Current challenges and developments related to management of mixed cropping systems

System Analysis

Authors | Ellen Bulten, Saskia Houben and Marcel van der Voort. With contributions from Herman Schoorlemmer and Boelie Elzen

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In this report we provide a system analysis of agricultural practices and developments at three interacting levels: the wider context or socio-technical landscape (macro level), the 'status quo' of current agricultural characteristics or socio-technical regime (meso level) and innovations that emerge in technological niches (micro level). This analysis describes the many (sustainability) challenges that current agriculture faces and focuses on mixed cropping systems as an alternative, sustainable agricultural system to deal with these challenges.

Keywords: Mixed cropping systems, system analysis, drivers of change

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Summary

In this report, we provide a system analysis of current challenges and developments related to management of mixed cropping systems. This system analysis is a starting point in de design and exploration of future farming systems based on socio technical scenarios. We described agricultural practices and developments at three interacting levels: the wider context or socio-technical landscape (macro level), the 'status quo' of current agricultural characteristics or socio-technical regime (meso level) and innovations that emerge in technological niches (micro level).

Focussing on agriculture in Northwest-Europe, our analysis shows that while modern agriculture has been very successful in reducing food shortages and feeding a growing world population, the current system also faces many challenges, both environmental as well as societal. Features of current agriculture, based on the Third Agricultural Revolution and the chemical revolution of the 20th century, include control of crops and their genetics, of soil fertility via synthetic fertilisation and irrigation, and of pests (weeds, insects, and pathogens) via chemical pesticides, high inputs of fossil energy. Agriculture in Northwest-Europe can furthermore be characterised by cropping systems with a specialisation in few crops, large scales and high dependence on inputs, high land prices, many actors that surround the farmer, a diverse and stable value chain and an extensive European policy in the form of the European Common Agricultural Policy. Despite the success of modern, intensive agricultural practices in feeding a growing world population and reducing food shortages, current agricultural practices have led to a number of environmental challenges. Depletion of natural resources, pressure on the natural environment, biodiversity loss, pollution and deterioration of soil quality are main environmental challenges caused by intensive agriculture.

At both the macro and the micro level we described developments that influence the development of alternative agricultural systems that could deal with these sustainability challenges, with a specific focus on mixed cropping systems. At de macro level, we described demographic, economic, socio-cultural, technological/agronomical, environmental/ecological and political macro-events that represent the wider context surrounding agricultural practices. Examples of such macro-events include a growing world population, increased agricultural food prices, (changing) consumer preferences, digitalisation of agriculture, climate change and the introduction of the European Farm to Fork Strategy. On the micro level, we identified innovations related to mixed cropping systems and related future farm technologies. We clustered innovations in four categories: technological innovation, agronomical innovation, market and value chain innovation, social innovation. Examples of such innovations include autonomous vehicles and robots, innovative decision support systems, innovative mechanisation to facilitate strip cropping, crop diversification, controlled traffic farming to improve soil quality, community supported agriculture and new certification schemes. Based on the system analysis, we identified 10 drivers of change that will likely influence the development and future uptake of mixed cropping systems in Northwest-Europe.

1 Introduction

Agriculture today faces many social and environmental challenges, such as the unavailability of skilled workers, societal scepticism about production methods, depletion of natural resources, biodiversity loss and decreasing soil quality. Current agricultural systems can only be improved marginally to address these challenges, and if such marginal changes are made, they in turn cause trade-offs such as higher costs for the farmer or negative environmental impacts. In other words: current agricultural systems are 'locked-in' by the context in which they operate and are therefore hard to change (Frison, 2016). Because of this lock-in and the corresponding inability of the current agricultural system to holistically address social and environmental challenges, agriculture needs a more radical system change towards an environmentally friendly and circular system (e.g. Frison, 2016; see also Synergia proposal). Within the arable use case in the Public Private Partnership (PPP) Agros (Evolution to sustainable AGRicultural Operation Systems)[1], we focus on a systems change towards arable systems with more than one crop species on a field (intercrops). Such mixed cropping systems are a way to deliver sustainable intensification, based on more efficient land- and resource-use, while exhibiting significantly lower disease incidence and weed and pest infestation compared to systems with only one species on a field (Brooker et al., 2015; Yu et al., 2016). In this report, we define mixed cropping systems as the practice of growing two or more crops simultaneously for at least part of their cycle on the same field.

Task 8.1 of Agros focuses on designing and exploring future uptake of future farming systems. This task consists of three subtasks:

- 8.1.1 System analysis: Analysis of current challenges and developments
- 8.1.2 Development of future visions (scenarios) in which mixed cropping will play a significant role
- 8.1.3. Development of transition pathways (development path from the present towards the future visions)

The current report concerns subtask 8.1.1, the system analysis. This describes the main features of the current agricultural system in Northwest Europe, along with the main sustainability problems related to this system. This system analysis gives us a starting point to explore possible mixed cropping futures in the next subtask by providing an overview of both societal and technological (socio-technical) challenges, opportunities and developments of the current agricultural systems and mixed cropping systems in particular. A system analysis is a first and necessary step to explore what the transition from current agricultural practices towards mixed cropping systems could look like by taking into account current trends and developments. The present system analysis will also provide an overview of niche innovations that are currently being developed and/or that are being used on a small scale. Though their current contribution is small, they might well become the 'seeds of a transition' that could play a role in the future in making agriculture more sustainable. The main objective of task 8.1.3, that will be carried out in 2021, is to explore how that might be realised.

1.1 Multi-level perspective on sustainability transitions

Our system analysis builds on the multi-level perspective (MLP) on sustainability transitions (Rip and Kemp, 1998; Geels, 2002). The MLP suggests that transitions come about through interactions between three levels: the socio-technical landscape (macro level), the socio-technical regime (meso level) and technological niches (micro level) (Figure 1). The regime represents the context of common agricultural practice. We can distinguish between three components in a regime: technical, network and institutional components (Elzen et al., 2012).

1 Agros is linked to NWO's Synergia (SYstem change for New Ecology-based and Resource efficient Growth with high tech In Agriculture) programme. Within Synergia, Agros focusses on three use cases: horticulture, dairy farming and arable crops. This report is part of the arable crops use case.

Here, technology is used in the broad sense, including machinery and equipment, agricultural practices (e.g. applying fertilizers or crop protection), infrastructures (e.g. for regional water management), etc. With network we refer to the network of actors that carry the regime (e.g. as suppliers, producers, consumers). With regards to institutions, we distinguish between formal (e.g. laws and regulations) and informal (e.g. norms, values, attitudes) institutions.

On the micro level, in technical niches, novelties (niche innovations) emerge that deviate and are protected from the dominant structures in the regime. These niche-innovations offer an alternative to the dominant structures, differing fundamentally from the regime and niches are the breeding ground for radical innovations that poorly fit the common practices in the regime. Finally, the landscape on the macro level is defined as the exogeneous, wider environment that influences both regime and niche developments. Examples of macro events are globalisation or an economic recession. Landscape developments are slow to change and difficult to influence.

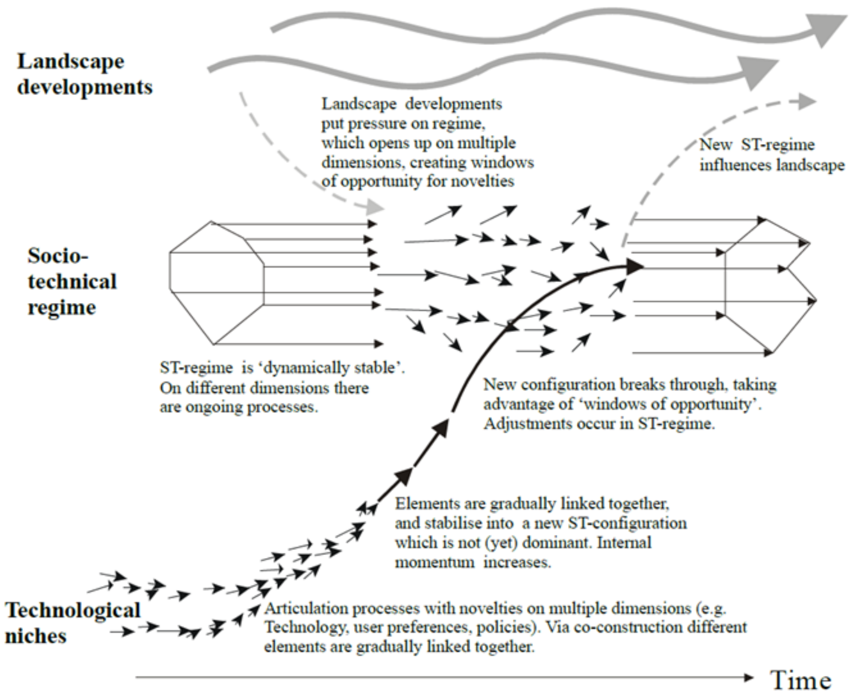

Figure 1 *The Multi-Level Perspective on transitions. Source: Geels, 2005.*

We use the MLP in order to get a better understanding of current agricultural practices and related sustainability challenges, but also developments that (influence) the progression of mixed cropping systems.

1.2 Methods

During the Kick-Off meeting of the Agros-arable usecase, we included a reflexive system analyse with partners involved in the PPP. The central question of this exercise was: What are opportunities, barriers and novelties for implementing mixed cropping systems in Northwest Europe? With regards to: technology & knowledge; markets & regulations; farm management & farm behaviour. The results of this session are included as an annex to this report. Building on this reflexive session, we based this report largely on literature review (grey literature and scientific literature). Additional interviews were carried out with experts on mixed cropping systems and partners within the PPP to validate and further inform our results (n=6). Additionally, we organised a session in October 2020 with the steering committee of the Agros arable usecase to reflect on Drivers of Change (DoC) and their influence on the development of mixed cropping systems.

1.3 Reading guide

In the next chapters, we follow the MLP as a framework. Starting at the meso level, we first describe main characteristics of the current agricultural system (Chapter 2) and its sustainability challenges (Chapter 3), then we describe landscape drivers for change (Chapter 4), third we describe a number of niche innovations related to mixed cropping systems and related smart technologies (Chapter 5). We finish this report with a concluding chapter (Chapter 6).

2 Characteristics of the current agricultural system in NW Europe

On the **meso level**, we structure our analysis according to the three components that make up the regime: technology, actors and network and institutions (formal and informal). This will focus on arable farming in Northwest-Europe and describe its main features.

2.1 Technology and agronomy

Most farms in Northwest-Europe are family farms, and farm sizes in the North-western countries are quite big compared to the rest of Europe (Eurostat, 2016). The average size of a family farm in North-western countries ranges from 32 hectare in The Netherlands to 66 hectare in the United Kingdom. Zooming in to The Netherlands, the range of farm sizes by means of their surface of arable land is remarkably wide. 54% of the arable farms are smaller than 50, 32% of farms are between 50 and 100 ha, 9% between 100 and 150 ha and the remaining 6% are farms with more than 150 ha of arable land (Agrimatie, 2018). A large group of Dutch arable farms is too small to achieve market-based remuneration for the deployment of their own labour and capital, this remains a strong driver for scaling up and for finding additional sources of income. Most farmers are over 40 years old, especially in the United Kingdom where only 5.3% of all farm managers were younger than 40 years old in 2016 and mostly men (Eurostat, 2018).

The total organic area across the EU was 12.6 million hectares in 2017, which corresponds to about 7% of the total utilized agricultural area (European Commission, 2019). Between 2012 and 2016, agricultural land with organic production grew by 1 percentage point, to 6.6%. Organic production is expected to increase steadily across Europe, to address the increasing demand for organic feed and food (European Commission, 2018b). Since organic farms have no access to synthetic crop protection, they depend stronger on robustness of their cropping system and on labour or alternative techniques for weed management. As a result, their crop rotations tend to be longer (Barbieri et al., 2017) and farmers of organic systems tend to use more cover crops.

Cropping systems with specialisation in few crops
Northwest-European arable cropping systems are generally characterised by high crop yields, as a result from high inputs of fertilisers and pesticides. Because of high costs for land and strong competition through globalisation of the world food market the productivity is optimized. Yield levels in western Europe are already high and increase only moderately (European Commission, 2018b). On one side the agricultural system with low crop diversity, the system is locked-in by strong competition on the global market of food and feed crops, which also keeps prices low. On the other side, the system is locked-in by a lack of attractive markets for certain key crops that could replace some of the main crops or that could be added to expand the crop rotation and allow diversification of cropping systems (Magrini et al. 2016; Meynard et al. 2013; Therond, 2017).

In most Northwest-European cropping systems, cereals are the dominating crops, especially winter wheat and spring barley (Eurostat, 2016). This is not expected to change quickly, given that wheat consumption continues to increase in Europe with 45% of it used for feed (Magrini et al., 2018; European Commission, 2018b). The demand for industrial use of cereals is also expected to increase in the coming years to 2030, in which the production of starch and ethanol plays an important role. Starch production of around 10 million tonnes in the EU, mainly produced by common wheat, maize and potatoes (European Commission, 2018b). Potato and sugar beet are other important crops in Europe. Potato production is widely spread across the EU member states, with Germany producing the highest volume (19,5% of the EU-28 total in 2015), the United Kingdom and the Netherlands producing also a relatively high volume, each accounting for between 10 and 14% of total production within the EU (Eurostat, 2015).

Besides Spain, most of the European production of sugar beets takes place in the North-western countries. The Netherlands differ considerably from the other countries in their crop rotation. Apart from some regions, cereals are grown there mainly to supplement the rotation cycle, not necessarily as a cash crop. Main cash crops in the Netherlands are potato (starch, seed and consumption), sugar beet, onion and other vegetables like carrot. The Netherlands together with Spain are EU's main producers of onion. The main carrot producing Member States include the United Kingdom with 13.9% of the EU total production, Germany (11.8%) and the Netherlands (10.1%) (Europstat, 2019).

In the crop rotation with cereals as main crops, cereals are alternated with grain legumes, oil seed rapes and root and tuber crops such as potato and sugar beet (Olesen, 2016). Minor crops became more and more excluded from the cropping systems through the increasing competitiveness between major crop species like wheat (Magrini et al., 2016; Olesen, 2016). However, we also see in some countries the yield of winter wheat declining and the area of silage and grain maize increasing in Northern Europe (Olesen, 2016; Elsgaard et al., 2012). Another reason for the limited diversity of crops, is that choices for crops are led by annual crop-based margins that are provided by accounting agencies who advise farmers (Magrini et al., 2018) and that farms have become more and more specialised, gaining most of their profit from one or two crop. Since the 1950's the yields of some main crops strongly increased thanks to developments in breeding, nutrients (synthetic fertiliser) and crop protection products that made it possible to correct for unfavourable growing conditions.

The warming climate promoted expansion of the area of silage maize in Northwest-Europe. This may further increase since the effects of observed climate change showed a higher yield potential for maize and sugar beet because of the longer growing season (Supit et al., 2010). The longer growing season as a result of climate change will also increase productivity of many other Northwest-European crops. Therefore, the warming climate could lead to further intensification of the cropping system but it could also result in the contrary, the introduction of new crops that are adapted to a different climate (Olesen, 2016).

Large scale and high dependence on inputs

Farm practices and technologies in Northwest-Europe are adapted for large scale and maximised production with a high efficiency:

- Big and heavy machinery designed for efficient management of large uniform parcels;
- Specialisation in only a few crops;
- Crops are mainly sold to wholesalers;
- It is common to outsource field operations to contractors. Over 50% of the agricultural operations in the EU are executed by contractors ("Ceettar sectors", 2020). This includes all types of agricultural work, e.g. sowing, cultivation, fertilisation, harvesting, transport.
- Available knowledge on crop management and advice are focused on dominating crops.

The farm systems rely intensively on inputs for energy, fertilisation and crop protection products because the farm practices and systems became very uniformed to reach a high efficiency. Moreover, farmers tend to apply more pesticides and fertilisers than required to avoid risks of reduced yields, due to their relatively low prices (Caron et al. 2014; Cordell et al. 2011; Struik et al. 2014; Therond, 2017; De Koeijer et al., 2002). The use of mineral fertiliser remained high in Northwest-Europe, in particular the large producers UK and Germany, with nitrogen fertiliser consumption of more than one million tonnes in each of these countries in 2018 (Eurostat, 2020a, see also Figure 2).

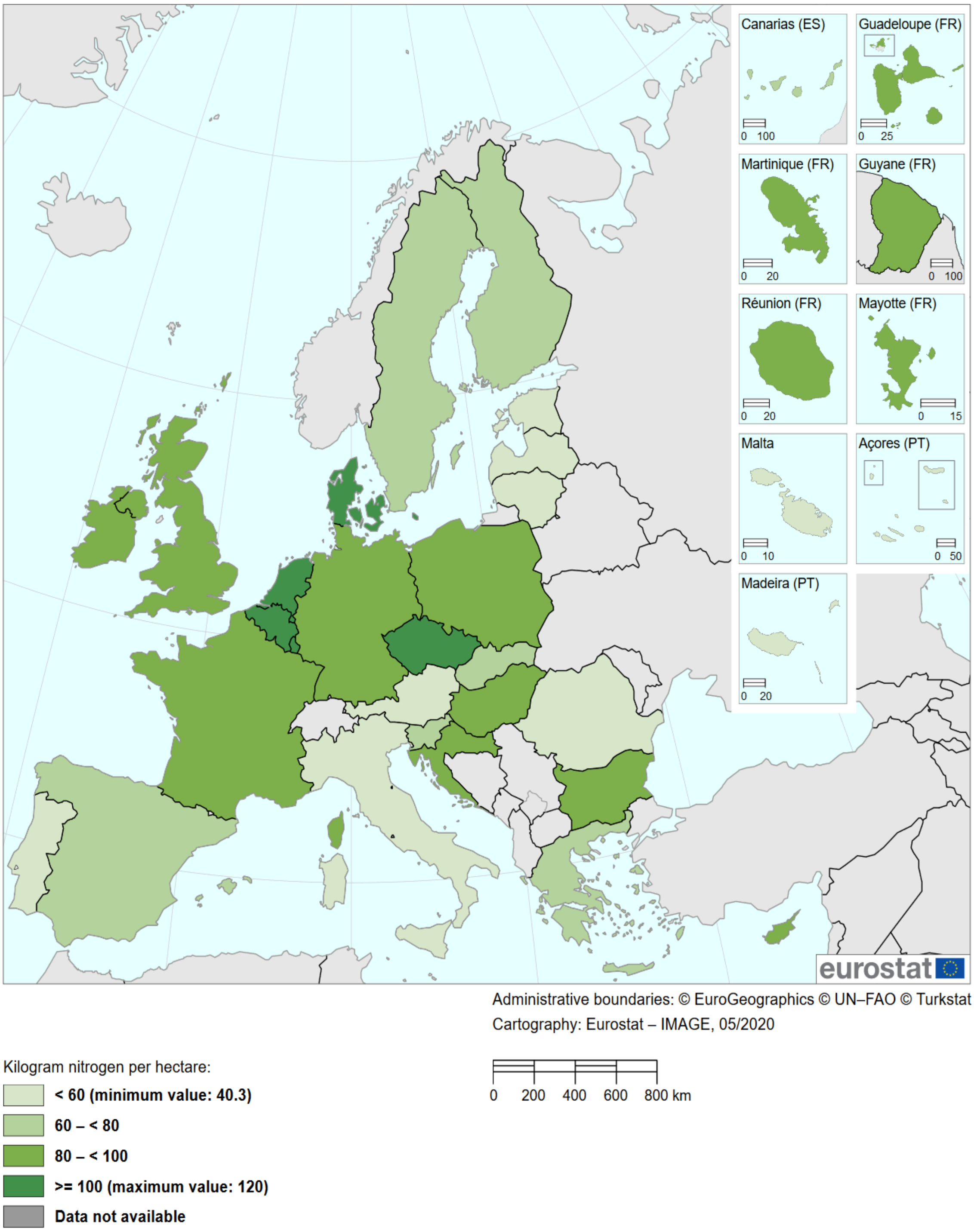

Figure 2 *Nitrogen fertilizer consumption (kgN/ha of fertilised utilised agricultural area) highest in North-western countries. Source: Eurostat, 2018a.*

Energy use is particularly high in the Netherlands with a share of 8.1% by agriculture in final energy consumption, compared to 3.2% in the EU in 2018 (Eurostat, 2020b). It should be noted, however, that in the Netherlands the relatively large horticulture sector consumes high levels of energy (Eurostat, 2020b), skewing the numbers for the agricultural sector as a whole.

Labour availability is a concern; the number of persons working on a farm is decreasing while the average holding size of farms is increasing. The Netherlands has the third highest average number of people working per farm (2.9) but with an average relatively smaller farm size (27 ha), this comes down to 9.3 ha per person. The United Kingdom has just 2.3 persons working per farm but with Europe’s second largest average farm area of 94 ha that means 40.9 ha per person (Schrijver et al., 2016).

Mechanisation in Northwest-European agriculture is developed for the large scale and large parcels with only one crop. To achieve high productivity, which is a way to cover the high land costs and to compete on the polarised food market, mechanisation as well as inputs such as crop protection products became focused on large scale arable farming with a high efficiency. In summary, features of current agriculture include control of crops and their genetics, of soil fertility via synthetic fertilisation and irrigation, and of pests (weeds, insects, and pathogens) via chemical pesticides and high inputs of fossil energy (Tilman, 1999; Détang-Dessendre et al., 2018). These features of current agriculture have resulted in the use of big and heavy machinery with the drawback that soil compaction is a major issue in Northwest-European agriculture.

For most operations, farmers have their own machinery and it is common to hire contractors for specific field operations such as harvesting. For transitions like the one to mixed cropping systems, this can be a bottleneck but also an opportunity. At the moment, contractors provide big heavy machinery but in the future they might also provide technologies that support mixed cropping systems, such as small robots. Within Europe, there is a lot of attention for precision farming in the North-western countries. Not the size of the companies in hectares but in revenue is decisive to use precision techniques (van der Wal et al., 2017). Most farmers in North-western countries already use precision technologies such as GPS-tracking[2] to make straight tracks when sowing, harvesting, fertilising or spraying. Technological development has now made it possible to automate cyber-physical systems by networking between different machines. Nevertheless, precision agriculture has not been widely established in crop production (Weltzien, 2016). Some technologies for precision farming are widely available but require research and experimentation to make good connections between data collection, interpretation of the data and follow-up in farm operations. It is important to realise that precision farming concerns different steps, and for all of these steps a lot of technology is being developed but these steps need to be connected to each other too. Not solely by digitally connecting the technologies to one another but also the interpretation of the data and translation into operations, e.g. applying precisely the required amount of a crop protection product at a precise location in the field. This integration requires wide knowledge and experience on different aspects (different soils, insects, effectivity of products and operations etc.): first to interpret the data correctly, secondly to decide on the correct amount, frequency and moment of an operation that follows from the monitored results. A following (or parallel) challenge is to develop a system in which these processes run autonomously. In any case, precision farming entails the following steps that need to be connected with each other:

- Sensing;
- Decision making;
- Actuation.

Sensors, an important basis for precision monitoring, still need further development before they can be applied for precision farming. Sensors for some important soil and climate properties and quantification of aboveground crop biomass made implementation of the first precision farming applications possible. Other sensors, for example for detecting pests and diseases, soil nutrients and crop quality, still require further development (Schrijver et al., 2016) Remote sensing data, for example satellite and drone images, are rarely used in practice to base farm operations on. The use of site specific variable rate applications is still at its infancy.

Arable land is expensive

Arable farmers produce on their own land and/or on rented land from other farmers, often from livestock farmers. In Northwest-Europe the price of land is relatively high and increasing as well, which forces farmers to increase efficiency and optimise production. The combination of relatively high prices for land and labour results in high cost prices for agricultural products. Consequently, farmers tend to apply production practices which need less labour and land, in order to reduce cost prices. The willingness to pay for land that can be managed with the same machines and labour is high, resulting in even higher prices for land (Berkhout et al., 2019).

The high land prices also result in intensification that puts pressure on soil quality, resulting in soil degradation, especially compaction caused by heavy machinery.

[2] More than 85% of the respondents in a survey by Rabobank under their customers in The Netherlands use a GPS guidance system (Rabobank, 2020)

Soil quality is also affected by the fact that person who manages the land is not necessarily the owner. In Europe, market-oriented farms rent on average 54% of their land. This differs strongly per country, for example in Ireland the share of rented land is only 20%. The share of rented land has increased since 2004 for the youngest and oldest farmers, while it remained quite stable for middle-aged farmers. On average, farmers use roughly 5% of their total costs for land rents, a moderate amount that does not differ much among age groups (European Commission, 2017a). Land rents were particularly high in the Hamburg region (Germany) with 2700 euro per ha and in the Netherlands, where it was 860 euro per ha in 2015 (European Commission, 2018c). In the case of one-year land rent for specific crops, this amount quickly becomes two till four times higher

2.2 Actors and networks

Main actors in the context of Northwest-European arable farming are described here for each component of arable farming, from actors and networks that are involved in the daily farm operations to actors and networks that provide knowledge for future farm strategies.

Related to on-farm management:

Of course farmers themselves are the main actors in on-farm operations but they involve various actors to gather knowledge, materials, advice, to exchange ideas and experience, to sell their products and to take over part of the operations. Some of these parties have a strong influence on the opportunities that farmers have but also the decisions and actions taken by farmers. The main actors in this field are:

- Farmers and farmer organisations;
- Cooperatives;
- Advisory services;
- Contractors;
- Suppliers of inputs and technologies;
- Researchers.

These actors are part of the Agricultural Knowledge and Information System (AKIS). AKIS is a concept to describe the collection of organisations and people that provide agricultural knowledge, the information flows between them, and the institutions regulating these relations (PRO-AKIS, n.d.). The European AKIS can be divided in the Micro-level Agricultural Knowledge and Information Systems (micro-AKIS) and the Regional Farm Advisory System (R-FAS). The micro-AKIS is assembled by farmers themselves, including a range of individuals and organisations that provide services and exchange knowledge with them, the involved processes and how this is all translated to innovative activities. All organisations providing advice to farms in a specific region and their connection to the wider AKIS organisations (up to the European level) form the R-FAS (Agrilink, 2018). Farmers cooperate and collect information on general practices and decisions but also for innovations in these AKIS's:

- through advisory services;
- through educational institutes (universities of applied sciences, universities);
- in cooperatives;
- with neighbours and colleagues;
- in study groups funded by the EU (e.g. Operational Groups) and private (e.g. organized by advisors, farmers or accountancy firms);
- through online platforms (EIP-AGRI, 2015);
- at field demonstrations organised in EU funded projects and in many private initiatives organised by farmers, advisory services and businesses (e.g. seed companies);
- at trade shows;
- from data (e.g. from online platforms).

As shown by Figure 3, the national AKIS are quite different. This has to do with their embeddedness in national laws, cultures and institutions. In the project PRO-AKIS, each country's AKIS within the EU was characterised based on their 'strength' and 'level of integration' (Figure 3). A strong AKIS is characterised by three factors: influential actors or organisations at national level that support the knowledge system or a part of it. It is also characterised by the fact that dedicated resources for knowledge are allocated to the AKIS. Finally, in a country with a strong AKIS, there is evidence that farmers benefit from advisory services and that they are being reached. The 'level of integration' refers to the formal links between AKIS actors; if the AKIS is fragmented, there are several independent knowledge networks that operate in parallel, not or rarely in cooperation with each other. They even might compete and they lack a coordinating structure. In contrast, a well-integrated AKIS is characterised by a good coordinating structure, often a public party, and the AKIS is supported by national policies that form a framework for (inter)actions of the AKIS actors. Also there is evidence for the connection between various actors (PRO-AKIS, n.d).

The Northwest-European countries clearly have strong AKIS, compared to the rest of Europe. Regarding their integration level, however, there is a great difference between Northwest-European countries. The UK and the Netherlands both have a strong but fragmented AKIS, while Luxembourg, Denmark and Ireland have a well-integrated AKIS. Germany's AKIS falls somewhere in between. Belgium is separated into Wallonia and Flanders, which both have strong AKIS, but differ in levels of integration, with Flanders having a more integrated AKIS compared to Wallonia.

Figure 3 *An overview of the European AKIS. Source: PRO-AKIS, n.d.*

Regarding the value chain:
The European food supply chain is quite diverse and stabile, this combined with a large consumer base with a relatively high purchasing power makes it low-risk. But the risk profile is deteriorating; the competition position is relatively weak. Together with a fragmented agricultural structure (including the supply chain), geopolitical risks and an increasing influence of global developments on the European food & agri sector, these are the main challenges for the European agricultural and food sector (Rabobank, 2016).
In the current agricultural system, it is difficult for farmers to change their farming strategy due to contracts with retail. The value chain of arable products is complex due to its diversity and the globalised market. There are relatively few traders to whom the farmers sell their products. Mainstream cooperatives and traders who buy farm products are generally large and highly specialised, and therefore not eager to collect, store and distribute small volumes of new crops. Individual farmers have limited capacity to bargain with the large-scale traders because the farmers do not easily cooperate to provide together with other farmers enough quantities to mitigate the costs of collection and management by themselves (Morel et al., 2020). To give an idea of the balance between producers and buyers: the Netherlands count about 10,000 arable farmers, while their products are sold to about 20 traders who then sell them to about 5 large supermarkets (Nederlandse akkerbouw vakbond, n.d.).

Typical for arable farming is that farms grow various crops and these crops are sold through various independent chains for each specific crops. It is striking that the main arable products specific chains and specialized companies and organisations have been formed (in the primarily, supply, processing, distribution chains as well as trade associations and cooperatives). The sale of specific crops such as potatoes can therefore be very complex.

First, there is the difference between seed, starch and consumption potatoes. In the Netherlands, mainly two large potato trading houses decide which variety or varieties their members should grow (in the case that the trading house is a cooperation) or their suppliers should deliver. The seed potatoes also come from the trading house and partly turn back as seed potatoes from the same farmers. Growers of starch potatoes are member of one cooperation and have delivery rights to deliver their potatoes to this processor. Growers with shares in the cooperation are obliged to deliver. From the consumption potatoes, the majority (over 70%) is contracted by the buyers before the potatoes are grown. These contracts exist in many different forms (e.g. hectare contracts, pool contracts, click contracts) but growers are also free to choose for free trade or the futures market. Retailers and other buyers are imposing increasingly strict, non-statutory requirements on potatoes, for example through the PlanetProof label (Bremmer et al., 2019). Main actors involved on the sales side of the value chain are:

- Producers/farmers;
- Processors;
- Traders and retail (Local, European, global), including cooperatives;
- Farmer interest groups;
- Trade association;
- Society and NGO's;
- Through the common agricultural policy (CAP) the EU:
  - provides income support with direct payments;
  - takes market measures to deal with market situations.
- Consumers. Important trends are:
  - the 'hybrid consumer', which means that consumers search for value (good enough) and extra (luxury);
  - a shift to convenience, resulting in more catering;
  - a growing interest and concern for health and sustainability;
  - the 'well informed consumer' who puts pressure on food businesses;
  - Online shopping for food (Rabobank, 2016).
- Livestock (purchase for feed)

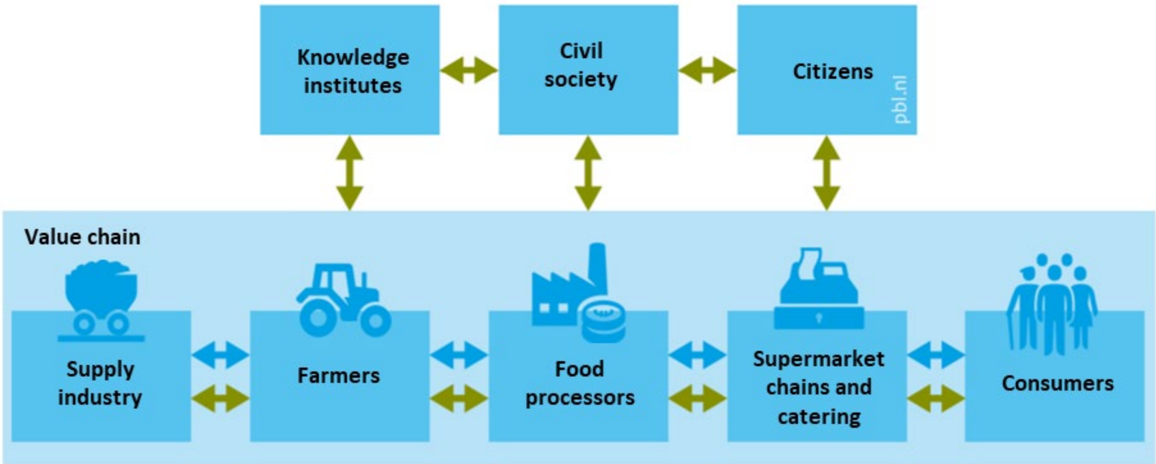

Figure 4 *Economic and discursive sources of power in value chain control. Blue arrows indicate economic sources of power (e.g. relative market position of companies), green arrows indicate discursive sources of power (e.g. good reputation). Adapted and translated from: PBL, 2019.*

Typical for West-Europe is the negative attitude of the consumer towards modern technology in relation to food. For instance, consumers' concern about genetic modification (GMO) has led to strict laws and complete restriction on GMO produced crops. This has a negative influence on the competition position of the European agriculture on the global market (Rabobank, 2016).

Also important to consider, there is a difference between what people find desirable as 'citizens' and how they act as 'consumers', as also indicated in Figure 4 by including consumers in the value chain and citizens outside of it. This sometimes means that citizens put pressure on value chain actors to produce sustainable products while consumers buy the product with the lowest price or products with the 'right' size and colour. Moreover, much of the influence from consumers on the production and trade process is outside the countries where the products are produced and processed; a great share of the Northwest-European arable farming products is produced for the global market. In the Netherlands for example, 0.8 million ha of arable land is used for consumption in the Netherlands. The other 0.9 million ha is used for consumption outside the country, as shown in Figure 5 (PBL, 2020).

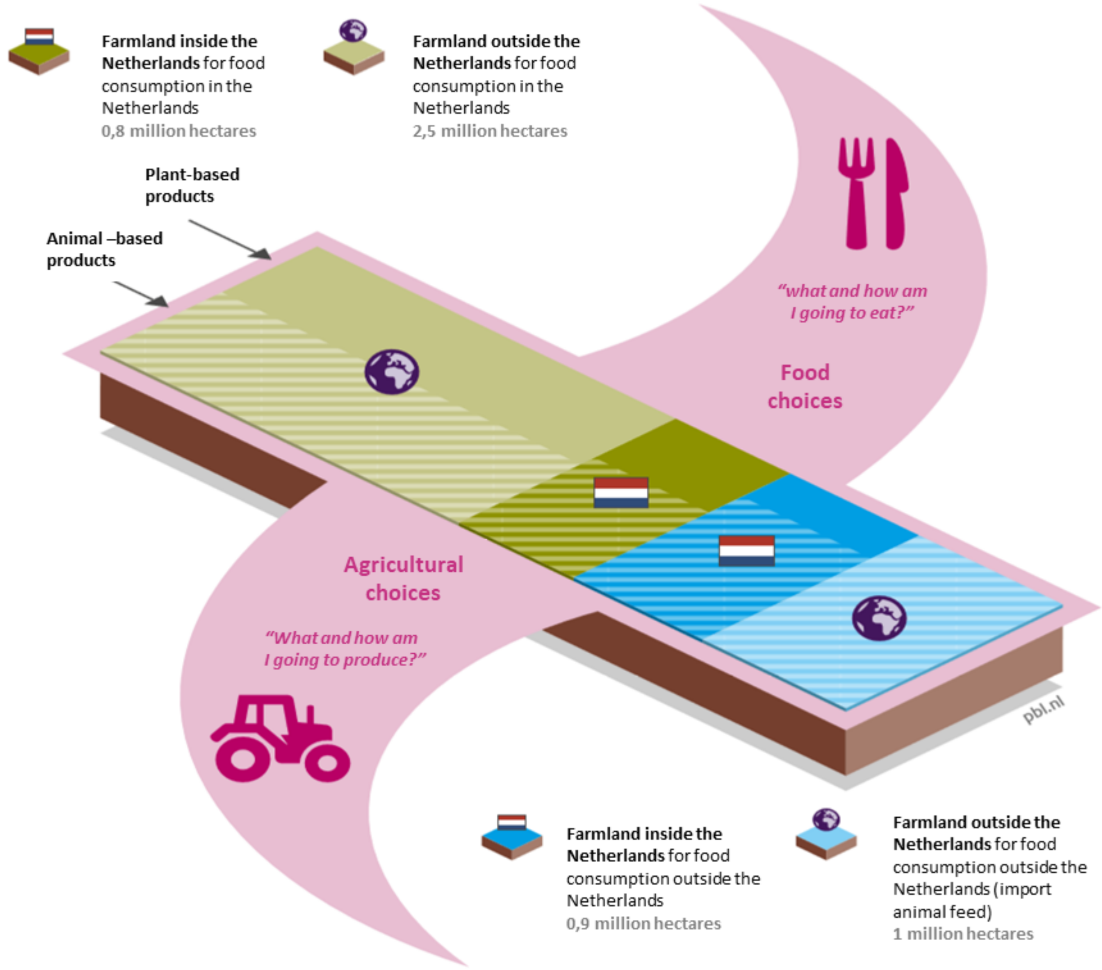

Figure 5 *Land use for food production in the Netherlands. Adapted and translated from: PBL, 2020.*

In education:
The majority of European farm managers learned their profession by practical experience alone (about 68% in 2013). This situation is changing for young farmers; about 20% of them followed a full agricultural training cycle, although 62% of the youngest farmers still only had practical experience in 2013 (European Commission, 2017a). In the Northwest EU however, farmers are more trained, which is reflected in the implementation of new technologies such as precision farming, which is highest in North-Western countries (EIP-Agri Focus Group, 2015).

Regarding research and innovation:
The European Union supports research and innovation organisationally and financially. With the agricultural European Innovation Partnership (EIP-AGRI), the European Union helps to accelerate innovation with an interactive approach, bringing together specific actors to work together in multi-actor projects to find solutions for specific issues or to develop a concrete opportunity in regional Operational Groups (OG). The Operational Groups are implemented through the EU-funded Member State rural development programmes (European Commission, 2020).
Innovation under EIP-AGRI can be either technological, non-technological, agronomical, organisational or social and based on new or traditional practices. A new idea becomes only a real innovation if it is widely adopted and proven to be useful in practice. The EIP-AGRI's proven value in mobilising the agricultural actors for innovation is recognised by the European Commission's communication. In this

context, the role of farm advisors is considered particularly important (European Parliament, 2019). Besides the OG's and multi-actor projects, there are research projects and thematic networks Europe-wide supported through the Horizon2020 programme. Together they are the main organisational and financial basis for research and innovation in Europe (see also Figure 6). Important actors within Northwest Europe, often co-innovating through the European networks for innovation and research are:

- Farmers;
- Farm advisors;
- Machinery builders;
- Contractors;
- Businesses;
- Farmer and business organisations (e.g. cooperatives);
- Start-ups developing new technologies, inputs and services in the wide context of agriculture (e.g. farm practices, machinery, data management, decision support systems, marketing, technologies underlying strategies such as precision farming);
- Research institutes (fundamental and practical research);
- Universities.

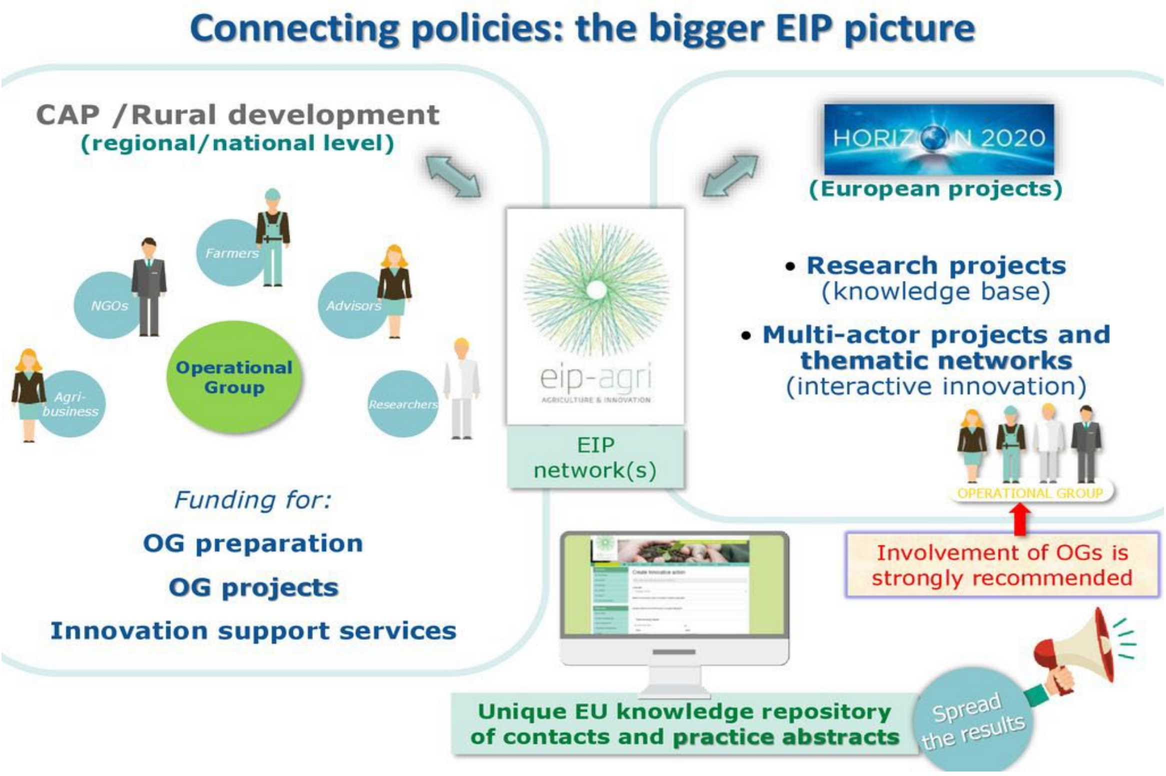

Figure 6 *Diagram of the strategic approach of EIP-AGRI to EU agricultural research and innovation showing Source: European Commission, 2018.*

2.3 Institutions

Both formal (e.g. laws and regulation) and informal (e.g. norms, values, attitudes) institutions shape agricultural development in Europe. Europe has an extensive environment policy, e.g. with policy to prevent water and air pollution and preserve biodiversity. National policies are adapted to European policies and national policies differ from each other according to local pressure on the environment and other specific circumstances. The European Common Agricultural Policy (CAP) is the most important agricultural policy and aims to ensure enough food produced in a sustainable way, with a reasonable consumer price as well as a reasonable income for farmers. Almost 40% of the EU budget is dedicated to agriculture and mainly consists of subsidies. Policy is mainly focused on income support for farmers, market regulation and rural development. To increase the sustainability of the European agriculture and to maintain biodiversity the European Commission developed the Farm to Fork strategy and a biodiversity strategy in the context of the Green Deal, a program to make Europe climate neutral before 2050 (European Commission, n.d. c).

Income support for farmers in the European Union consists of direct payments, all EU countries offer obligatory payments for sustainable farming methods (greening) and can additionally offer income support to help small and medium sized farms, young farmers, farmers who operate in areas of natural constraint and/or sectors undergoing difficulties (European Commission, n.d. b). Each farmer who meets the regular environment and sustainability requirements of the European Union receives 260 euro per ha agricultural land. Besides this, farmers can receive support if they contribute to biodiversity conservation, through the European Greening requirements, with a 'greening premium' of 115 euro per ha. Furthermore, the European agriculture policy implements the sustainability and biodiversity strategies by supporting rural development with investments in nature, landscape, environment, a local and vital countryside and water quality (European Commission, n.d. c). Figure 7 provides an overview of the two important European policies for research and innovation in agriculture: the CAP and Horizon 2020, and how they strengthen each other.

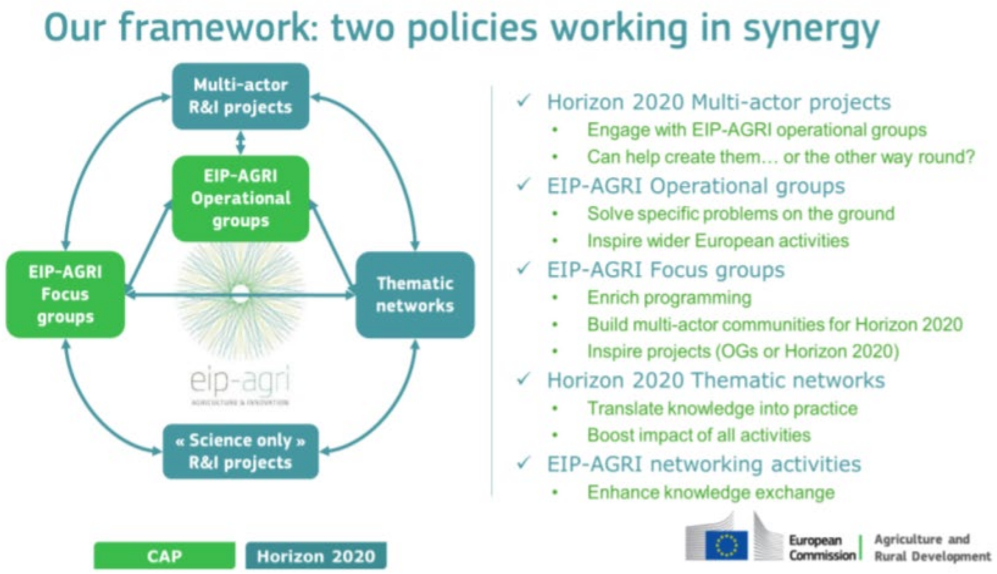

Figure 7 *The framework of the European Commission for agricultural research and innovation. Source: European Commission, 2018.*

Processes of crop diversification have also been started in the last years thanks to (research) projects and the European Greening requirements, including protein and leguminous crops cultivation (alfalfa, peas, soybean). Such legislation could be important for the development of mixed cropping systems in Europe. To summarise: although there is no legislation specifically focused on crop diversification, the European governmental institutions promote a more sustainable agriculture by:
- Restrictions (e.g. limited authorisation of pesticides);
- Subsidies that promote:
- innovations;
- promotion and support knowledge exchange;
- (financial) support of investment in new technologies.

Ecological interactions between (soil) organisms (affecting production) are complex. Thus, the long term effects of new methods like intercropping – whether this is strip cropping, pixel cropping or any other scale of intercropping – is hard to predict. Experiments with combinations of crops at one location, one soil type and for a few years is no proof for its success at a farm somewhere else. At the same time, land is expensive and together with the globalized market, low or fluctuating prices and the limited bargaining capacity of farmers this results in a situation where risks are avoided. From this perspective, it is risky for farmers to start intercropping, never mind choosing the right combination of crops. This has resulted in a conservative approach towards risks. A farmer can deal with the uncertainties related to ecological interactions by locking out all risks as much as possible, in other words, block natural processes such as the interactions between organisms associated with mixed

cropping systems. Another way to deal with the uncertainties is to trust the self-regulating capacity of biological processes, e.g. by following agro-ecological principles: sustain and promote soil quality (and soil life), crop diversity in time and space and landscape elements.
This alternative, more challenging approach has started among some front-runner farmers but this group is still minor. Alternative food systems, circular economies and integrated landscape approaches can open doors for non-exclusive diversification as well (Therond et al., 2017). In Chapter 4, we elaborate more on aspects such as (changing) consumer patterns which also influence agricultural development.

3 Sustainability challenges of the current agricultural system

The Green Revolution or Third Agricultural Revolution, occurring after the second world war, made it possible to greatly reduce food shortages due to an increase in agricultural production worldwide (most notably of cereals) (e.g. Pingali, 2012). These increased yields were mainly caused by the introduction of new crop varieties, fertilisers, pesticides and irrigation technologies. The features of current agriculture are still based on the hallmarks of the Green Revolution, combined with the chemical revolution of the 20th century: control of crops and their genetics, of soil fertility via synthetic fertilisation and irrigation, and of pests (weeds, insects, and pathogens) via chemical pesticides, high inputs of fossil energy (Tilman, 1999; Détang-Dessendre et al., 2018). Modern agriculture has proven to be very successful with high crop yields, low prices for consumers and a reasonable income for the farmer. However, there is a downside: current agricultural practices have led to a number of environmental challenges and modern agriculture is now considered to be environmentally unsustainable by many. In this chapter we discuss depletion of natural resources, pressure on the natural environment, biodiversity loss, pollution and deterioration of soil quality as main environmental challenges related to agriculture.

Agriculture makes ample use of scarce natural resources such as fossil energy, fresh water and land. For example, current agricultural practices are responsible for 70% of freshwater use (Steffen et al., 2015). Agricultural systems are already putting major pressure on these natural resources, and this will worsen with a growing world population and increased food demands (Foley et al., 2011). Figure 8 compares land use versus ecosystem services and their trade-offs. The hypothetical landscapes show that intensive cropland admittedly achieves abundant food production, but at the cost of all other ecosystem services. If, on the other hand, all other ecosystem services are (almost) optimally used, there is a huge trade-off for crop production, making it impossible to feed a growing world population. This figure shows that land use inherently asks for trade-offs between maintaining ecosystems and their services on the one hand and feeding a growing world population on the other hand (Foley, 2005). Currently, agricultural systems are largely focused on achieving high yields, while putting pressure on other natural resources and ecosystem services.

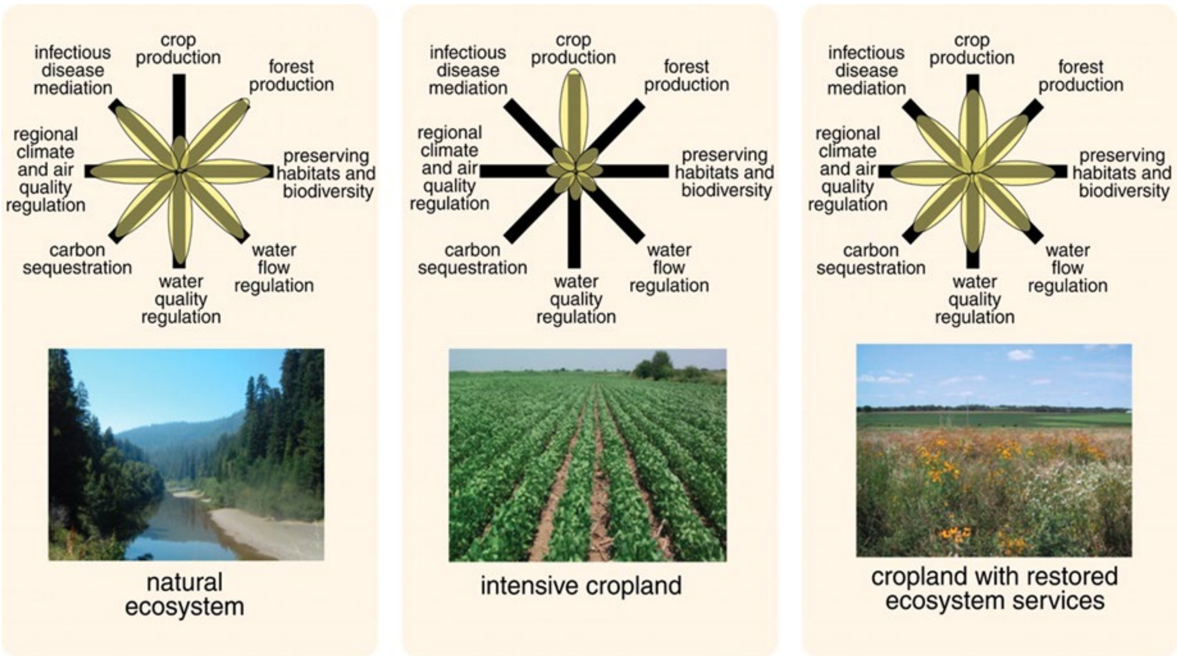

Figure 8 *Land use and trade-offs of ecosystem services. Source: Foley, 2005.*

Food systems rely on natural resources such as land, soil, water and minerals. Agriculture is a dominant user of many natural resources, in particular land, biodiversity, fresh water, nitrogen and phosphorus. However, these resources are often overexploited or not used to their full potential. For example, efficiency of inputs from nitrogen and phosphorus fertilisers (natural resources which are essential to grow crops) is very low, meaning that there is a major loss of these resources to the environment (Sutton et al., 2013).

This inefficient use of resources in agriculture leads to pollution of the surrounding environment. Excesses of nitrogen and phosphorus lead to emissions of the greenhouse gasses (GHG) nitrous oxide (N2O) and ammonia (NH3) to the atmosphere and losses of nitrate, phosphate and organic nitrogen and phosphorus compounds to water, potentially contaminating soils and fresh water bodies (Sutton et al., 2013). GHG emissions are now the highest they have ever been, and agriculture contributes largely to these emissions. Over the past 50 years, GHG emissions that result from agriculture, forestry and other land use have nearly doubled and are expected to further increase in the coming decades. Although GHG emissions are often linked to livestock production, these emissions are also caused by land use and soil and nutrient management (FAO, 2017): approximately one-quarter of global GHG emissions are a result of land clearing, crop production and fertilisation (Burney et al., 2010). It should be noted, however, that within EU member states, GHG emissions resulting from agriculture have declined by 20% between 1990 and 2015. Part of that decline can be attributed to a reduction of 17% in nitrous oxide emissions from agricultural soils, mainly due to reduced use of nitrogenous fertilisers (Eurostat, 2017b). Pesticides, used to control weeds and insect pests (and therefore improving yields and protecting quality, reliability and price of produce), can contaminate soil, water and the surrounding environment (Aktar et al., 2009). Overuse of pesticides is a related issue, where farmers tend to apply more pesticides and fertilisers than needed, in order to avoid risks of reduced yields (Caron et al. 2014; Cordell et al. 2011; De Koeijer et al., 2002; Cook et al., 2011). Pesticide sales within the EU have been more or less stable between 2011 and 2018, at around 360 000 tonnes per year. In the Netherlands, total pesticide sales have decreased slightly in the same time period (Eurostat, 2020b).

Land use by humans has the biggest impact on biodiversity loss worldwide (Sala, 2000). Biodiversity is indispensable for agriculture, providing services such as pollination, pest and disease control and soil and water related ecosystem services. However, homogenisation of agriculture through agricultural intensification has been a driving force of biodiversity loss (FAO, 2019). In Europe, biodiversity losses are predominantly caused by eutrophication, climate change and fragmentation. In the Netherlands, nature exploitation, agricultural intensification and urbanisation have led to a decline of 50% of species' population size (PBL, 2012). Pesticide use has also raised concerns about its potential negative consequences on biodiversity (Geiger et al., 2010; Gibbens et al., 2015).

Lastly, healthy soils are a requirement for optimal crop production. Farming (including natural grassland) makes up 48% of total EU land surface area. In 2013, 60% of the actively farmed area was used for arable crops, 33% for permanent grassland and 7% for permanent crops (European Commission, 2017c). These numbers illustrate both the dependence of agriculture on healthy soils as well as the major influence agriculture has on soil's resources. However, over-fertilisation acidifies natural and agricultural soils, while a shortage of nitrogen and phosphorus leads to soil degradation (Sutton et al., 2013). Heavy machinery and inappropriate soil management have caused soil compaction in many places, resulting in an impermeable soil for water, air and roots (Batey, 2009). Pesticide use can negatively influence soil quality as well, as it can cause the decline of beneficial soil microorganisms. Losing these microorganisms (e.g. fungi or bacteria) leads to soil degradation (Aktar et al., 2009). Salination can occur as a result of salt accumulation from irrigation water and fertiliser, which can eventually make soils unsuitable for plant growth. Salination affects approximately 3.8 million ha in the EU (European Commission, 2017c). Soil organic matter (SOM) is important for soil fertility but also for water retention capacity and biodiversity. Moreover, SOM plays an important role for climate change regulation as soils are the world's greatest terrestrial carbon sink. Permanent grassland is an effective carbon sink, but arable land poses a significant risk of carbon loss. However, the rate of SOM loss generally varies a lot depending on cultivation practices, types of crop, drainage status of the soil and weather conditions (European Commission 2017c).

All these effects of agriculture on our natural environment have brought a wide consensus that EU agriculture is not sustainable (e.g. Détang-Dessendre et al., 2018).
Current agricultural practices can only marginally be further optimised, while a growing world population leads to a higher food demand, putting even more pressure on agricultural systems. Sustainability remains important in all arable production systems, and focus should be on healthy and safe products, transparency in the food system, minimal inputs of fertilisers, pesticides and fossil energy, climate, healthy soils, clean water, biodiversity, reduction of waste (Bremmer et al., 2019). A transition towards a different, sustainable agricultural system seems therefore necessary to be able to sustainably feed a growing world population. There are already many initiatives initiated by growers, organisations surrounding them, buyers or initiatives that respond to societal wishes and demands.

4 The sociotechnical landscape: drivers of change

On the **macro level**, we can look at relevant Drivers of Change that accelerate developments in one direction or another. The DESTEP (Demographic, Economic, Socio-cultural, Technical, Environmental/Ecological, Political factors) analysis uncovers macro-events that influence the development of mixed cropping systems in Northwest-Europe. These macro-events represent exogenous, major social changes in domains such as politics, culture, world views and natural occurrences. These events are difficult to influence and usually change slowly. In practice, this means that agricultural systems have to adapt to (changes in) these macro-events and/or use them as windows of opportunity. The DESTEP analysis focuses on macro-event in Demographic, Economic, Socio-cultural, Technical, Environmental/Ecological and Political domains.

In this section, we will elaborate on relevant events within each of the DESTEP domains that influence the development of mixed cropping systems in Northwest Europe. The analysis is based on a literature review of grey and scientific literature and complemented by interviews with experts on mixed cropping systems as well as partners in the Agros project.

4.1 Demographic

Three major demographic trends influence the development of agriculture in Northwest Europe: urbanisation, greying of society and growing world population.

Around 2007, the world's urban population exceeded the world's rural population for the first time in history (UN, 2018). This trend of urbanisation goes hand in hand with growing and changing demands towards more energy- and greenhouse gas emission-intensive foods (Satterthwaite et al., 2010). For example, urbanisation often comes with an increased demand for meat products, vegetable oils and luxury products (De Hean et al., 2003), although this trend may be more relevant in developing countries compared to developed countries (Hoffman, 2001).

Because of better health care services and increasing income, the world population is also aging which consequently creates shifts in dietary patterns and preferences (European Commission, 2015). It is projected that, in the European Union, the old-age dependency ratio (people aged 65 and over relative to the number of working age people) will steadily increase in the coming decades (European Commission, 2018a). Agriculture in Europe is especially affected by the greying of society, since more than a third of farmers in Europe is aged 65 or over (European Commission, 2017a), many of them struggling to find a successor. To illustrate, 59 per cent of Dutch farmers 55 years and older do not have a successor. This problem is especially pressing for (very) small farms (CBS, 2021).

Finally, the growing world population is a demographic trend that also affects agriculture. Population growth in developed countries is mainly caused by decreasing mortality rates of both elderly and infants, due to increased medical health services and better nutrition (European Commission, 2015). Obviously, growing populations cause increased food demands, although demands for certain products (e.g. vegetable oils) outpace other foods (e.g. meats) (European Commission, 2015).

4.2 Economic

Major economic trends impacting agriculture include global economic growth, growing trade and food prices, competition for natural resources, (the need for) increased agricultural production and innovation and changing food systems (FAO, 2017). These trends are related to economic conjuncture or (international) food markets. Of course, trends such as urbanisation and population growth also influence food economics. However, in this DESTEP analysis we have discussed these trends under demographics. Nevertheless, it is important to keep in mind that many, not strictly economic, factors also affect food and agricultural economics in Europe.

Annually, the world economy has continued to grow in the last three decades and is projected to keep growing, with different projections of how fast economic growth will be to 2050 (FAO, 2017). The rise of a global middle class, resulting from fast income growth in emerging countries, is followed by changing dietary demands with higher meat and dairy consumption, which consequently requires a shift in outputs and more resource-intensive foods (FAO, 2017).

Since the mid-2000s, agricultural food prices have increased in parallel with prices of other commodities, which at times have also been rather volatile. Due to these trends, consumers are faced with increased food prices, which in turn leads to concerns about food security (European Commission, 2015). It is worth mentioning, though, that compared to other products, agricultural trade has grown much slower and agricultural share of global GDP has decreased (Anderson, 2010). Development of future food prices depend, among other factors, also on how well food production is capable of dealing with increasing pressure on natural resources and effects of climate change. In order to meet increasing global demands, agricultural yields need to increase in some regions of the world. If climate change inhibits these increases in yield, food prices are likely to increase further (FAO, 2016; FAO, 2017). To indicate: in order to meet demands in 2050, agricultural production needs to produce 50% more food, feed and biofuel compared to 2012 (FAO, 2017).

Globally, food systems are changing, partly due to demographic developments such as globalisation and urbanisation with subsequent shifts in food preferences (FAO, 2017). Food systems are now increasingly reliant on global supply chains and large-scale distribution systems (Nguyen et al., 2019). This has also resulted in long supply chains that cross international borders (Nguyen et al., 2019), which may have a larger ecological footprint (FAO, 2017).

Most of the above mentioned trends have a global character. Although agricultural trade is increasingly influenced by accelerating globalisation (Anderson, 2010), there are also economic and market trends that are more specific to European agricultural practices. According to the European Commission, the main economic challenges that European agriculture faces, are: pressure on farm income, weaknesses in productivity and competitiveness, and imbalance in value chains (European Commission, 2017b). Related trends that drive these challenges include high price volatility, lower price levels, increase in total costs of production, margin squeeze, limited uptake of new technology, investment gap in agriculture (making it difficult to obtain investment loans), a fragmented sector, lack of market transparency, uneven price transmission along the supply chain, lack of vertical integration initiated by primary sector (European Commission, 2017b). This list of drivers already indicates that economic trends are complicated and influenced by many other factors such as demographic developments, but also unforeseen developments such as the COVID-19 pandemic, which has resulted in global economic downturn (European Commission, 2020).

Specifically for arable crops, the European Commission projects that demand for sugar will decline with 5% in the coming 10 years within the EU. In cereal markets, production is expected to further grow, due to an increase of industrial use of cereals, rise in feed demand and anticipation of export. Next, it is also expected that demand for protein crops (both for feed as for food) will continue to be strong, although protein crops cover only 1.4% of total crop area which limits overall growth of crop proteins. Lastly, due to limits of biofuel policy after 2020, no further growth is expected for rapeseed crop area (European Commission, 2018b).

4.3 Socio-Cultural

Consumption patterns and (changing) consumer preferences shape agricultural demand. Over the past decade, there has been a global shift (although more prominent in developed countries) towards a diet high in sugar, salt and fat content and an increase in consumption of animal products (Nguyen et al., 2019). The European Commission expects EU consumers and citizens to become more demanding towards food and its sourcing, the impact of food on the environment and climate change. These growing demands often mean higher production costs for farmers and producers. On the other hand, it also comes with the opportunity for farmers to differentiate and add value to their products while they reduce negative environmental impacts (European Commission, 2018b). In developed countries, there have been counter movements opposing current consumption patterns and/or agricultural practices, which are indicated to grow in coming decades. These groups have shifted their preferences, for example, towards organically produced foods, natural foods, slow food and ethical foods. This counter-reaction is a response to a number of concerns about current food production, such as animal welfare, sustainability or food safety (Nguyen et al., 2019). The European Commission expects such alternative food production systems to further grow within the EU (European Commission, 2018b).

GMO's have especially become a contested topic among citizens, with debates around its use dating back to the 1990's. Main concerns for citizens are GMO's contribution to potential risks to human and animal health and the environment (FAO 2017). Although both biotechnology and nanotechnology offer opportunity for agricultural innovation, these innovations are faced with heavy citizen resistance resulting in limited use and spread of available technologies The FAO warns that because of this long-running debate, other biotechnologies are being overshadowed (FAO, 2017).

The proportion of workforce employed in agriculture, forestry and fishery within EU member states has been declining over the past decade. To illustrate, in 2008 4.7% of the total workforce was employed in this sector while by 2016, this had declined to just below 4% (Williams & Horodnic, 2018). Similarly, availability of labour is a concern with the number of persons working on farms decreasing while the average holding size of farms is increasing (Schrijver et al., 2016). To illustrate, the total number of agricultural holdings in the Netherlands decreased from 97.390 in 2000 to 52.710 in 2020 (CBS, n.d. a) and the numbers for regularly active labour force dropped from 280.584 to 175.828 in the same time frame (CBS, n.d. b). Agriculture is characterised by seasonal work, where large numbers of labourers are hired for short amounts of time in peak periods. While skilled agricultural workers are important for the agricultural sector, their share of the work force is declining in EU member states (European Commission, 2014). The availability of skilled agricultural workers remains a societal challenges in most of Europe.

Lastly, it is interesting to note that there has been a decline in public investments in agricultural research and development (R&D). In the EU in 2009, 2.4% agricultural gross value added was spent on agricultural R&D, while in 2014, spending had declined to just 1.8% (European Commission, 2017d).

4.4 Technological/agronomical

Technological innovation is often mentioned as the way to deal with (sustainability) challenges that agriculture faces (e.g. Détang-Dessendre et al., 2018). While technical solutions can certainly make a big difference, we include in this section agronomical innovation as well.

Digital agriculture, agriculture 4.0, precision farming or smart farming all describe a recent trend of digitalisation of agriculture. Digitalisation of agriculture includes the use of big data, robotics, sensors, machine learning, blockchain, drones, digital twins, augmented reality etc. Of course, technologies such as GPS have been around for a while, but technological development has now also made it possible to automate cyber-physical systems by networking between different machines (Weltzien, 2016).

Digital, or 'smart', technologies are now considered the future of farming (e.g. OECD and FAO, 2020; De Clercq, 2018), mainly stressing increased productivity and efficiency to meet rapidly growing demands for food as benefits (e.g. Jayaraman et al., 2016). Bacco et al. (2018) expect 21st century farming to be run by "interconnected vehicles: an enormous potential can be provided by the integration of different technologies to achieve automated operations requiring minimum supervision". Rotz et al. (2019) state that the digital agricultural revolution is further developing by combining technologies that make use of both cloud computing and the Internet of Things, while simultaneously making use of the large amounts of farm data that modern farms are now generating.
There is growing attention for a bio-economy, in an effort to redesign food systems. The European Commission defines the bio-economy as "the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy" (European Commission, 2012). For agriculture, this means that agricultural activities should be linked to bio-economy chains, to supply food with minimum losses of produced biomass (Détang-Dessendre et al., 2018). Bio-economy and circular economy are often linked to each other. Circular agriculture focusses on producing enough food in a way that keep residuals of agricultural biomass and food processing within the food system as renewable resources (Thigssen, 2018). In 2018, the Dutch ministry of agriculture, nature and food quality launched their vision for a circular Dutch agriculture, illustrating the growing attention for a circular, bio-based economy.

Conservation agriculture is a growing trend that is based on efficient use of natural resources and reduced soil disturbance. The FAO defines conservation agriculture as "a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment" (FAO 2010). Worldwide, conservation agriculture is adopted on around 8% of total crop land (FAO 2017). By taking on an agroecological approach, farmers shift from 'ready-to-use' to 'custom-made' production systems, by re-introducing biological complexity (FAO, 2015; FAO 2017).

While there are thus many technological advancements in agriculture, take-up of innovation among a large group of farmers is still limited. Frontrunners will adopt newest technologies, while other farmers stay behind, creating a technology (and income) gap within the agricultural sector. This technology gap is mainly an issue for small and medium sized farms in Europe (European Commission, 2017d).

4.5 Environmental/Ecological

In an assessment of climate and environmental challenges that European agriculture faces, the European Commission formulated three main challenges: climate change, unsustainable resource management (water, soil and air), and loss of nature and landscapes (European Commission, 2017c). Climate change will likely have a range of negative effects on agriculture in (Northwest) Europe (IPCC, 2014), such as extended seasonal activity of pest and plant diseases, lower yields of some arable crop species and an increase of vector-borne diseases in ruminants. Moreover, (prolonged) droughts and heatwaves will increase the need for irrigation (European Commission, 2017c, IPCC, 2014), while heavy rainfall with consequent floods and storms are also increasing in North Europe (European Commission, 2017c; Forzieri et al., 2016). It should be kept in mind that agriculture conversely also impacts climate change, most notably through greenhouse gas emissions such as methane (European Commission, 2017c). Although rising temperatures can improve crop growth, studies show that yields decline significantly when temperatures exceed crop-specific levels (FAO, 2016).

Water, soil and air are important natural resources for agriculture. Agriculture is highly depended on high quality water supply. This is indicated by the fact that in 2015, agriculture was responsible for about 40% of annual water use, by far the biggest user of all relevant sectors (European Environmental Agency, 2019). Water pollution and water scarcity can greatly influence yields and quality of production. Water pollution as a result of fertilisation in agriculture leads to eutrophication and acidification of waters (European Commission, 2017c). In agriculture, water use is of course highly dependent on the weather. For example, in 2018 the Dutch agricultural sector used four times more surface water and ground water compared to 2017 due to severe droughts that year (CBS, n.d. c). Although water is relatively abundant in Europe (European Commission, 2017c), large areas of Europe are increasingly facing water scarcity and droughts (European Environmental Agency, 2019). Climate change is only projected to increase water shortages and droughts across Europe.

Erosion of the fertile top layer of the soil has negative consequences for soil fertility and consequently for crop productivity. The annual cost of productivity loss due to erosion is estimated at around 1.25 billion euro's in the whole of the EU (Panagos et al., 2018). It should be noted, however, that Northern and Western European countries are only marginally effected by soil erosion (Panagos et al., 2018). Other soil related effects on agriculture include soil organic matter and soil compaction and salination of the soil (also influenced by rising sea levels) (European Commission, 2017c).

When it comes to air as a natural resource, the agricultural sector is mainly pointed at as a culprit of air pollution, most notably through ammonia (NH3) emissions. Although important, air pollution is not further discussed in this DESTEP analysis, as it is more a result of agricultural practices rather than an external development influencing agriculture.

Lastly, biodiversity is decreasing within Europe, eradicating natural resources. A densely populated country like the Netherlands has seen a long-term decline of biodiversity, which has mainly been attributed to the intensification of agricultural production. For example, the population of meadow birds has declined with 30% since 1990 and is still declining further (Sanders et al., 2019). The FAO warns that with the erosion of biodiverse resources, we will lose the potential to adapt to changing socio-economic and environmental conditions such as growing populations and climate change. This will in turn result in a reduced capacity of ecosystems to deliver goods and services, among which food and water (FAO, 2012).

4.6 Political

In May 2020, the European Commission introduced the Farm to Fork Strategy (F2F), a comprehensive 10-year plan for a fair, healthy and environmentally-friendly food system. The F2F strategy is at the heart of the European Green Deal, which stipulates how to make Europe the first climate-neutral continent by 2050. In Europe's transition towards sustainable food systems, the European Commission underlines the urgent need to reduce dependency on pesticides and antimicrobials (reduction of 50% by 2030), reduce excess fertilisation (reduction of at least 20% by 2030), increase organic farming (to 25% of EU's agricultural land in 2030), increase animal welfare and reverse biodiversity loss (European Commission, 2020).

One of the oldest agricultural policies in Europe is the Common Agricultural Policy (CAP). In 2018, the European Commission presented a legislative proposal for the CAP beyond 2020 (period 2021-2027). The European Commission has formulated 9 CAP objectives to ensure access to high-quality food and strong support for the unique European farming model (European Commission, 2018c):

1. Ensure fair income to farmers;
2. Increase competitiveness;
3. Rebalance power in the food chain;
4. Climate change action;
5. Environmental care;
6. Preserve landscapes and biodiversity;
7. Support generational renewal;
8. Vibrant rural areas;
9. Project food and health quality.

Within the current CAP, the green direct payment (or 'greening') requires farmers with more than 10 ha of arable land to grow a minimum of two crops. A minimum of three crops is required on farms with more than 30 ha. An additional requirement is that the main crop may not cover more than 75% of the land (European Commission, n.d.). Key aspects of the new CAP proposal (2021-2027) are: better targeting for a fairer deal, higher ambition on environmental and climate action and farmers at the heart of Europe's society (European Commission, 2018c).

Of course, policies on national and/or regional level also influence direction of change. For example, the Dutch ministry of agriculture, nature and food quality launched their vision for a circular Dutch agriculture in 2018. Circular agriculture was introduced as a "logical and conclusive answer" to issues of climate change and resource scarcity. Circular agriculture is then defined as "closing cycles of minerals and other resources as far as possible, strengthening our focus on biodiversity and respecting the Earth's natural limits, preventing waste and ensuring farmers are paid a fair price for their hard work" (Government of the Netherlands, n.d.).

4.7 Drivers of Change

The further development of alternative agricultural systems such as mixed cropping systems, will depend on Drivers of Change that can accelerate developments in one direction or another. During a brainstorm session with the arable use case's steering group, we discussed our analysis as described in report so far and collectively identified 10 Drivers of Change (DoC) that could have a considerable impact on the development of mixed cropping systems in Northwest-Europe. These 10 DoC are:

- Accountability to society about production methods (license to produce);
- Effects of climate change (to society at large and to agriculture; e.g. droughts, flooding, heat stress);
- Changing food markets;
- EU and national policies (CAP, Green Deal/F2F strategy, (N) emissions);
- Digitalisation/smart farming/agriculture 4.0;
- Changing consumer demands (e.g. flexitarianism, slow food, healthy foods);
- (un)availability of skilled workers + availability of successors;
- Degrading soil quality (compaction, soil life);
- Need to change inputs (e.g. fertiliser, fossil energy, pesticides);
- Biodiversity and nature inclusiveness.

These DoC are not meant to be exhaustive, but provide a starting point for identifying main drivers that will determine our exploration of future visions (scenarios) for mixed cropping systems in Northwest-Europe. This work will be carried out under the following two tasks of the PP Agros that were mentioned in the introduction.

5 Niche innovations

On the **micro level**, we can identify innovations related to mixed cropping systems and related future farm technologies. As supplementary material, we can provide an excel file where we provide an overview of novelties, including links to websites and additional information. This overview is by no means exhaustive, but gives a good indication of initiatives going on at the moment. In this chapter we summarise the types of innovations and provide examples. We cluster innovations in four categories: technological innovation, agronomical innovation, market and value chain innovation, social innovation.

5.1 Technological innovation

Many technological innovations are emerging, many of which relate to digitalisation of agricultural as also described in Chapter 4. In this section, we discuss 5 types of technological innovation in agriculture: technologies related to autonomous vehicles, robots and drones; technologies related to decision support, scouting and sensing systems; technologies related to mechanisation; technologies related to energy, power trains and power generation; and technologies related to post-harvest processes.

5.1.1 Autonomous / robotics / drones

Multiple parties are active in the development of autonomous farming vehicles and robots, such as AgroIntelli, Clearpath Robotics, Naio, Fendt, Farming Revolution, Pixel Farming Robotics and Steverink Techniek. The developed vehicles can be split up in two groups. The first group of autonomous vehicles are compatible with current mechanisation regarding the hitch and PTO. The second group of autonomous vehicles require specifically designed mechanisation for operations in the field. Or the autonomous vehicles are designed for one specific task, e.g. weeding or harvesting. The weeding robotics have a number of suppliers such as EcoRobotix, Naio, Odd.Bott and Farm wise. For strawberries Agrobot supplies a harvest robot and Grimme an autonomous single row potato harvester.

The current application in the field with drones are related to crop protection. Precision spraying by drone is offered as service by ADAMA/Tactical Robotics Ltd. The Dutch company ProfytoDSD sprays predator mite with a drone in onions as service to farmers.

5.1.2 Decision support, scouting and sensing systems

The decision support theme also includes systems that interconnect different platforms, e.g. AgriRouter. Communication between different systems of suppliers is a problem. Even if standardised communication standards are used, problems related to compatibility of older and newer version can occur. There is also a development of a platform to combine farm data which results in decisions or actions in the field, e.g. Akkerweb and Field View. Akkerweb combines available geographical farm data in an open platform where developers can offer their solution (apps). Field View is a commercial platform.

Scouting systems are combined with robotics or drones. The crops in the fields are scouted for weeds, pests and diseases. Parties such as EcoRobotix, AgEagle and Farming Revolution provide such scouting equipment.

Sensing systems include actual sensors in the field as well as satellite based sensing. Parties such as Hermess provide geo-service information for agriculture.
Parties such as Dacom, Agrometius, AppsForAgri and RMA provide sensors that can be placed in the field to monitor soil, light and weather. This data is used for exmaple to predict irrigation need of crops.

5.1.3 Innovations in current mechanisation

There are also innovation based on or designed for current mechanisation. Examples are a camera guided weeding equipment (e.g. Steketee), killing weeds with electric current (e.g. Zasso), precision spraying equipment (Agrifac/Exel) and bug vacuum systems (Agrobot). Furthermore there are innovations on mechanisation to facilitate strip cropping and CTF (Controled Traffic Farming). Steverink Techniek is currently developing a plough suited for strip cropping.

5.1.4 Energy / power trains / power generation

Energy solutions can be divided into two groups: use and production. The first refers to the energy needed to power equipment on the farm. A number of manufactures are developing electric powered equipment, e.g. Kramer, Tobroco-Giant, Siloking, Fendt and Rigitrac. A new development is the introduction of hydrogen. Parties such as H2-Trac, Toyota Material Handling, Linde, Keyou/Deutz and Hysolar are currently developing or suppling hydrogen powered farm equipment. Keyou/Deutz and Hysolar are parties that supply hydrogen systems on existing diesel engines, which converts current engines to dual-fuel engines.

5.1.5 Post-harvest innovations

There is little innovation in storage technology. Most innovations are found in sorting and packaging. Multiple companies offer optical sorting equipment, e.g. IST Sort, ProTec Italy, Newtec and Tomra. The sorting equipment varies per crop and on the nature of defects, e.g. size, quality and shape. Companies as Tomra and NewTec also supply automated packaging equipment.

5.2 Agronomical innovation

Regarding agronomical innovation, we differentiate between: diversification, soil quality and green crop protection.

5.2.1 Diversity

The theme of diversity can be split up in crop diversity and biodiversity. Developments in crop diversity are agroforestry, strip cropping, intercropping and pixel farming. Diversity of crops prevents the spread of diseases and increases natural predators in the field. In both cases, this helps to reduce the need for chemical inputs. Further benefits are improved soil quality and water conservation.

The developments on biodiversity are non-productive flower strips and banker strips. The goal is to improve the natural balance and increase the presence of natural predators, in order to reduce the need for chemical inputs.

5.2.2 Soil quality

A number of systems are being developed to improve soil quality, such as controlled traffic farming, no-tillage and other crops in the crop rotation. Controlled traffic farming is a system with fixed traffic lanes for mechanisation. The unridden soil between the lanes is better in quality, which results in an increase in production and water conservation within these systems. No-tillage reduces the tillage of the soil. This prevents soil compaction, improves water retention and increases organic matter in the soil. Additionally, constant cover of crop on the soil is a development which is gaining momentum. The cultivation of green manuring crops is related to the vision of keeping the soil covered throughout the year. The constant cover prevents soil erosion and soil degradation.

Adaptions in the crop rotation could also improve soil quality. In Dutch arable farming, there was a trend toward root crops which were harvested in late autumn. These bulk crops such as potatoes, sugar beets and carrots are harvested in autumn with a high risk of harvest in wet soil conditions.

To reduce the risk of damaging the soil, a shift away from root crops and towards crops that can be harvested earlier in the growing season can prevent damaging the soil.

5.2.3 Green crop protection

Green crop protection is developed to reduce or eliminate chemical inputs. This development has two main approaches. First is the development of natural/biological alternatives of current chemicals used by e.g. EcoStyle and Pireco. The second option is the production of natural predators which can be introduced in the field when a pest is detected, this is developed by e.g. Koppert.

5.3 Market and value chain innovation

Direct sale is a common option for farms to sell their own produce. Another viable option is to shorten the supply chain by storing and processing produce on farm. A growing number of farms has additional turnover from direct sales (Van der Meulen et al., 2019). Developments and innovations seen related to direct sales are internet sales, CSA (Community Supported Agriculture), vending machines and self-harvest initiatives. Furthermore, a growing number of cooperatives of farmers or farmers and consumers are involved in short supply chain initiatives. In most cases, local or regional produce is the main focus.

Agricultural land banking is an economical innovation. Although it is not new, land banking is currently used to buy agricultural land that was converted to organic farming and keep it converted. This is achieved by buying the land and leasing it to organic farmers. This option is also suggested to counteract the strong increase in agricultural land prices.

5.4 Social innovation

Farming can support multi-functional activities. Activities such as care and day-care services, education, on farm sale of products, recreation and nature preservation. In the Netherlands, about 25% of the agricultural businesses include multi-functional activities on their farm (Agrimatie.nl; Van der Meulen et al., 2019). Nature preservation and direct sales of own products are the biggest activities. Education, care and day-care are relatively small in share in the multifunctional agriculture. From an economic perspective, direct sales and care activities provide the biggest amount of additional turnover. Multi-functional activities provide an additional economic pillar to the business. These activities provide social and cultural connections between agriculture and society. Since risk of poverty and social exclusion is higher in rural areas (Eurostat, 2017), including multi-functional activities can be a way to secure more income.

Consumer behaviour influences certification schemes for agriculture. Themes such as animal welfare, climate change and sustainability find their way in certification schemes. An increasing number of schemes introduces criteria to achieve a reduction in greenhouse gas emissions or increase in animal welfare. Most of these schemes originated as food safety schemes, such as Global-GAP. The additional criteria play an important role in agriculture. Certification schemes are most often required by buyers and supermarkets, so noncompliance to these standards limits market access. This influences developments such as cultivation systems and energy.

6 Conclusion

In this system analysis we described agricultural practices and developments at three interacting levels: the wider context or socio-technical landscape (macro level) that exerts pressure on the agricultural system to change; the main characteristics of the current agricultural system (or socio-technical regime in MLP terms; the meso level); and innovations that emerge in technological niches (micro level). The system analysis is the starting point for designing and exploring transition pathways for future uptake of niche innovations that could eventually lead to very different future farming systems. Within Public Private Partnership (PPP) Agros, we specifically focus on mixed cropping systems as a future farming system that could mitigate the many social and environmental challenges that current agriculture faces. A system analysis is a first and necessary step to explore what the transition from current agricultural practices towards mixed cropping systems could look like by taking into account current trends and developments.

6.1 Lock-in and the need for radical change

Our report shows that modern agriculture has been very successful in reducing food shortages and feeding a growing world population. However, the current system also faces many challenges, both environmental and societal. As described before, the current agricultural system is locked-in, making it complicated to drastically change practices and the lock-in discourages farmers from adopting alternative production systems (Meynard et al. 2013; Frison, 2016). On the one hand, the current agricultural system (characterised by high inputs, high yields and low crop diversity), is locked-in by strong competition on the global market, which keeps prices low. On the other hand, the system is also locked-in by lack of attractive markets for certain key crops that could allow diversification of cropping systems. 'Tweaking' current agricultural practices may provide (temporary) solutions to specific problems, but is unlikely to provide more long-term solutions and such incremental innovation will merely modify or optimise existing practices instead of more systemically and holistically addressing problems in agriculture (Frison, 2016).

To break free from these vicious cycles and accomplish large and durable benefits, more radical (agroecological) change is needed (e.g. Altieri et al., 2015). In chapter 5 we have provided a (non-exhaustive) overview of niche innovations related to mixed cropping systems and future (smart) farm technologies that offer an alternative to the dominant agricultural system. Within PP Agros, we explore mixed cropping systems in the context of 'technology-4-ecology based farming' (T4E-farming). In T4E-farming biological and ecological principles are leading in the development of new farming systems. This means that T4E-farming explores how farming systems can enable and support truly ecology-based agricultural systems (technology4ecology, n.d.). In this context, intercropping methods are a way to face the challenges described in this report and convert arable agriculture to an environmentally friendly, biodiverse and circular production system (technology4ecology, n.d. a).

6.2 Outlook

In the next task of PPP Agros (Development of future visions (scenarios) in which mixed cropping will play a significant role), we will develop scenarios of what mixed cropping systems can look like in the future. In doing so, we will consider changes in technologies, user practices, legislation, policy, infrastructure, networks, and institutions. This means that these scenarios take into account a combination of technical and social change, i.e.: they are socio-technical scenarios (Elzen et al., 2002). These scenarios are a way to explore radically different agricultural futures, that aim to more systemically address problems of current agricultural practices. Socio-technical scenarios are a tool to create a 'mental map' of what a radically different futures can look like, helping actors to consider alternative developments and stretch imagined possibilities beyond dominant thinking around incremental innovations (Elzen et al., 2002). In this way, we aim to move beyond the lock-ins that keep current, unsustainable agricultural practices in place and explore what sustainable agricultural systems can look like.

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Annex 1 Reflexive system analysis

During the kick-off meeting of the arable use case, we carried out a reflexive system analyse with partners involved in the PPP. The central question of this exercise was:

What are opportunities, barriers and novelties for implementing mixed cropping systems in North-West Europe? With regards to:
- **Technology & knowledge;**
- **Markets & regulations**
- **Farm management & farm behaviour**

The results of this exercise were used as input and inspiration in this report.

Opportunities	Barriers	Novelties
Technology & Knowledge		
Reduce soil compaction	Lack of practical knowledge among farmers	Autonomous steering
Smaller equipment platforms	Machinery needs to be adapted	Yield prediction using AI
Improving crop productivity with lower inputs	Cost effective equipment	Monitoring form the sky (drones and software)
Increase yields in a more sustainable way (e.g. nutrient trapping, more resistant to pests	Dogmatic discussion whether it should be organic or not? Join forces and put science based sustainability first	Robotics, sensor fusion
Increase biodiversity	Knowledge about flora/fauna interactions	Technology to make it beneficial for farmers
5G	Machinery needs to be adapted	Connected equipment and sensor
Lower use of crop protection chemicals	Usability; must be easy to use	We still have to develop a lot of tech
Improved soil health	Scale and cross-contamination of chemicals	Robotics, FieldView
Increased carbon sequestration	Lack of research funded knowledge developed	Data analytics & AI
More and more technology available	Less open innovation	Yield prediction using novel sensors and AI
There is a need to better combine technology and agro-ecology in farming systems	Niche targeted, too narrow applications	Attractive landscape
Internet of Things and Big data	Knowledge of farmers and advisors	Visualisation of data
High level of education in NW Europe	Training and knowledge	AI, machine learning
Less disease pressure	Connectivity issues in rural areas	Deep learning tools to make it possible
Sustainable farming	Societal worries about combining technology and biology	Combining different data sources
Tackle labour shortage	Still the idea that bigger is beautiful instead of small and smart	Mixed cropping and smaller platforms of equipment
Sensors replacing the farmers eye: monitoring takes a lot of time (how to make it more effective)	Science versus emotions	

Just by starting now we will learn a lot related to ecological effect (learning curve!)	Changing from one farming system to another investments are high	
Focus on 'low hanging fruit' technology: start with applications that help farmers to make a profit	Exchangeability of data, many different systems	
Smaller equipment	Lack of practically proven technologies	
	Difficult to implement when infrastructure is not in order. More traffic when fields are spread out over larger area.	
	New tech must be low energy. The trend goes the other way.	
Markets & Regulations		
Licence to produce	Legislation	Introducing new crops in area due to change in soil use
Local initiatives connecting farmers and consumers directly	Market acceptance	Working to Integrated Farm Management instead of Integrated Pest Management
Locally produced and marketed	Are consumers willing to pay more for products coming from such a system (increase income)?	Farmers to be rewarded for CO2 fixation along certification system
EC and NW-countries want to innovate	Higher prices for consumers	Shared value pool farmers being part of consumer/value chain
Production optimised to local markets	Legislation for autonomous activities in the field	
Consumer power: locally grown	Majority consumers focus on price	
Have holistic system; combined dairy and arable farming	Legislation related to drones	
Market parties and governments want more and more data about farm production	Bigger chance on shortage of food	
This type of farming system(s) get valued by the value chain and consumers	Many different labels/certifications	
Growth in % of organic food in e.g. supermarkets	Regulation based on dreams?	
Distinctive	Cost effectiveness of new solutions	
In the current situation it is difficult to organise labour. This stimulates the wish for robotisation	New legislation goes slow, less possibilities for practical experiments	
New start-ups have a good chance	EU regulations, drawing mixed cropping farm in CAP is a challenge	
Link to certificate schemes 'on the way to planet proof'	Weather impact on different crops (while seeding, during the season and harvesting)	
More benefits for this type of farmers in terms of e.g. fertilising 'space' – meeting actual crop needs (even if these are higher than in regulations)	Added value differentiation versus conventional farming	
	The CAP and Dutch legislation is not adapted for mixed cropping systems	

	Do start-ups have 'enough fat on their bones' to survive this phase of product development?	
Farm Management & Farmer Behaviour		
New technology saves time for the farmer	Farmers sticking to old habits	Better insights thanks to data
Integrated Farm Management	Integrated Farm Management	Integrated Farm Management (explanation: very complex, even when you only look at 1 intervention/aspect. Difficult to decipher real benefits and draw-backs. Don't only focus on success stories)
New generation of farmers are interested in innovation and technology	Conservative farmers	Use stimulation tools by the government to promote the step-over to this type of farm management
New technologies reduce risk on farm income	Tradition	
Tech-savvy millennials are willing to embrace new technology	How to keep it profitable?	
Better use of water and soil	Less R&D on family farms	
The management tools need to be robust and time effective	The management tools need to be robust and time effective	
Balance between nature and production level	Farmers are entrepreneur; they want 'proven technology'	
Tradition of exchanging information and experiences	Rusted thinking, many generations on more and bigger	
Circularity	Current machinery is not suitable (too big). Investments for more than 10 years.	
Farmer's collectives	Less possibilities for experiments because of their financial situation	
Let nature fix its own problems (where possible and realistic)	Fact-based data generation under farmer conditions to support farmer income	
Long-term based farming	Farmers have many tasks. New innovations should make their work more easy	
Sharing technology is possible	Even more external advisors necessary	
	Hard to implement changes within one season; how do you do it while keeping production (and income) going at the same time?	
	Proved added value before willing to invest in new systems	
	Logistical challenges for farmers	
	Knowledge intensive, education	
	Desired conditions (can) differ for all crops	
	Adoption of new crops e.g. move to holistic farmer versus specialised farmer	
	It doesn't fit with the personal goals of the farmer	

	Farms get bigger and travel/transport increases; all new implantations need to be easily moveable. Now tractors combine these tasks	
	Size of machinery of contract workers does not fit	
	Worries to get locked-in (become too dependent)	
	Lack of practical usability	
	Nature management regulations sometimes conflict with practical situation on farms	
	Trust in data sharing	

To explore the potential of nature to improve the quality of life

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