWU)^2 for VL farms.

3.2 Radar charts arable

Fig. 6 summarises the results of the VL farms compared to the national average at a) indicator and b) principle level. It shows that the main differences between the two groups was observed for the indicators of crop yield and farm income (Fig. 6a). Hence, the VL farms can be identified as slightly more intensive and as more socio-economically sustainable than the national average (Fig. 6b). Since the latter was solely based on a significantly higher income, it has to be highlighted that the VL farms were identified as mainly economically more sustainable, which does not necessarily include the social aspect.



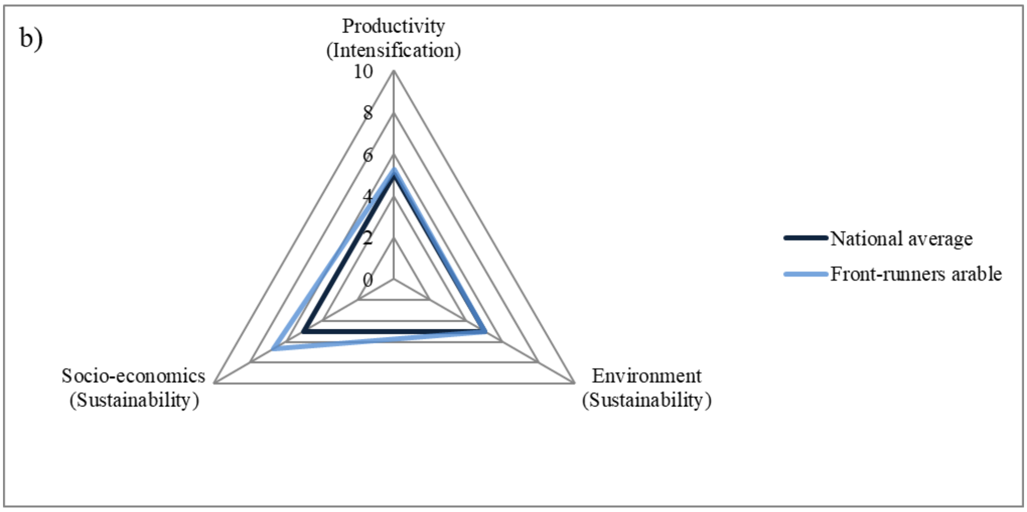


Fig. 6: Radar charts to summarise the level of SI of the national average and front-runner arable farms at a) indicator level and b) principle level. The national average was selected as reference point and scaled at 5. Scaling of front-runner farms was carried out based on significance levels of differences between the two groups over the years 2013 – 2017 (see chapter 2.6 Materials & methods for more details). Income per entrpr. = Income per entrepreneur.

3.3 Dairy farms

For the dairy farms, significant differences were tested in the averages over 2012 – 2017 between the two groups, national average dairy and C&O farms.

3.3.1 Yield

For yield, significant differences were observed between the national average and C&O farms at farm level in terms of revenues ($p = 0.0015$**), livestock yield in euros/ha ($p = 0.0010$***), and livestock yield in kg/ha ($p = 0.0006$***). At farm level, the mean yield of the national average was 7,319 €/ha, that of C&O farms 2,067 €/ha higher. The Std of the farm level yield was 3,029 €/ha for the national average and 2,834 €/ha for the VL farms. For livestock yield in euros/ha, the national mean was 6,367 €/ha, the mean of C&O farms was 1,849 €/ha higher with a Std of 2,546 €/ha for the national average and 2,498 €/ha for the C&O farms. For livestock yield in kg/ha, the mean yield was 15,569 kg/ha for the national average farms and 4,997 kg/ha higher for C&O farms. The Std was 6,510 kg/ha for the national average and 6,853 kg/ha for C&O farms. Fig. 7 shows the development of the three different yield levels over the six years. For the three levels, the average yield of C&O farms was higher than that of the national average for all years. A trend for an increase in the physical milk yield/ha over time was observed for the national average (Fig. 7).

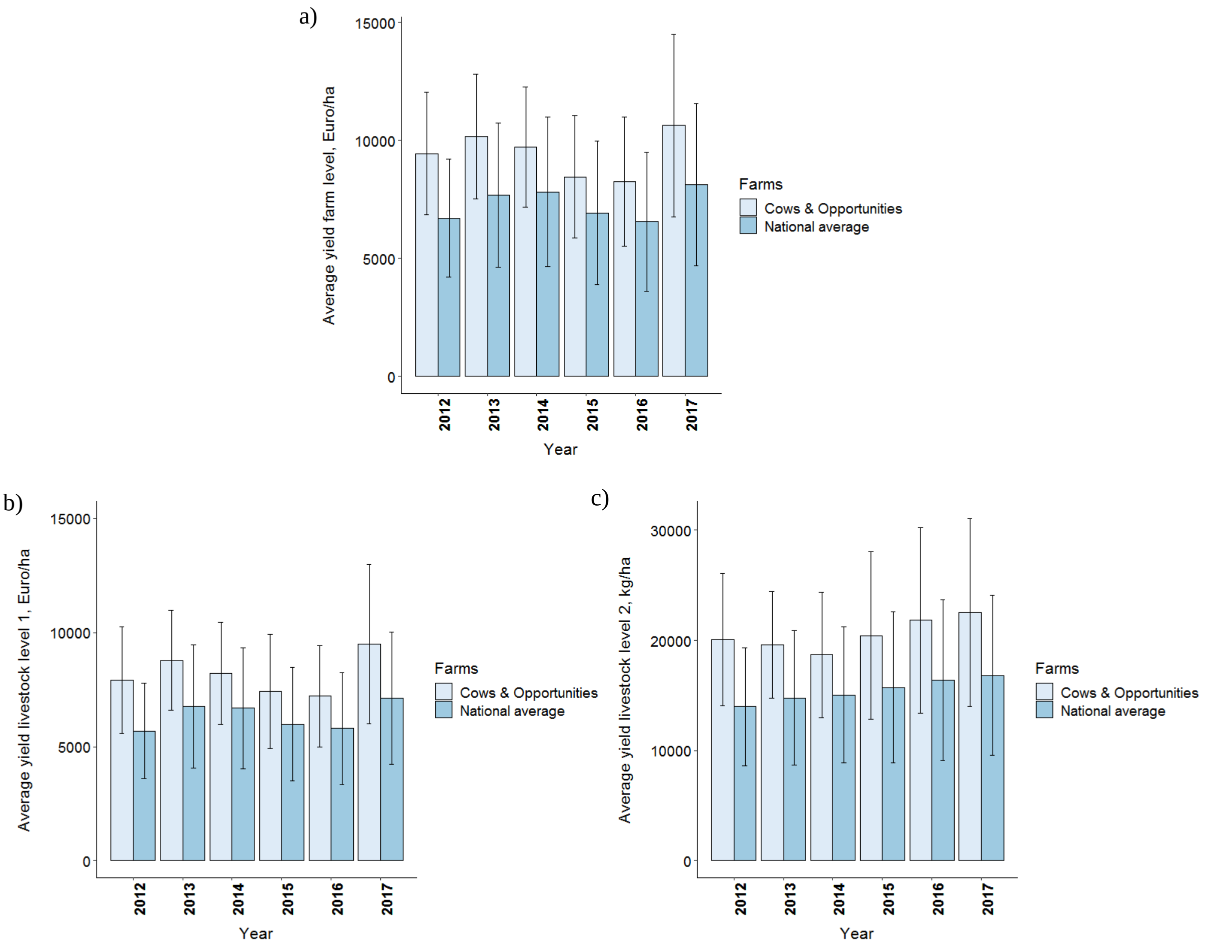


Fig. 7: Average yield at a) farm level as total revenues per area (€/ha), b) livestock level 1 as the revenues associated to the dairy production per area (€/ha), and c) livestock level 2 as the physical milk yield per area (kg/ha) for Cows & Opportunities farms and the national average and the years 2012 – 2017. Error bars show the standard deviations of the respective years.

3.3.2 Use of inputs

3.3.2.1 Fertiliser use

No significant differences were observed in the use of nitrogen fertiliser ($p = 0.455$) and phosphate fertiliser ($p = 0.252$). The mean N fertiliser use of the national average was 236 kg active N/ha and that of C&O farms 11 kg N/ha higher. The Std was 67 kg N/ha for the national average and 78 kg N/ha for C&O farms. The mean national average P_2O_5 fertiliser use was 77 kg P_2O_5/ha and that of C&O farms on average 4 kg P_2O_5/ha higher. The Std was respectively 17 and 18 kg P_2O_5/ha.

Fig. 8 shows the average fertiliser use over time. The share of the type of fertiliser used for the two nutrients was similar for the two groups of farms. N fertiliser was almost equally applied via artificial fertiliser and animal manure whereas P_2O_5 fertiliser was mainly applied via animal manure. Other organic manure was a very small fraction of the fertiliser input. For N, no trend was observed for the development of fertiliser use over time. For P_2O_5, a considerable decrease in fertiliser use was observed for the national average between 2014 – 2015 (Fig. 8).

a) b)

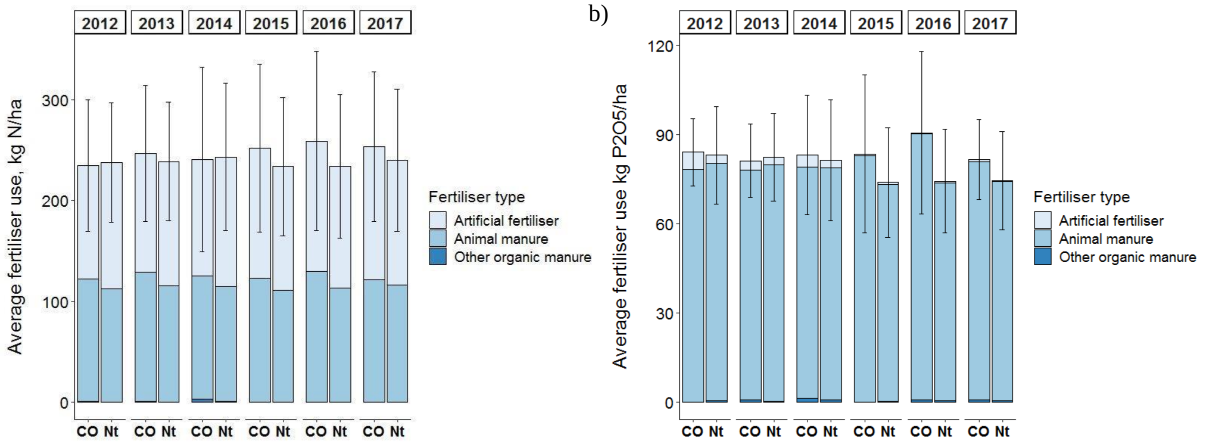


Fig. 8: Average fertiliser use in a) kg active N/ha and b) P_2O_5/ha for Cows & Opportunities farms (CO) and the national average (Nt) and the years 2012 – 2017. Error bars show the standard deviations of the total farmland fertiliser use of the respective years.

3.3.2.2 Feed costs

No significant difference was observed for feed costs (p = 0.232). The mean of the national average was 39 €/ha, that of C&O farms 9 €/ha higher. The Std was 36 €/ha and 34 €/ha respectively.

3.3.3 Nutrient use efficiency

No significant difference was observed for NUE (p = 0.067) or PUE (p = 0.560). The mean NUE of the national average was 0.41, that of the C&O farms 0.06 higher. The Std of NUE was 0.15 for the national average and 0.11 for C&O farms. The mean PUE of the national average was 0.95, that of the C&O farms 0.04 higher. The Std of PUE was 0.37 for the national average and 0.23 for C&O farms.

3.3.4 Nutrient surplus

No significant difference was observed for nitrogen surplus (p = 0.250) or phosphate surplus (p = 0.249) per unit area. The mean national average N surplus was 201 kg/ha, that of the C&O farms 17 kg/ha more, with a Std of 81 kg/ha for the national average and 82 kg/ha for C&O farms. The mean national average P_2O_5 surplus was 6.3 kg/ha, that of the C&O farms 3.9 kg/ha less. The Std of P_2O_5 surplus was 21 kg/ha for both, the national average and C&O farms.

A significant difference was observed for N surplus at livestock level (p = 0.011*). The mean of the national average was 0.014 kg N/kg milk, that of C&O farms 0.003 kg/kg less. The Std was 0.0013 kg/kg for the national average and 0.0009 kg/kg for C&O farms. Fig. 9 shows the development of the livestock N surplus over the six years. The average N surplus per kg milk was lower for C&O farms compared to the national average in every year. No trend was observed in the average livestock N surplus over time, whereas there seemed to be a tendency for a decrease over the last years, especially for the national average (Fig. 9).

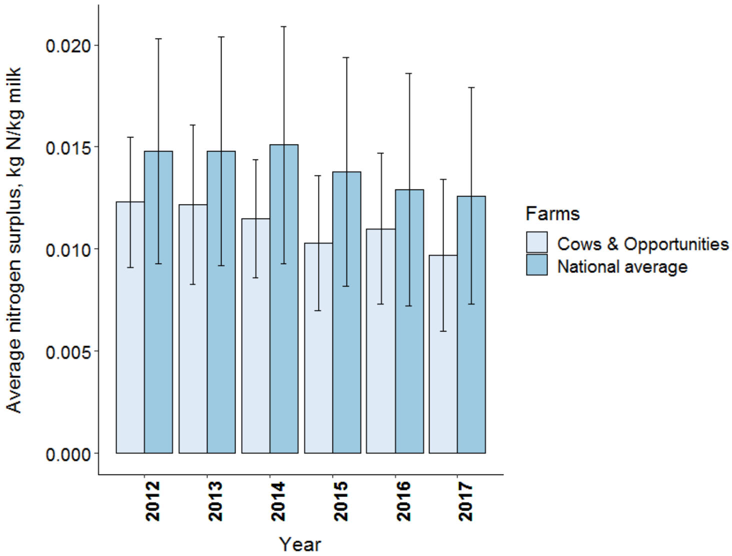


Fig. 9: Average nitrogen surplus per kg milk for Cows & Opportunities farms and the national average and the years 2012 – 2017. Error bars show the standard deviations of the respective years.

3.3.5 Water use efficiency

No significant difference was observed for WUE at farm ($p = 0.907$) or livestock level ($p = 0.888$). At farm level, the mean of the national average was 1,439 €/m^3, that of the C&O farms 155 €/m^3 less. The Std was 4,443 €/m^3 for the national average and 2,864 €/m^3 for C&O farms. At livestock level, the mean of the national average was 3,010 kg/m^3, that of the C&O farms 397 kg/m^3 less. The Std was 9,164 for the national average and 5,684 for C&O farms.

3.3.6 Greenhouse gas emissions

A significant difference was observed for GHG emissions at farm level ($p = 0.011$*). The mean emissions per area were 20,340 kg CO_2 equiv./ha for the national average and 3,895 kg CO_2 equiv./ha more for C&O farms. The Std was 6,927 kg CO_2 equiv./ha for the national average and 7,644 kg CO_2 equiv./ha for C&O farms. Fig. 10 presents the development of farm level GHG emissions over time and the share of CH_4, CO_2, and N_2O in the total emissions. It shows that the proportion of the individual gases was similar for the two groups: CH_4 and CO_2 made up the biggest share of the emissions whereas N_2O emissions were relatively little. No trend was identified in the development of GHG emissions over time (Fig. 10).

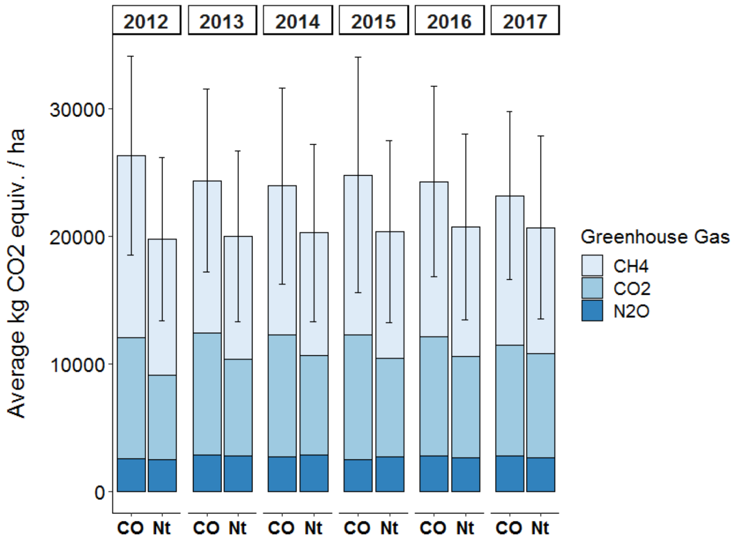


Fig. 10: Average greenhouse gas emissions in kg CO2 equivalents/ha for Cows & Opportunities farms (CO) and the national average (Nt) and the years 2012 – 2017. Error bars show the standard deviations of the total emissions of the respective years.

Moreover, a significant difference was observed for GHG emissions at livestock level (p = 0.011*). The mean emissions per kg milk were 1.19 kg CO_2 equiv./kg for the national average and 0.09 kg CO2 equiv./kg less than this for C&O farms. The Std was 0.18 kg CO2 equiv./kg for the national average and 0.11 kg CO2 equiv./kg for the C&O farms. Fig. 11 shows the livestock level GHG emissions for the two groups over time. It shows that average livestock level emissions were lower for C&O farms compared to the national average in every year. At livestock level, a tendency for a decrease in emissions over time was observed, for both, C&O farms and the national average (Fig. 11).

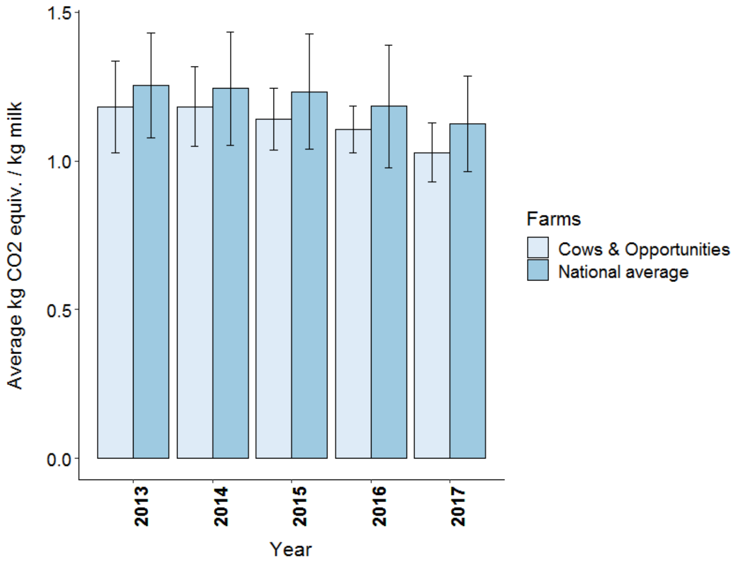


Fig. 11: Average kg CO2 equivalents/kg milk for Cows & Opportunities farms and the national average and the years 2012 – 2017. Error bars show the standard deviations of the respective years.

For the national average, as well as C&O farms, 29% of emissions took place in the chain and 71% of emissions on the farm itself (Fig. 12). In general, the proportion of the sources of GHG emissions were very similar for the two groups (Fig. 12).

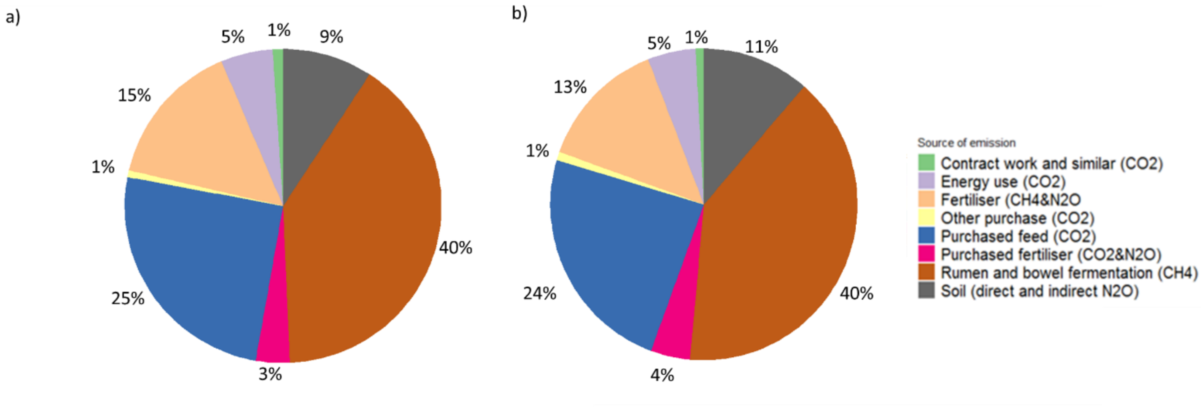


Fig. 12: Average proportion (over 2012 – 2017) of the sources of the greenhouse gas emissions for a) Cows & Opportunity farms and b) the national average.

3.3.7 Feed self-sufficiency

No significant difference was observed for feed self-sufficiency ($p = 0.403$). The mean of the national average was 67.0%, while that of the C&O farms was 1.4% more. The Std was 7% for the national average and 6% for C&O farms.

3.3.8 Biodiversity

No significant difference was observed for biodiversity ($p = 0.136$). The mean cutting percentage of the national average was 307%, that of the C&O farms 38% more. The Std of biodiversity was 120% for the national average and 88% for the C&O farms.

3.3.9 Preservation of grazing

A significant difference was observed for preservation of grazing ($p = 0.0065$**). The mean number of grazing days of the national average was 177 days per year, that of the C&O farms 27 days/year less. The Std was 39 days/year for both, the national average and C&O farms. Fig. 13 shows the average number of grazing days per year for the two groups over time. It was lower for C&O farms compared to the national average in every year. No trend in the development over time was identified for the national average, whereas for the C&O farms a tendency for an increase in the number of grazing days over time was observed (Fig. 13).

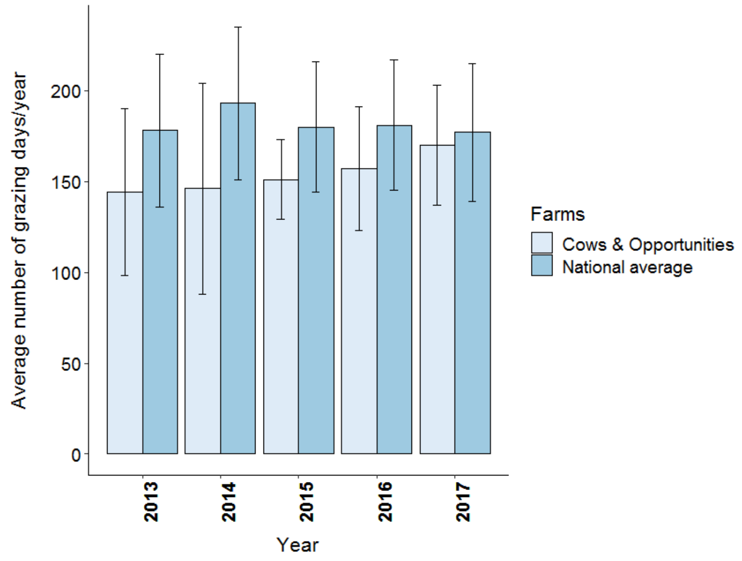


Fig. 13: Average number of grazing days for Cows & Opportunities farms and the national average and the years 2013 – 2017. Error bars show the standard deviations of the respective years.

3.3.10 Age of farmer

A significant difference was observed in the age of the farmer (p = 0.029*). The mean age of the national average farmers was 55 years, that of the C&O farmers five years less. The Std of the national average was ten years, that of C&O farms eight years. Fig. 14 shows the average age of the oldest entrepreneur for the two groups over time. It was lower for C&O farms compared to the national average in every year. No clear trend can be identified in the development over time (Fig. 14)

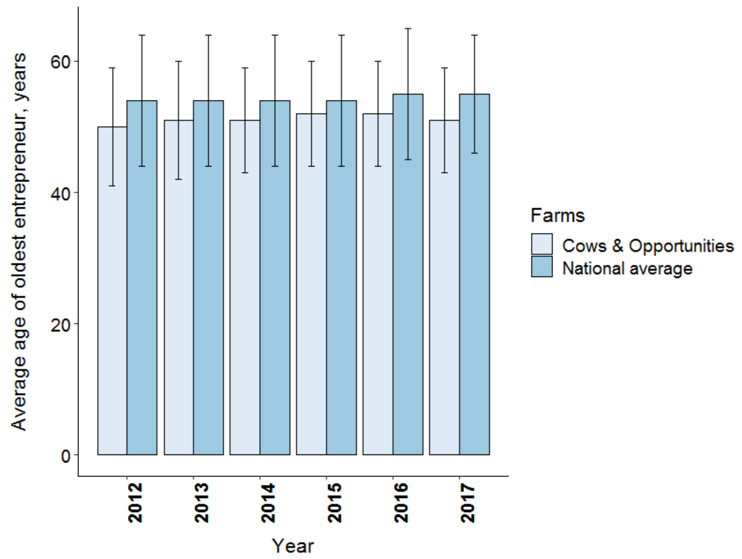


Fig. 14: Average age of the oldest entrepreneur for Cows & Opportunities farms and the national average for the years 2012 – 2017. Error bars show the standard deviations of the respective years and labels the average.

3.3.11 Farm income per entrepreneur

No significant difference was observed for farm income per entrepreneur (p = 0.072). The mean of the national average was 37,877 €/unpaid AWU, that of the C&O farms 19,095 €/unpaid

AWU more. The Std was 53,885 €/unpaid AWU for the national average and 66,954 €/unpaid AWU for C&O farms.

3.3.12 Income variability

No significant difference was observed for income variability ($p = 0.720$). The mean variance of income per entrepreneur of the national average farms was 1,142,000,000 $(€/\text{unpaid AWU})^2$, that of the VL farms 273,900,000 $(€/\text{unpaid AWU})^2$ more. The Std was 30,818 $(€/\text{unpaid AWU})^2$ for the national average and 37,619 $(€/\text{unpaid AWU})^2$ for the C&O farms.

3.4 Radar charts dairy

Fig. 15 summarises the results of the C&O farms compared to the national average at a) indicator and b) principle level. It shows that the main differences between the two groups were observed for the indicators yield at farm and livestock level, N surplus at livestock level, GHG emissions at farm and livestock level, preservation of grazing, and farmer's age (Fig. 15a). Hence, in comparison to the national average, the C&O farms can be identified as considerably more intensive, slightly more environmentally sustainable and slightly less socio-economically sustainable (Fig. 15b). The latter was based only on grazing, so the C&O farms were identified as mainly socially, and not economically, less sustainable.

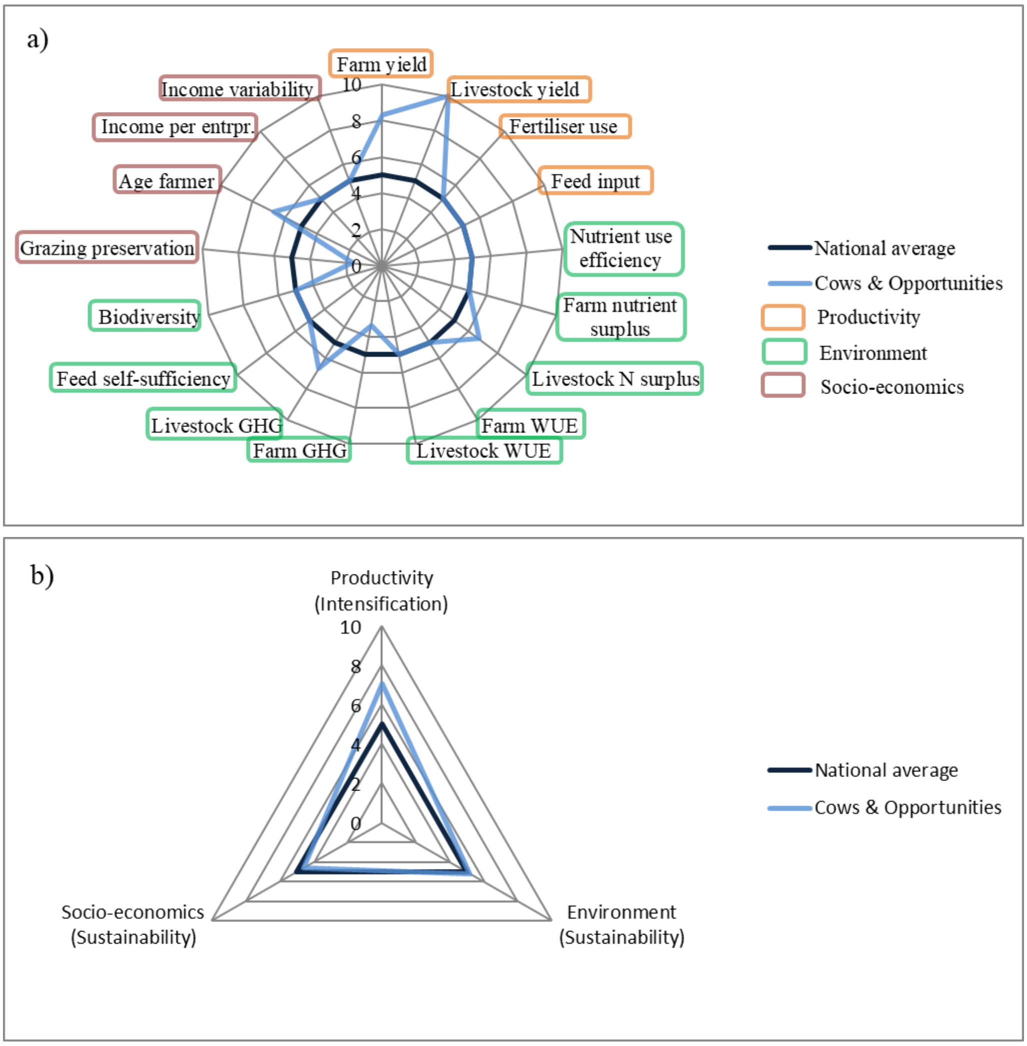


Fig. 15: Radar charts to summarise the level of SI of the national average and Cows & Opportunities farms at a) indicator level and b) principle level. The national average was selected as reference point and scaled at 5. Scaling of front-runner farms was carried out based on significance levels of differences between the two groups over the years 2012 – 2017 (see chapter 2.6 Materials & methods for more details). Income per entrpr. = Income per entrepreneur.

4 Discussion

The discussion of this thesis is divided into four parts. First, limitations in the methods used to address the research questions are discussed. Secondly, the performance of front-runner farms compared to the national average is addressed, separately for arable and dairy farms, followed by, thirdly, a short conclusion on the main differences between front-runner arable and dairy farms, and, fourthly, a general discussion on SI in the Netherlands. The socio-economic principle is discussed separately, as the social and economic sustainability indicators diverged in their results. Indicators that showed significant differences, tendencies in differences, and indicators that were decided to be important are discussed.

4.1 Discussion of the methods

4.1.1 Data availability

First of all, limitations in the methods of the SI assessment were connected to the availability of data. It was possible to obtain data only for a period of maximum six years, which is too short to identify a process of SI. In addition, no direct data on biodiversity or animal welfare was available in the BIN database to draw meaningful conclusions. Therefore, it was not possible to assess the whole picture of SI. It is recommended to WEcR to discuss with experts of both subjects which indicators at farm level are best and which data should thus be monitored to assess animal welfare and biodiversity, in order to consequently expand the registration. Suggestions for possible indicators for biodiversity would be e.g. protection measures for meadow birds, buffer zones of pesticide use, and the area of flower strips. For animal welfare, possible indicators may be related to animal health, e.g. body condition, integument, behaviour, locomotion, and claw condition (E. Bokkers, Associate professor Animal Production Systems, 05/04/2019, personal communication).

4.1.2 Indicator selection

The decision about which indicators to select for an SI assessment is strongly subjective (Marinus et al., 2018). Therefore, in order to provide clarity about underlying assumptions, and to decrease the level of subjectivity, a hierarchical framework of aspects, principles, and indicators, similar to the one described by Florin et al. (2012), and a participatory selection by the KNSI researchers were used. The KNSI researchers decided that the number of indicators should not be too large (10 – 15) to get a clear picture, and that the indicators should align with the most commonly used indicators in other frameworks to prevent double work. This resulted in a first list of indicators that was consequently revised based on discussions with further experts and literature research. Furthermore, the reasons for selection of the indicators were explained. However, it remains an issue that different people might have selected different indicators.

4.1.3 Radar charts

While radar charts give a straight-forward and clear visualisation of results, there are two main issues related to their use. The presented averages mask underlying variation of individual farm data. Consequently, providing box plots in addition to the radar charts would provide a clear picture of the inherent variability of the individual farms (Marinus et al., 2018). However, due to privacy reasons, it was not permitted to show box plots. Hence, yearly standard deviations were shown in the bar graphs. Yet, this does not give the same level of detail on the variability of individual farms, as e.g. it does not allow to identify individual farms within the groups that present the top level of what is currently feasible. Furthermore, for the radar charts, crop, nutrient and livestock yield data had to be averaged for the different crops, for N and P_2O_5, and for the livestock yield in euros/ha and in kg/ha respectively. Yet, little underlying variation in terms of significant differences was masked, as they each showed similar results.

The decision how to scale the indicators for the radar charts, and the process of scaling itself, are highly subjective (Marinus et al., 2018). The front-runner farms were scaled based on their level of significant difference compared to the national average. Through this, important underlying information was lost. The scaling was based on discrete, and not continuous, differences (once a certain p value was reached, a certain score was attributed). Therefore, it did not consider differences within a certain level of significance, and neglected any non-significant differences. Furthermore, it gives the impression that an indicator that reached the highest level of significant difference, i.e. $p < 0.001$, has reached the maximum (or minimum) performance of the corresponding indicator, while this is not necessarily the case.

More specifically, the radar charts at indicator level may present a biased picture because the different principles were presented by different numbers of indicators. Especially for the dairy farms, there were many more environmental indicators than socio-economic or productivity indicators. Hence, visually, the principle of environmental sustainability gains more importance than the other principles. At the same time, for calculating the score at principle level, it meant that it had to be averaged over a larger number of indicators, so that the effect of individual indicators was smaller. Moreover, as some indicators were calculated at multiple levels (i.e. crop/livestock level and farm level), whereas others were only calculated at farm level, there was a visual over-representation of those with multiple levels. In addition, for some indicators it may be ambiguous which principle they belong to, e.g. CPA use can, besides intensification, be considered as an indicator of environmental sustainability.

Finally, when aggregating the indicators to principles, it was decided to give equal weighting in order to increase the transparency of the results. However, this did not consider that some issues may be more important for SI than others. When summarising the indicator results at principle level, some underlying differences were lost. For example, for dairy farms, the relatively high score of the farmer’s age was evened out by the relatively low score of preservation of grazing, leading to a score for socio-economic sustainability similar to that of the national average, implying that there was no difference between the two groups. Hence, the radar charts at principle level provide few insights and by themselves only allow for a quick overview of the differences (Marinus et al., 2018).

4.1.4 Indicator assessment

There are two sides to an assessment of SI using indicators. On the one hand, quantifying indicators allows to measure the effects of changes, and permits to identify what can be done to improve. On the other hand, quantifying too many indicators may reduce the intrinsic motivation of farmers. The former president of VL highlighted that results are very individual, and that doing the best in every year does not necessarily imply doing better in every year (A. Vermeulen, (potato) farmer, 27/02/2019, personal communication). Therefore, the results of this assessment should be assessed carefully, keeping this in mind.

4.2 The performance of front-runner farms compared to the national average

Based on the aims of the two front-runner farm projects, and a first overview of the results from literature, it was hypothesised that both, arable and dairy front-runner farms, perform better in terms of SI than the national average. In how far this was observed, will be assessed separately for arable and dairy farms.

4.2.1 Arable farms

For arable farming, two indicators showed significant differences between the VL farms and the national average. The VL farms displayed a significantly higher physical yield at crop level for four out of five crops (sugar beet, wheat, ware potato, and seed potato, n.s. for onion), and a significantly higher income per entrepreneur.

It is striking that significantly higher yields were observed for the majority of the assessed crops, but that this was not reflected in a significant difference in terms of farm revenues. Crop yields were measured in terms of kg/ha, whereas farm revenues in euros/ha, taking also prices into account. Thus, there may be two reasons to explain this divergence in results. Firstly, VL farms may be receiving lower prices for their products. Secondly, the non-significant difference in revenues may be based on a difference in the share of different crops in the rotation. VL farms tend to have a wider rotation, with 0.3 more crops per year, although not significant (Fig. 24). Farmers generally prefer the more profitable crops (within some boundaries). Therefore, if the number of crops is expanded, the share of the more profitable crops easily becomes less. Moreover, it is surprising that a higher income per entrepreneur was observed for VL farms, while there was no significant difference in farm revenues. Considering that the number of entrepreneurs was larger for VL farms (1.8 unpaid AWU per farm) compared to the national average (1.4 unpaid AWU), VL farms must have considerably lower costs than the national average.

There are two main reasons for the advanced performance of VL farms in terms of crop yield and income compared to the national average. First of all, it is a result of the focus of the VL project. “Product value” is the first out of ten indicators of the VL project, highlighting the economic sustainability of the farm, to achieve high yields with an optimum use of resources (Stichting Veldleeuwerik, 2019). Similarly, when starting the project, Heineken’s aim was based on having better results without further environmental impact, and with reduced costs (Stichting Veldleeuwerik, 2019). Hence, the main focus of the project, to achieve high yields and incomes with little costs, is clearly reflected in the results. Furthermore, the advantage in yield and income are a result of VL farmers being better managers, as they are more passionate and engaged than average farmers. This was supported by the former VL president (A. Vermeulen, (potato) farmer, 27/02/2019, personal communication), who highlighted that, by giving a direction, but leaving the decision up to the farmers, VL inspires them to improve, and makes their work more satisfactory. He described the main effect of VL to be a change in the mindset of the farmers, which eventually leads to changes in the way of farming. To him, this is mainly based on the regular meetings between VL farmers, where they discuss and challenge each other. Furthermore, he explained that since farmers have to pay in order to be part of VL, but do not receive a higher margin from it, they clearly have an intrinsic motivation to improve their farming practices and are eager to get as much as possible out of the project (A. Vermeulen, (potato) farmer, 27/02/2019, personal communication).

The advantage in income presumably is based on lower costs of the VL farms. This corresponds with findings of Kuneman, (2017). For 2002 – 2017, he observed an advantage of VL farms compared to the national average in terms of “product value”, as a result of lower costs, especially for crop protection and energy. Additionally, as VL farms tend to have a larger farm area, they experience a scale advantage in terms of labour costs.

In terms of soil and nutrient management, i.e. fertiliser use, nutrient use efficiencies and nutrient surpluses, no significant differences were observed between the two groups. Only a tendency for a higher N fertiliser use of VL farms compared to the national average was observed (Fig. 4). In combination with the higher yields, this further implies a tendency for a higher level of intensification. This trend for a higher N fertiliser use can be the result of a difference in crop rotation. The share of ware potato, as the most fertiliser-demanding crop (De Haan & Van Dijk, n.d.), in the cultivation area of VL farms and of the national average farms was compared (Table 10). A tendency for a slightly higher share of ware potato was observed for VL. However, as this was mainly observed in most recent years, and tendencies in differences of fertiliser use have been present also for 2013 and 2014, this cannot be the sole explanation.

Table 10: Average share (% of total area) of ware potato in the area of Veldleeuwerik (VL) farms and the national average (Nt) for the years 2013 – 2017, as well as the average over these years.

Group	2013	2014	2015	2016	2017	Average
VL	18.2	21.8	21.4	24.1	21.9	**21.5**
Nt	20.8	21.9	20.3	21.6	19.7	**20.8**

Another explanation may be that VL farmers pay more attention to fertility management, which in turn explains the higher yields. This explanation is supported by Kuneman (2017) who identified soil management (in terms of soil fertility and erosion) to be the most important advantage of VL farms. He observed that, in contrast to the national average, the soil organic matter of VL farms is slightly increasing. Furthermore, VL farms use more site-specific fertilisation (27%) compared to the national average (20%) and are pioneers in the use of green manures (Kuneman, 2017). This was further reiterated by the former VL president who described that within VL, there is a strong focus on soils. He explained that every new member starts with improved soil management, e.g. by introducing a 1:5 rotation, growing more winter wheat, spading at 20 cm depth instead of ploughing at 35 – 40 cm depth, and giving P and K mostly via organic manure. Only after this, they move on to the "softer parts", such as biodiversity measures and water management (A. Vermeulen, (potato) farmer, 27/02/2019, personal communication). The aspect of the 1:5 rotation was confirmed by the tendency for VL farms to have a higher agro-diversity, in this case crop diversity, compared to the national average (Fig. 24).

For CPA and energy use, no significant differences were observed between VL farms and the national average, only tendencies for VL to have a lower CPA use at crop level (Fig. 19) and a lower diesel use (Fig. 23). These tendencies were reaffirmed by Kuneman (2017) who observed VL to be at the forefront of CPA use with enhanced use of low-drift techniques, and considerably more mechanical weeding compared to the national average in 2016. Similarly, he identified VL farms to be leading in terms of green energy, with 50% of VL farms producing solar energy, compared to 2% of the national average, and with VL farms applying multiple further measures such as using LED lamps and more energy-efficient motors. Furthermore, VL are currently trying to introduce the COOL farm tool which would allow to measure GHG emissions, and underlines that they are paying attention to the issue of energy use (H. Boerrigter, director VL, personal communication). It might have provided a clearer picture to look in more detail into the sources of the energy use, but this was not possible based on the BIN database.

The only indicator for social sustainability assessed for arable farms in this thesis was the age of the farmer. For this, no significant difference was observed. This finding is supported by Kuneman (2017) who advised VL to involve more the young generation of farmers. In addition, he has found that VL farms are much more socially involved, e.g. 38% of VL growers are part of an Agrarische Natuur Vereniging (ANV, English: Agricultural Nature Association), compared to 9.5% of national average, and that the network of colleagues makes changes easier through knowledge exchange and exemplary effects. He concludes that group discussions are the bottom-line of the project (Kuneman, 2017). This was confirmed by the former VL president, who sees a great value in VL as a platform to support and challenge each other. According to him, it allows farmers to expand their horizon and learn more (A. Vermeulen, (potato) farmer, 27/02/2019, personal communication).

4.2.1.1 Sustainable intensification of arable farms

The overall observation is that VL farms perform better than the national average in terms of intensification and economic sustainability, mainly because of a focus of the project on these aspects and a high motivation of VL farmers. Regarding environmental sustainability, the outcomes are ambiguous, as no significant differences, but only tendencies were observed. Furthermore, this is a question of the definition of SI. If higher yields can be achieved with the same environmental impact, does that mean that the environmental sustainability is improved? For this, it might be helpful to assess environmental indicators at crop level per kg product, in addition to the assessment per unit area. For social sustainability, no conclusions can be drawn from the data analysis in this study. However, the interview with the VL farmer, as well as other literature findings show that VL farms are socially more sustainable than the national average, especially in terms of networking and knowledge support.

4.2.2 Dairy farms

For the dairy farms, significant differences were observed for seven indicators. Compared to the national average, C&O farms had significantly higher yields at farm and livestock level, lower N surplus per kg milk, higher GHG emissions per ha and lower GHG emissions per kg milk, as well as less grazing and younger farmers.

It is striking that a significantly higher yield was observed for C&O farms compared to the national average, but only a tendency, and no significant difference, for a higher income per entrepreneur for C&O farms (Fig. 32). The number of entrepreneurs per farm was about the same for C&O farms (1.68 unpaid AWU) compared to the national average (1.64 unpaid AWU). This may imply that C&O farms have higher costs than national average farms, reflected also in a tendency for higher feed costs per area (Fig. 26), although not significant.

The advantage in yield of the C&O farms compared to the national average was confirmed by Doornewaard et al. (2016) who reported that in 2014, C&O farms produced 13% more milk per farm and 30% more per hectare compared to the national average. There is a combination of two reasons for this. Firstly, C&O farms are more intensive, they have more cows/ha than the national average, which results in a higher output production per area (Doornewaard et al. (2016). Secondly, they are more ambitious in their management. As C&O farmers tend to be very engaged, entrepreneurial and future-oriented farmers (Oenema et al., 2001), they are better managers than the average farmer.

For GHG emissions a significantly worse performance (Fig. 10) and for N surplus a tendency for a worse performance (Fig. 28) were observed for C&O farms compared to the national average, when assessed per unit area. The non-significant difference in terms of N surplus per area was reaffirmed by Doornewaard et al. (2016). At the beginning of the C&O project, a considerable decrease in N surplus was observed for C&O farms (Oenema et al., 2001), and the N surplus of C&O farms was below that of the national average (Doornewaard et al., 2016). However, since 2008, there has been no further decrease, and C&O farms have no longer shown a lower N surplus compared to the national average (Doornewaard et al., 2016). The decrease in N surplus was based on a reduction in fertiliser use, which occurred earlier for C&O farms compared with the national average. This is because C&O farms were ahead of regulation, supported by research, whereas the national average caught up as fertiliser regulations got stricter (Doornewaard et al., 2016). The higher GHG emissions per unit area are most likely based on the higher intensity of C&O farms. As rumen and bowel fermentation and purchased feed represent the largest sources of the GHG emissions (Fig. 12), the emissions are higher if more cows are present per unit area. Doornewaard et al. (2019) have observed that on C&O farms the production of renewable energies is increasing, as an increasing number of them introduce wind turbines or solar panels. Therefore, for a complete assessment it may also be relevant, to also look at the sources of energy.

Contrary to the results per area, when assessed per kg of product, a significantly better performance of C&O farms compared to the national average was observed in terms of GHG emissions and N surplus. This implies an ambiguity in the assessment of environmental sustainability, depending on whether decreases in the environmental impact per unit area, or increases in productivity while maintaining the same environmental impact, are valued as more important (Schröder et al., 2003).

Considering indicators of social sustainability, first of all, significantly less grazing was observed for C&O farms compared to the national average. This is connected to a tendency for a higher cutting percentage of grassland for C&O farms compared to the national average (Fig. 31). There are three reasons for this. First and secondly, the relatively low grazing is a result of the high intensity of C&O farms and depends largely on farm set-up, i.e. whether fields are located close to the stables (J. Oenema, C&O expert, 21/03/2019, personal communication). Thirdly, reduction of grazing is a measure in order to improve nutrient management, and reduce leaching (Oenema, 2013; Oenema et al., 2001). Therefore, this indicator presents a trade-off of environmental and social sustainability. This was supported by Doornewaard et al. (2016) who highlights that C&O farms should be careful to consider all aspects of sustainability, especially socially relevant topics such as pasture grazing, and not only focus on the management of nutrients. Still, C&O farms have achieved the "preservation of grazing" target of the Duurzame Zuivelketen, to maintain the share of farms with grazing at the same level as 2012 (81.2%) (Doornewaard et al., 2019). Furthermore, C&O farms showed a tendency for an increase of grazing days per year (Fig. 13). Grazing has become an increasingly important issue in the public over the last years. As a result of growing consumer demand for pasture milk, dairy farms receive a grazing premium from companies (Duurzame Zuivelketen, 2019b). Thus, also within C&O farms, awareness for this has increased.

Furthermore, a significantly lower age was observed for C&O farmers compared to the national average. This is most likely based on the fact that C&O farmers tend to be more innovative and engaged farmers, which are often younger (Oenema et al., 2001). For the project, farms were selected in such a way that they are open to research and innovative, especially in the field of manure, minerals and the environment which may have influenced this result (Koeien & Kansen, 2019).

While no significant differences were observed for fertiliser use, there was a tendency for 2015 – 2017 that C&O farms use more fertiliser than the national average (Fig. 8). In combination with the higher yields, this underlines the fact that C&O farms are more intensive. C&O farms have been participating in pilot projects of the Dutch regulation, introducing the "bedrijfseigen fosfaatnorm" (BEP, English: proprietary phosphate norm) and the "bedrijfseigen stikstofnorm" (BES, English: proprietary nitrogen norm) (J. Oenema, C&O expert, 21/03/2019, personal communication). These pilot projects allow for farm-specific fertilisation norms, in contrast to the standard fertiliser norm. The BEP is based on the P_2O_5 extraction by crops. If the P_2O_5 extraction is higher than the standard fertilisation norm, a farm has a so-called BEP advantage and is permitted to work with a higher P_2O_5 fertilisation norm (Hilhorst & Evers, 2016). However, on many farms, a higher P_2O_5 fertilisation, as a result of a BEP advantage, is limited by the standard fertilisation norm for N. Therefore, the BES pilot aims to solve this by allowing to increase the P_2O_5 application with animal manure, without limiting it by the N application standard (Verloop & Hilhorst, 2017). Hence, the BES is closely linked to the BEP. Since C&O farms have higher yields than the national average (Fig. 7), an explanation for the higher P_2O_5 and N fertiliser use compared to the national average may be the participation in the BEP and BES pilots. This was confirmed by Evers & Hilhorst (2017) who observed that the BEP of C&O farms was on average 2% higher for 2014, 8% higher for 2015 and 11% higher for 2016 compared to the standard application norm. The reason for the increase in difference between C&O farms and the national average in 2015 is that between 2014 – 2015, the standard P_2O_5 fertiliser norm was lowered by 5 kg, resulting in a higher difference between the BEP and the standard norm from 2015 onwards (Evers & Hilhorst, 2017).This confirms the findings of this thesis that the tendency in differences between C&O farms and the national average started in 2015.

For nutrient use efficiencies, no significant differences, but a tendency for C&O farms to have a higher NUE compared to the national average was observed (Fig. 27). This implies a tendency for a higher level of environmental sustainability. Doornewaard et al. (2016) observed that for 2010 – 2012 C&O farms achieved higher N and P use efficiencies (33% NUE and 84% PUE) compared to reference groups (29% NUE and 77% PUE). The reference groups were made up of farms comparable to C&O farms in terms of soil type, ground water level and milk production/ha. Thus, a reason for the non-significant difference in this thesis may be that C&O farms were compared to the national average. Since the proportion of sandy soils is higher in C&O farms compared to the national average, they may be disadvantaged in this regard, and C&O farms may have had higher efficiencies if they were compared to a sample of farms with similar soil types (Oenema, 2013). Otherwise, a reason for no advantage of the C&O farms in NUE, may be the high stocking density of C&O farms compared to the national average, which results in high N-losses to the environment (Oenema, 2013).

Furthermore, despite no significant difference, a tendency for higher feed costs per area was observed for C&O farms compared to the national average. In every year, the average feed costs tended to be higher for C&O farms compared to the national average (Fig. 26). This again underlines the relatively high level of intensification of C&O farms. There are two possible explanations for this. On the one hand, C&O farms tend to have more cows/ha (chapter 2.1), resulting in a higher feed demand, and hence higher feed costs/ha. On the other hand, C&O farmers may be paying more attention to the quality of feed compared to the average farmer, thus may be buying more expensive feed (J. Oenema, C&O expert, 21/03/2019, personal communication).

Moreover, no significant difference was observed for feed self-sufficiency. In combination with the higher number of cows/ha and the lower area of feed production (Table 2), this implies that C&O farms produce more feed per area. Therefore, it again highlights their high level of intensification. This may positively influence the environmental sustainability of C&O farms. Furthermore, in combination with the higher milk yields of C&O farms (Fig. 7), no difference in feed self-sufficiency means that C&O farms have a better feed efficiency (i.e. they produce more milk per kg dry matter). Overall, it suggests that C&O farmers pay more attention to both fields and livestock, compared to the national average, and highlights their advantage in management.

Not captured in the results of this thesis is the social framework provided to C&O farmers which makes up an important part of their social sustainability. Within the project, farmers share their experiences with each other and have intensive discussions with extension services, advisers from the industry, researchers, and policy makers (Oenema et al., 2001). Furthermore, study groups to enhance knowledge transfer between research and practice, as well as excursions are organised (Oenema et al., 2001). In addition, 50% of C&O farms were members of an ANV in 2017, compared to 41% of the national average (Doornewaard et al., 2019).

4.2.2.1 Sustainable intensification of dairy farms

The overall observation is that C&O farms perform better than the national average in terms of intensification, mainly because of the more intensive farm structure of C&O farms, and because they tend to be more engaged than average farmers. Regarding environmental sustainability, the outcomes are ambiguous, as C&O farms can be considered as environmentally more sustainable when the impact is assessed per kg product, whereas no difference or a worse environmental sustainability are observed if assessed per unit of area. Results on social sustainability are similarly inconclusive, as on the one hand C&O farms have less grazing, but on the other hand, farmers are younger, and are embedded in a supporting social structure. The level of economic sustainability is the same for the national average and C&O farms.

4.3 The main differences between front-runner arable and dairy farms

It can be concluded that both arable and dairy front-runner farmer groups are more intensive than the national average. In terms of environmental sustainability, no advantage was observed for the two front-runner groups when assessed per area, but per kg product an advantage was observed for C&O farms, and it is expected that for VL farms a similar advantage could be identified. Moreover, while in terms of social sustainability for both groups no clear conclusion can be drawn from the results of this thesis, in both cases, social embedding in a network is an important aspect of the project. This leads to an advantage in social sustainability. The main difference was therefore observed in terms of economic sustainability, where a strong advantage was observed for VL farms compared to the national average. However, for C&O farms no difference was identified in comparison with the national average.

As embedding in social structures and knowledge exchange were identified as important aspects of the social sustainability of both arable and dairy front-runner groups, it may be relevant to define these as indicators of SI, and also include them in further data collection by WEcR.

4.4 Sustainable intensification in the Netherlands

As explained above, both front-runner farm groups are more intensive than the national average. Furthermore, social benefits in terms of a networking structure, as well as an economic advantage of VL farms compared to the national average were observed. The most ambiguous principle is that of environmental sustainability, where two open questions remain: whether environmental sustainability should be assessed per unit area or per unit product, and connected to this, whether an increase in yields with no difference in environmental sustainability, should in the Netherlands be considered as an improvement in the level of SI.

Assessing the environmental impact per area or per unit product is a question of whether extensive or intensive farming systems are valued as more sustainable. An assessment per unit area is advantageous for extensive farming systems, and per unit product for intensive systems (Schröder et al., 2003). Extensive systems are attractive, as they allow to combine food production with other functions, such as nature conservation on the same land (land sharing). This reduces the local environmental impact through de-intensification (Phalan, Onia, Balmford, & Green, 2011). However, these systems may require more area in order to achieve the same levels of outputs as an intensive system (Godfray & Garnett, 2014; Phalan & Green, 2011; Schröder et al., 2003). On the contrary, while intensive systems may have higher environmental effects per area, they allow for more area to be kept out of agricultural production. Hence, they separate land for nature conservation from agricultural land, and protect remaining natural areas from agricultural expansion, which may lead to more sustainability at a higher level (Phalan & Green, 2011; Schröder et al., 2003). So, the question remains which of the two systems is better representative for environmental sustainability in an SI assessment. SI aims, besides sustainability, for an increase in yields. The assessment of the environmental sustainability per unit product includes both of these SI aspects, and thus draws a complete conclusion on the topic. Therefore, as the term "intensification" in SI also implies, it is more meaningful, to assess the environmental effect per unit product, and hence advantage intensive systems, if emissions per unit area stay within limits. Consequently, in the context of an SI assessment, C&O farms can be considered as environmentally more sustainable than the national average, and due to their higher yields per unit area, for the VL the same is speculated.

However, this assumes that an improved level of SI is reached if yields are increased, and the environmental effect remains the same. It is questionable whether this is actually what should be aimed for in the Netherlands or Europe. In several papers it is argued that SI should not be used as a justification for focussing too much on productivity, or continuing with *business-as-usual* (Garnett et al., 2013; Godfray, 2015; Struik & Kuyper, 2017). Hence, it is stressed to not focus solely on the intensification aspect of SI (Garnett et al., 2013; Godfray, 2015; Struik & Kuyper, 2017). Struik & Kuyper (2017) even call for *sustainable de-intensification* of the European high-input agriculture. They argue that in Europe such high levels of intensification have already been reached that the focus should be on sustainability, and the level of intensification should be reduced. As a result, Struik & Kuyper (2017) conclude that SI should only be relevant for low-yielding countries, where yield gaps still need to be closed in order to combat food insecurity, or that two different forms of SI should be considered for European high-input agriculture, and low-input agriculture of the South. This was confirmed by Bos et al. (2013) for the Netherlands. They argue that especially in the Netherlands, SI is characterised by efficiency gains which comprise specialisation, increases in scale of farming and regional concentration, and neglect multiple sustainability issues. As Dutch agriculture is already highly intensive (the livestock density is among the highest in the world, resulting in pressure on biodiversity and the environment), it is important to focus on environmental sustainability, and not on intensification (Bos et al., 2013). Moreover, according to them, a focus on land sparing carries the risk of having negative environmental effects, while not necessarily preventing further agricultural expansion. Therefore, while the front-runner farms have been identified to, to some extent, have a higher level of SI than the national average, it is debatable whether in the Netherlands and Europe the focus should not be on SI but only on sustainability, especially environmental sustainability, as this is where currently the largest negative effects can be observed. Alternatively, SI should have a stronger weighing of environmental sustainability compared to the other principles.

5 Conclusions

In this thesis, the level of SI of arable and dairy front-runner groups in the Netherlands was compared to the national average, in order to identify the current state-of-the-art in the level of SI of better-performing farms in the Netherlands. It was not possible to assess the full picture of sustainability because of a lack of data on biodiversity and animal welfare in the BIN database. Therefore, in order to allow for complete assessments of SI, it is advised to WEcR to expand the registration on these indicators. Moreover, the assessment carried a certain level of subjectivity connected to the selection of indicators, as well as to the scaling and weighing for the radar charts.

It was identified that both front-runner groups are more intensive than the national average. They have advantages in social sustainability, as they experience more embedding in social structures, and the dairy front-runner farms engage a younger generation of farmers, but have less grazing than the national average. In terms of environmental sustainability, no advantages were observed for the front-runner farms per unit area. However, as a result of higher yields, a better environmental sustainability in terms of GHG emissions and N surplus was observed per unit product for dairy farms, and presumed (but not observed) also for arable farms. Thus, if intensification is valued as more relevant for SI than extensification, front-runner farms can be identified as more environmentally sustainable than the national average. For the arable front-runner group, an advantage in terms of economic sustainability was observed compared to the national average, while for the dairy front-runner group there was no difference. Thus, economic sustainability is the main difference between the front-runner arable and dairy farms in terms of their level of SI compared to the national average.

The main underlying reasons for differences in the level of SI between the front-runner groups and the national average were similar for arable and dairy farms. Firstly, they were based on the farm structure of the two front-runner groups: front-runner arable farms tended to have a larger area than national average, and front-runner dairy farms to have more cows/ha. Secondly, the front-runner farmers seemed to be more motivated and engaged than the national average, resulting in them being “better entrepreneurs”.

Overall, the results allow the conclusion that in the Netherlands, in comparison with the national average, SI-pilot farms produce higher yields, and have a higher level of socio(-economic) sustainability, with the same environmental impact. However, since Dutch agriculture is already at a high level of intensification, the focus should be more on a reduction of the environmental impact, hence on an increase of environmental sustainability, than on an increase in yields. This study gives an overview of the current state-of-the-art of front-runner farms but, based on its results, it is not possible to suggest how these increases in environmental sustainability can be reached.

On another note, for C&O the name is straight-forward, as the project is related to cows and has proven to give the farmers the opportunities to achieve higher yields, while staying within environmental legislation. However, for the Veldleeuwerik foundation, it is recommended to give more value to their name, e.g. through specifically assessing measures related to the protection of veldleeuwerik birds, in order to be able to better evaluate effects in this regard.

6 Suggestions for further research

For this study, it was not allowed to look into data of individual farms. However, for a complete assessment of the level of SI of better-performing farms in the Netherlands, it would be interesting to follow up on the outliers of high farm yields, and to look into the reasons for being outliers. What are underlying reasons that make them exemplary in their level of SI, and could that be extrapolated to other farms, or were they only data errors?

Furthermore, in this study, statistical data was analysed because it proved to be very difficult to get into contact with individual pioneer farms. As a result, it was decided to create a first overview of the level of SI of front-runner farms. As a next step, it would be interesting to visit and interview individual farmers that are performing better than the national average in terms of environmental sustainability, and to go into more detail with them why this is the case, how they do it, and how it can be extrapolated to other farms. This would allow to draw further conclusions on how improvements in terms of environmental sustainability can be achieved on a broader scale.

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Appendix

Appendix A: Protocol of data requested from non-Dutch farms

The following data was requested from England, Ireland, Finland and Denmark. The protocols for arable and dairy farms have been merged. The variables 7) Feed input use, 9) Feed self-sufficiency and 14) Animal welfare were requested only for dairy farms.

1) General

- Agricultural land by soil type -
  - Sand, clay, peat, loess
- Number of dairy cows
- Prices
  - Milk and dairy products, per 100 kg, factory price milk, per 100 kg, prices received for the different crops
- Surface cultivated land (ha)
  - Surface grassland (ha), surface fodder crops (ha), surface other crops (ha)

2) Yield

- Total revenues (€)
  - Revenues from milk, dairy products, sales and growth of cattle, crops and compensation
- Dairy farms: Milk production per farm or feed surface (kg or l / ha)
- Arable farms: Crop yields of the different crops (kg/ha)

3) Water use

- Amount of irrigation water used (m^3)
- Source of the irrigation water (m^3 or %):
  - Groundwater, surface water and rain or tap water
- For dairy also: Amount of tap water used (m^3)

4) Fertiliser use

- Nitrogen and phosphate fertilisers per ha ((kg N/ha) and (kg P_2O_5/ha))
  - Artificial fertiliser use
  - Animal manure
  - Other organic manure

5) Nutrient use efficiency and nutrient surplus

- Nitrogen and phosphate inputs besides fertilisers.
  - Feed, animals, seeds and planting material ((kg N/ha) and (kg P_2O_5/ha))
  - Atmospheric deposition and biological fixation of N (kg N/ha)
- Nitrogen and phosphate outputs:

- Animals, animal products, feed, organic manure ((kg N/ha) and (kg P_2O_5/ha))

6) Crop protection agent use

- If available: Total environmental impact points per ha
- Otherwise:
  - Which pesticide used for which crops:
  - At which dose (kg/ha or l/ha)
  - At what drift (%) *(The percentage that reaches the watercourses)*, if not available: what kind of nozzle used.

7) Feed input use

- Total costs of cattle feed (€)

8) Greenhouse gas emissions

- Total emissions by type (kg or CO_2 equiv.)
  - CO_2, CH_4, N_2O
- Source of the emission included in the assessment and if available, their proportion in the emission

9) Feed self-sufficiency

- Total feed value intake by dairy herd (kJ)
  - Concentrate, moist feed, milk products, maize, grass
- Amount of feed produced on the farm (kJ or kg)
- Amount of feed taken up by herd (kJ or kg)

10) Biodiversity

- Cutting percentage of grassland (%)
- Share of grassland torn (%)
- More specific data on biodiversity available?

11) Farm income

- Farm income already calculated? Otherwise the following variables in €:
- Total revenues, total costs (total paid costs, total calculated costs), depreciation, extraordinary expenses and benefits.

12) Income per labourer

- Hours of own (farmer's) labour.

13) Age farmer

- Age of oldest entrepreneur

14) Animal welfare

- Number of grazing days per year
- Days with a minimum of 6 hours of grazing

15) Subsidy dependence

- Which subsidies received and how much

Appendix B: Tables of indicators with significant differences and fertiliser use

Arable farms

Crop yield

Table 11: Average crop yield in kg/ha of sugar beet, wheat, and ware potato for Veldleeuwerik (VL) and the national average (Nt) for the years 2013 – 2017.

Crop	Group	2013	2014	2015	2016	2017
Sugar beet	VL	81,728	100,727	87,992	84,036	98,185
	Nt	78,180	90,457	83,147	78,379	93,522
Wheat	VL	9,385	9,804	9,994	7,984	9,386
	Nt	8,720	9,087	9,289	7,857	9,129
Ware potato	VL	49,740	53,973	54,404	48,415	55,865
	Nt	45,285	47,881	48,168	44,074	48,931
Seed potato	VL	38,514	38,318	41,260	40,557	38,248
	Nt	35,539	37,028	38,486	35,875	37,137

Fertiliser use

Table 12: Average fertiliser use in kg active N/ha and kg P_2O_5/ha for Veldleeuwerik (VL) and the national average (Nt) and the years 2013 – 2017.

Fertiliser use	Group	2013	2014	2015	2016	2017
N	VL	186	203	197	191	192
	Nt	165	178	178	182	172
P_2O_5	VL	69	70	59	60	64
	Nt	60	62	61	60	56

Farm income per entrepreneur

Table 13: Average farm income per unpaid work unit for Veldleeuwerik (VL) and the national average (Nt) and the years 2013 – 2017.

Group	2013	2014	2015	2016	2017
VL	127,370	66,103	151,402	123,074	93,448
Nt	70,930	29,181	85,946	55,742	41,920

Dairy farms

Yield

Table 14: Average yield at farm level (€/ha), livestock level 1 (€/ha), and livestock level 2 (kg/ha) for Cows & Opportunities farms (CO) and the national average (Nt) and the years 2012 – 2017.

Yield	Group	2012	2013	2014	2015	2016	2017
Farm	CO	9,445	10,180	9,731	8,460	8,265	10,638
level	Nt	6,715	7,690	7,830	6,938	6,562	8,139
Livestock	CO	7,931	8,787	8,208	7,416	7,217	9,491
level 1	Nt	5,692	6,762	6,687	5,981	5,805	7,117
Livestock	CO	20,081	19,603	18,683	20,450	21,818	22,540
level 2	Nt	13,975	14,791	15,060	15,740	16,398	16,808

Fertiliser use

Table 15: Average fertiliser use in kg active N/ha and P_2O_5/ha for Cows & Opportunities farms (CO) and the national average (Nt) and the years 2012 – 2017.

Fertiliser use	Group	2012	2013	2014	2015	2016	2017
N	CO	234	246	240	251	259	253
	Nt	238	239	243	234	234	240
P_2O_5	CO	84	81	83	83	91	82
	Nt	83	82	81	74	74	75

Nitrogen surplus livestock level

Table 16: Average nitrogen surplus per kg milk for Cows & Opportunities farms and the national average and the years 2012 – 2017. Error bars show the standard deviations of the respective years.

Group	2012	2013	2014	2015	2016	2017
CO	0.012	0.012	0.012	0.010	0.011	0.010
Nt	0.015	0.015	0.015	0.014	0.013	0.013

Greenhouse gas emissions

Table 17: Average greenhouse gas emissions at farm level (CO2 equiv./ha) and livestock level (CO2 equiv./kg milk) for Cows & Opportunities farms (CO) and the national average (Nt) and the years 2012 – 2017. No data was available at livestock level for 2012.

GHG emission	Group	2012	2013	2014	2015	2016	2017
Farm level	CO	26,272	24,326	23,912	24,764	24,252	23,157
	Nt	19,743	19,956	20,255	20,374	20,710	20,663
Livestock level	CO	n.a.	1.18	1.18	1.14	1.11	1.03
	Nt	n.a.	1.25	1.24	1.23	1.18	1.12

Preservation of grazing

Table 18: Average number of grazing days for Cows & Opportunities farms (CO) and the national average (Nt) and the years 2012 – 2017.

Group	2013	2014	2015	2016	2017
CO	144	146	151	157	170
Nt	178	193	180	181	177

Age of farmer

Table 19: Average age of the oldest entrepreneur for Cows & Opportunities farms and the national average for the years 2012 – 2017. Error bars show the standard deviations of the respective years and labels the average.

Group	2013	2013	2014	2015	2016	2017
CO	50	51	51	52	52	51
Nt	54	54	54	54	55	55

Appendix C: Graphs of indicators with non-significant differences

Arable farms

Yield

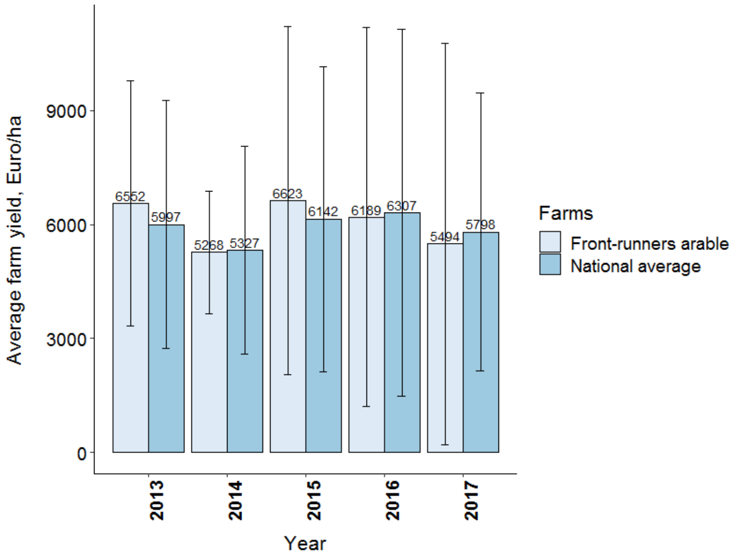

Fig. 16: Average farm level yield in Euro/ha for front-runner arable farms and the national average for the years 2013 – 2017. Error bars show the standard deviations of the respective years and labels the average.

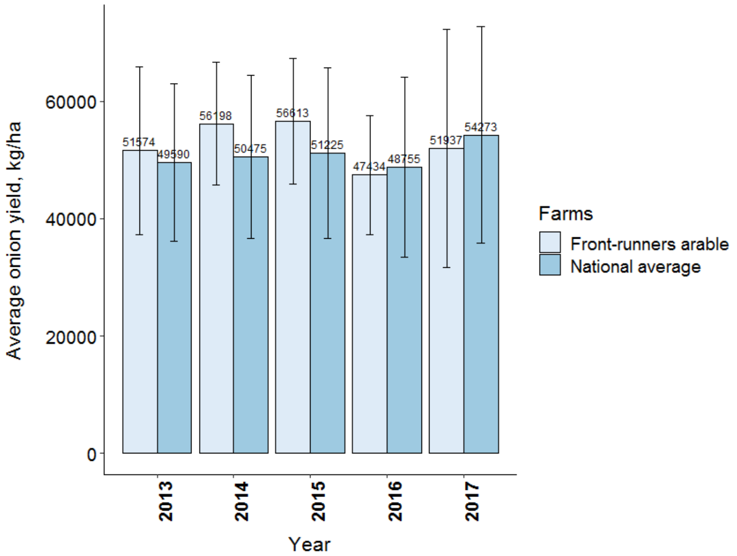

Fig. 17: Average crop yield in kg fresh weight/ha of onion for front-runner arable farms and the national average for the years 2013 – 2017. Error bars show the standard deviations of the respective years and labels the average.

Crop protection agent use

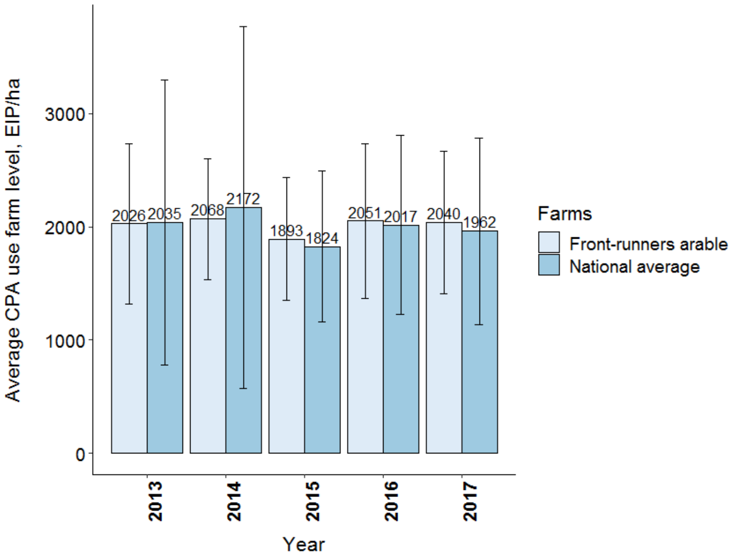

Fig. 18: Average crop protection agent (CPA) use in EIP/ha at farm level for front-runner arable farms and the national average for the years 2013 – 2017. Error bars show the standard deviations of the respective years and labels the average.

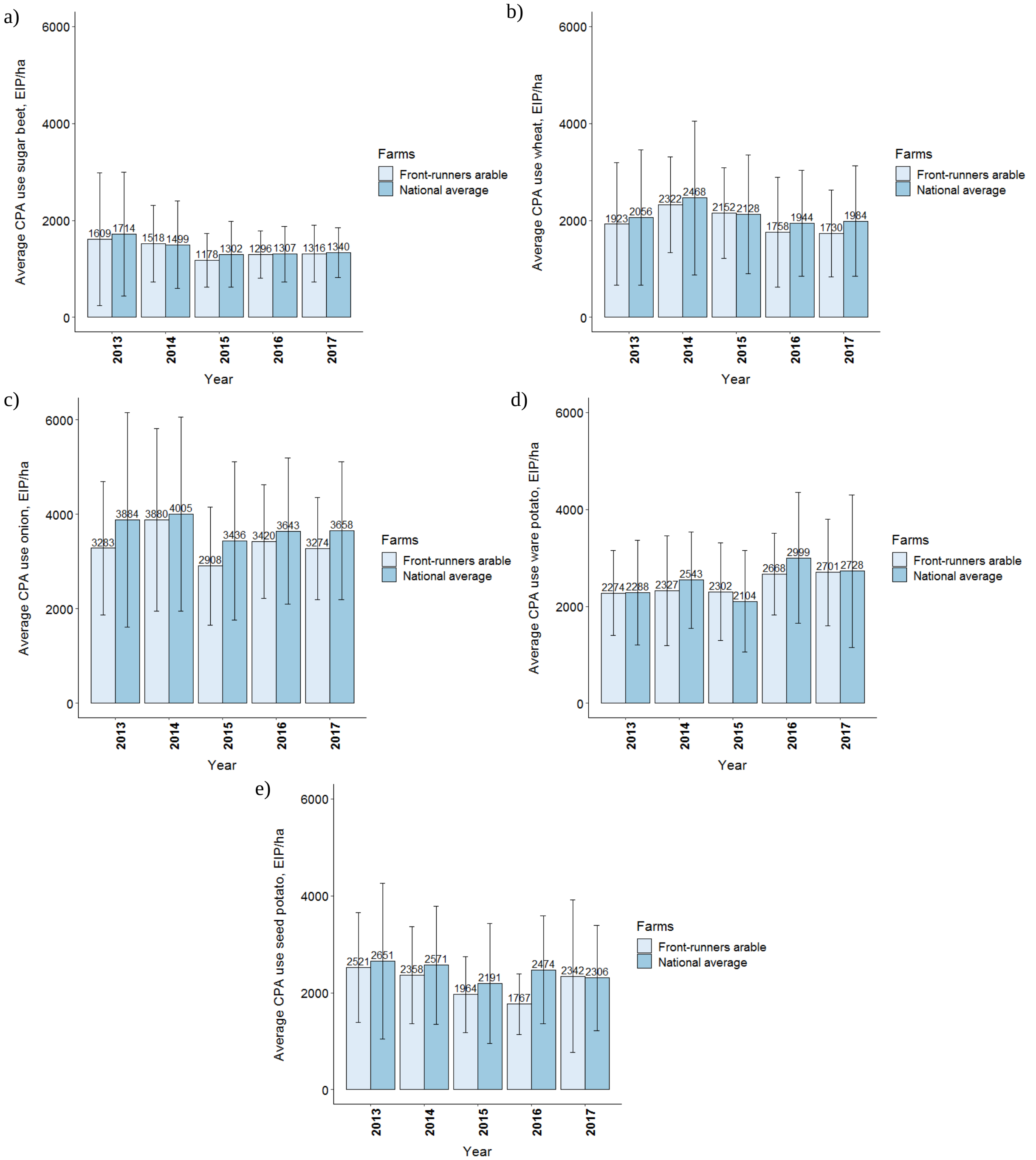

Fig. 19:Average crop protection agent (CPA) use in EIP/ha of a) sugar beet, b) wheat, c) onion, d) ware potato, and e) seed potato for front-runner arable farms and the national average for the years 2013 – 2017. Error bars show the standard deviations of the respective years and labels the average.

Nutrient use efficiency

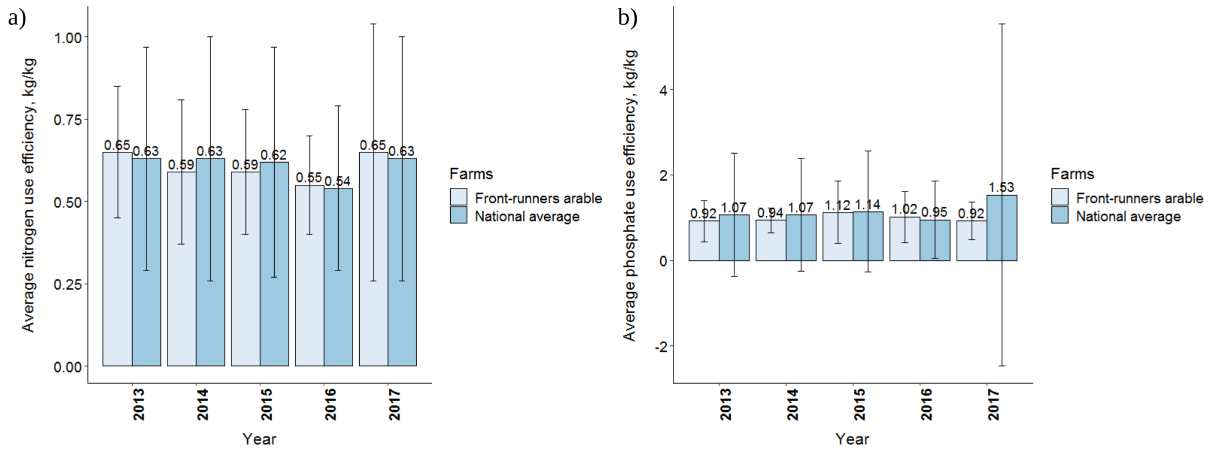

Fig. 20: Average nutrient use efficiency for a) nitrogen and b) phosphate for front-runner arable farms and the national average for the years 2013 – 2017. Error bars show the standard deviations of the respective years and labels the average.

Nutrient surplus

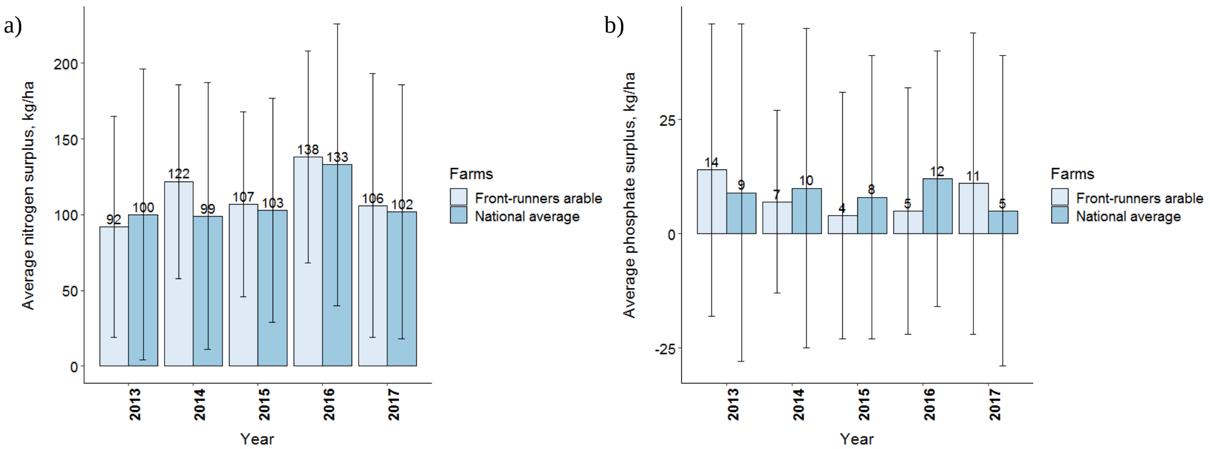

Fig. 21: Average nutrient surplus in kg/ha for a) nitrogen and b) phosphate for front-runner arable farms and the national average for the years 2013 – 2017. Error bars show the standard deviations of the respective years and labels the average.

Water use

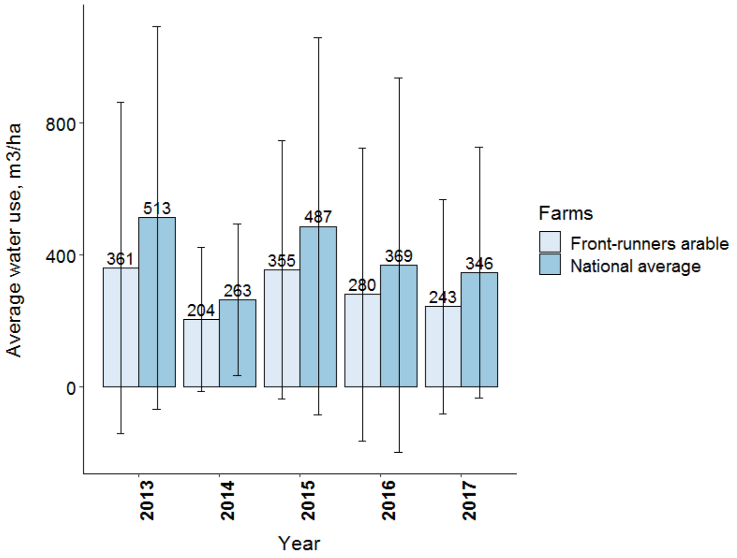

Fig. 22: Average water use in m3/ha for front-runner arable farms and the national average for the years 2013 – 2017. Error bars show the standard deviations of the respective years and labels the average.

Diesel use

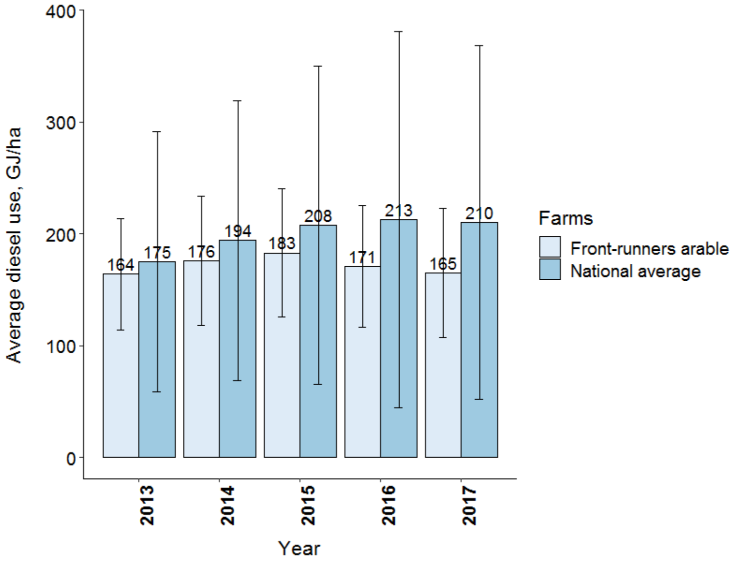

Fig. 23: Average diesel use in GJ/ha for front-runner arable farms and the national average for the years 2013 – 2017. Error bars show the standard deviations of the respective years and labels the average.

Biodiversity

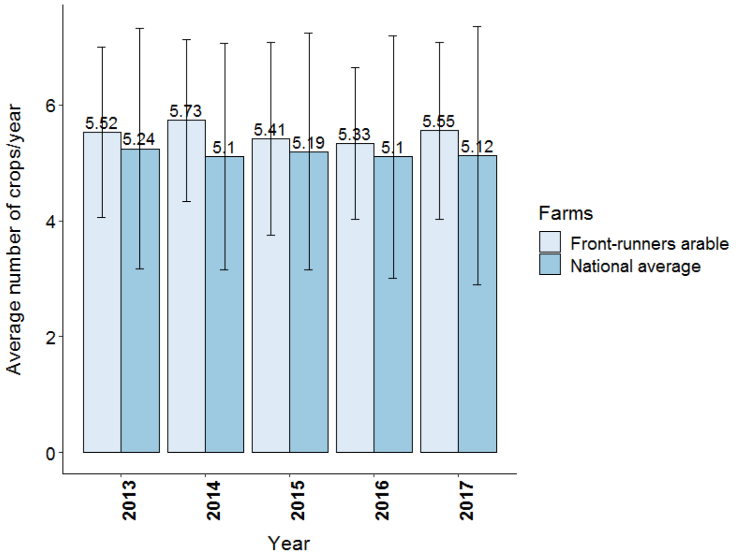

Fig. 24: Average number of crops for front-runner arable farms and the national average for the years 2013 – 2017. Error bars show the standard deviations of the respective years and labels the average.

Age of farmer

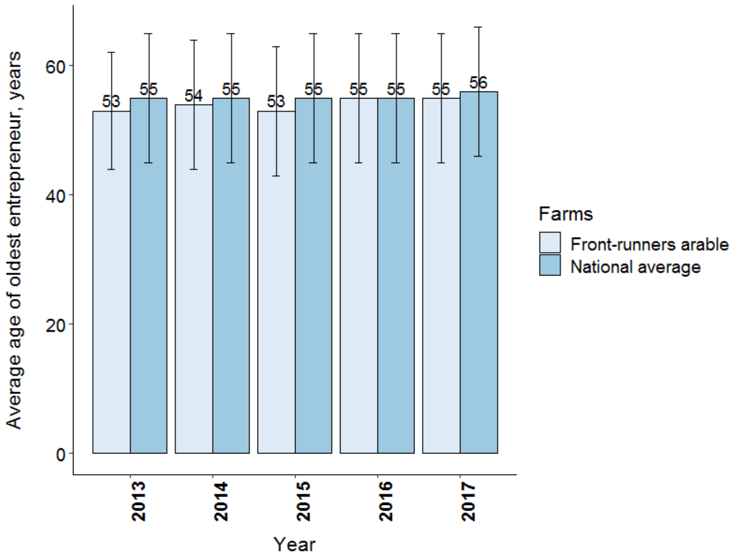

Fig. 25: Average age of the oldest entrepreneur for front-runner arable farms and the national average for the years 2013 – 2017. Error bars show the standard deviations of the respective years and labels the average.

Dairy farms

Feed costs

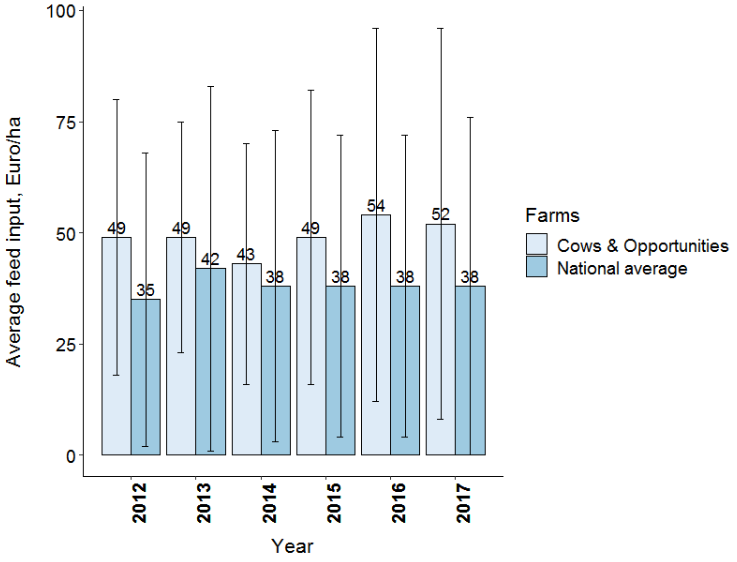

Fig. 26: Average feed costs in Euro/ha for Cows & Opportunities farms and the national average and the years 2012 – 2017. Error bars show the standard deviations of the respective years.

Nutrient use efficiency

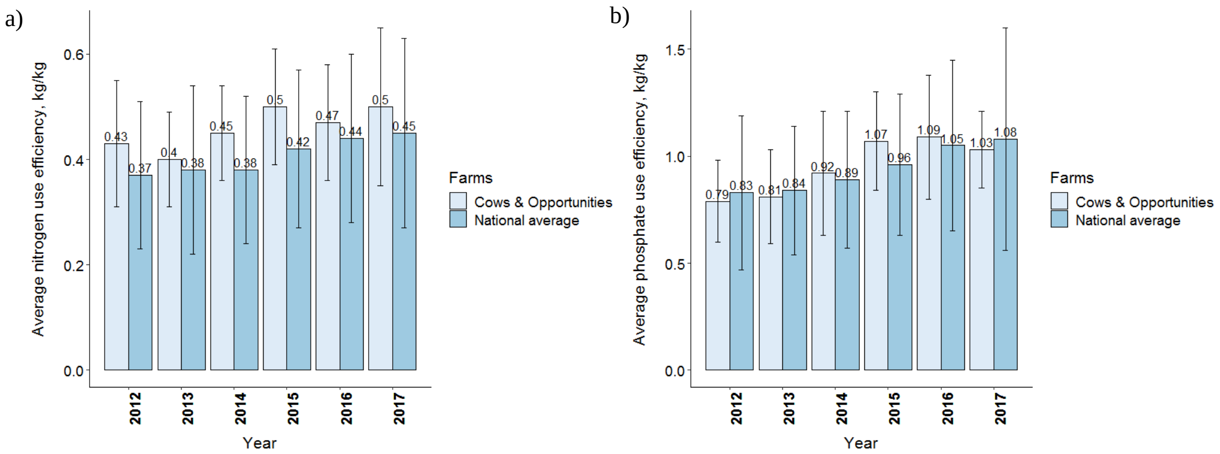

Fig. 27: Average nutrient use efficiency for a) nitrogen and b) phosphate for Cows & Opportunities farms and the national average for the years 2012 – 2017. Error bars show the standard deviations of the respective years and labels the average.

Nutrient surplus

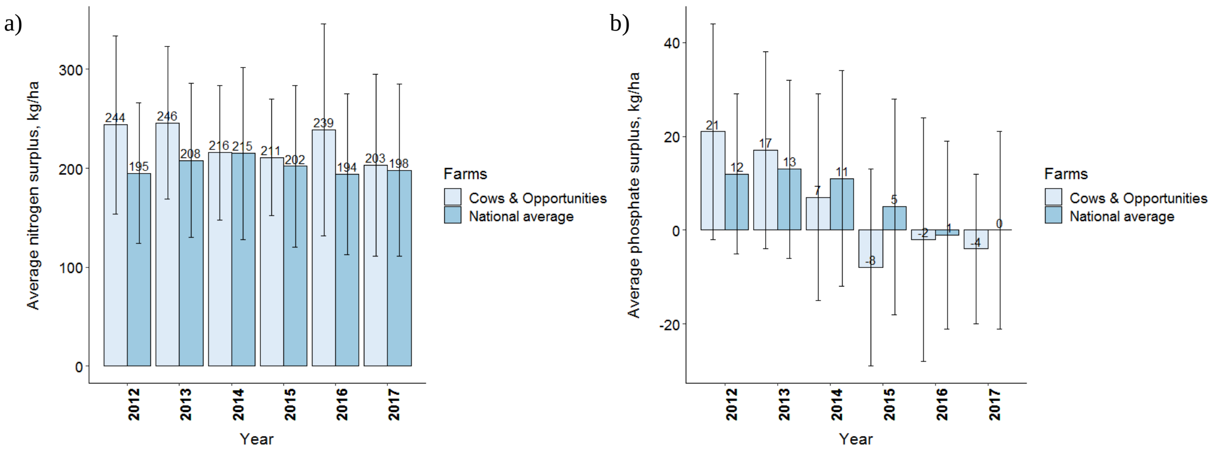

Fig. 28: Average nutrient surplus in kg/ha for a) nitrogen and b) phosphate for Cows & Opportunities farms and the national average for the years 2012 – 2017. Error bars show the standard deviations of the respective years and labels the average.

Water use efficiency

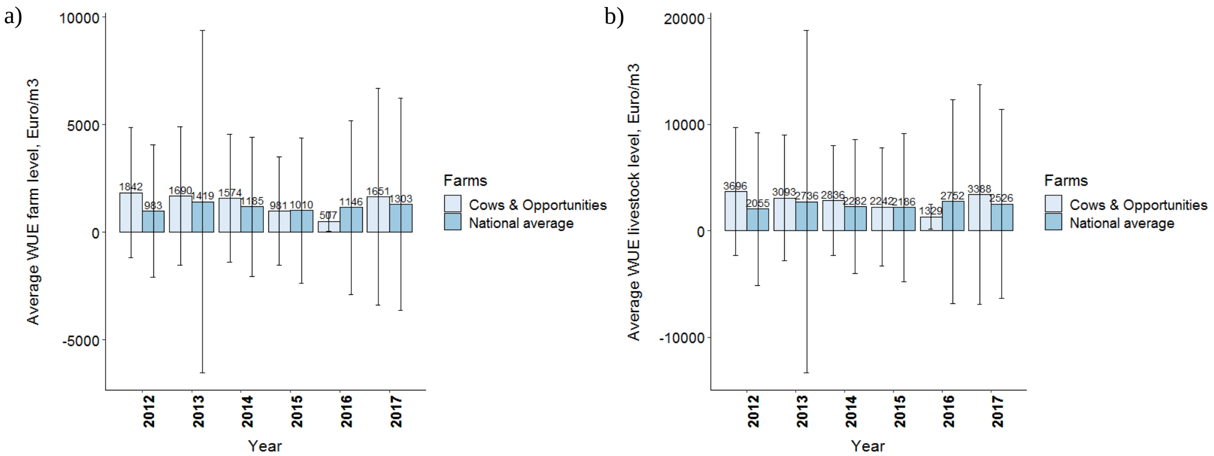

Fig. 29: Average water use efficiency (WUE) for a) farm level (€/m3) and b) livestock level (kg/m3) for Cows & Opportunities farms and the national average for the years 2012 – 2017. Error bars show the standard deviations of the respective years and labels the average.

Feed self-sufficiency

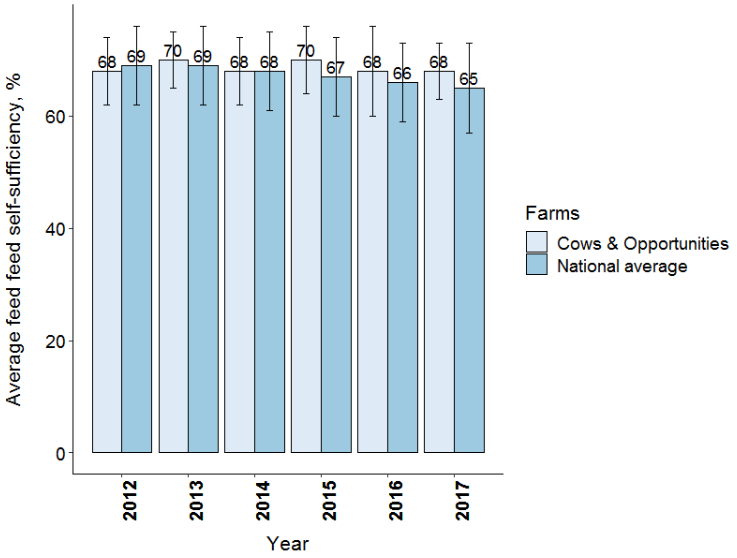

Fig. 30: Average feed self-sufficiency in % for Cows & Opportunities farms and the national average and the years 2012 – 2017. Error bars show the standard deviations of the respective years.

Biodiversity

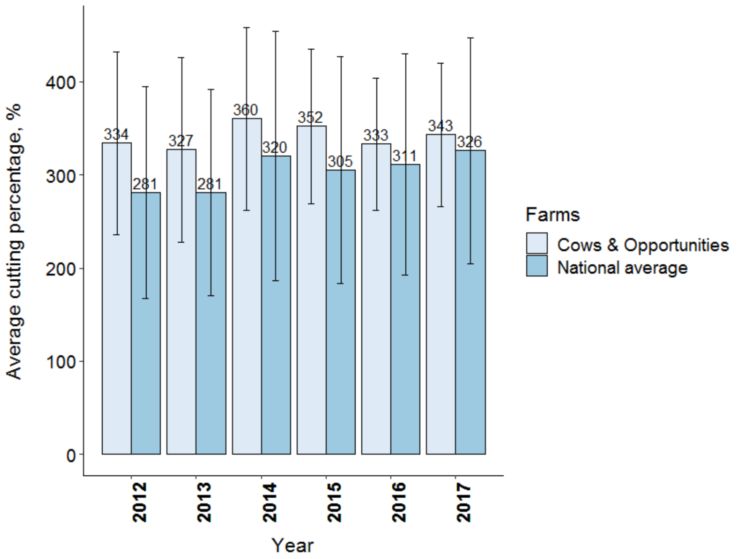

Fig. 31: Average cutting percentage of grassland in % for Cows & Opportunities farms and the national average and the years 2012 – 2017. Error bars show the standard deviations of the respective years.

Farm income per entrepreneur

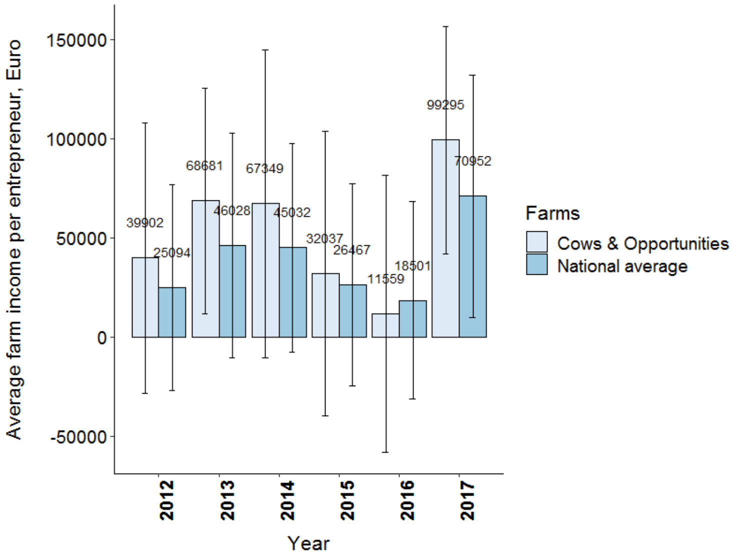

Fig. 32: Average farm income per unpaid work unit for Cows & Opportunities farms and the national average and the years 2012 – 2017. Error bars show the standard deviations of the respective years.