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D1.6 –Final Report on Research Results, Research Projects and Industry Solutions

smartAKIS
Smart Farming Thematic Network

Document Summary

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1 Abstract

The Smart AKIS project aims at examining the suitability and use of Smart Farming Technologies (SFT) in the EU Agriculture involving farmers, the agricultural machinery industry, academia, research centers, agricultural engineering and public bodies.

This document is the third update and final report on research results, research projects and industry solutions. As such it repeats and extends the information presented in previous deliverables. An introduction is given in Section 2. Farming is challenged to reduce the use of pesticides, fertilizers

and energy, to decrease adverse effects on the environment, to achieve safe and transparent agri-food chains, and to implement the Greening of the Common Agricultural Policy (CAP) of the EU. Smart Farming Technologies (SFTs) are expected to help realize these goals. Materials and methods are given in Section 3. In particular, we collected SFTs from research papers, from research projects and from industry. A survey was developed to collect information about each SFT.Quantitative results from the survey are given in Section 4. Overall we collected 1064 SFTs. An assessment of the practical value of selected SFTs is given in Section 5. For recording technologies, we describe the accuracy of the measurement under farming conditions. For actuation technologies, we quantify the effect of profitability and environmental sustainability. In Section 6 it is described how a factsheet was generated for each SFT. This factsheet presents information about the SFT in a concise format and is available for download from the project's website. In Section 7 we conclude that the inventory of SFTs described in this report is important in the sense that it provides farmers with an opportunity to acquaint themselves with the SFTs that are available, and that a follow-up to the present work is needed in which an inventory is created of data-related technologies, practices, standards, and agreements.

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List of abbreviations

CAP	Common Agricultural Policy
CEC	Cation Exchange Capacity
CTF	Controlled Traffic Farming
FMIS	Farm Management Information System
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
MIR	Mid-infrared (region of the electromagnetic spectrum)
NIR	Near-infrared (region of the electromagnetic spectrum)
SFT	Smart Farming Technology
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
UAV	Unmanned Aerial Vehicle ("drone")
VIS	Visual (to the human eye) region of the electromagnetic spectrum

2 Introduction

Farming faces several challenges, amongst which are the need to reduce the use of pesticides, fertilizers and energy, to decrease adverse effects on the environment, to achieve safe and transparent agri-food chains, and to implement the Greening of the Common Agricultural Policy (CAP) of the EU. New opportunities are emerging in farming, as a result of rapid development of communication networks (mobile telephony, high speed connections and narrow band, short and long range) and availability of a wide range of new sensors. In an agricultural context, these technologies help capture and transmit geo-localized real-time information at low cost. Once gathered, processed and analyzed, these data can help to measure the state of the agro-environment (e.g. soil, crop and climate) and when combined with agro-climatic and economic models, forecasts and advices for better tactical decisions and management of technical interventions can be given. Precision agriculture has a major significance for future cropping systems.

Precision agriculture is a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops. Multiyear crop characteristics are tied to topological terrain attributes. Precision agriculture was largely made possible by the emergence of widely available GNSS technology. This has resulted in the possibilities for farmers and researchers to geo-reference many agronomic variables.

Attention for precision agriculture and smart farming technology is growing rapidly. It is therefore necessary to gain more insight in the types of Smart Farming Technologies (SFTs) that are being developed or have been developed. There have been several overviews of the current status of SFT development. Previous research includes a survey about adoption rates of proposed technologies, the CropLife/Purdue Precision Ag Survey developed at Purdue University, where it was based on retail crop input dealers (in the US) regarding their use of precision agriculture services. Moreover, multiple reviews have been done on farm management information systems (FMIS). Fountas et al. (2015) have reviewed the state of the art in FMIS from both an academic and commercial perspective. Lewis (1998) provided information on the evolution of FMIS and Kaloxylos et al. (2012), Kitchen (2008) and Kuhlmann and Brodersen (2001) took an outlook on FMIS in the future. These efforts have contributed to an increased understanding of previous, current and possibly future developments in SFT.

The underlying concept for Smart Farming Technology (SFT) is precision agriculture. The Smart-AKIS project (www.smart-akis.eu) was set out to investigate the role of SFT in the development of future agriculture and try to close the research and innovation divide in the SFT sector. Smart farming technology can help achieve higher production outputs with fewer costs in compliance with agricultural environmental standards. Smart-AKIS aims to provide an extensive overview of SFTs. Although some progress has already been made to synthesize current knowledge on smart farming, many important questions remain. The objective of this study was to create an inventory of SFTs and assess their value for farming practice.

3 Materials and methods

A systematic review was conducted of the scientific literature, current and past research projects, and commercially available products. We started by determining KPIs that are important for open field agriculture (Section 3.1). Based on that information a questionnaire was developed to record information about SFTs (Section 3.2). Separate search procedures were developed for a scientific articles, research projects and commercial products (Section 3.3). When we had collected information about SFTs we developed an ontology of SFTs (Section 3.4). Finally, for the most important types of SFTs we made an effort to quantify their practical value Section 3.5).

3.1 KPIs for open field production

Smart-AKIS focuses on open field production. We considered arable farming, fruit production, and vegetable production. For each of these sectors, we identified the most important challenges and based on that we determined Key Performance Indicators (KPIs).

3.1.1 Arable Farming

Arable farming is by far the largest agricultural sector in the EU in terms of acreage and number of primary production holdings. EU member states have according to EUROSTAT (2013) together 174 Mha of land used for agriculture[1], of which 60% is used for growing arable crops. A variety of arable crops is grown in EU, with regional differences. Wheat and maize are dominant in almost every region, and so, having the largest acreages in the EU. Other important arable crops are oilseed rape, potatoes, sugar beet, protein crops and field grown vegetables like onions. They serve different demands in the EU: human and animal consumption, bio-fuels and compounds for the bio-based economy. The EU has developed modern production, processing and distribution chains for these different uses of arable crops.

Table 1 presents specially highlighted challenges in the field of arable farming. In Table 2 there is a series of KPIs for SFT application in arable farming in particular.

Table 1. Challenges in arable farming

Challenge	Relevant Smart Farming Technologies
Resource efficiency (e.g. water, nutrients)	• Sensors, • Networks, • big data analytic tools
Management / prevention of diseases, weeds, etc.	• Sensors, • Networks, • Specific farm machines.
Risk management (e.g. food safety, pesticide residues elimination and emission of agro-chemicals …)	/
Compliance with legislation and standards (Greening of CAP, and specific regulations on soil management, pesticide, fertilizer and water use apply)	• Monitoring technologies
Communication, coordination and collaboration across the supply chain (Supply chain of companies and processors)	/

[1] EUROSTAT report (http://ec.europa.eu/eurostat/documents/2995521/7089766/5-26112015-AP-EN.pdf/e18e5577-c2a4-4c70-a8c7-fd758ea7b726)

Table 2. KPIs and measurement techniques – arable farming

Number	Key Performance Indicator	Measurement Technique
1	Crop yield	Harvest measuring (weighing/vision)
2	Crop production variable costs	Economic review
3	Pesticide use	Registration, compared to standard (recepy)
4	Fertilizer use	Registration, compared to standard (recepy)
5	Crop quality (e.g. potato)	NIRS, vision
6	Pesticide residue	Residues in tubers, lab test (normal= MRL)
7	Greenhouse Gases (CO_2-eq)	Calculation on inputs (Diesel, N fertilizer)
8	Reduce Nitrogen and Pesticide emissions to ground and surface water	Lab test
9	Effective Time Use	Registration operation time hours/tons/day
10	Planning conflicts	Comparison ‘as done’ registration with planning
11	Stress reduction, better monitoring	Observations send to monitoring system
12	Determine profitability of the tool by cost-benefit analysis	Monitoring and comparison of technics
13	Promoting the product thanks to discussion with stakeholders	Presentation to stakeholders
14	Irrigation Water use	Reach the low flow target
15	Time saving for farmer	Crop management work rate
16	Dissemination of the tool	Attendance at meetings, number of subscribers…
17	Protein produced per water, inputs unit	At harvest, analysis of protein content production/water used and inputs used
18	Farmer revenues on the crop rotation	€/ha on 5 years crop rotation including soya
19	N leaching	Analysis of drainage water along the crop rotation
20	Diversity in soil and environment	Counting of indicator species
21	Soil fertility	OM and microbial activity
22	Percentage of soya EU self-sufficiency	Percentage on imports

23	Service provision	Farmers access to data for fields, vehicles, market, weather and other services
24	Practical use	Clear user benefit from devices that are not fixed in one place – Smart Farming Moving Technologies (SFMT)
25	Crop produced/input resources ratio	The ratio between total production volume and input as farmers adopt and use non-fixed device practice for soil fertility
26	Competitiveness	Short term gross margin increase
27	Importance of non-fixed devices - Smart Farming Moving Technologies (SFMT) for farmers in industrialized countries	Increase in total livelihood and levels of farmer dependence on SFMT
28	Farmers capacity to invest in SFMT technologies	Farmers with the ability to invest in their farming activity—either through credit, savings, or other means—will be more able to adopt sustainable practices and be more productive
29	Cost-benefit of site-specific and SFMT based soil fertility control	Productivity of the soil fertility
30	Soil fertility & climate gases	Organic matter increase
31	Climate gases	Reduction in fuel consumption
32	Nursing of the ecosystem services	C/N ratio short term improvement (5 years)
33	Sale increase	No. of units
34	Engineering costs of implementing SFMT	Additional unit costs

3.1.2 Fruit Sector

Fruit consumption is important for human nutrition because fruits contain vitamins and minerals. According to World Health Organization (WHO) low fruit and vegetable intake is among the top 10 selected risk factors for global mortality being responsible for 1.7 million (2.8%) of deaths worldwide[2]. In 2013 there was 790 million tons of fruit produced globally compared to 730 million tons that were produced in 2012. For 2013, EU produced 67 million tons of fruit while the total fruit

[2] http://www.who.int/dietphysicalactivity/fruit/en/index2.html

consumption was 74 million tons. Orchards covered an area of 1.29 Mha in the EU[3]. Fruits production is important for EU's economy not only for consumption purposes but also for exports. EU imported 7 million tons of fruit (almost €10 billion) while European countries exported fresh fruits of €18.7 billion in total for 2014 (including intra-EU trade)[4]. At the same time EU wastes 100 million tons of food annually with forecasts for increase at 120 million tons of food waste until 2020[5]. The yield losses in fruits and vegetables is estimated at 20% before harvest according to FAO[6] while the post-harvest food losses and waste reach 30% of the harvested product due to reasons such as (i) the unsafe production of food, (ii) food losses due to premature harvesting and (iii) high 'appearance quality standards' from supermarkets for fresh products for fresh products[7].

Nowadays, the high demand in yield and quality of fruits has led to more intensive cultivation practices. Therefore, farmers have increased their inputs in response to these continuously increasing demands. This approach has driven fruit production to abnormalities; as farmers tend to apply more inputs to achieve higher production, especially fertilizers, water and pesticides. This leads not only to toxicity symptoms in fruit plantations, but also to side effects such as soil and water pollution. Over application of crop protection products is a key problem also for selling the products, as the residues on fresh fruits is a major issue for consumer consumption. The above are responsible for increased production cost due to higher labor time and higher input quantities, encased losses at harvest time and reduced quality attributes at post-harvest due to improper resource allocation. Moreover, when farms apply deficit irrigation (less than needed) it causes problems to plants that affect fruit yield and quality due to water stress, while over-irrigation causes nutrients leaching. Fruit sector requires many manual operations, especially for pruning, thinning and especially for harvesting, which demands high resources in labor, being one of the highest cost in the whole production chain, especially in EU countries with high wages. Finally, fruit sector face increasing

[3] http://ec.europa.eu/eurostat/documents/3217494/6639628/KS-FK-14-001-EN-N.pdf/8d6e9dbe-de89-49f5-8182-f340a320c4bd

[4] https://www.cbi.eu/sites/default/files/trade-statistics-europe-fresh-fruit-vegetables-2015.pdf

[5] http://ec.europa.eu/food/safety/food_waste/index_en.htm

[6] http://www.nrdc.org/food/files/crop-shrink-IB.pdf

[7] http://www.fao.org/fileadmin/user_upload/suistainability/pdf/Global_Food_Losses_and_Food_Waste.pdf

market pressure to produce quality products and require a detailed traceability system for the origin of the product including, the treatments and the conditions that have occurred during each production stage.

Technology has made huge leaps ahead the last two decades. SFT allows different objects to interact with each other (e.g. data exchange, machine control, data collection) using an existing network infrastructure. So, sensors measuring soil moisture, temperature, humidity and/or other parameters can interact with each other through internet and software applications (FMIS, DSS) for monitoring fruit crops development and suggesting resources needs.

The fruit sector faces a series of challenges that could find their solution through SFT application. Table 3 presents the main challenges that could be faced by applying SFTs for better yield and quality results. Table 4 presents KPIs that Smart-AKIS consortium perceived as important for fruit sector.

Table 3. Challenges in the fruit sector

Challenge	Relevant Smart Farming Technologies
Resource efficiency (e.g. water, nutrients, labour)	• A decision support tools • farm management information system (FMIS) • intelligent water application system • variable rate fertilization system
Management / prevention of diseases, weeds, etc.	• farm management information system (FMIS) • decision support tool for appropriate infestation management • variable rate spraying system
Risk management (e.g. food safety, traceability)	• Sensors (e.g. weather station, multispectral cameras, thermal cameras etc.) • Traceability technology • Different Smart Farming Technologies (barcodes, QR codes, RFID) • Packaging technology • Smart packaging technology for elongating product shelf time will be deployed
Compliance with legislation and standards	• Monitoring technologies
Coordination and collaboration across the supply chain	• smart traceability system • smart logistics system
Communication and dissemination	/

Table 4. KPIs and measurement techniuqes for the fruit sector

Number	Key Performance Indicator	Measurement Technique
1	Yield (kg/ha)	With or without, before and after the implementation of the proposed technology
2	Crop value (Euro/ha)	
3	Quality (Euro/kg; color; sweetness…)	
4	Water productivity (kg/m^3)	
5	Crop water needs (m^3/ha)	
6	Shelf life (days)	
7	Water usage (m^3/ha)	With or without, before and after the implementation of the proposed technology
8	Rejection proportion of the harvested crop (%)	
9	Crop wastage in the post harvesting (storage, transport and packaging) process	
10	Sales of the solutions	Sales
11	Reducing pesticides costs	Invoice of pesticides (accounting)
12	Reducing fertilizers costs	Invoice of fertilizers (accounting)
13	Productivity gains	Salaries and social charges
14	Average selling price per bottle	Sale invoices (accounting)
15	Average annual saving due to accident prevention	Wine lot value after accident or additional restoring cost
16	TFI (Treatment frequency index)	19.5
17	Potable Water consumption / 1 Litre per produced	4.4 L
18	Energy consumption (equivalent fuel Tones)	1.32 T
19	GHG emission	Carbon footprint
20	Total production cost per Kg of olive oil	Average full cost per category
21	Lot size and product info (product segmentation)	Average lot size (kg) Added product information
22	Water and energy per crop unit (m^3/kg, kWh/kg)	Full crop consumption / production

23	Differential growth (%) organic / eco-friendly crops	% on official IOC statistics
24	% of knowledge based jobs surrounding olive oil sector in rural production areas	Survey
25	Olive oil market share in global edible fats market	IOC statistics
26	Returnable transport items (RTI) detection rate for forecasting of movements and deliveries	Detection of RTIs on site
27	Workload Reduction for product flow documentation	Time based measurement
28	Pay-back period	Calculation based on use case findings
29	Lifetime of Smart Farming Technology	Time from applying the SFT in the tray till it's replacement
30	Completed cycles per RTI	Number of times a tray has been returned to a EPS Service Centre
31	Number of sector based application scenarios making use of data created in the use case	Quantitative

3.1.3 Vegetable Sector

Fresh vegetables are one of the most important categories in European supermarkets. Over the last five years, European production and consumption of fresh vegetables have been stable. In the EU-28, the vegetables sector accounts for 10% of the total agricultural output value. The importance of the sector is higher in southern Member States, representing between 1/3 and 1/4 of their total agricultural output (on average for the period 2011-2013, more than 30% in Greece, Cyprus, Malta and Portugal, and between 25% and 30% in Spain, Italy and Romania). Most of the EU's production of fresh fruit and vegetables is consumed internally. Over 80% of EU exports go to other European countries[8] . Spain is the largest exporter, with exports consisting predominantly of its own production, while the Netherlands and Belgium are major trade hubs due to their logistical positioning. Only 7% of vegetable production (in value) is exported outside the EU. Large retail

[8] Eurostat, report 2015 (http://ec.europa.eu/eurostat/documents/2995521/7089766/5-26112015-AP-EN.pdf/e18e5577-c2a4-4c70-a8c7-fd758ea7b726)

organizations are increasing their requirements concerning food safety and sustainability. Exporters are affected by the increasing supply chain transparency required by retailers and wholesalers. Suppliers are being made responsible for food safety. In addition, consumers increasingly want more information in relation to vegetable produce.

Organic production

The EU organic market, driven by consumer demand, has increased significantly to 19.7 billion euro with a 9% growth rate in 2011. During the last decade, the number of organic producers as well as the surface under organic production has grown steadily. Each year in the EU, 500.000 ha of agricultural land is converted to organic. In the period 2000-2012, the total organic area increased by 6.7% yearly on average, reaching an estimated 9.6 Mha, which is 5.4% of the total utilized agricultural area in the EU. In 2013, 11.5 Mha were farmed organically in Europe and slightly more than 10.2 Mha in the EU. The countries with the largest areas of organic land are Spain, Italy, France and Germany. Globally, 43 Mha of farmland were organic in 2013, and approximately 27 percent of the world's organic farmland was in Europe. Particularly in Italy, Spain, Turkey, and Poland, large areas are under conversion, and therefore, a major increase in supply may be expected from them in the near future. The sector encompasses producers, as well their suppliers, food manufacturers and distributors who all comply with strict rules. The overall challenge faced by the organic sector is to ensure a steady growth of supply and demand, while avoiding fraudulent practices and maintaining consumers' trust[9].

Challenges

Challenges that were identified in vegetable sector are briefly presented in Table 5. The KPIs regarding vegetable sector are given in Table 6.

[9] (Action Plan for the future of Organic Production in the European Union http://ec.europa.eu/agriculture/organic/documents/eu-policy/european-action-plan/act_en.pdf

Table 5. Challenges in the vegetable sector

Challenge	Relevant Smart Farming Technologies
Resource efficiency (e.g. water, nutrients, labor)	Smart Farming Technology (RFID tags)
Management/prevention of diseases, weeds, etc.	Early warning virtual sensors
Risk management (e.g. food safety, traceability, etc)	Real time monitoring systems
Compliance with legislation and standards	Web-based, open, and interoperable standards for end-to-end tracking systems
Coordination and collaboration across the supply chain	Traceability tools, various analytical tools
Communication and dissemination	Smart Farming platforms

Table 6. KPIs and measurement techniques for the vegetable sector

Number	Key Performance Indicator	Measurement Technique
1	Predictable production (independent of weather conditions or transport conditions)	• Supply performance • Standard nutrition tests • Water usage measurement • Standard residue test
2	Consistently high nutrition level	
3	Less resource usage (less water usage)	
4	Absence of pesticide usage	
6	Absence of pesticide usage	Standard residue test
7	Perceived taste of city farming bred lettuce	Panel session
8	Greenhouse vegetable exportation business rate (based not only an increase in production, but in value of production)	Comparison with previous years
9	Underground contamination	Analysis of leakages
10	Efficiency of the water and energy use	Crop measurement through of water-consumption sensors and wattmeter
11	Farmer knowledge and confidence	Interviews
12	Growers profit	Benefits
13	Quality control	Certification

14	Food wasted	Weight
15	Weeding data is made available for every m^2 on field level	2D plot of the field
16	Access to other stakeholders to discuss the value is realized (2 farmers, service provider, trader, technology providers)	Nr connections
17	Average price per crop	Cost-price in €
18	Time required by operators to manage certification data	Comparison with previous systems
19	Reduced fraud potentials	Qualitative assessment by simulation
20	Number of certified operators	percentage
21	Surface under certified management	percentage
22	Increase reliability	simulations
23	Consumers trust	interviews
24	Market positioning improvement	Certification and interviews

3.2 Survey construction

A survey was constructed for recording data about SFTs. The survey included questions from the EIP-AGRI common format[10] as much as possible. The survey was distributed online via a link on the www.smart-akis.com webpage.

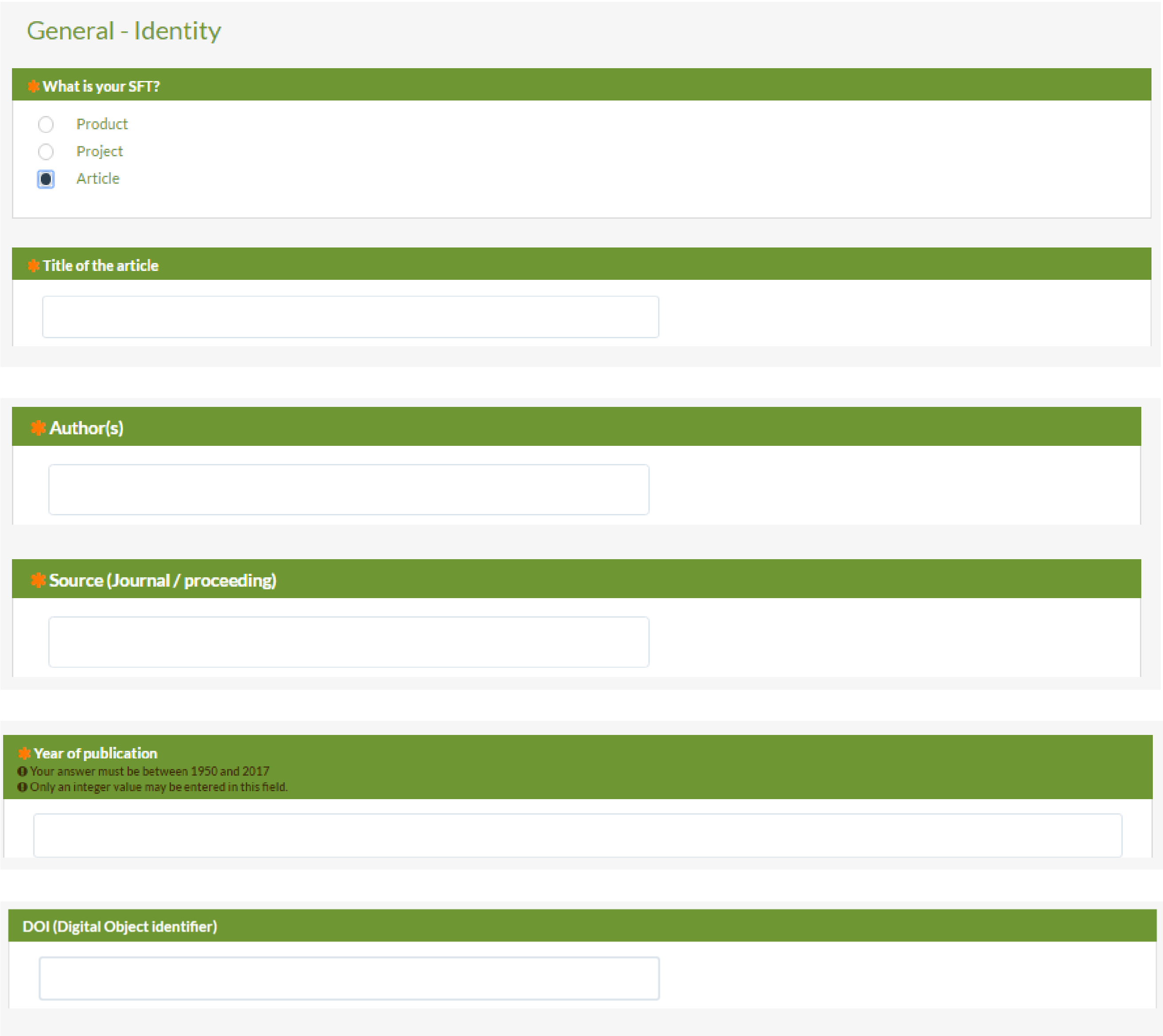
The survey is about roughly a few categories of relevant information on SFTs from articles and projects:

- Required general background information on articles and projects
- Questions about innovation
- Questions about the adoption of the SFT.

[10] https://ec.europa.eu/eip/agriculture/en/eip-agri-common-format

3.2.1 Questions for scientific articles

The survey contains some questions that are specific for the scientific articles (Figure 1). We asked for the title, author(s), source (eg. journal), year of publication and the Digital Object Identifier (DOI).


General - Identity

What is your SFT?

Product

Project

Article

Title of the article

Author(s)

Source (Journal / proceeding)

Year of publication

Your answer must be between 1950 and 2017

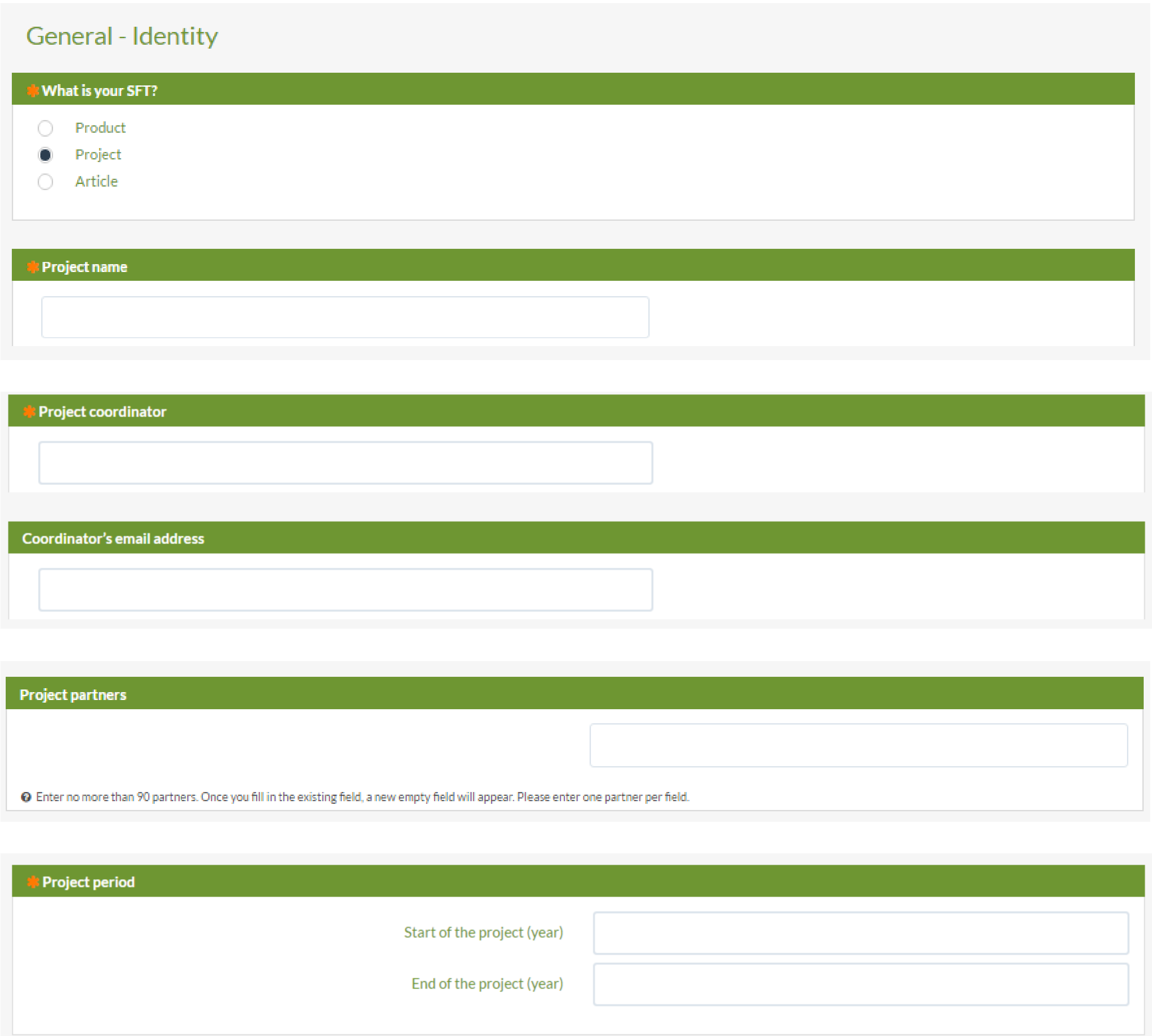
Only an integer value may be entered in this field.

DOI (Digital Object identifier)

Figure 1: Survey questions for articles

3.2.2 Questions for projects

The Smart-AKIS survey questions specific to the SFT type “project” are listed in Figure 2. The survey for projects starts off with general identity questions, including Project name, Project coordinator and his/her email address. A next step is to retrieve information on possible project partners that are involved, up to 90 project partners could be entered. The project period could be entered. The project status could be ongoing or finished. A few suggestion where done for the source of funding, with the option to enter other sources of funding that were not included in the options. The objective and a description of the project were also asked.


General - Identity

What is your SFT?

Product
Project
Article

Project name

Project coordinator

Coordinator's email address

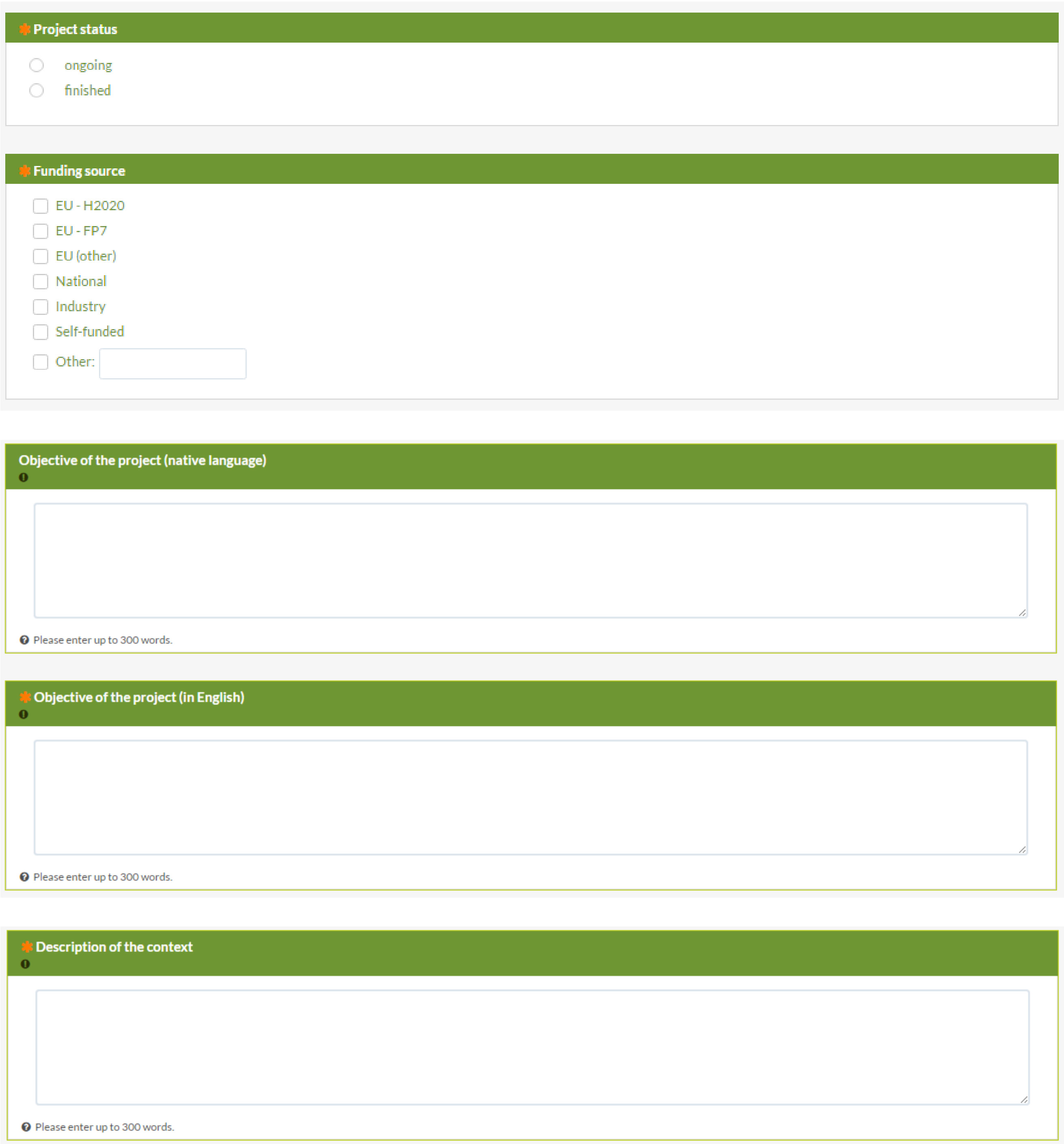
Project partners

Enter no more than 90 partners. Once you fill in the existing field, a new empty field will appear. Please enter one partner per field.

Project period

Start of the project (year)

End of the project (year)



Project status

- ongoing
- finished

Funding source

- EU - H2020
- EU - FP7
- EU (other)
- National
- Industry
- Self-funded
- Other:

Objective of the project (native language)

Please enter up to 300 words.

Objective of the project (in English)

Please enter up to 300 words.

Description of the context

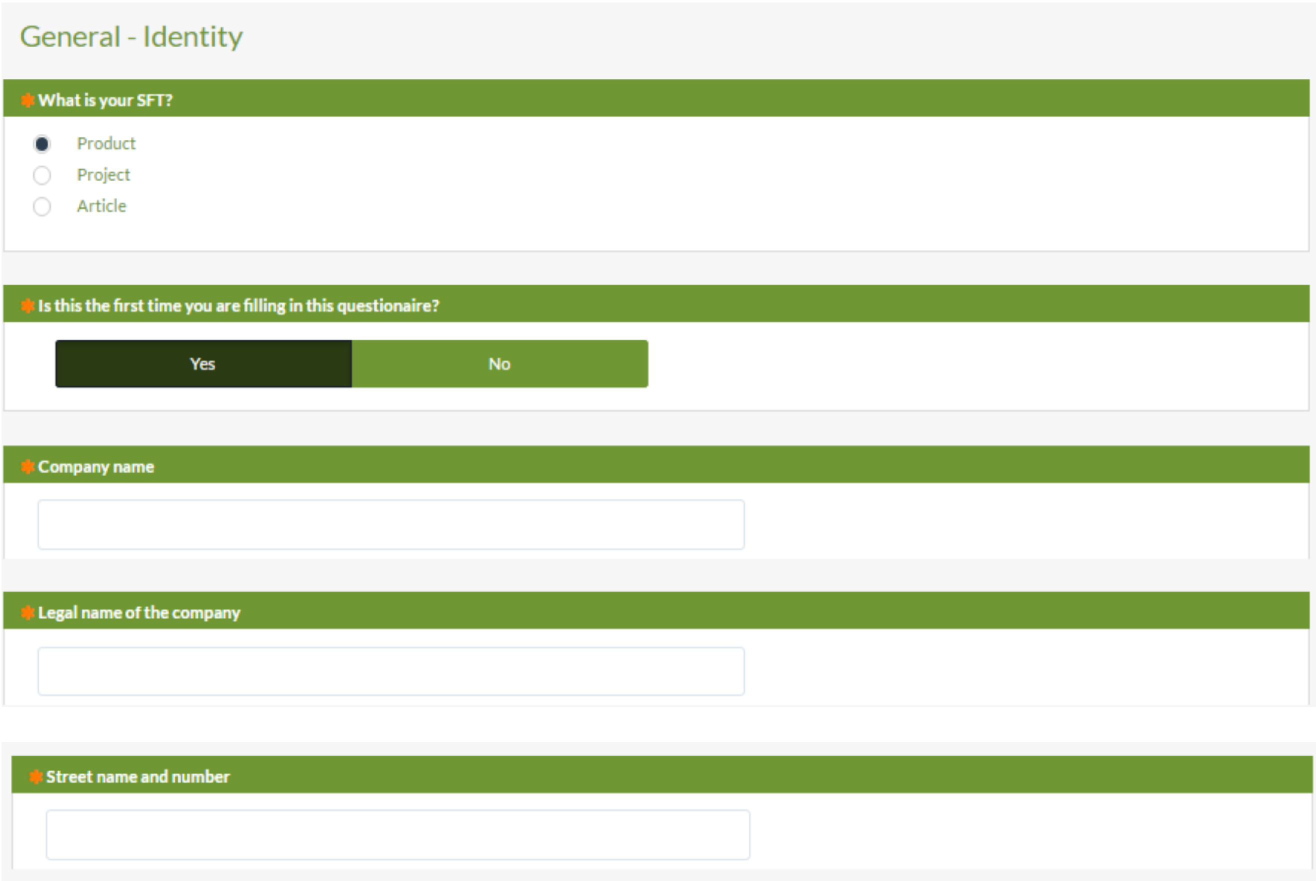
Please enter up to 300 words.

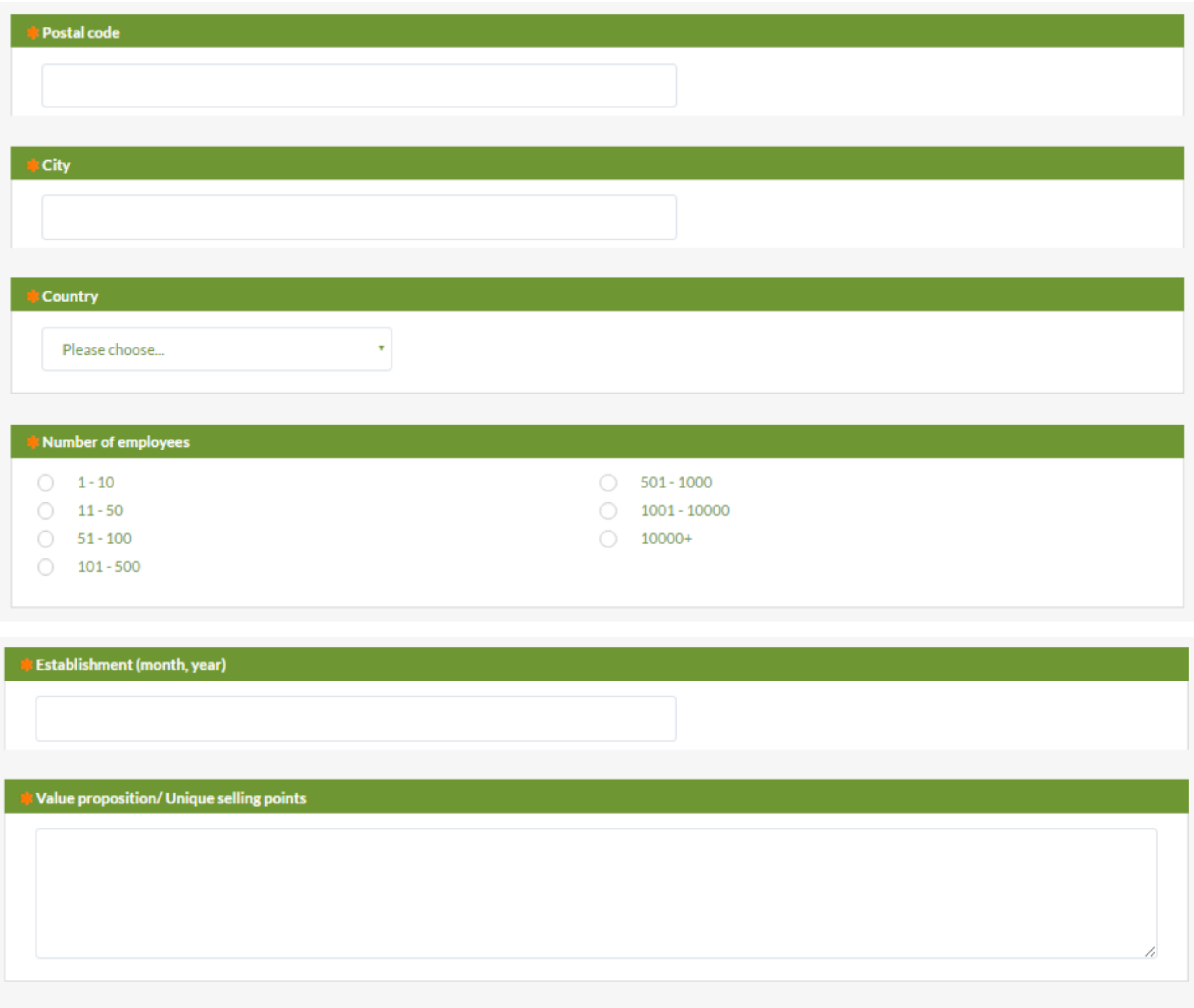
Figure 2: Survey questions for projects

3.2.3 Questions for products

Figure 3 shows the general identity questions related to commercial products. There are questions about the provider of the product, such as the company name, the legal name of the company and address information. We asked for the country in which the company related to the SFT is situated. To get an impression on the size of the company, a question on the number of employees was added. We were also interested in the date of establishment and "unique selling points" of the company. Unique selling points are business characteristics that distinguish the business in question from other businesses in the market and makes the business stand out. We considered this an important aspect in order to get an impression on the ambitions related to SFT development by this particular provider of SFT(s).

For commercial products, an important aspect is the price of the SFT - this was included in a separate question (Figure 4).




Postal code

City

Country

Please choose...

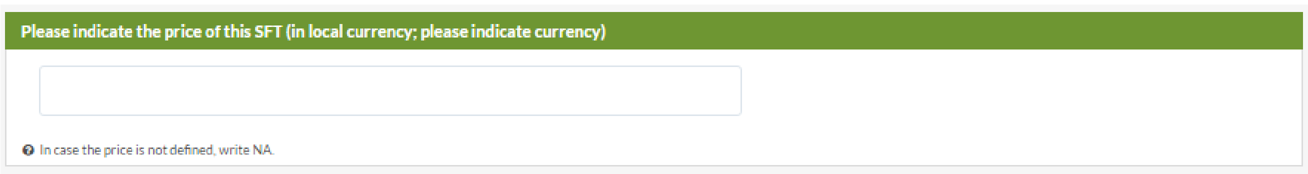
Number of employees

1 - 10
11 - 50
51 - 100
101 - 500
501 - 1000
1001 - 10000
10000+

Establishment (month, year)

Value proposition/ Unique selling points

Figure 3. Identity of, and descriptive information about, a company.


Please indicate the price of this SFT (in local currency; please indicate currency)

In case the price is not defined, write NA.

Figure 4: Price of the SFT

3.2.4 Basic information about SFT

After questions that were specific for the type of entry (scientific article, research project, or commercially available product), some basic information questions were asked about the SFT.

The survey basic information starts by asking to give up a general name for the SFT (Figure 5). This can also be done in a native language, so users will have the option of reading information in their own language.

A large box in the survey was used to get a detailed description of the SFT (Figure 6). An option to answer in a native language was also provided. After this a question was asked on the objective of the SFT, in order to find out what this SFT was actually set out to achieve.

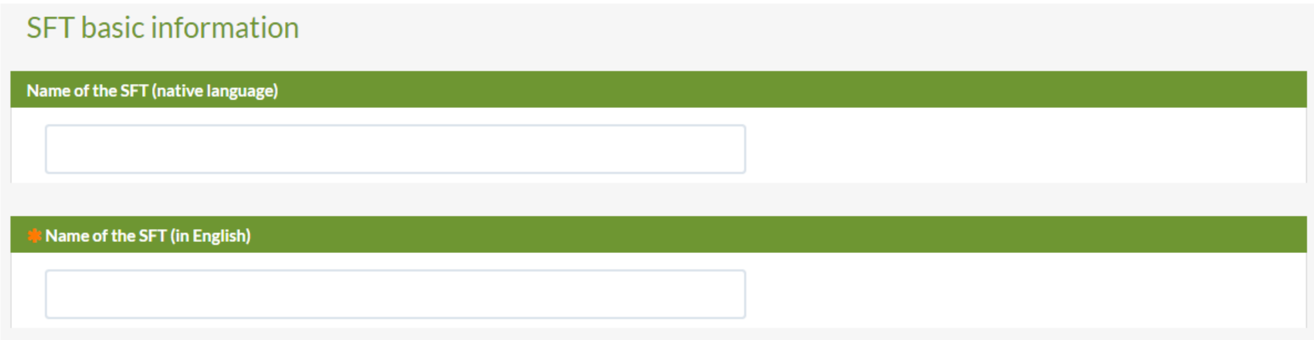


Figure 5: Name of SFT

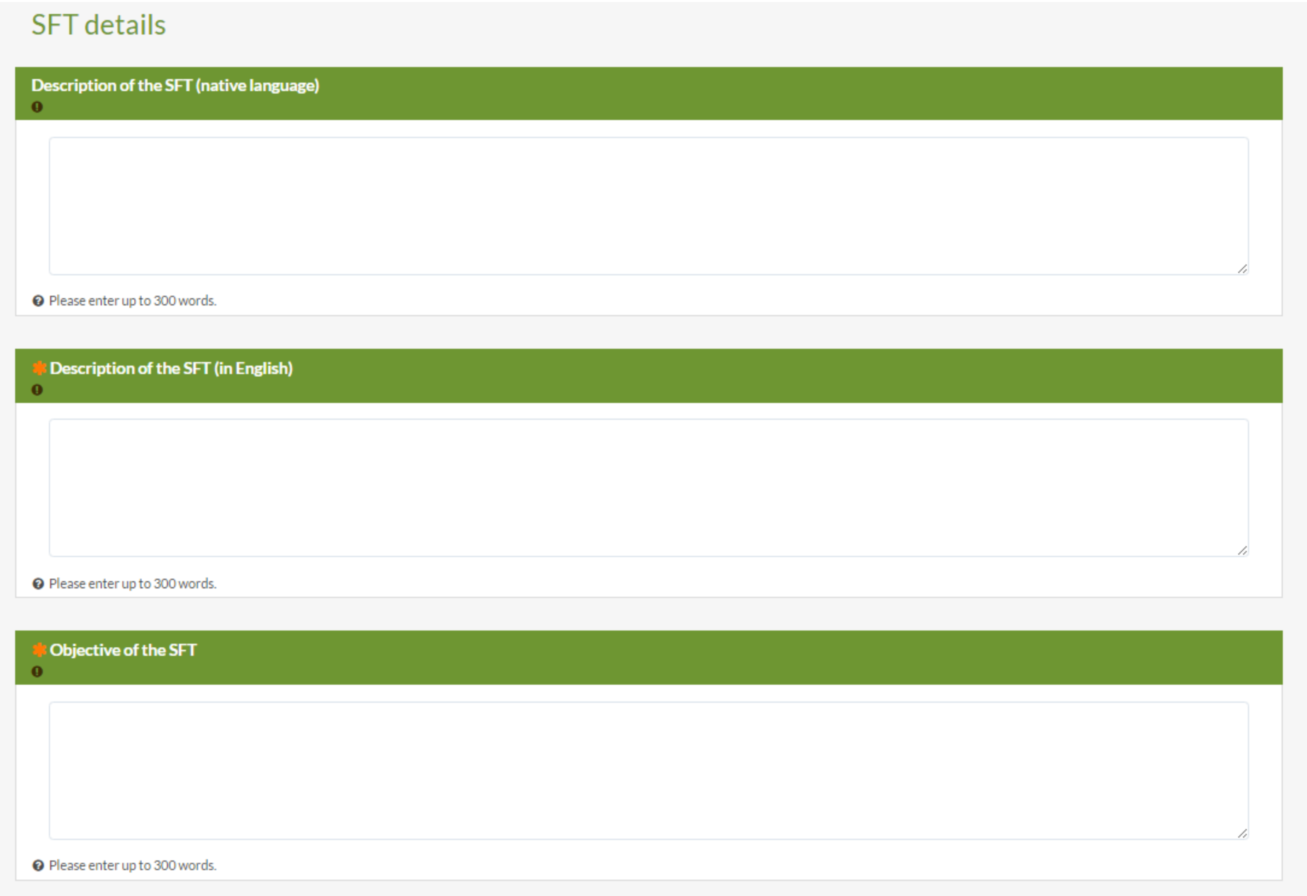


Figure 6. Description and objectives of the SFT

3.2.5 Typology of Schwarz et al.

For a better understanding of the SFT landscape, the classification of Schwarz et al. (2011) is used in our project. These authors classified SFTs as recording, reacting, or guiding technologies. In addition to these classes, in this project we additionally use “Farm Management Information System (FMIS)” and “robot or automatic system”. Please note that these five classes are not mutually exclusive. For example, a particular SFT may be recording and reacting at the same time. A robotic SFT will typically use some kind of guiding technology and at the same time either record or react, and possibly do both.

In order to find out more on what kind of SFT is presented a yes/no checkbox was included asking to check on whether the SFT is a recording/mapping technology, a reacting/variable rate technology, a guidance/ controlled traffic farming technology, a farm management information system/application or a robotic system/smart machine (Figure 7).

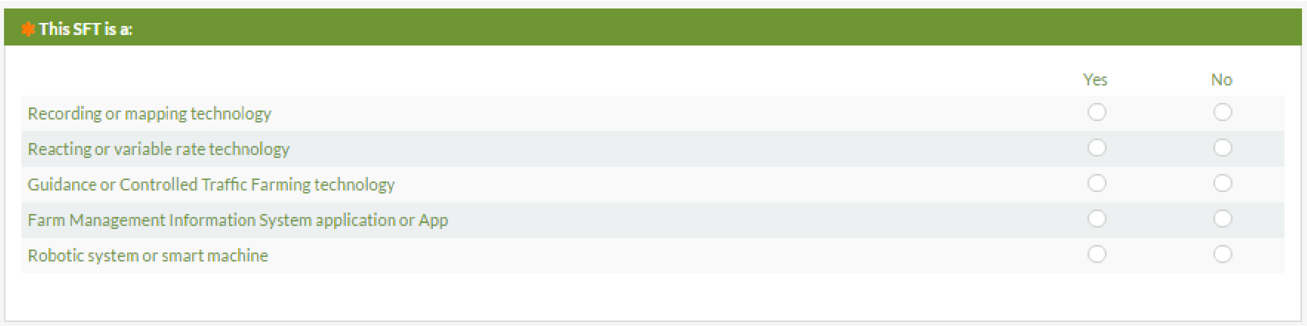
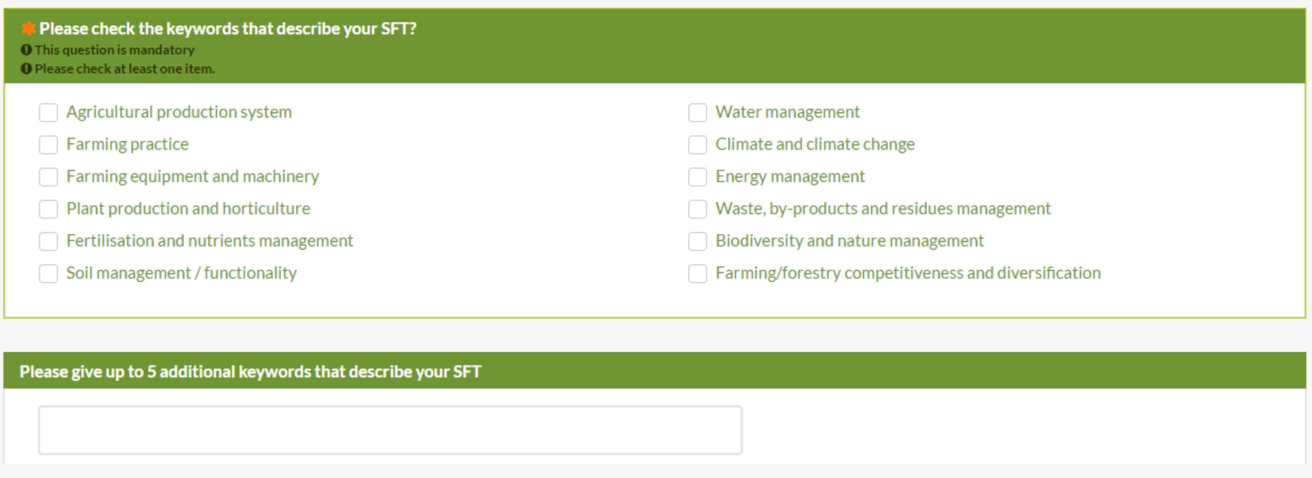


Figure 7: Kind of the SFT

3.2.6 EIP-AGRI keywords

The EIP-AGRI common format[11] has a set of keywords. We included in the survey those keywords that can apply to SFTs in open field agriculture (e.g. we excluded "animal husbandry and welfare"). (Figure 8). These keywords give a general impression of the SFT. The SFT can be about the agricultural production system, so this keyword can be chosen when the SFT is about the actual agricultural system, (e.g. weed suppression in organic farming, farming practice, how to navigate on the field). Another keyword is about the equipment and machinery that is used in the field, mainly for SFTs with technical features. The SFT can be about plant production and horticulture specific crop growth elements. They can also be specifically designed for targeting fertilization, soil management and/or functionality, water management, climate aspects, energy management and the management of waste by-products and residues. A specific keyword was also added for the management of biodiversity and nature as a SFT goal. Lastly, SFTs can be about farming/forestry competitiveness. The option was given to provide five additional keyword to properly describe the SFT in term of keywords.

[11] https://ec.europa.eu/eip/agriculture/en/eip-agri-common-format

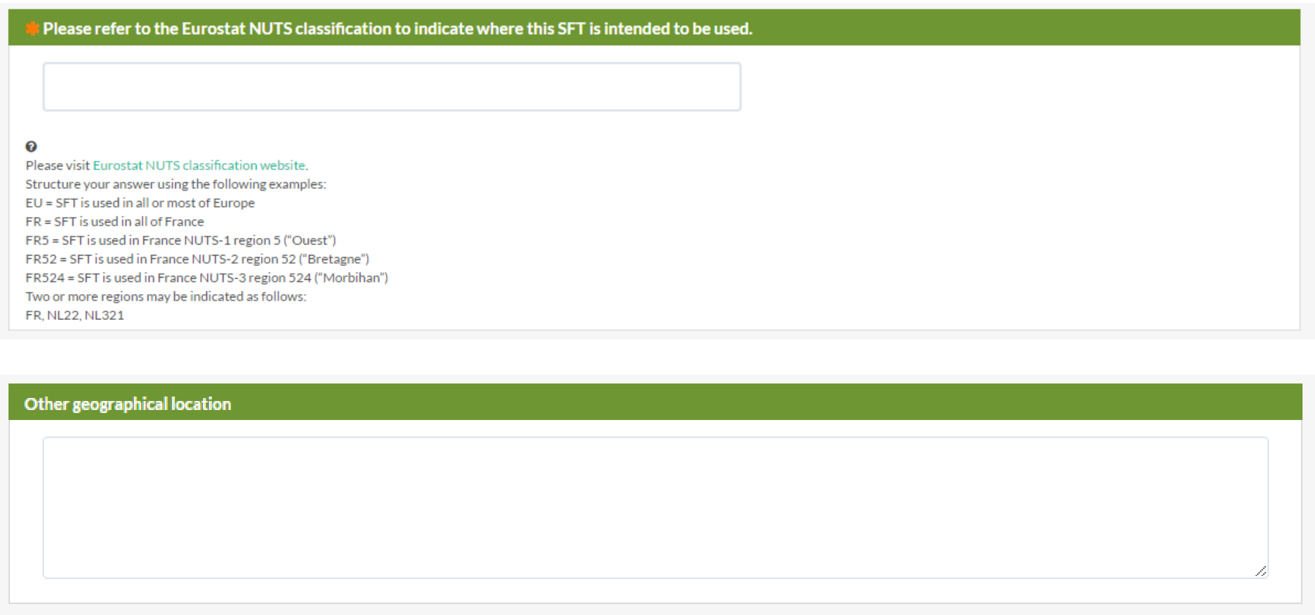

Please check the keywords that describe your SFT?
This question is mandatory
Please check at least one item.
- Agricultural production system
- Farming practice
- Farming equipment and machinery
- Plant production and horticulture
- Fertilisation and nutrients management
- Soil management / functionality
- Water management
- Climate and climate change
- Energy management
- Waste, by-products and residues management
- Biodiversity and nature management
- Farming/forestry competitiveness and diversification

Please give up to 5 additional keywords that describe your SFT

Figure 8: Keywords characterizing the SFT

3.2.7 NUTS

The geographical location where the SFT is intented to be used was retrieved systematically via the entry of NUTS regions (Figure 9). A link was provided to give more detail on what this is about to the survey applicant. For situations in which a region did not meet the classification properly, an open field on the geographical location was provided.


Please refer to the Eurostat NUTS classification to indicate where this SFT is intended to be used.

Please visit Eurostat NUTS classification website.
Structure your answer using the following examples:
EU = SFT is used in all or most of Europe
FR = SFT is used in all of France
FR5 = SFT is used in France NUTS-1 region 5 ("Ouest")
FR52 = SFT is used in France NUTS-2 region 52 ("Bretagne")
FR524 = SFT is used in France NUTS-3 region 524 ("Morbihan")
Two or more regions may be indicated as follows:
FR, NL22, NL321

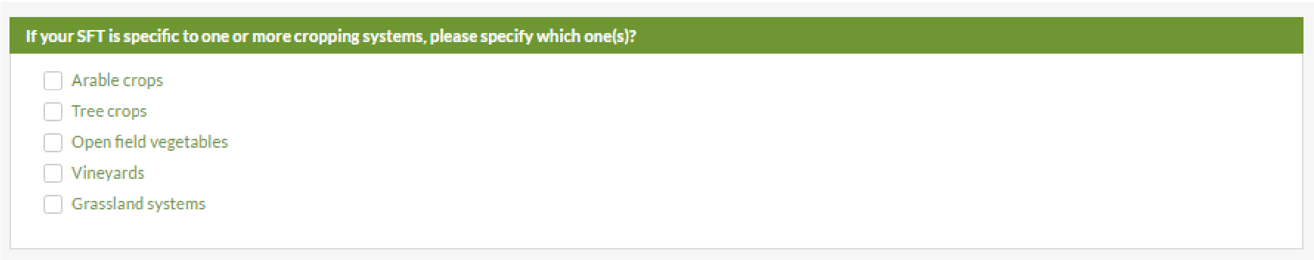
Other geographical location

Figure 9: Geographical clasification of the SFT

3.2.8 Cropping system and specific crops

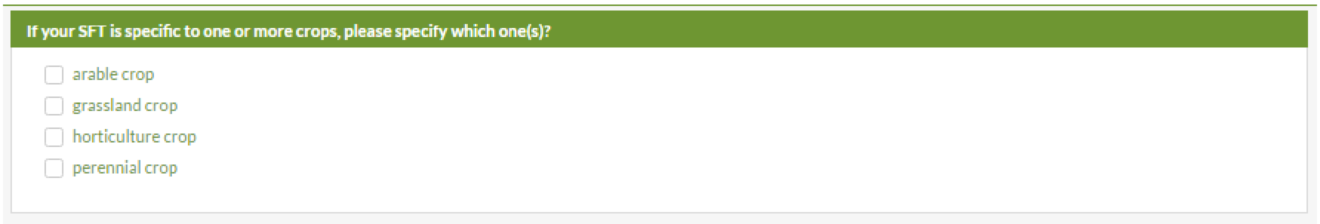
SFTs are expected to be specific to one or more of five major cropping systems: arable crops, tree crops, open field vegetables, vineyards and grassland systems (Figure 10). Applicants were asked to check one or multiple boxes.

A similar question was added for the type of crop with which the SFT could be dealing (Figure 11). We distinguished between arable crops, grassland crops, horticultural crops and perennial crops. It was also possible to indicate the exact crop in a new box that appears after filling out this question.


If your SFT is specific to one or more cropping systems, please specify which one(s)?

- Arable crops
- Tree crops
- Open field vegetables
- Vineyards
- Grassland systems

Figure 10: Cropping System where the SFT is used


If your SFT is specific to one or more crops, please specify which one(s)?

- arable crop
- grassland crop
- horticulture crop
- perennial crop

Figure 11: Specific crop for the SFT

3.2.9 Field operation

A few field operations can be chosen namely: tillage, sowing, transplanting, fertilization, pesticide application, weed control, pest- and disease control, irrigation, harvesting, post-harvest storage[12]

[12] Post-harvest activities should not have been included in the survey considering an earlier decisions on the scope of the SFT's to include. This field operation was therefore not included in the analysis.

and the scouting of crop, for example in the situation of field data retrieval (Figure 12). The option to include another field operation was provided in the "other" box.

* In what kind of field operations is this SFT meant to be used?
This question is mandatory
Please check at least one item.
If you choose 'Other:' please also specify your choice in the accompanying text field.

- tillage
- sowing
- transplanting
- fertilization
- pesticide application
- weed control
- pest and disease control
- irrigation
- harvesting
- post-harvest storage
- scouting of crop and/or soil
- Other:

Figure 12: Field operation for this SFT

3.2.1 Effect of using the SFT

A large box is included to find out more about the effects of the SFT (Figure 13). Effects were expected on 26 possible critical subjects identified in Section 3.1: productivity (crop yield per ha), the quality of a product, revenue-, profit and farm income, soil biodiversity, biodiversity (other than soil), input costs, variable costs, post-harvest crop wastage, energy use, emmissions of CH_4, CO_2, N_2O, NH_3 and NO_3, the use of fertilizer and pesticides, irrigation, labor time, stress and fatigue, the amount of physical labor, number and severity of accidents, number and severity of accidents resulting in spills, property damage or the incorrect application of fertilizers and pesticides, pest residue on products, weed pressure, pest pressure (insects) and disease pressure from for example bacteria and fungi. Effects could be expressed using a scale ranging from a large decrease up to a large increase. An open checkbox provided the possibility to supplement this scale with relevant percentages, providing the option to give an even more precise indication of the effects of the SFT when this is possible.

*
This SFT has the following effect on:

	Large decrease	Some decrease	No effect	Some increase	Large increase	If possible, please quantify percentage of change
Productivity (crop yield per ha)	○	○	●	○	○	
Quality of product	○	○	●	○	○	
Revenue, profit, farm income	○	○	●	○	○	
Soil biodiversity	○	○	●	○	○	
Biodiversity (other than soil)	○	○	●	○	○	
Input costs	○	○	●	○	○	
Variable costs	○	○	●	○	○	
Post-harvest crop wastage	○	○	●	○	○	
Energy use	○	○	●	○	○	
CH4 (methane) emission	○	○	●	○	○	
CO2 (carbon dioxide) emission	○	○	●	○	○	

Figure 13. Effects of the SFT.

3.2.2 User

It was considered important to retrieve some information on the person that is expected to use the specific SFT (Figure 14). This could be a farmer, contractor (including consultants), supplier, buyer of farm products or a processor of farm product.

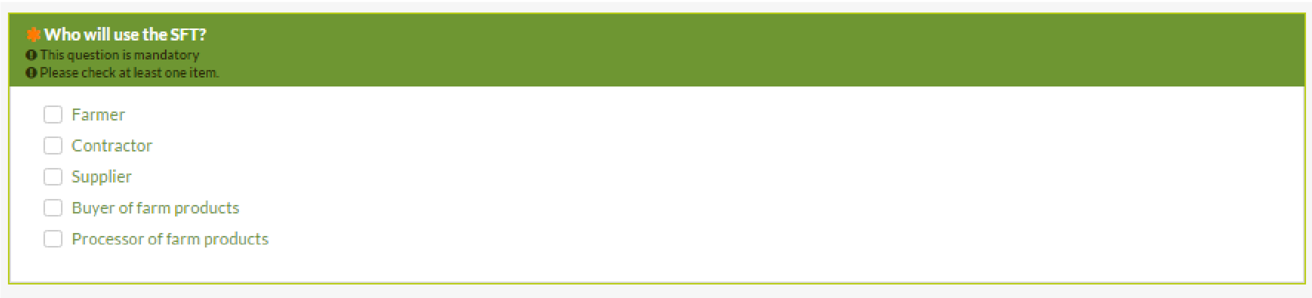

Who will use the SFT?
This question is mandatory
Please check at least one item.
- [ ] Farmer
- [ ] Contractor
- [ ] Supplier
- [ ] Buyer of farm products
- [ ] Processor of farm products

Figure 14: User type of the SFT

3.2.3 TRL

The Technology Readiness Level (TRL) of a technology indicates its maturity level. The TRL concept originated in the space industry[13] and was adopted by the European Union[14]. In the EU version, maturity ranges "Basic principles observed" to "Actual system proven in operational environment" (Table 7).

The first level (TRL1) means that only basic principles have been observed, meaning that the SFT is just available on a conceptual level with or without a research plan. The second level (TRL2) stands for 'technology concept formulated', so on this level the SFT is assumed to have a clear conceptual basis. The third level (TRL3) assumes a 'experimental proof of concept' meaning that the SFT is proven to be of interest in for example a lab setting. The fourth level (TRL4) goes one step further by stating that the SFT is actually validated in a lab. The fifth level (TRL5) assumes validation in a more relevant environment, for example in a test field. The sixth readiness level (TRL6) assumes that the technology is actually demonstrated in a relevant environment. The seventh level (TRL7) assumes there is a prototype that has been demonstrated in a relevant environment. The eighth readiness level (TRL8) means that we have a complete system that is also qualified for the job that was targeted. The last, ninth level of technological readiness (TRL9) assumes that the entire actual

[13] https://en.wikipedia.org/wiki/Technology_readiness_level

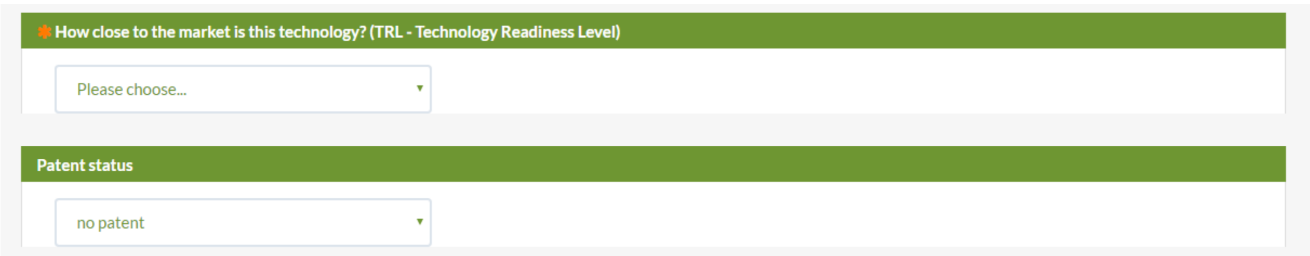
[14] https://ec.europa.eu/research/participants/portal/desktop/en/support/faqs/faq-2890.html

system is proven to be effective in the operational environment, meaning the environment in which the SFT will be used.

The survey question on TRL is shown in Figure 15.

Table 7: Technological Readiness Level (TRL)[15]

	TRL (Technology Readiness Level)
1	Basic principles observed
2	Technology concept formulated
3	Experimental proof of concept
4	Technology validated in lab
5	Technology validated in relevant environment
6	Technology demonstrated in relevant environment
7	System prototype demonstration in operational environment
8	System complete and qualified
9	Actual system proven in operational environment


* How close to the market is this technology? (TRL - Technology Readiness Level)

Please choose...

Patent status

no patent

Figure 15: Technology Readiness Level of the SFT

[2]https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

3.2.4 Patent status

It was considered relevant to know if there is any patent on the SFT (Figure 16). There could be no patent, the patent could be pending, submitted, expired or in-force. If no information was available the answering box can be left blank.

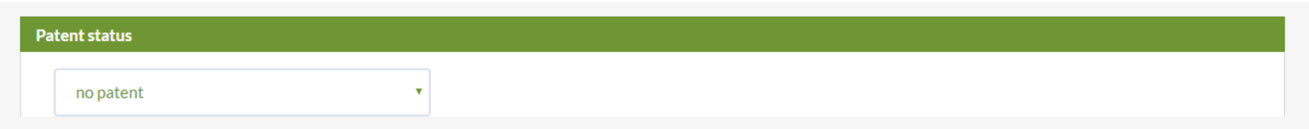


Figure 16: Patent of the SFT

3.2.5 Adoption using Rogers' framework

In addition to characteristics of SFTs that relate to the challenges that farmers face, the survey included also some questions related to the adoption of SFTs. We made use of Rogers's (Rogers, 1995) method for evaluation of the innovations (here: SFTs). Rogers is well-known for originating the *Diffusion of innovations* theory and for introducing the term *early adopter*. Rogers's method for evaluation of innovations is ilustrated in Figure 17.

According to Rogers, potential adopters evaluate an innovation on:

- its relative advantage (the perceived efficiencies gained by the innovation relative to current tools or procedures),
- its compatibility with the pre-existing system,
- its complexity or difficulty to learn,
- its testability,
- its potential for reinvention (using the tool for initially unintended purposes), and
- its observed effects

Diffusion occurs through a five-step decision-making process. The first stage is the stage of *knowledge*, where an individual is first exposed to an innovation, but lacks information about it and is not motivated to search for further information. *Persuasion* is the second stage, where the individual is interested in proposed innovation and actively seeks for related information. *Decision* is the third stage where the individual takes the concept of the change and weighs the advantages/disadvantages of the usage of innovation and makes a decision whether to adopt or to reject it. The next step is the *implementation* phase, where the individual employs the innovation to a varying degree depending on situation. During this stage, if the individual is interested in further usage, may search for further information about the innovation. The last stage is *confirmation* – the phase when the individual finalizes his/her decision to continue using the innovation.

Clearly, this process relies on human capital, so all dimensions of each innovation must be carefully considered. Since the innovation must be widely adopted in order to be self-sustainable, Rogers introduces five main categories of an adoption rate. Namely, those are: innovators, early adopters, early majority, late majority, and laggards (Figure 18).

The following question consisted of a few statements one could agree with or not, considering the relevance of the statement for the SFT (Figure 19). The check box included a scale ranging from strongly agree up to strongly disagree. The seven statements are:

1. *This SFT replaces a tool or technology that is currently used. The SFT is better than the current tool.*

This question is specifically aimed at SFTs than are aiming at creating added value over existing tools.

2. *The SFT can be used without making major changes to the existing system*

Some SFTs are expected to require more changes to the existing system than others.

3. *The SFT does not require significant learning before the farmer can use it*

The answer to this statement can give an indication on the learning effort that need to be made by the farmer. This can be useful information in order to compare the difference in learning requirements between different SFTs

4. *The SFT can be used in other useful ways than intended by the inventor*

Some SFTs may hold multiple purposes making them useful for the achievement of many very different effects.

5. *The SFT has effects that can be directly observed by the farmer*

It is considered an advantage when effects can be directly observable by a farmer, because this will make it more likely that the farmer will find the SFT relevant for his/her situation.

6. *Using the SFT requires a large time investment by farmer*

The answer to this statement will give an indication on the time investment that is needed from the farmer in order to use the SFT. The time investment will play a role in how attractive the SFT is to use.

7. *The SFT produces information that can be interpreted directly (example of the opposite: the SFT produces a vegetation index but nobody knows what to do with it)*

It is desirable when results are presented in such a manner that they are easy to interpret. This makes the results more interesting for end-user and results in consistency in the interpretation.

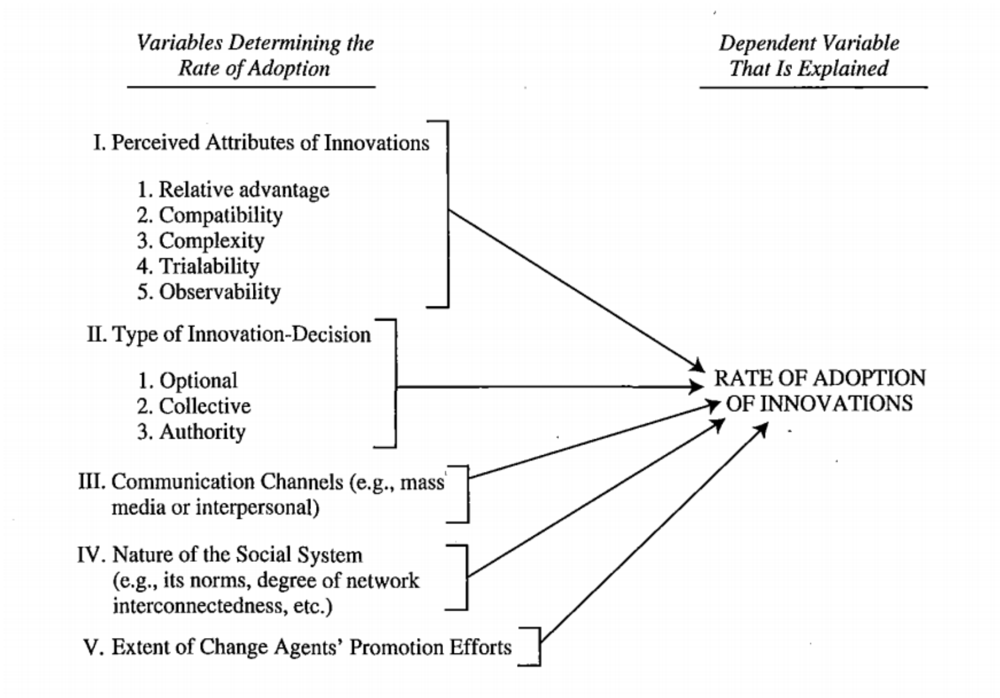


Figure 17: Rogers's method for evaluation of the innovations

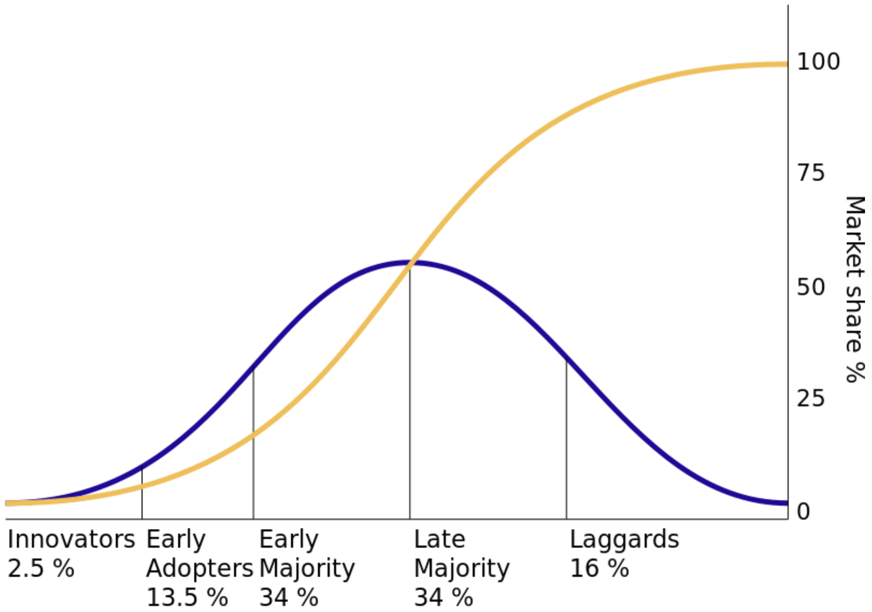


Figure 18: Adopter categories according to (Rogers, 1995).

	strongly disagree	disagree	no opinion	agree	strongly agree
This SFT replaces a tool or technology that is currently used. The SFT is better than the current tool.	○	○	●	○	○
The SFT can be used without making major changes to the existing system	○	○	●	○	○
The SFT does not require significant learning before the farmer can use it	○	○	●	○	○
The SFT can be used in other useful ways than intended by the inventor	○	○	●	○	○
The SFT has effects that can be directly observed by the farmer	○	○	●	○	○
Using the SFT requires a large time investment by farmer	○	○	●	○	○
The SFT produces information that can be interpreted directly (example of the opposite: the SFT produces a vegetation index but nobody knows what to do with it)	○	○	●	○	○

Figure 19: Statements regarding the SFT

3.2.6 Area

To be able to estimate the current applicability of the SFT, we asked to give an indication of the total area in Europe in which this SFT is used (Figure 20).

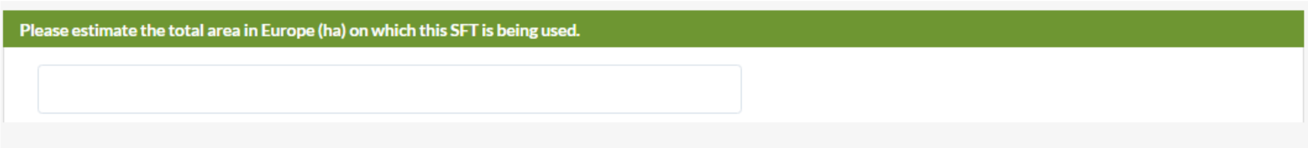

Please estimate the total area in Europe (ha) on which this SFT is being used.

Figure 20. Total area in Europe where this SFT is used

3.2.7 Education level

The education level required to operate the SFT is considered, this can be all farmers, farmers with a primary education, farmers with secondary education, farmers with an education at a technical school and farmers with university education (Figure 21). An open answering box was included to be able to enter other types of education, when this is necessary.

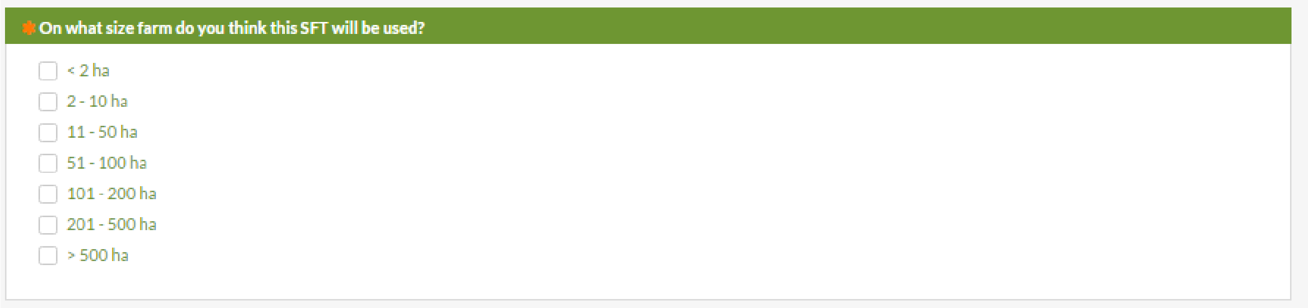

Who will use this SFT?

- all farmers
- Farmers with primary education
- Farmers with secondary education ("high school")
- Farmers with apprenticeship and/or technical school
- Farmers with university education
- Other:

Figure 21: Eduction level required to operate the SFT

3.2.8 Farm size

Another detail that has been included is the farm size, answering field ranges from less than 2 ha to more than 500 ha (Figure 22).


On what size farm do you think this SFT will be used?

- < 2 ha
- 2 - 10 ha
- 11 - 50 ha
- 51 - 100 ha
- 101 - 200 ha
- 201 - 500 ha
- > 500 ha

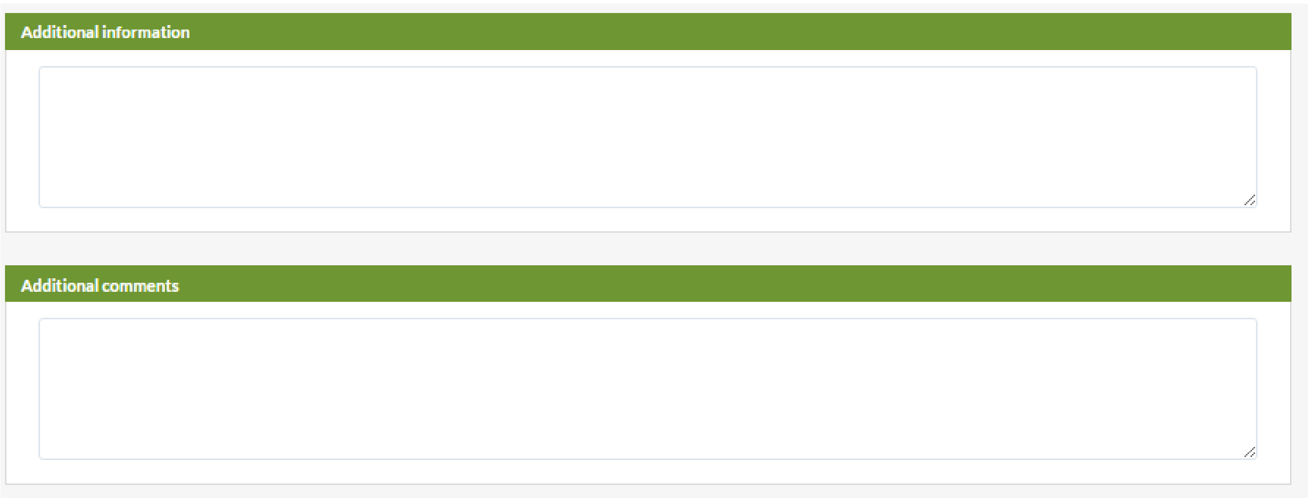
Figure 22: Farm size to use the SFT

3.2.1 Other

There is room for additional information and comments (Figure 23).

A question in this category presents a box in which a link to other websites can be provided that could be of relevance for clarification of the basic information on the SFT (Figure 24).

An option is provided to add audiovisual material on the SFT if this is available (Figure 25). A link could be provided as well as a direct upload. We also asked for relevant webpages of the SFT company that may be involved or just a general SFT web page.


Additional information

Additional comments

Figure 23: Aditional information on the SFT

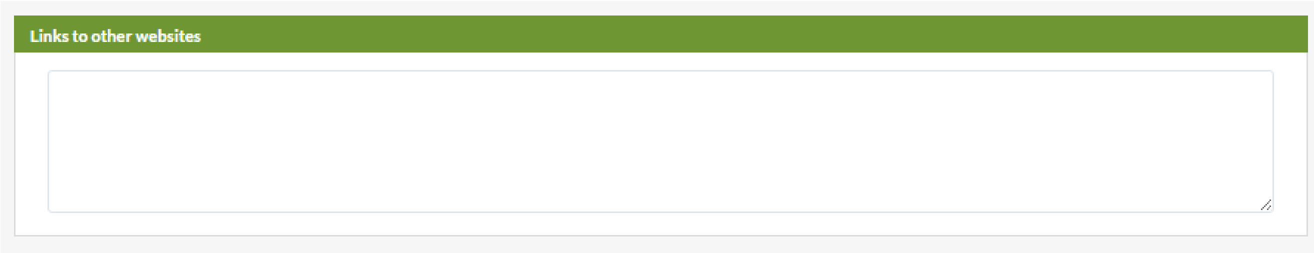


Figure 24: Other websites relevant to the SFT

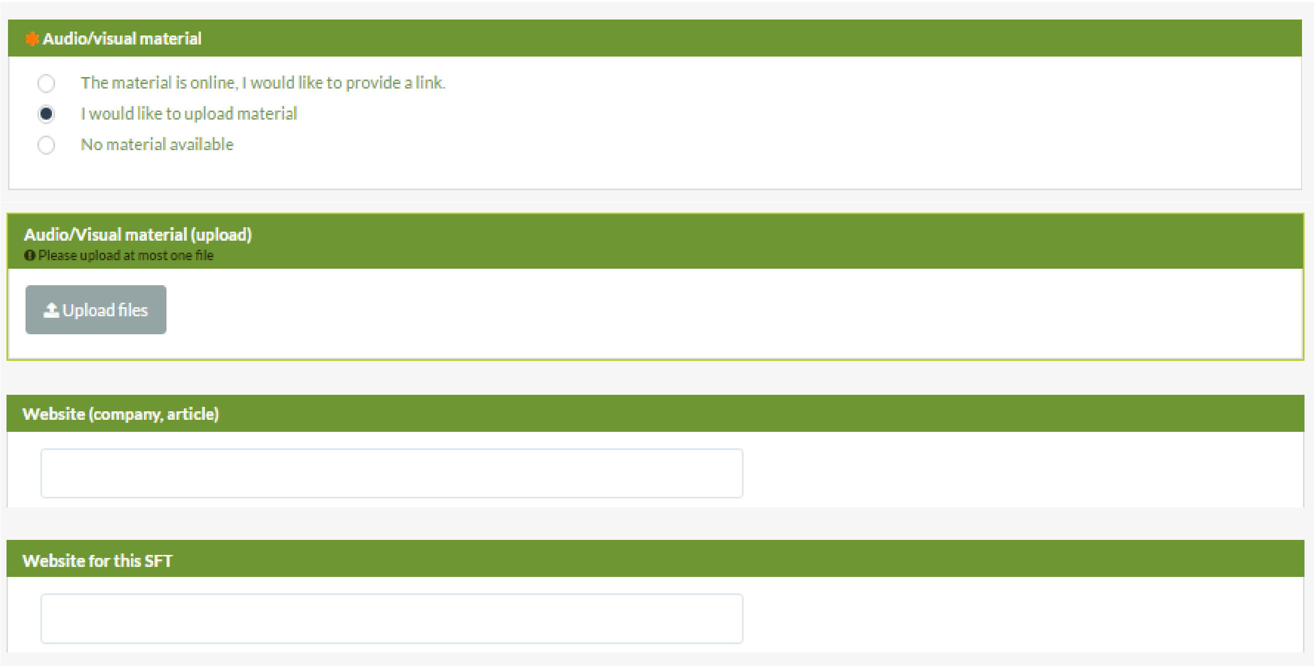


Figure 25: Audiovisual material for the SFT

3.3 Search

3.3.1 Peer-reviewed scientific articles

The following reference databases were considered for searching peer-reviewed scientific articles:

- Scopus (www.scopus.com): broad coverage: not only agriculture, not only top journals
- Web of Science (www.webofknowledge.com): coverage focused on top journals
- CAB Abstracts (http://www.cabi.org/): only agriculture, presence of grey literature
- Agricola (https://www.ebscohost.com/): only agriculture, presence grey literature

- Agris (http://agris.fao.org/): specific for agriculture

It was decided to use the database with the highest possible coverage in order to answer our research questions in the best possible manner. Therefore Scopus was used to collect scientific articles.

A query was developed to search articles that might describe SFTs. The query consisted of two parts: a first part that aimed to select all articles related to technology, and a second part that aimed to select all articles related to arable farming. The two parts of the query were joined with an "AND" clause. The selection of keywords was supplemented by considerations on the scope of relevant time and subject related settings. A copy of part of the query is written below as it was used to select articles by formulation of keywords:

> *[sensor, decision-support, dss, database, ict , automat*, autonom* ,robot*, gps, gnss ,information system, image analysis, image processing, precision agriculture, smart farming, precision farming, agriculture, crop, arable, farm, vineyard, orchard, horticulture or vegetable]*

where keywords ending with "*" could have different endings (e.g. automat* will retrieve "automatic" as well as "automated"). The complete query can be found in Section 9.2.

Results were limited by year, document type (article), subject type (agriculture) and language (English). For our purpose we have collected papers only from 2010 and later, in order to focus on recent SFTs that are likely of interest to modern farmers. Ten key papers considered relevant for our subject were used to verify the results of the query. When these 10 papers were included in the query result, this increased confidence that we had formulated an appropriate query.

Manual selection procedure

The Scopus query resulted in a large number of articles that are expected to be holding information on smart farming technology. From these papers there were many that were not relevant to the Smart-AKIS project. Therefore, a manual selection procedure was used to select only the articles that are relevant for our project, namely, articles describing a technology that can (or could be) used by a farmer in his or her daily farming practice. Throughout we focused on the question *"Is this a relevant SFT?"*. We used an exclusion approach and removed the following kinds of papers based on information contained in the abstract:

- Remove anything related to post harvest, processing, distributing, or marketing
- Remove anything related to evapotranspiration calculations
- Remove anything related to land suitability (select only DSS related to crops suitability)
- Remove anything related to water management, like droughts (but include anything related to irrigation)
- Remove anything related to tractor engines
- Remove anything related to greenhouse cultivation

The manual selection of articles was done in three rounds. First, we used the title to remove papers that are not relevant. For example, a paper with the title "A New Assessment of Soil Loss Due to Wind Erosion in European Agricultural Soils Using a Quantitative Spatially Distributed Modelling Approach" was selected by our query because its abstract contains the terms "*Geograhic information system*" and "*Arable land*". However, from the title it is clear that this paper does not describe a tool that can be useful to farmers. Therefore, simply based on the title, we removed it from our list.

Second, for those papers with promising titles, we read the abstract. Again, this may lead to removal of the paper. As an example, the paper with title "Wireless sensor network and internet of things (IoT) solution in agriculture" seems of interest. The abstract makes clear that this paper describes network infrastructure that could certainly be used to in a farm. However, this will not be used directly by farmers. Rather it will be a component in the development and operationalization of a sensor network that in turn will support tools for decision-making by farmers. In short, this paper does not describe an SFT as defined in Smart-AKIS.

As a third step, it was attempted to locate the full text of the paper. If that proved impossible, or if paper turned out to be written in, for example, Chinese, then once again this was reason to remove the paper from the list. If the full text indicated that the paper was not relevant to our project, it was removed from the list. For papers left at the end of step three, we answered the questions of the survey using the full text of the paper.

3.3.2 Research projects

For the retrieval of projects, an active search was carried out for EU-Funded projects. Horizon 2020 and FP7 programmes were collected from the CORDIS website of the European Commission. A selection query was used in order to select relevant articles from the Horizon 2020 and FP7 collection. In this selection relevant keywords have been used to identify SFT related projects.

['%sensor%, '%automat%', '%decision-support%', '%dss%', '%database%', '%ict%', '%autonom%', '%robot%', '%gps%','%gnss%', '%information system%', '%image analysis%', '%image processing%', '%precision agriculture%', '%smart farming%', '%precision farming%', '%agricult%', '%crop%', '%arabl%', '%farm%', '%vineyard%', '%orchard%', '%horticult%' '%vegetabl%']

where the '%' helps to also get words from which the keywords is a part.

3.3.3 Industry results (commercially available products and services)

For the collection of industry results, a call was announced through the project newsletter, as well through the network of SFT companies through the European Association of Agricultural Machinery (CEMA) companies that was partner in the Smart-AKIS project. A web search gave insight in the companies that are possibly involved in the development of SFTs. We searched for companies with relevant credentials for smart farming, such as involvement in the production of farming equipment and machinery or stakeholders involved in the development of agronomic software. The relevant networks of FIWARE FRACTALS, and Smart Agrifood II were consulted. Furthermore we used our own network of advisers to contact relevant stakeholders.

3.4 Ontology

When we try to be more expressive in a classification, it may be that an object falls in two or more classes, or that there is a relationship between two classes. A simple classification is then not sufficient. Therefore, in this project we also develop an ontology of SFTs. An ontology is a formal naming and definition of the types, properties, and relationships that exist between objects in a particular domain (Gruber, 1993). In the end, we only fully understand a "thing" if we can give a name to it and indicate the relationships it has with other "things".

We created an ontology of SFTs based on survey results. An ontology is a structured vocabulary describing the domain of interest. It is typically constructured using semantic web technologies (Berners-Lee et al., 2001). A good overview is given in (Allemang and Hendler, 2011).

The SFT ontology was created as an expansion and partial restructuring of the VALERIE ontology. VALERIE (www.valerie.eu) is a FP7-funded project that ran from 2014-2017. The objective of VALERIE was to develop a semantic search engine for the agricultural domain for valorisation of research results (Bechini et al., 2016). The VALERIE ontology currently consists of more than 6000 terms (Bechini et al., 2016). The VALERIE ontology does not specifically focus on SFT and thus had only a few concepts that are related to this.

Two actions were performed. The first action consisted of making a list of concepts related to SFT, principally by scanning reports, project proposals, and scientific articles, and noting relevant terms. These terms were then added to the VALERIE ontology (of course, some terms were already present). The second action consisted of linking concepts to each other. The main organizing principle is that concept B may be “a kind of” concept A (“B is-a A”), which gives rise to a hierarchy of concepts. The second principle is that concept C may be “related to” concept D.

All adding and restructuring of the VALERIE ontology was done using ROC+ (Koenderink et al., 2008) which offers various views and drag-and-drop editing.

3.5 Assess value for farming

Technologies that deliver a benefit directly to the farmer are either recording/mapping technologies or actuation (reacting / guiding / robotic) technologies. Recording/mapping technologies provide a measurement of a certain variable; this measurement can then be used to make decisions. We reviewed the literature to assess how accurate and precise the technologies are. Actuation technologies have the potential to reduce the cost of field operations or help to achieve a reduction in input use. We reviewed the literature to quantify the benefits of actuation technologies. Often, a FMIS is the connecting tissue between recording and actuation. FMIS are thus very important in realizing practical benefits but we attribute this benefit to the actuation technologies.

4 Survey results: numbers and kinds of SFTs

The number of articles describing an SFT is growing rapidly (Figure 26). In total, more than 13,000 scientific papers have been found in the citation database Scopus with the query described in Section 3.3.1. The number of SFTs was far smaller than then number of papers because many scientific papers describe a smart technology that is not directly useful to farmers, i.e. it is not an SFT).

In total we found 1064 records of SFTs for which we were able to fill out the survey; this number can be broken down into 531 scientific articles, 94 research projects, and 439 commercial products and services (Table 8).

The number of SFTs alone does not give any insight into the kinds and the diversity of SFTs. A somewhat better understanding is formed by looking at Table 9 which gives examples of six SFTs (a physical product and a service that are available commercially; two SFTs that are being investigated or developed in an applied research project; and two SFTs that are described in a scientific paper).

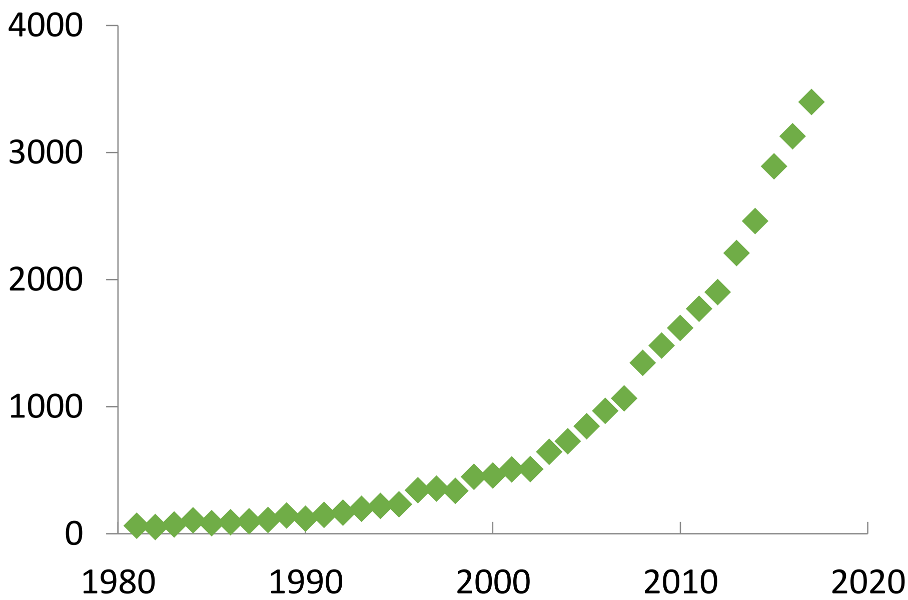


Figure 26 Number of articles per year (1981-2017) that are found with the Scopus query (as of 18 July 2018).

Table 8. Total number of Smart Farming Technologies identified.

Type	Total number
Research articles	531
Research projects	94
Industry solutions	439
Total	**1064**

Table 9. Examples of six Smart Farming Technologies, grouped by whether they are available as a product or service on the market; investigated in a research project; or described in a scientific paper.

Product/ Service	New Holland IntelliSteer®: automatic steering system https://smart-akis.com/SFCPPortal/#/app-h/technologies?techid=1000
	365FarmNet: Farm Management Information System https://smart-akis.com/SFCPPortal/#/app-h/technologies?techid=1056
Project	VinBot: robot to estimate the amount of leaves and grapes on the vine for yield estimation https://smart-akis.com/SFCPPortal/#/app-h/technologies?techid=151
	MISTRALE: GNSS reflectometry for soil humidity mapping and water management https://smart-akis.com/SFCPPortal/#/app-h/technologies?techid=156
Paper	A mobile sensor for leaf area index estimation from canopy light transmittance. https://smart-akis.com/SFCPPortal/#/app-h/technologies?techid=792
	Automatic detection of tulip breaking virus (TBV) in tulip fields using machine vision. https://smart-akis.com/SFCPPortal/#/app-h/technologies?techid=347

4.1 Technology readiness levels

Nine different levels for technology readiness have been distinguished ranging from a project or article addressing just basic principles (TRL1) up to a system that has thoroughly been proven to work in the relevant operational environment (TRL9). Figure 27 presents the differences in technology readiness levels (TRL) between the scientific articles and research projects (by definition, the TRL of products is 9). Most technologies are in the stage where they are validated in a relevant environment. In all cases a few entries are of the earliest stages in which only basic principles are observed or technology concepts formulated.

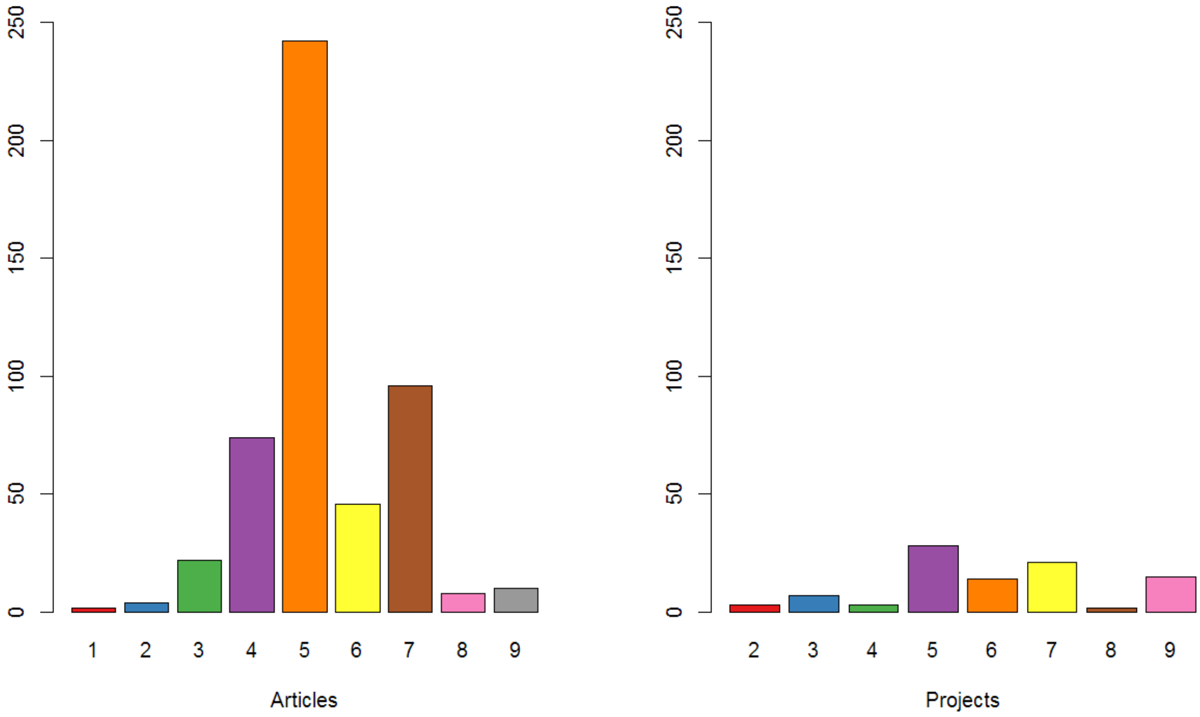


Figure 27 Technological Readiness Levels

4.2 Types of SFT

Different types of SFT can be distinguished (Figure 28). Let's zoom in on just peer-reviewed scientific papers. When taken across the six years under consideration, the Figure suggests that there is a focus on recording, with relatively little attention on reacting. This is not a comforting picture, because it suggests that while there is a large effort on measurements, there is a lack of effort on translating measurements into practical actions on the farm. It should be noted that corresponds uncomfortably well with the feeling of some that smart farming and precision agriculture promise more than they deliver (e.g. Merfield, 2016).

But the above only holds if we lump the data from all six years together. If we consider the years 2012-2016 (Figure 29), it emerges that over time the focus shifts from recording to robots and to FMIS. In most cases a robot is designed to perform some action in the field and the FMIS generates fertilizer and crop protection recommendations. In all, it seems that the work currently being reported in the scientific literature will in all likelihood lead to new SFTs becoming available to the farmer. The Figure also shows that papers published in 2017 again focused heavily on recording. It will be interesting to see what happens in 2018. Nevertheless, if we look at relative numbers we see that of the robot and FMIS papers, a larger fraction has been published recently than is the case for the other types of SFT (Figure 30).

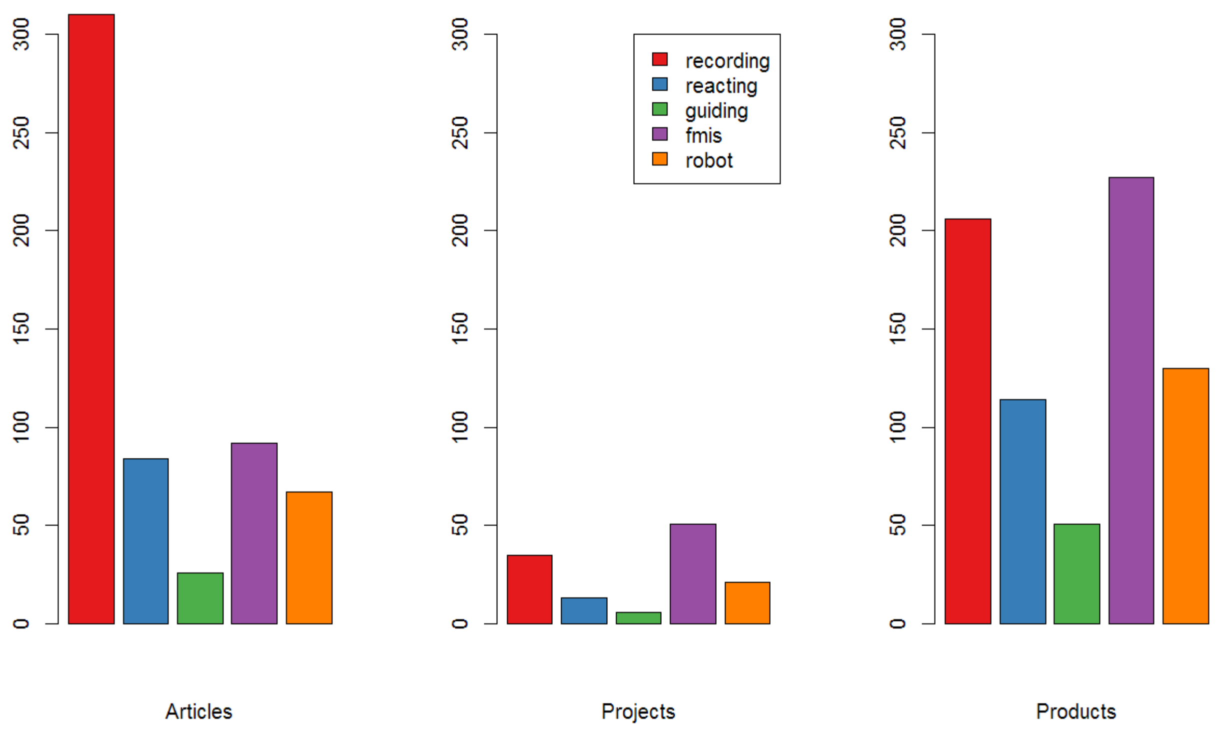


Figure 28. Types of SFT.

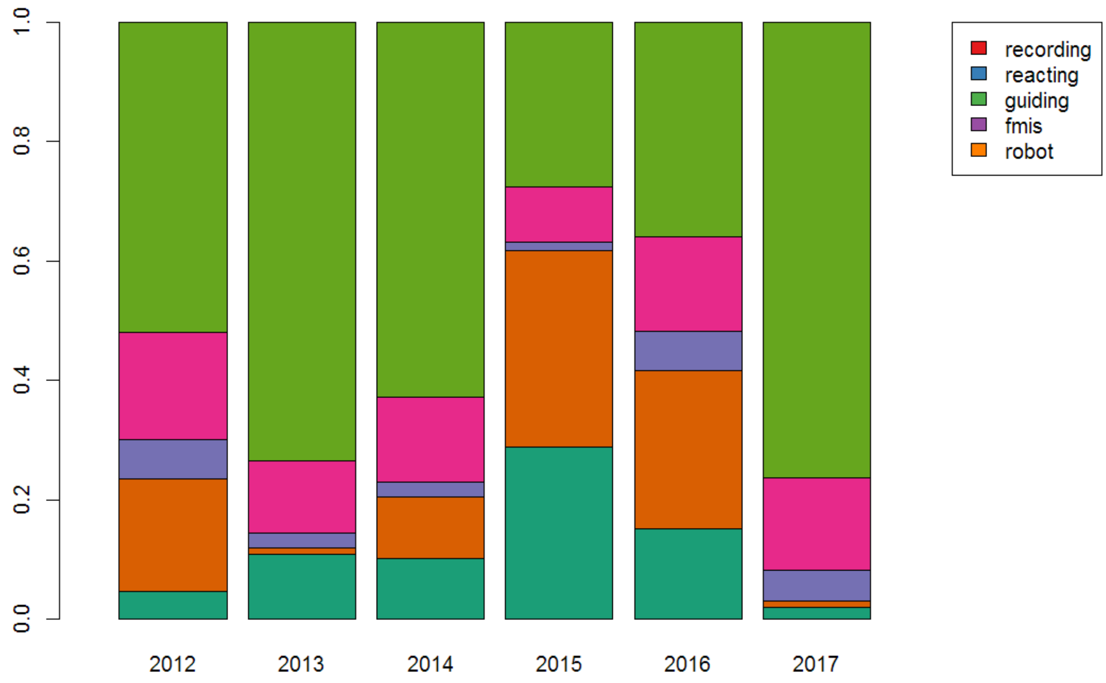


Figure 29. The fraction of peer-reviewed scientific papers that mention a SFT in each of the five classes. Each vertical bar sums to 100% of the papers in that year.

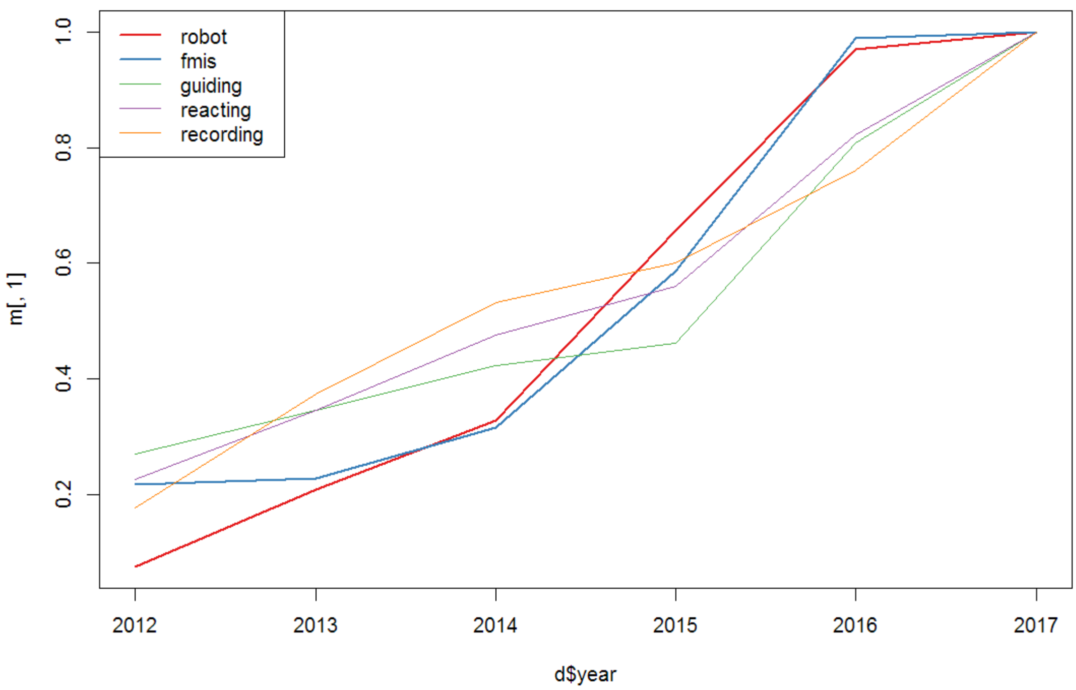


Figure 30. Cumulative fraction of scientific papers during 2012-2017 that mention one of five types of SFT.

4.3 Keywords

The keywords that are most relevant for our SFTs are presented in Figure 31. The keywords for scientific articles are mostly about farming equipment and machinery, the farming practice and agricultural production system. These keywords are very often combined with other keywords, such as plant production and horticulture, fertilisation and nutrients management, water management and soil management and functionality. The other keywords related to farming/forestry competitiveness, biodiversity and nature management, waste by-products and residues management, energy management and climate and climate change were also considered relevant but were chosen in fewer entries.

In the case of research projects equipment and machinery, farming practice and plant production and horticulture are also the keywords that were considered relevant in most cases, however fertilisation and soil- and water management were slightly more important when compared to the entries for scientific articles.

There is variation in the application of SFT over different topics (Figure 32) in research articles. Topics that are recurring and important are the agricultural production system, the farming practice, farming equipment and machinery and plant production and horticulture. Less frequently mentioned topics are climate and climate change, biodiversity, waste by-products and residues management, energy management and farming/forestry competitiveness and diversification.

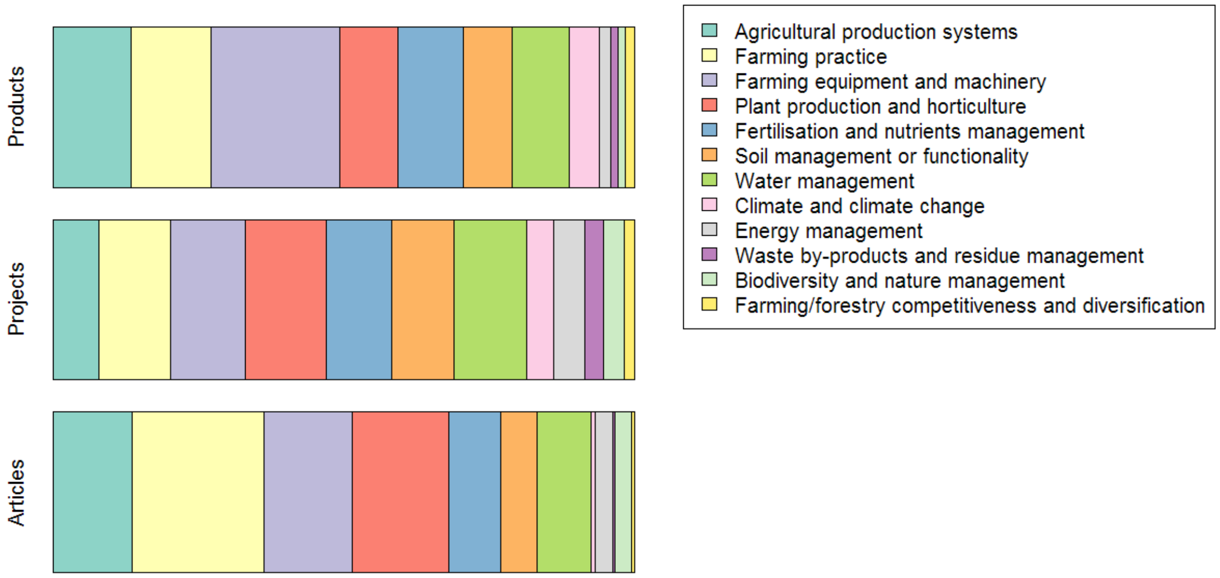


Figure 31. Fraction of SFTs that relate to a certain topic

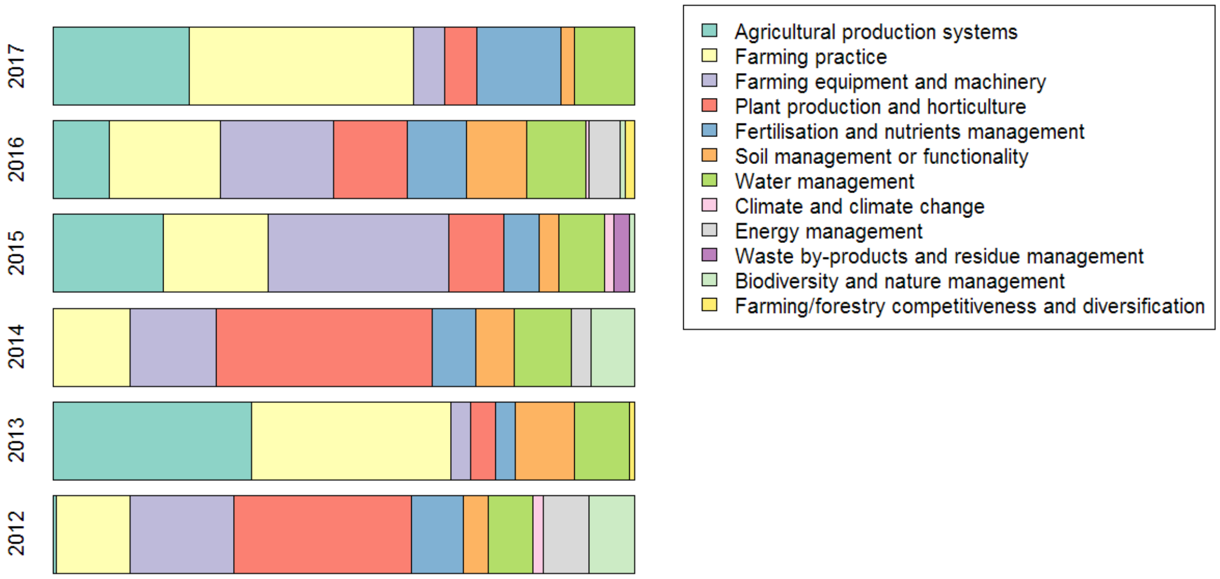


Figure 32. Fraction of scientific articles that mention a topic, per year

4.4 Field operations

The results for different field operations are summarised in Figure 33. In the scientific articles the scouting of crops and/or soil is a very well represented subject. The best represented subject in the case of the projects is fertilisation, which is also a large subject in the scientific articles that have been selected.

The field operation Scouting of crop and/or soil is often chosen simultaneously with other field operations.

In 22% of cases the scouting of crops and/or soil was the only chosen field operation. Scouting of crops and soils was most often chosen together with fertilisation.

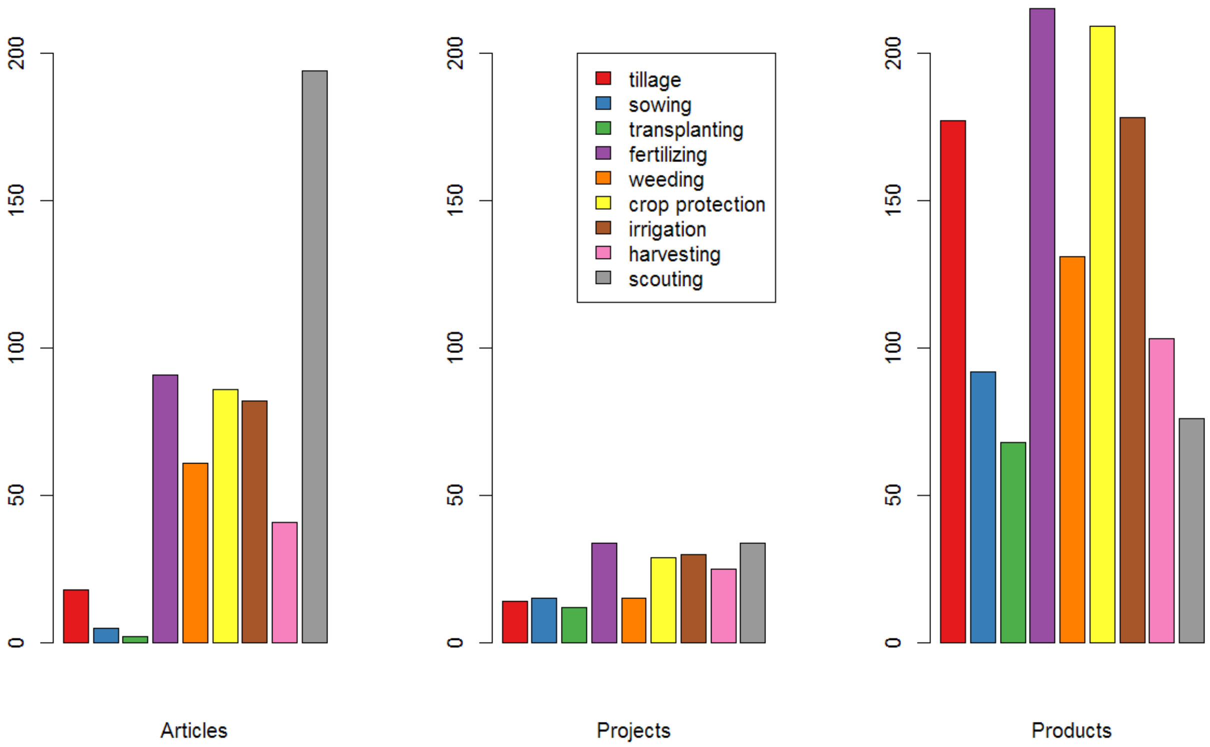


Figure 33 Number of SFTs in each catetory that address a certain kind of field operation.

4.5 Applicable to regions

Apart from different types of SFT we also found many variations in the applicability of SFTs. Most of the SFTs are applicable to the entire area of Europe. In the case of the scientific articles and research projects no specific regions were entered.

4.6 Factors that can be expected to affect adoption of SFTs

Seven statements on the application of the SFT could be filled in by level of agreement.

The results for articles are shown in Figure 34, for projects in Figure 35, and for products in Figure 36. 40% of the scientific article entries replace an already existing technology. Mostly, this does not require major changes to the existing system. The question on the amount of learning that is required before a farmer can use the SFT is answered mostly with disagreement, meaning that often significant learning is required. In many situations there is more than one application to a SFT and the effects of the SFT can be observed directly by the farmer. SFTs do not often require large time investments from the farmer and the information that is being produced can be observed directly.

80% of the research project SFTs replace an existing tool or technology. In most cases no major changes to the existing system are required. Many SFTs require significant learning before it can be used by a farmer. SFTs have multiple effects that can be directly observed by the farmer. In most cases no large time investments are required from farmers in order to get familiar with SFTs. SFTs often produce information that can be used directly.

Regarding industrial products, 73% of them replace an existing tool/method, while they do not require major changes for the common practice (80%) or extra learning on behaf of the end-users (76%). In addition, the commercial SFTs's effects in everyday agricultural practices are evident in many cases (62%), while the information derived by them can be interpreted to something useful in a high extent (75%).

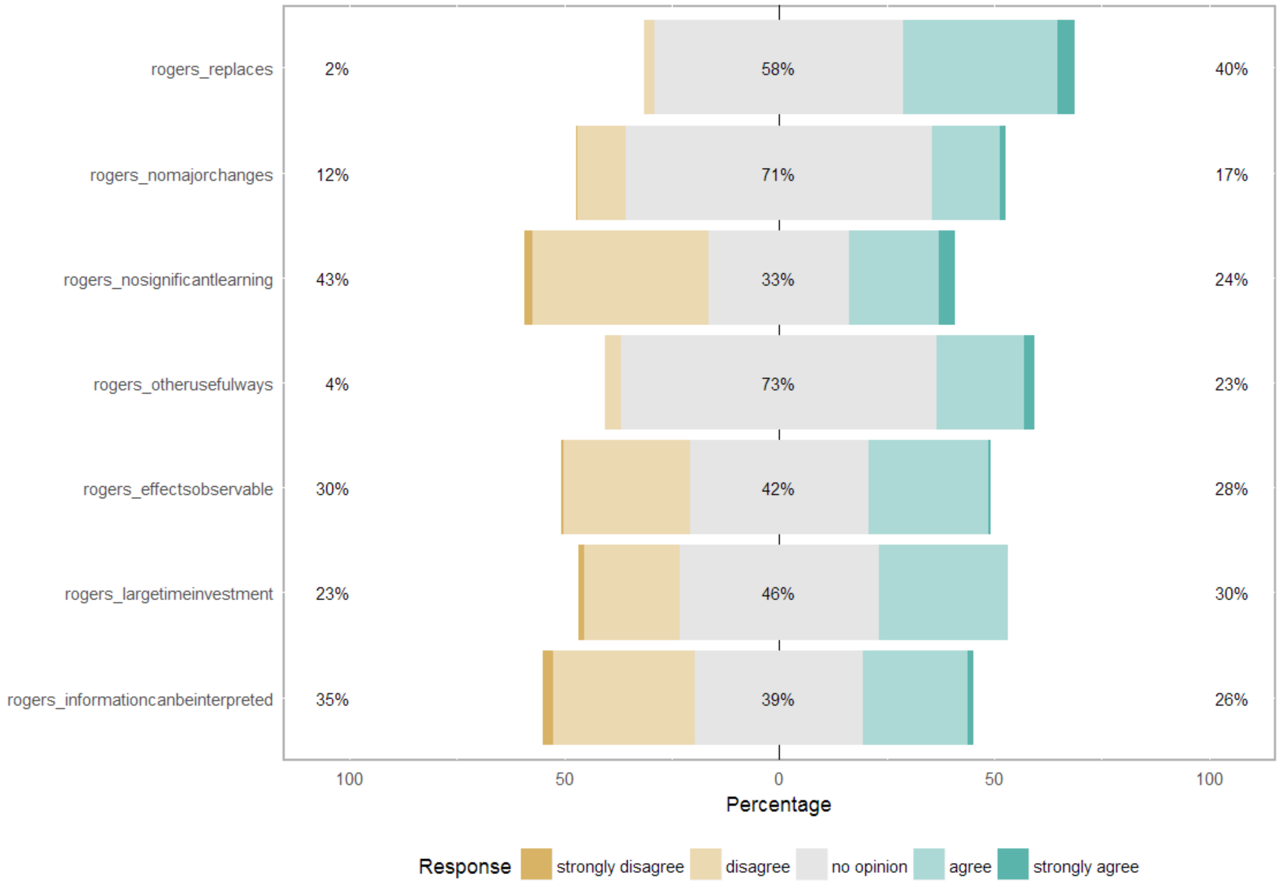


Figure 34. Responses regarding adoption of SFTs in articles.

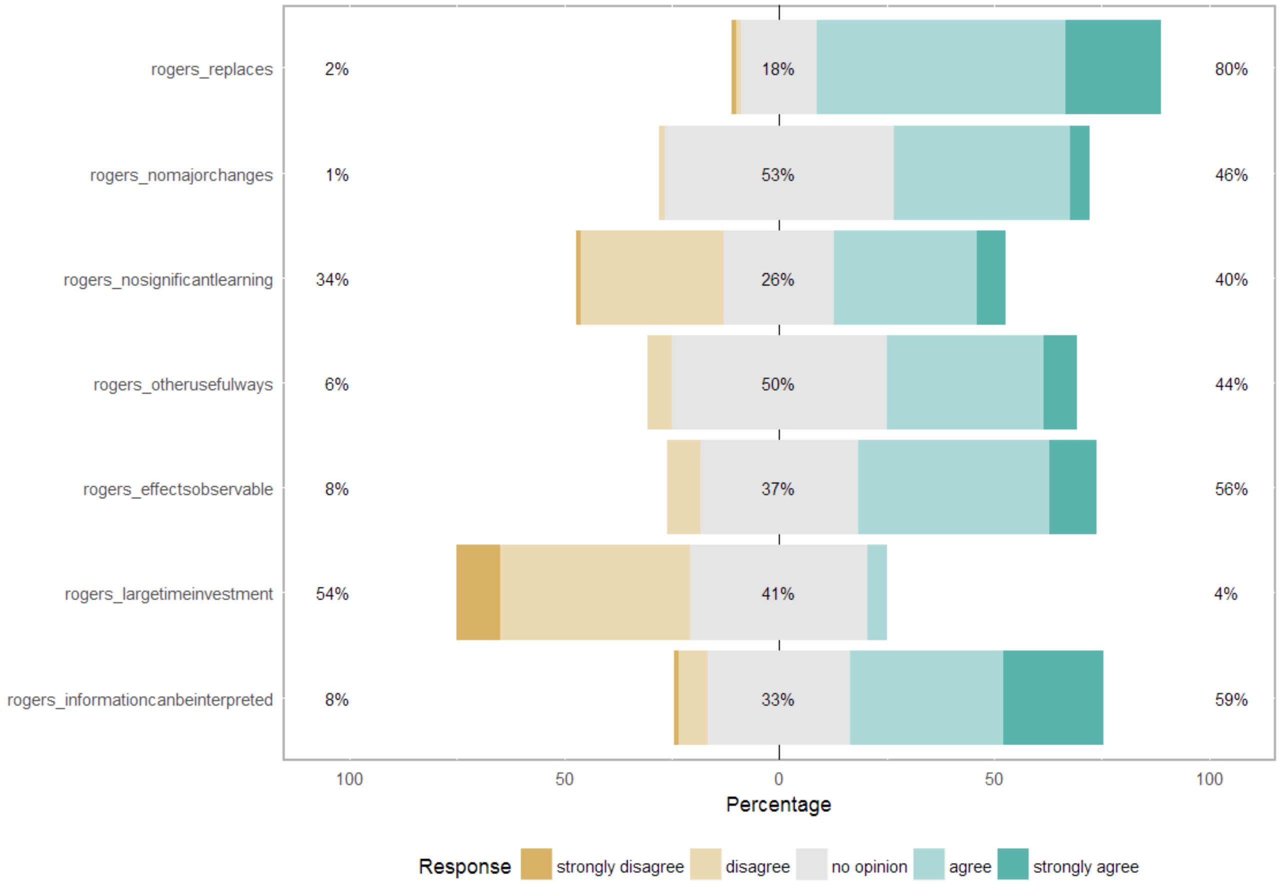


Figure 35. Responses regarding adoption of SFTs in projects.

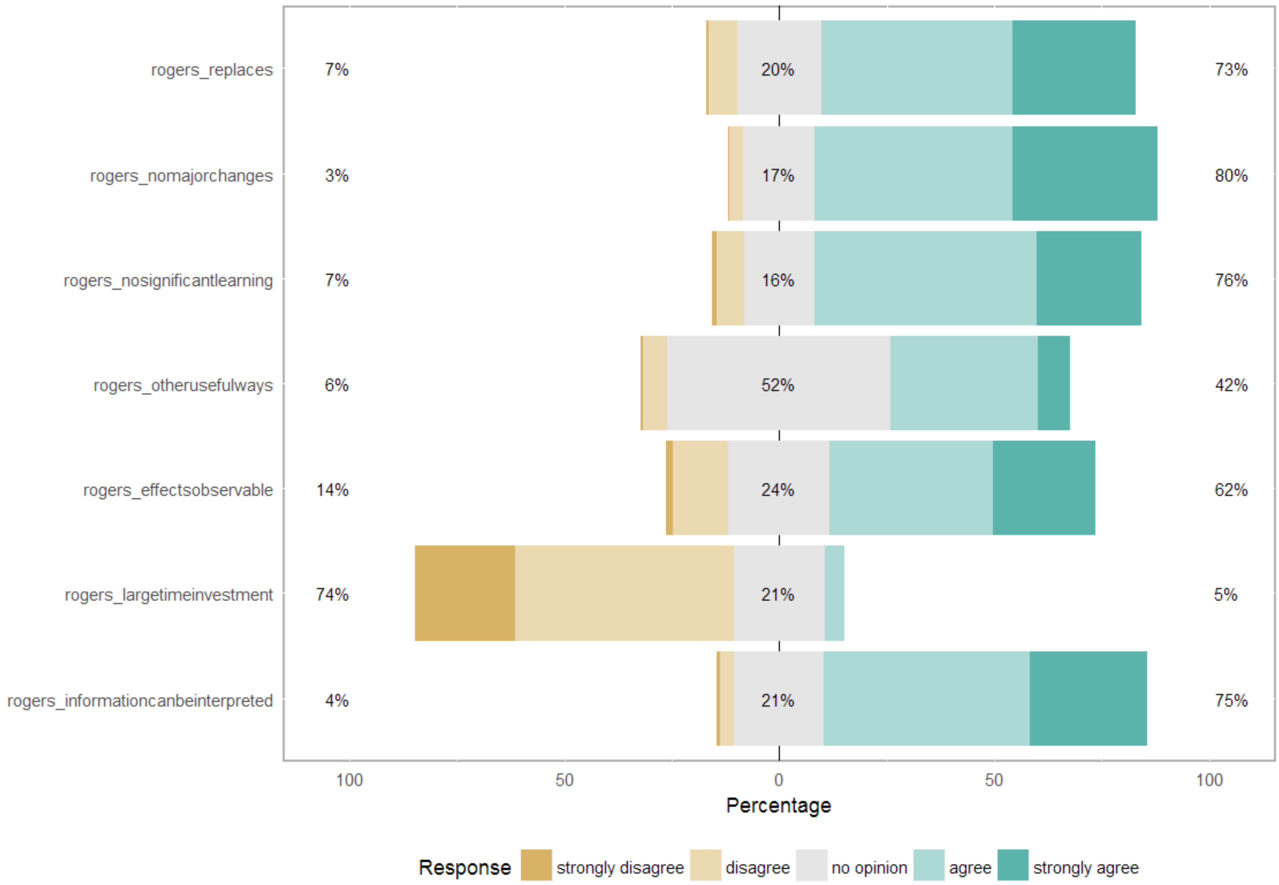


Figure 36. Responses regarding adoption of SFTs in products.

4.7 Effects on profitability and sustainability

The effects on 26 different agronomic aspects for the scientific articles are presented in Figure 37. Many of the selected scientific articles show decreased negative effects and increased positive effects. Increases are expected in productivity and quality of products. Article entries indicate an increase in revenue and productivity. Although smaller, an increase is also expected in quality soil biodiversity and biodiversity. Large decreases are expected in the amount of labour time and energy use. The use of inputs such as irrigation water and pesticide and fertiliser use can be reduced by smart farming. The expected reduction in emissions is small.

In the case of the research projects (Figure 38) increases are also expected in productivity and quality of products. The articles indicated an increase in revenues, profits and/or farm income and opportunities for an increase in (soil) biodiversity could be seen. Strong decreases are expected in variable- and input costs and the use of fertiliser, pesticides and irrigation water. Smart farming technology could also lead to strong reduction in post-harvest crop wastage and energy use. In around one fifth of the cases a reduction in emissions was expected.

Effects in products are shown in Figure 39. It is interesting to see that productivity and revenue (directly connected to each other) are influenced in a high extend (80%) and they are followed by quality of products (72%) that are crucial for EU consumers. Input costs follow with 21%, showing that SFTs are directed to increasing production with lower input. Finally, an increase in (soil) biodiversity can be identified, as rational input use has a significant positive impact in environmental protection and biodiversity increase. Comercial SFTs also provide low but not negligible impact on energy use, fertilizers and pesticides use and und-user stress and labour pressure.

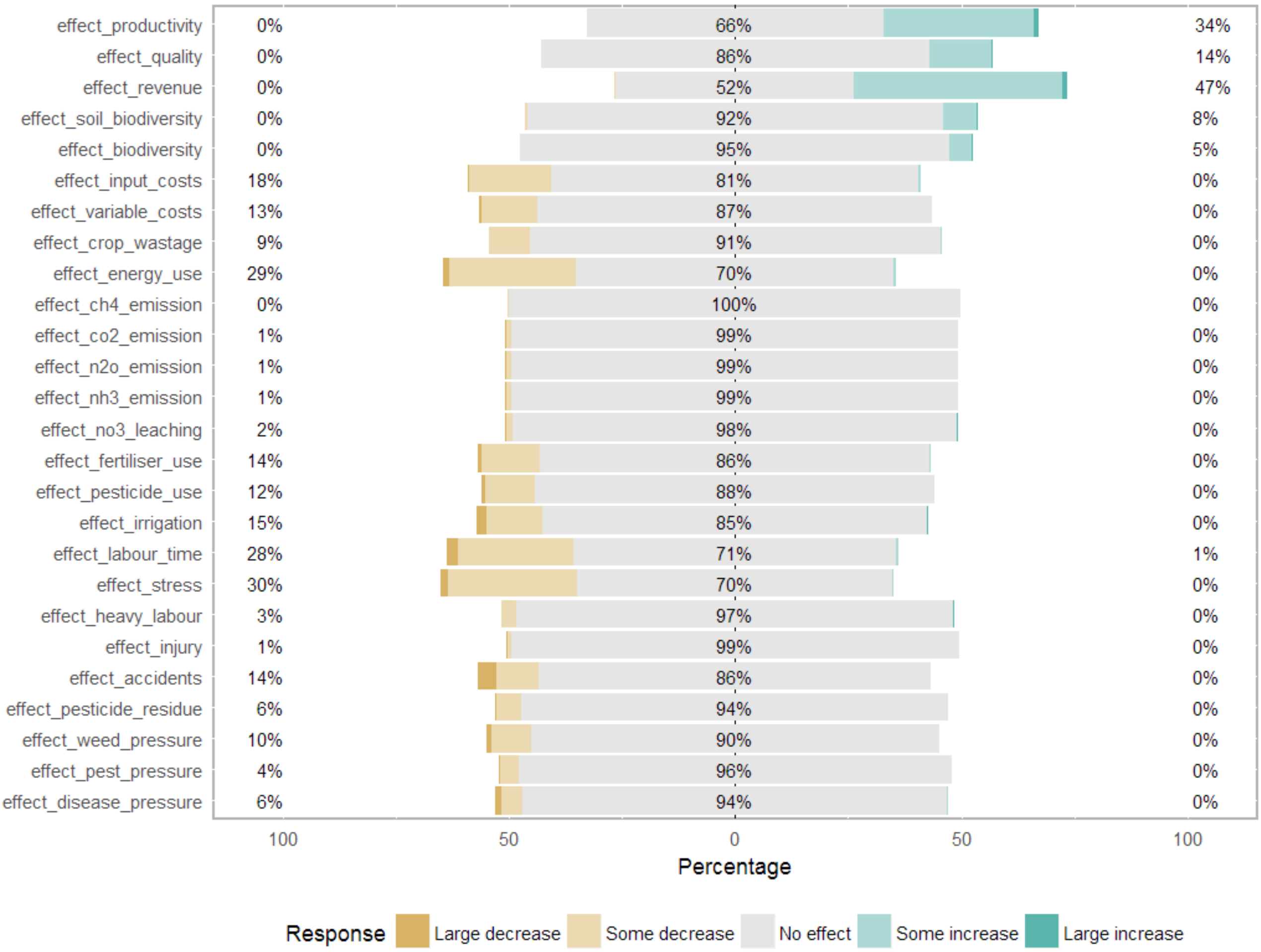


Figure 37: Effects in scientific articles

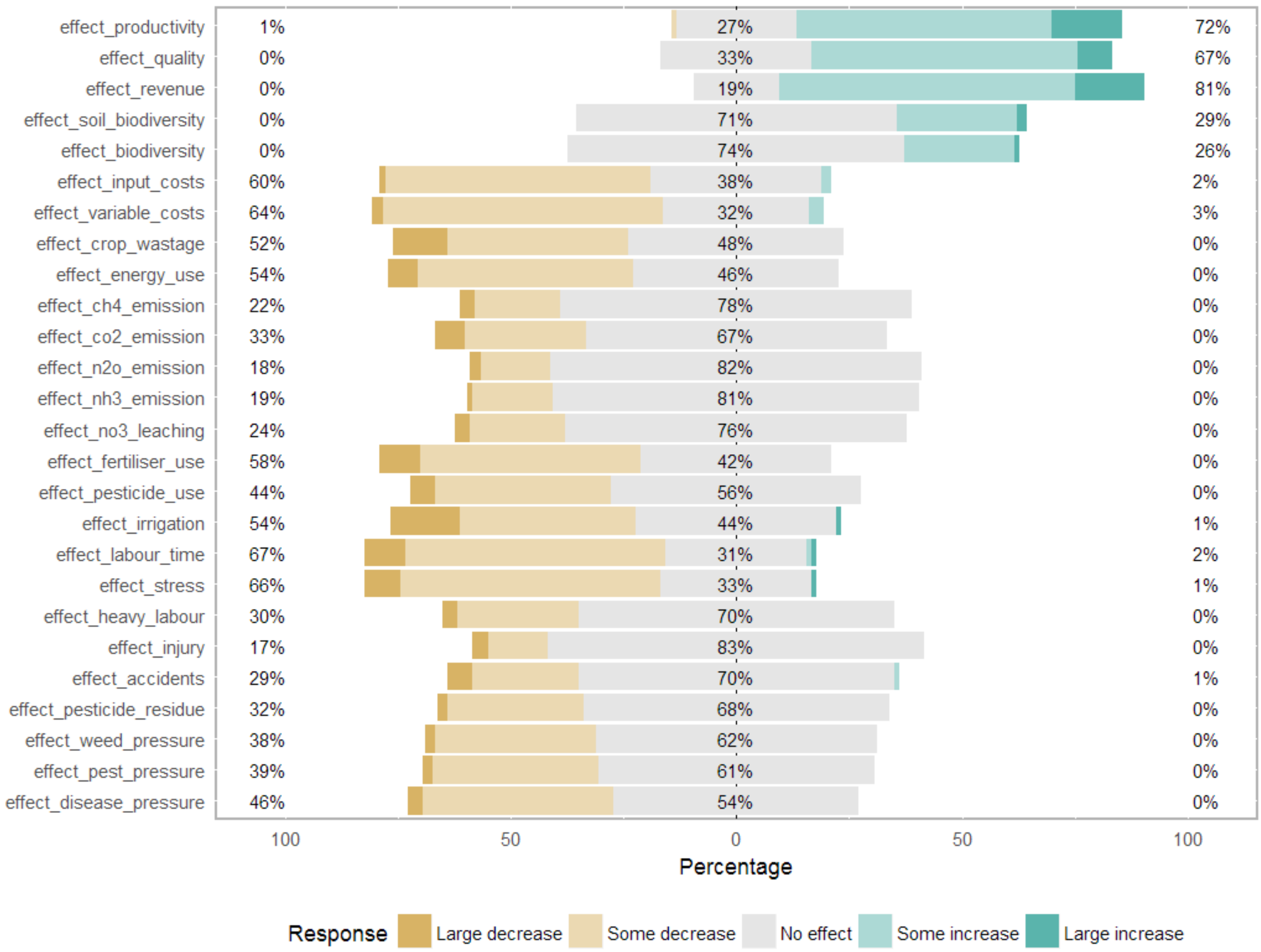


Figure 38: Effects in research projects

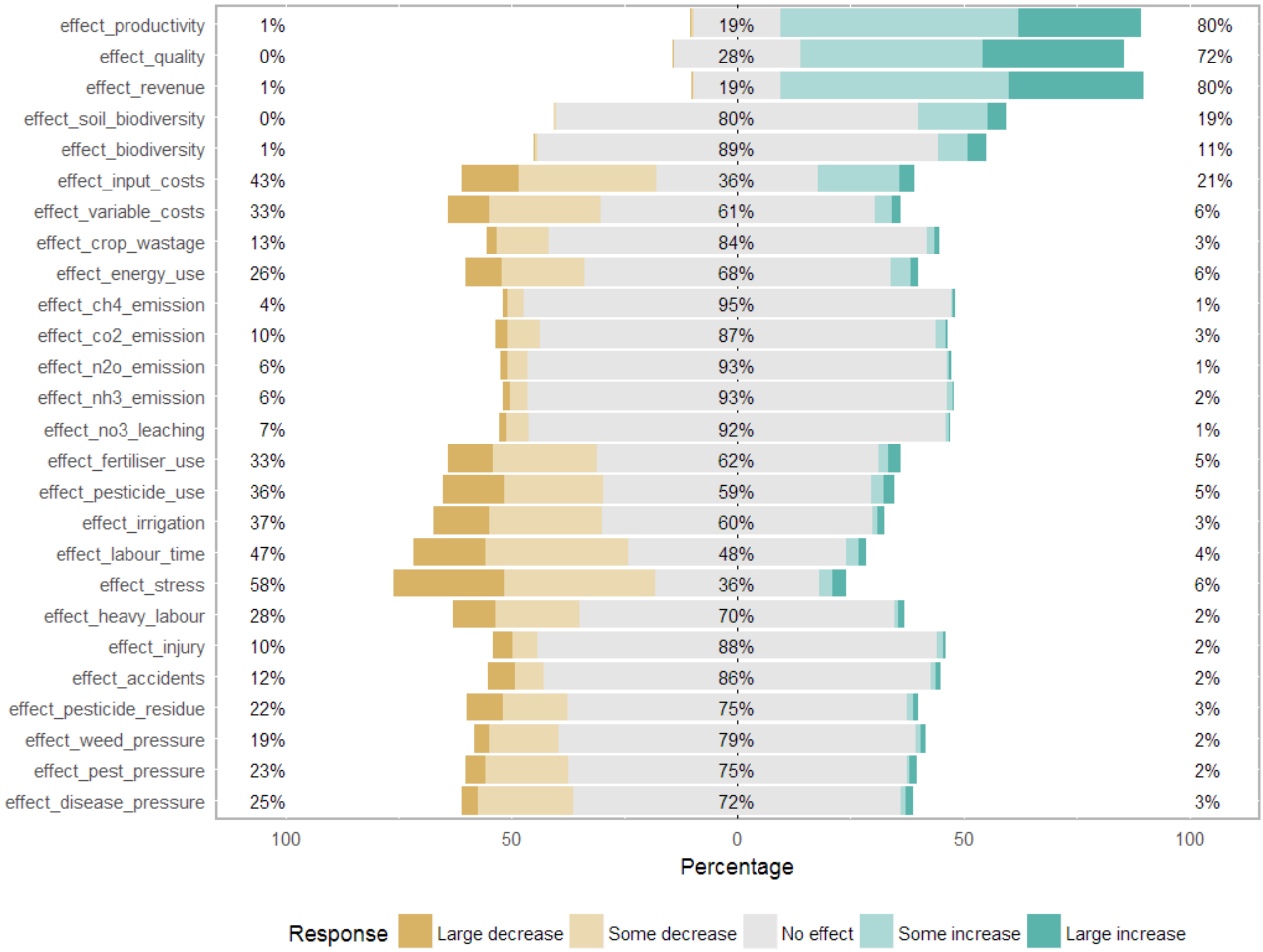


Figure 39: Effects in products

4.8 Farm size

There was no large variation in farm-size found (Table 10), most SFTs are reliant on very small or very large farms. In the case of scientific articles, more work was found to be preferably applied in somewhat smaller farmsizes, probably due to experimantal plot sizes. However, articles and prjects on average refered to all sizes, while commercial products were mainly directed to larger farms, something that have been reported earlier (Balafoutis et al., 2017, Lawson et al., 2011, Polling et al., 2010)

Table 10. Farm size.

Farm size (ha)	Articles	Projects	Products

<2	302	68	239
2-10	306	73	293
11-50	320	77	370
51-100	455	74	388
101-200	345	69	390
201-500	272	68	389
500>	253	65	390

4.9 Users

The users of SFTs are mostly expected to be farmers or contractors (Figure 40), this category includes advising stakeholders, like consultants. Suppliers are next in the list. Very few of the selected SFTs are expected to be used by buyers of farm products and processors of farm products.

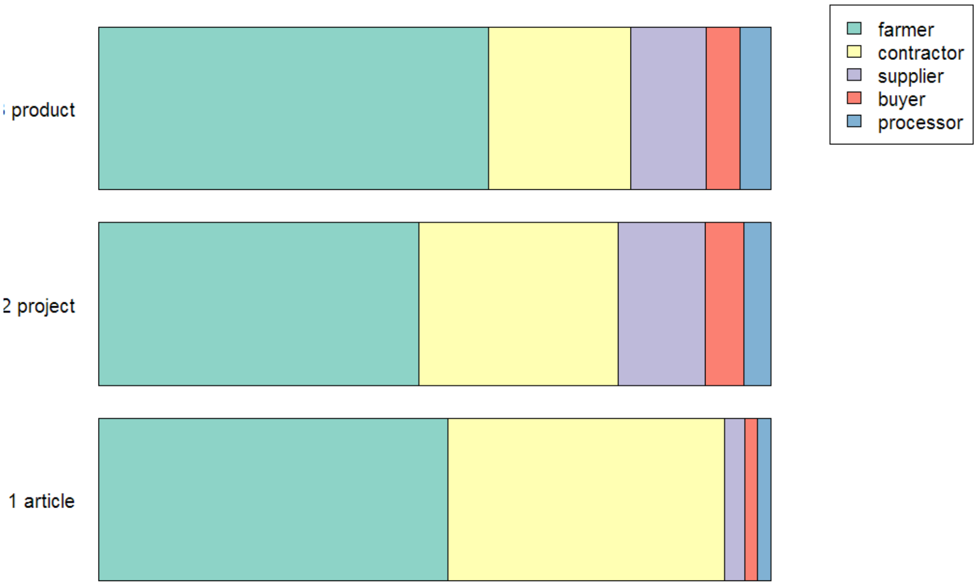


Figure 40. Users of SFTs.

4.10 Correlation matrix

We searched for correlations between survey questions by computing a correlation matrix (

Figure ***41***). The matrix shows some correlations between questions that are related by nature. For example, there is a positive correlation between "This SFT reduces variable costs" and "This SFT reduces input costs" which is unsurprising because input costs are a form of variable costs. Similarly, if a particular SFT works on farms between 51 and 100 ha it very likely will also be suitable for farms between 101 and 200 ha in size. In summary, the correlation matrix revealed no interesting information.

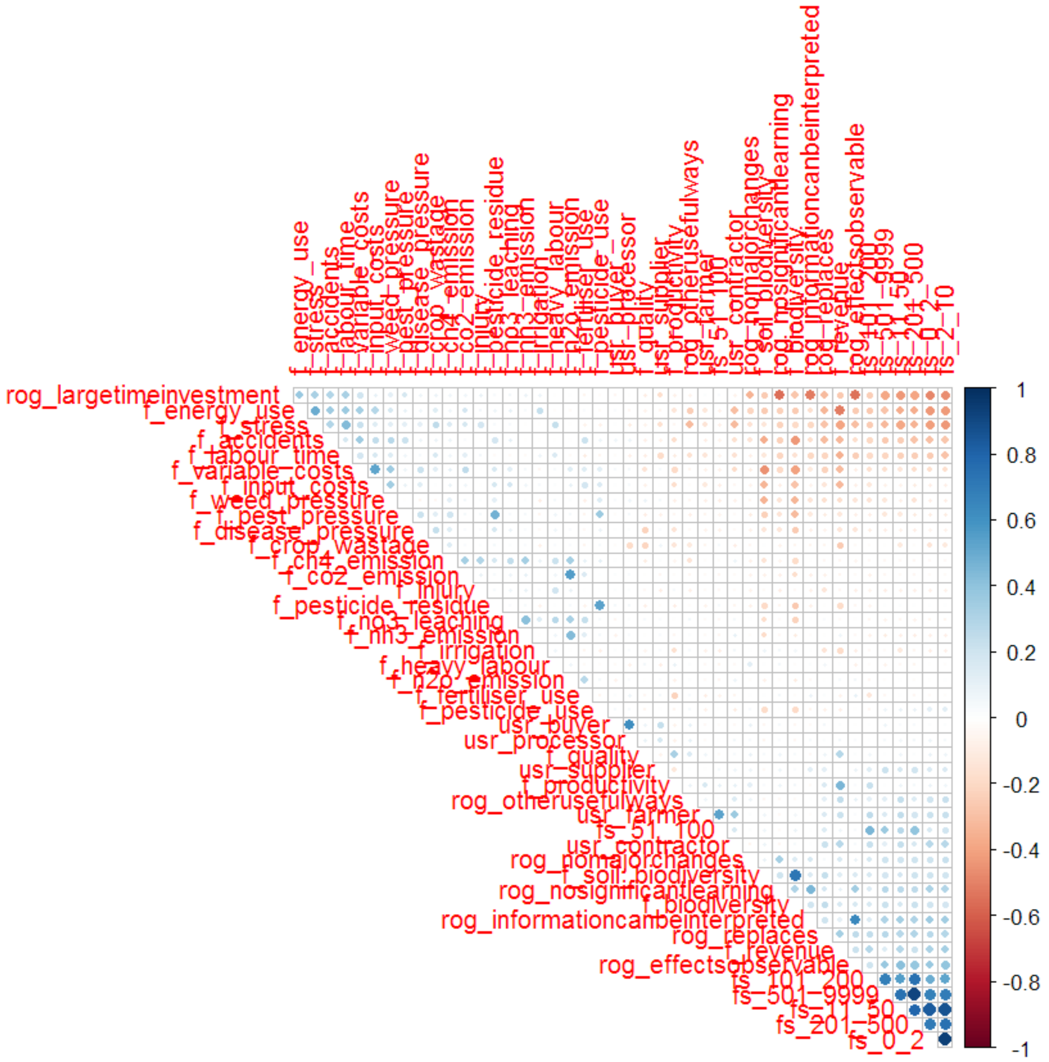


Figure 41. Correlation matrix for questions about SFTs.

4.11 PCA for effects

We investigated whether there is structure in the effects of SFTs. Effects were addressed in the survey with statements such as “The SFT has the following effect on productivity”, with possible responses “Large decrease”, “Some decrease”, “No effect”, “Some increase” and “Large increase”. We coded these responses numerically as 1-5 (if no response was given, this was re-coded to “No effect” = 3). This made it possible to run a Principal Components Analysis (PCA).

When all SFTs are taken together, the PCA is not very successful: the first two components explain only 41% of the variation (Table 11). If we take this in stride, then the biplot (Figure 42) shows that there are three groups of effects: a group mostly related to productivity, a group containing emissions (NO_3, CO_2, N_2O, CH_4, NH_3), and a group containing all other effects.

When the analysis is done just for articles or projects, the PCA is even less successful (

Figure ***43*** and Figure 44). For products, a somewhat better result is obtained, moreover the outcome (shown Figure 45) is roughly the same as for all SFTs together. Thus it seems that the grouping of effects is caused in large part by the products but holds for the other categories.

Table 11. Result of PCA for effects (all SFTs) (first six PCs only)

	PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**
Standard deviation	2.7559	1.745	1.4665	1.27656	1.2375	1.11624
Proportion of variance	0.2921	0.1171	0.08272	0.06268	0.0589	0.04792
Cumulative proportion	0.2921	0.4092	0.49194	0.55462	0.6135	0.66145

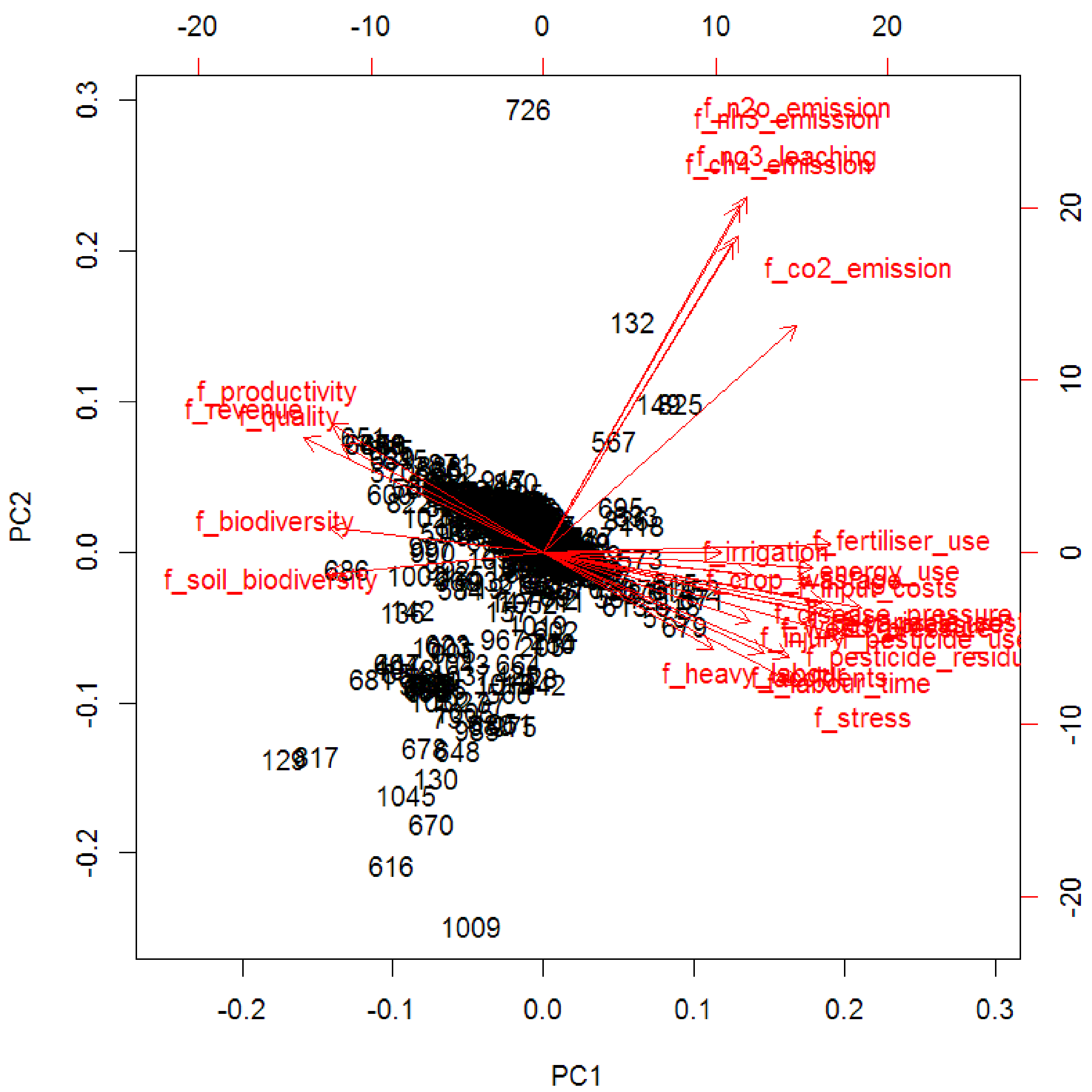


Figure 42. PCA for effects of all SFTs

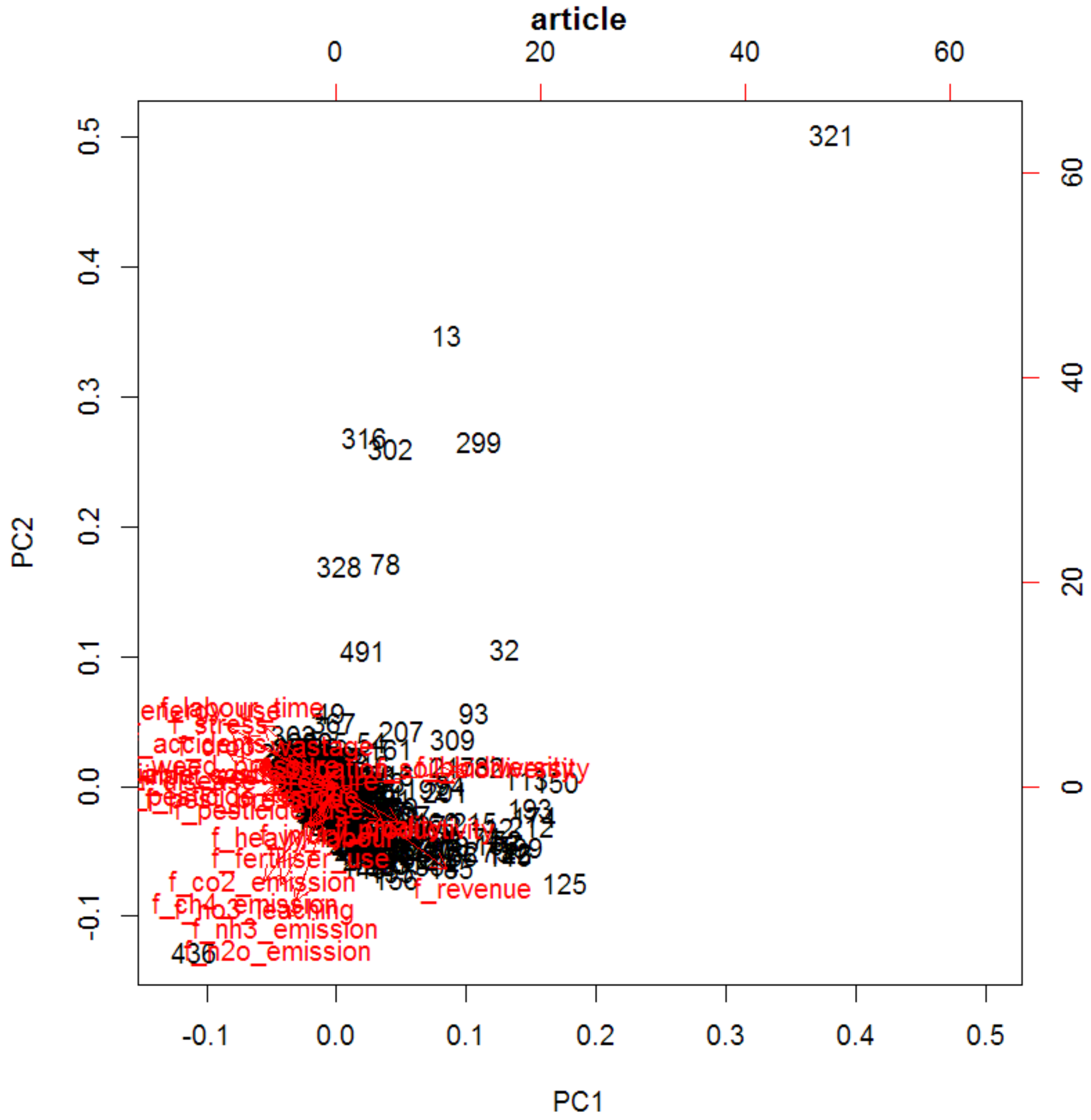


Figure 43. PCA for effects of articles

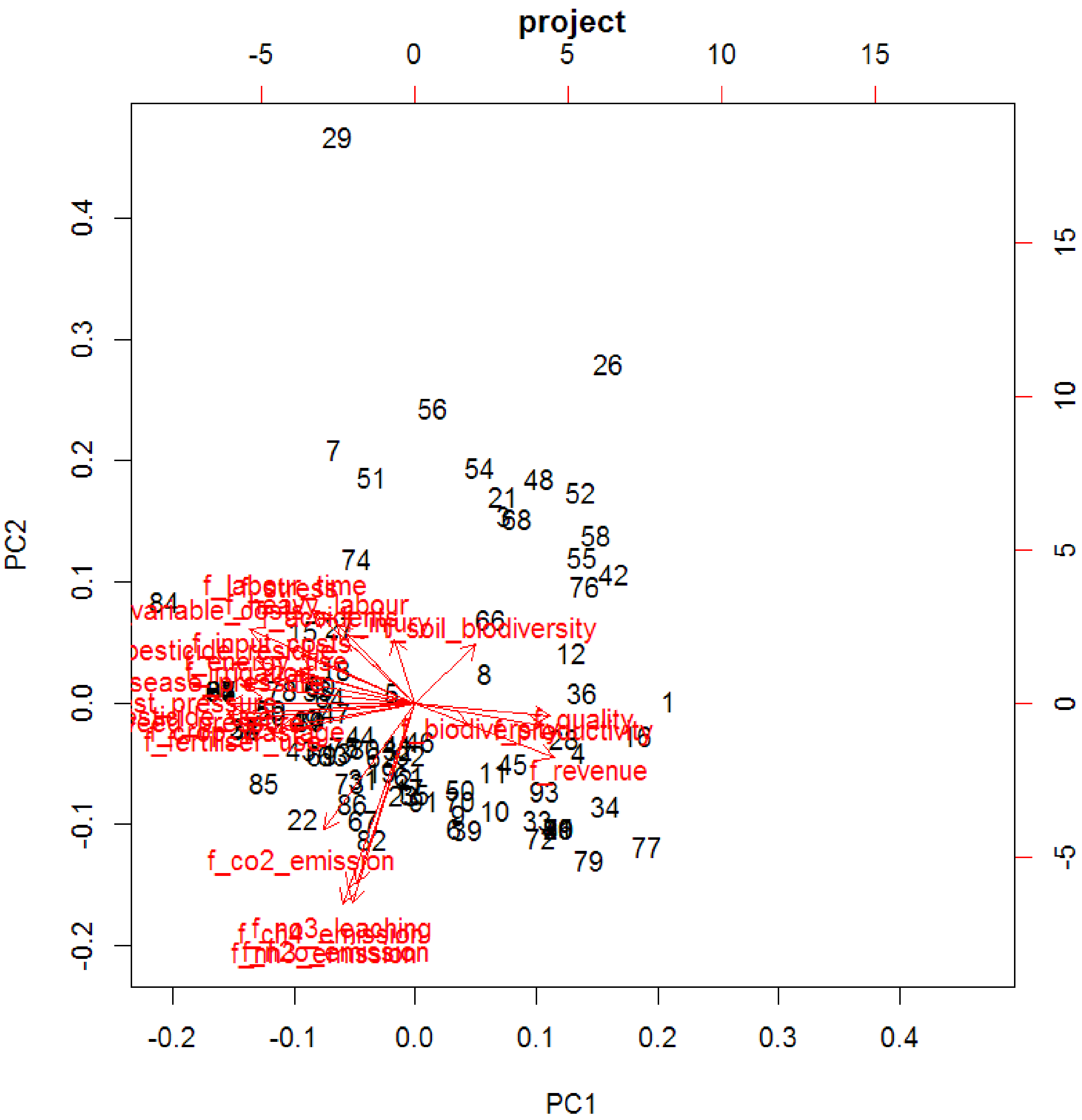


Figure 44. PCA for effects of projects

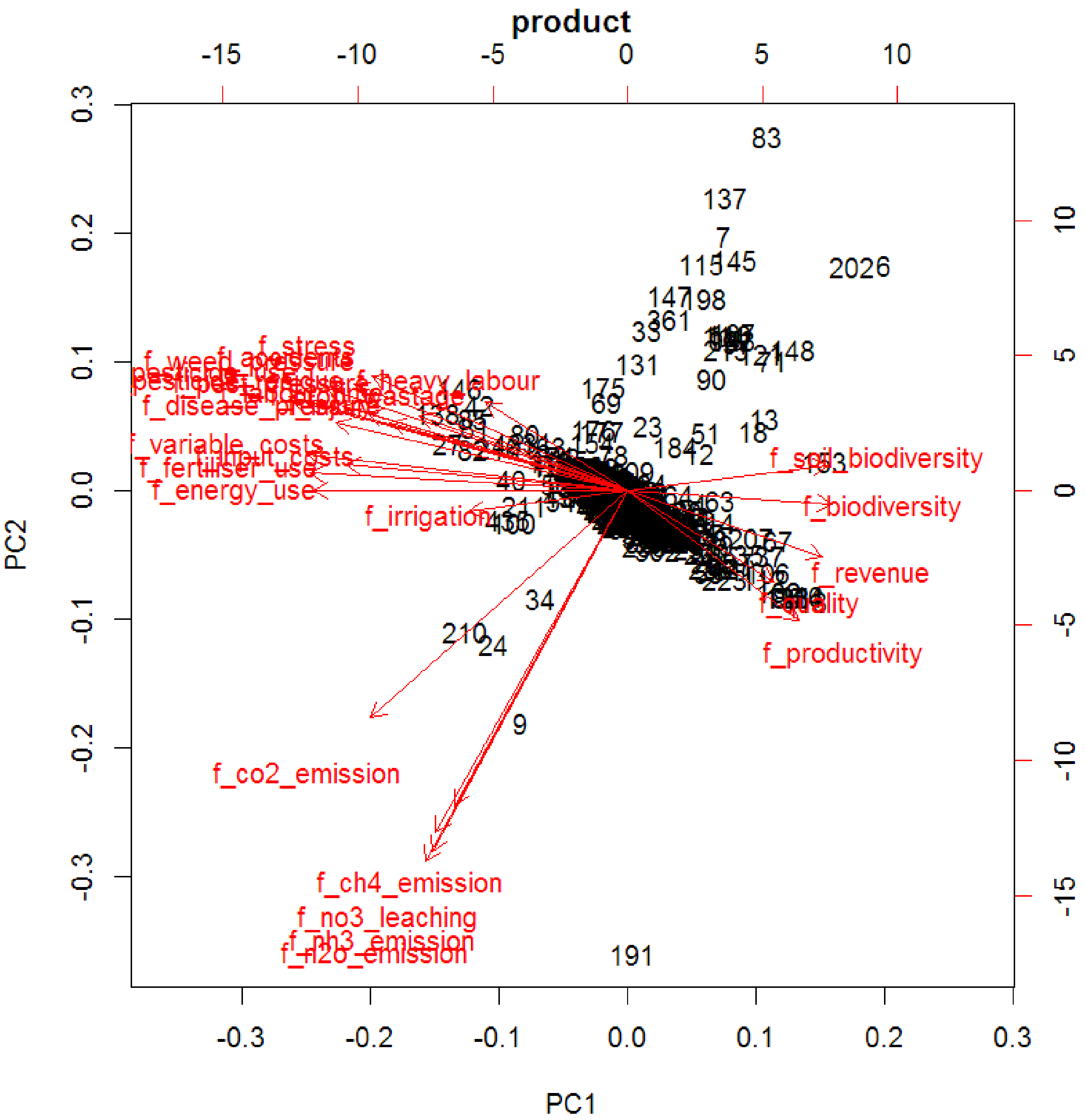


Figure 45. PCA for effects of products

4.12 PCA for questions about adoption

The results of PCA about adoption are shown in Table 12 and Figure 46.

Table 12. Result of PCA for Rogers (all SFTs) (first three PCs only)

	PC1	PC2	PC3
Standard deviation	1.8245	1.0084	0.8749
Proportion of variance	0.4755	0.1452	0.1094
Cumulative proportion	0.4755	0.6208	0.7301

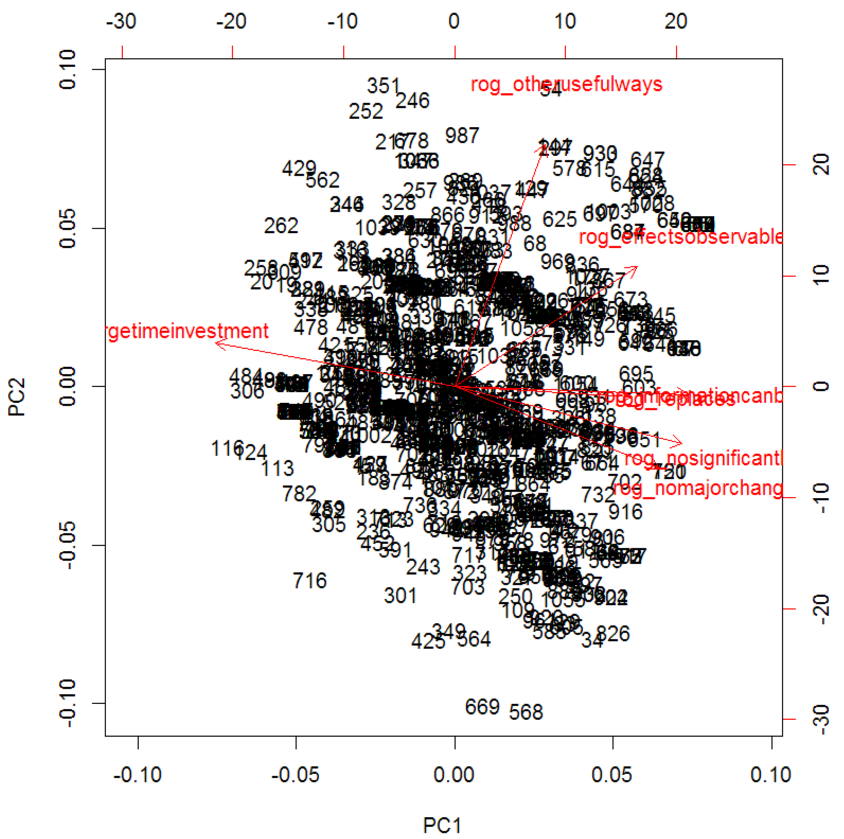


Figure 46. PCA for questions about adoption (all SFTs)

4.13 Effect and ease of adoption

We calculated an aggregated effect for each SFT. We first converted each question about an effect to a numerical score as follows:

score =	-2	when	'Large decrease'
	-1		'Some decrease'
	0		'No effect
	1		'Some increase'
	2		'Large increase'

The scores of the 26 questions were then added, where the negative was taken for those effects where one desires to achieve a decrease (emissions, accidents, and so on).

Similarly we calculated an aggregated effect for the ease with which an SFT might be expected to be adopted. A similar procedure as for effects was followed for the 7 adoption questions. During the aggregation the negative was taken of the question "The SFT requires a large time investment".

The two scores are summarized in Figure 47.

A visual display of the results is given in Figure 48, Figure 49 and Figure 50.

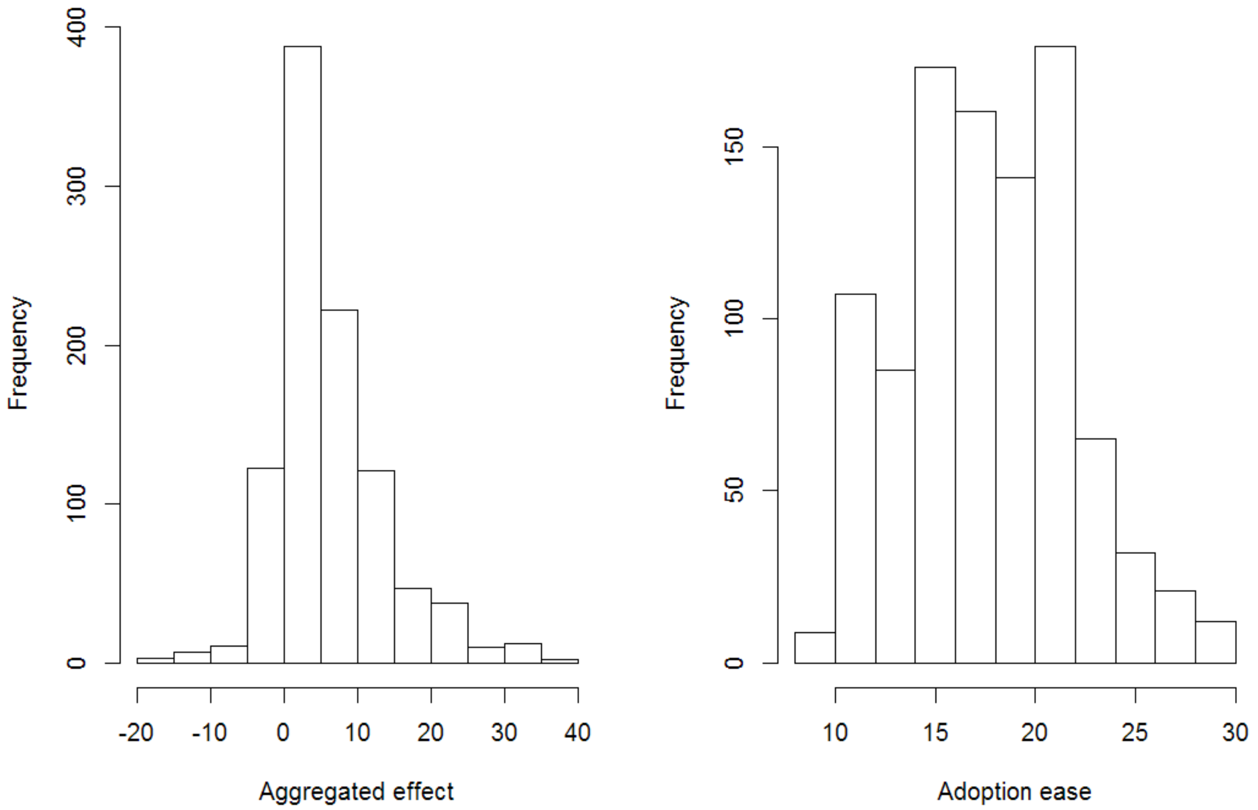


Figure 47. Histogram of aggregated effect and adoption ease scores.

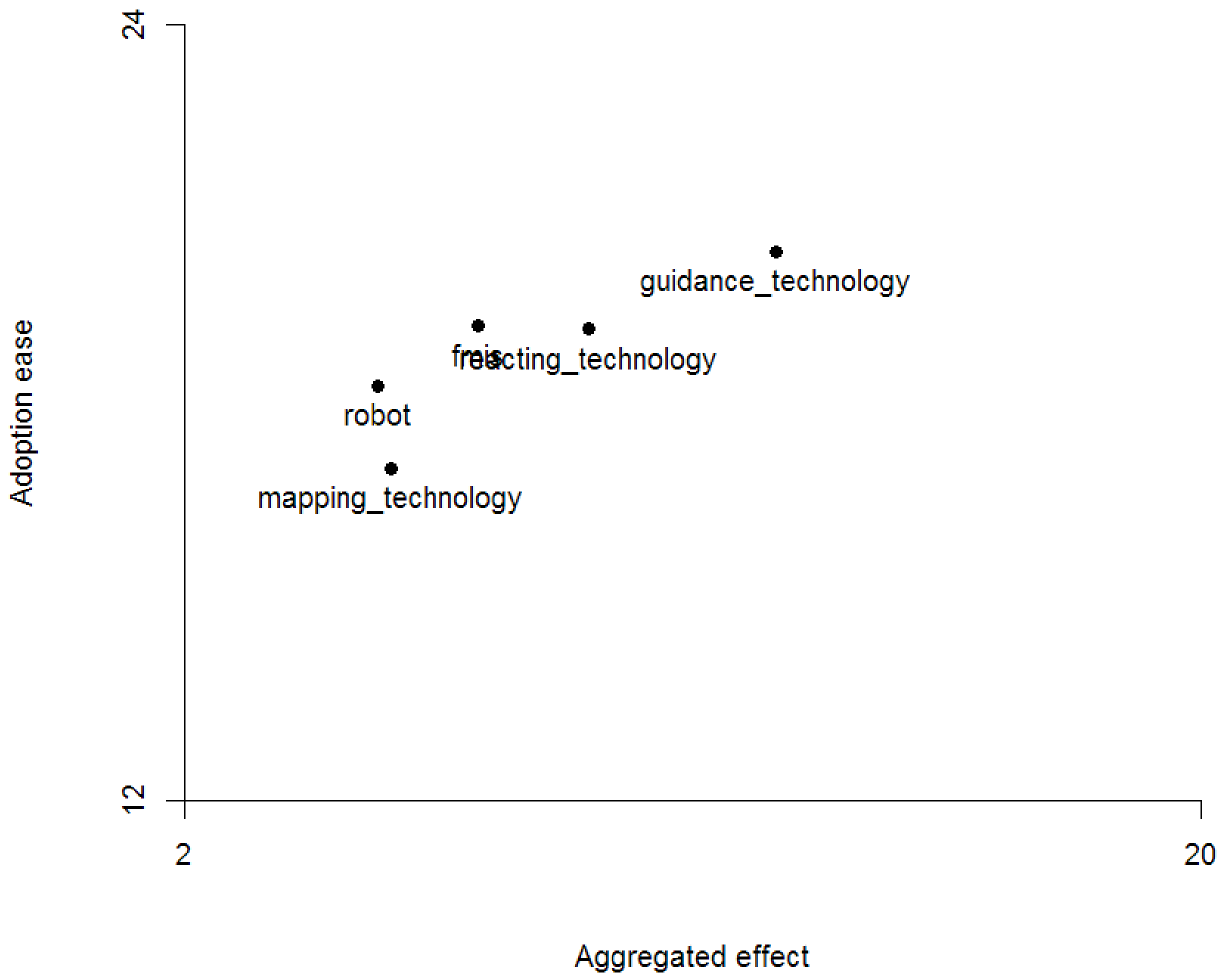


Figure 48. Aggregated effect and ease of adoption for five types of SFT.

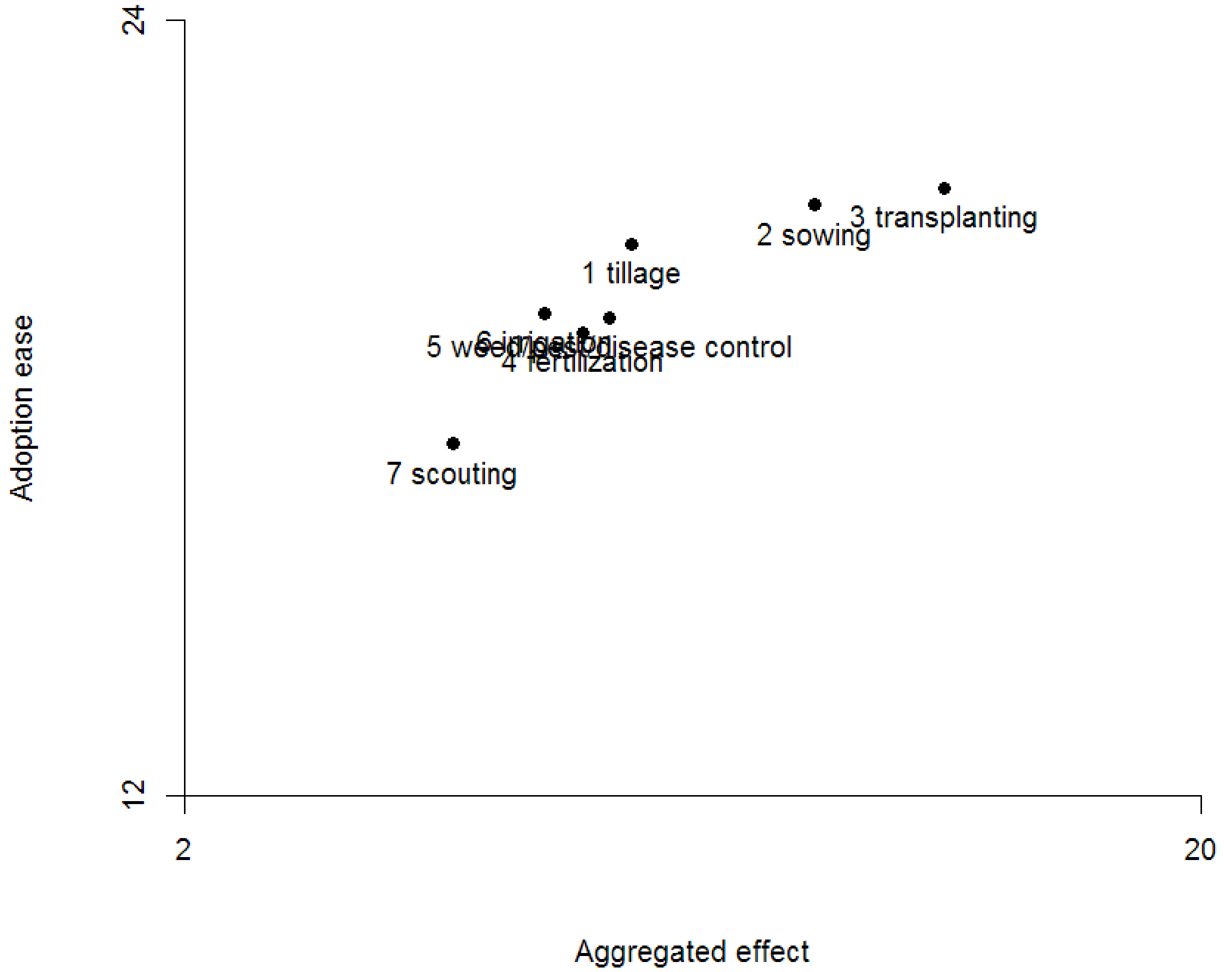


Figure 49. Aggregated effect and ease of adoption for SFTs from articles, projects and products.

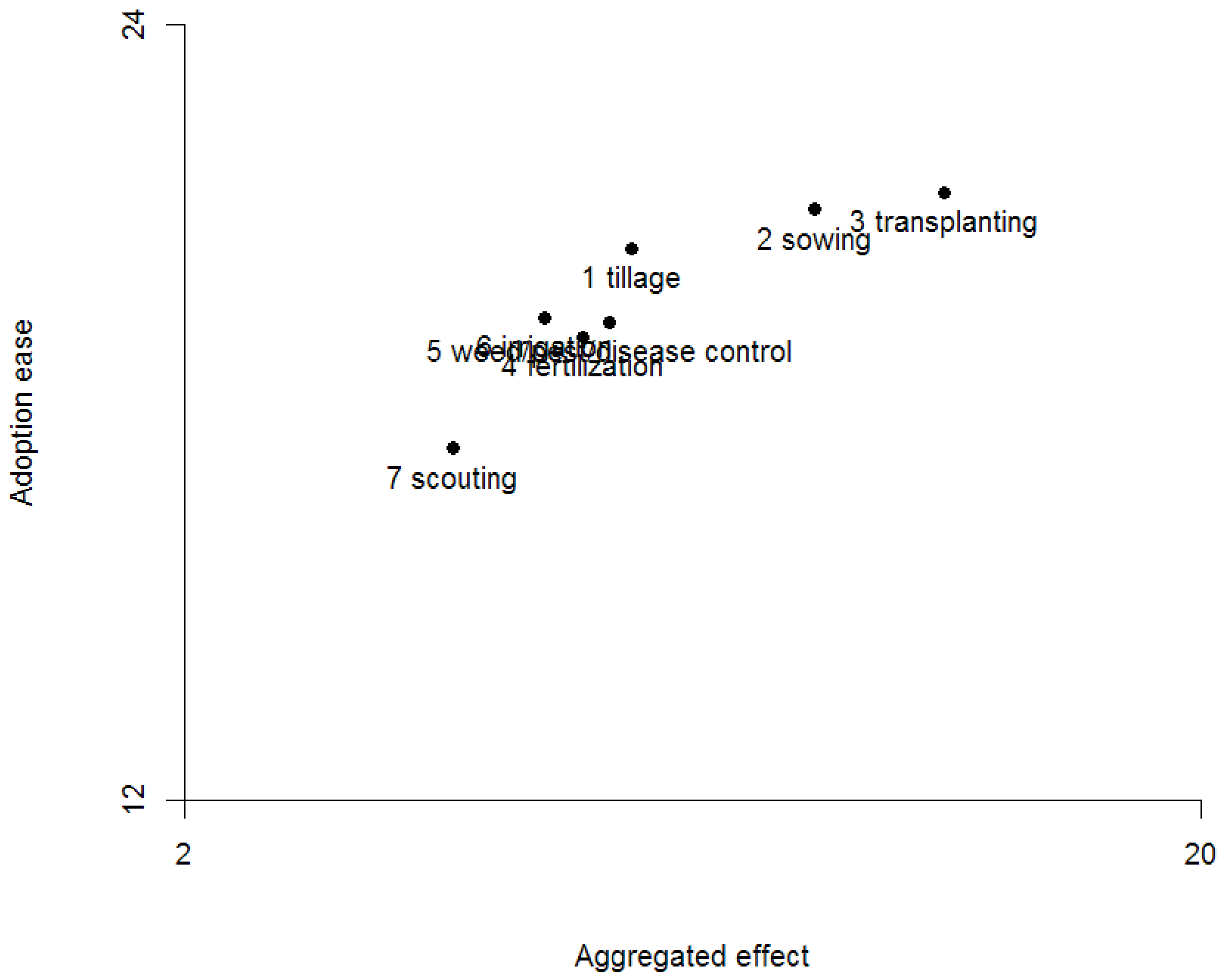


Figure 50. Aggregated effect and ease of adoption for SFTs in production phases.

4.14 Effects on people, planet and profit

We calculated aggregated effects in the three categories People, Planet and Profit that are often used in sustainability studies. The scoring method outlined in Section 4.13 was used to convert qualitative answers to a numeric value. Effects were grouped as indicated in Table 13.

Table 13. The 26 questions of effects were aggregated into the three commonly used categories People, Planet and Profit. A '+' in the table indicates that an SFT increases the indicator if the answer to the question is "Some increase" or "Large increase". A '-' indicates that an SFT increases the indicator if the answer to the question is "Some decrease" or "Large decrease".

	People	Planet	Profit
productivity			+
quality			+
revenue			+
input_costs			-
soil_biodiversity		+	
biodiversity		+	
ch4_emission		-	
co2_emission		-	
n2o_emission		-	
nh3_emission		-	
no3_leaching		-	
fertiliser_use		-	
pesticide_use		-	
irrigation		-	
stress	-		
heavy_labour	-		
injury	-		
pesticide_residue	-		

4.14.1 By type of SFT

The results are shown in Figure 51, Figure 52 and Figure 53.

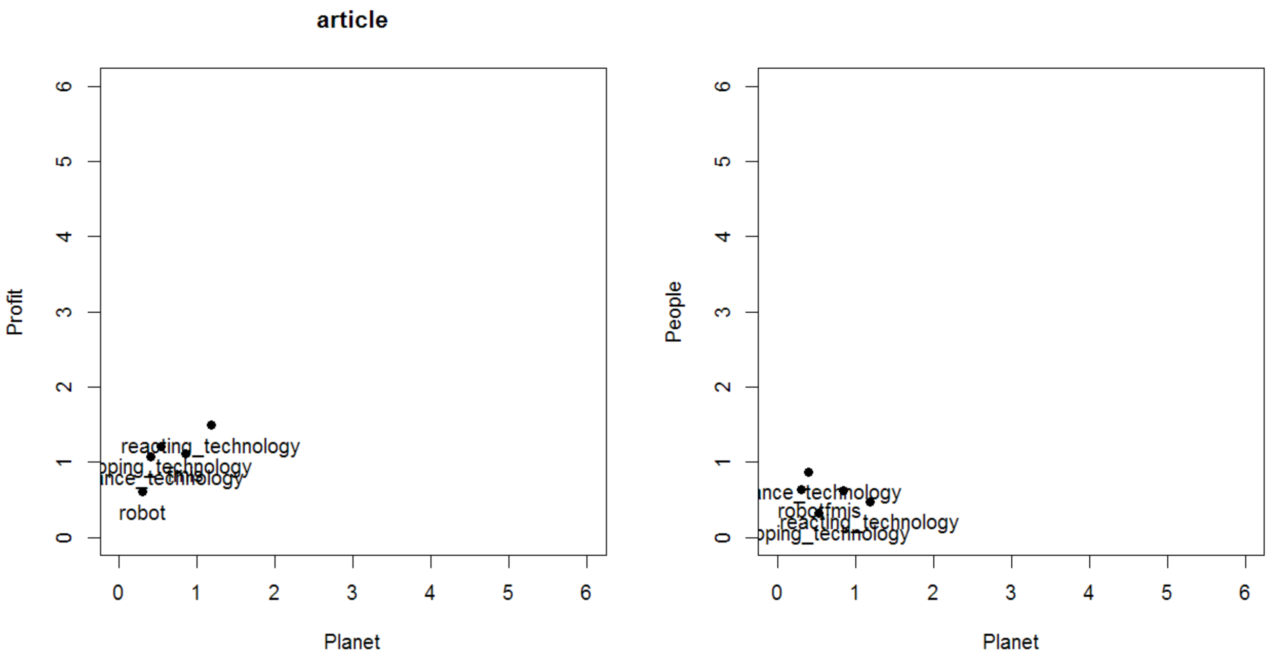


Figure 51. PPP by type of SFT for articles.

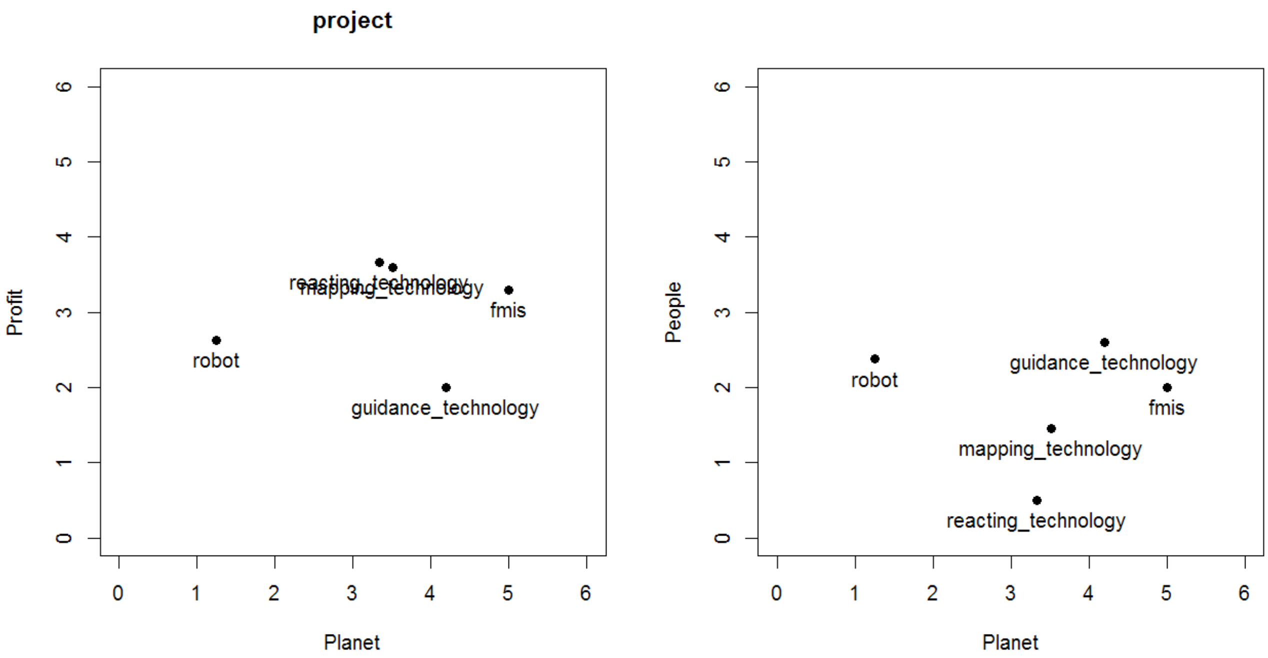


Figure 52. PPP by type of SFT for projects.

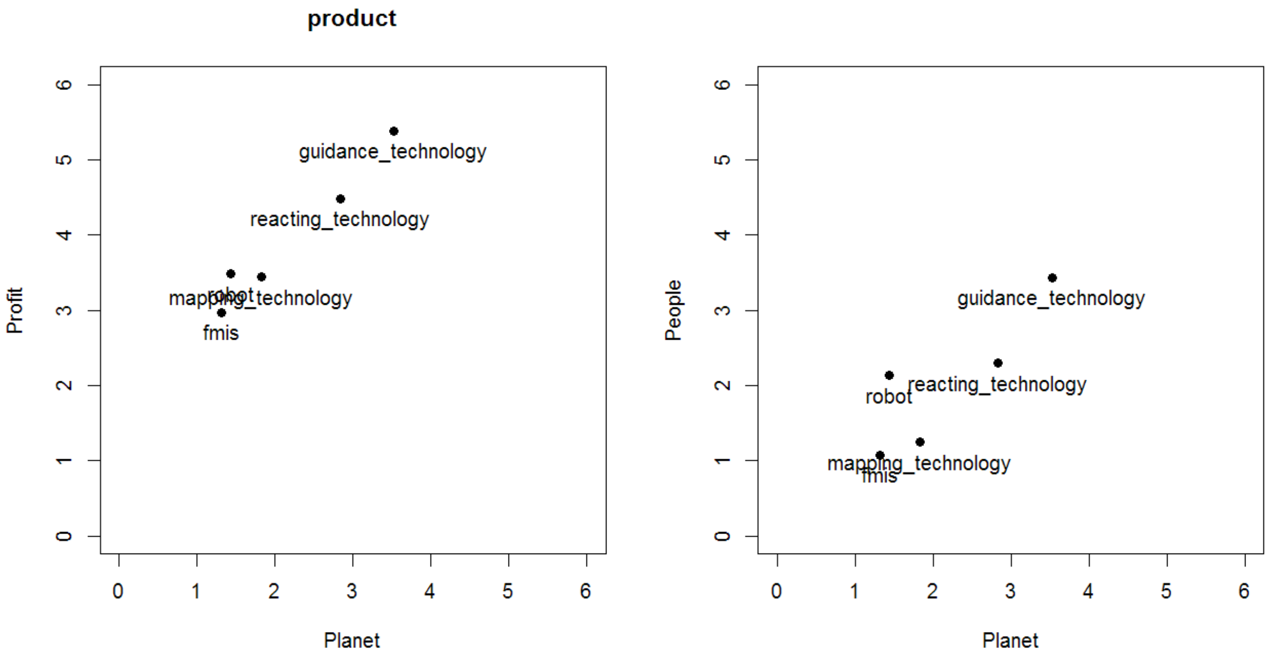


Figure 53. PPP by type of SFT for products.

4.14.2 By type of field operation

The results for PCA by type of field operation are shown in Figure 54, Figure 55 and Figure 56.

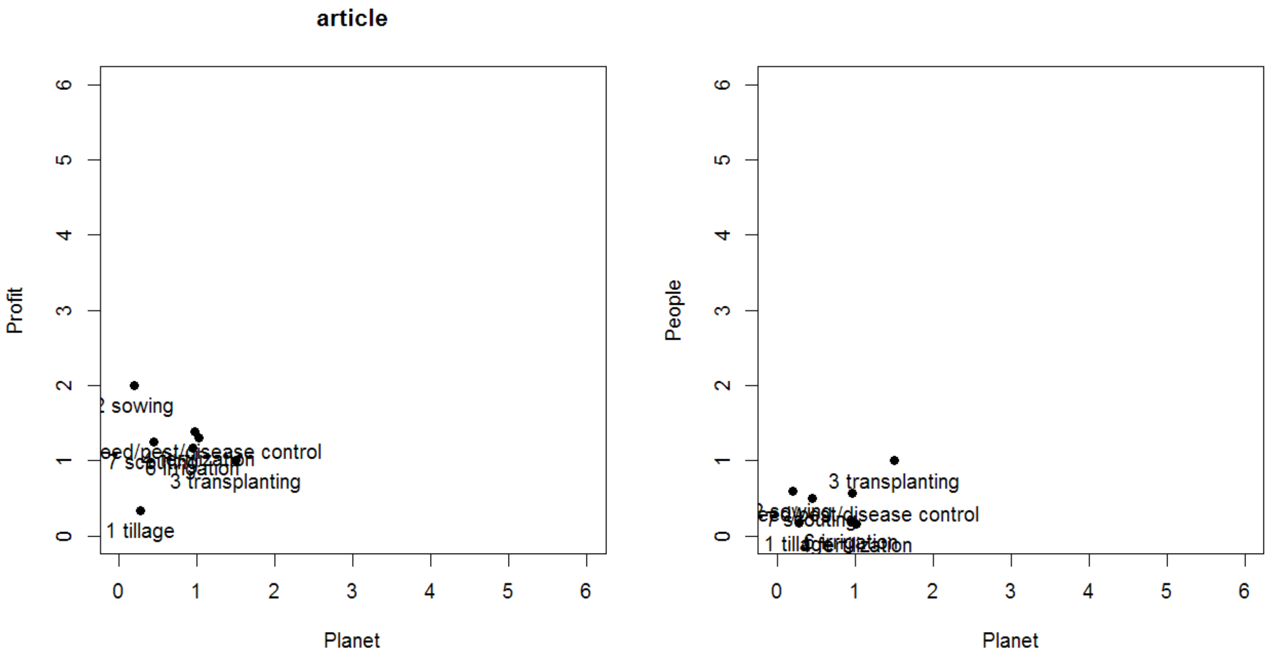


Figure 54. PPP by type of field operation for articles.

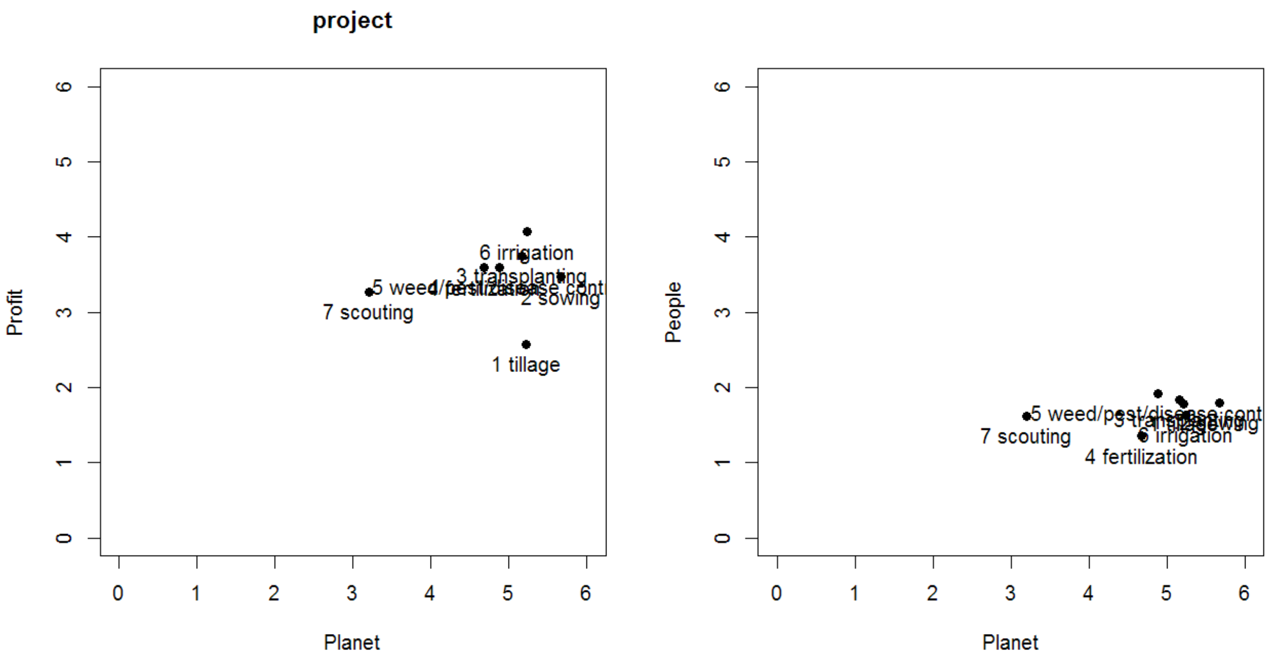


Figure 55. PPP by type of field operation for projects.

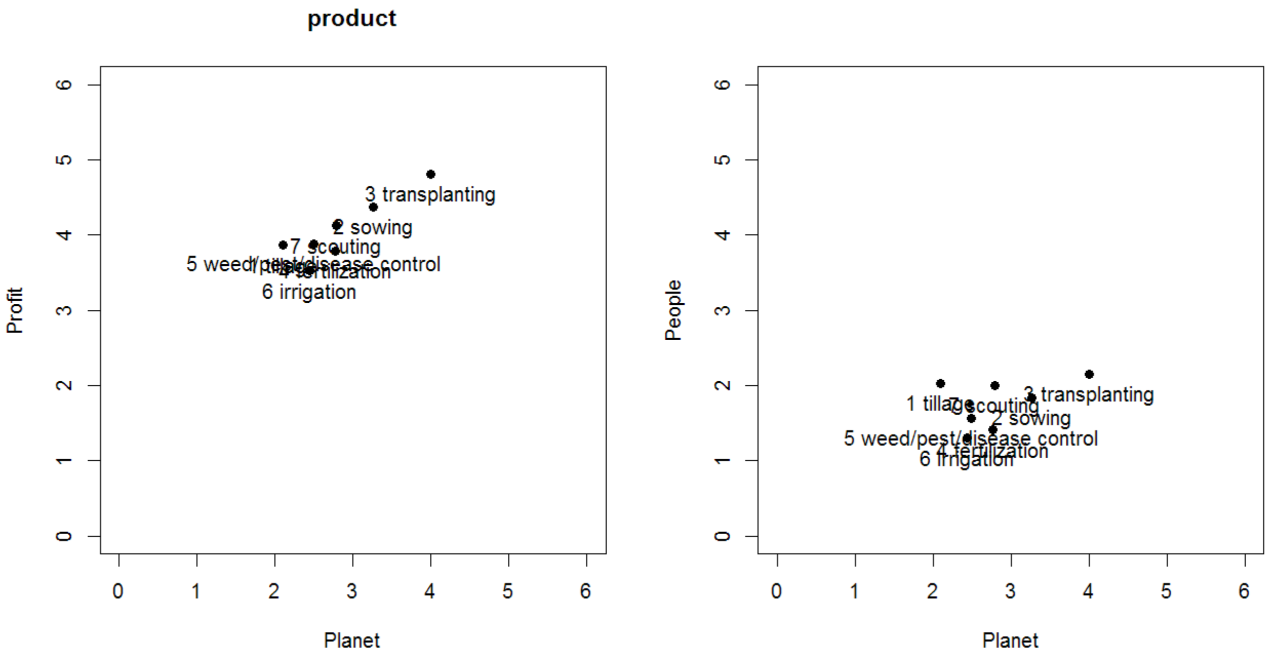


Figure 56. PPP by type of field operation for products.

4.15 An ontology of SFTs

Figure 57 shows an early version of an ontology of SFTs. It was created by considering the SFTs in the inventory and grouping them in a way that seemed to fit. The goal was to have as few groups as possible; at the same time, a group is only useful if the SFTs in the group are very similar. Later, we have expanded and refined the ontology in Figure 57, by building on the VALERIE ontology and by using the ROC+ tool. The full ontology can be viewed online[16] but a screenshot is shown in Figure 58.

[16] http://www.foodvoc.org/page/Valerie-9

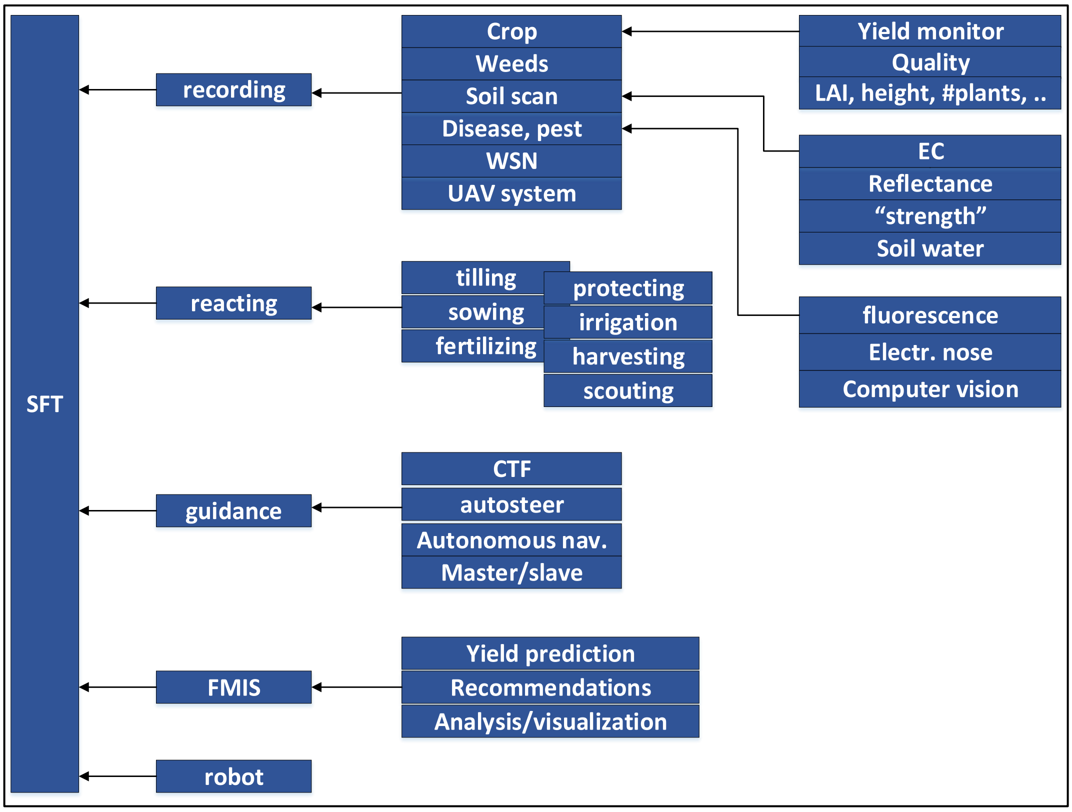


Figure 57. Initial (incomplete) version of an ontology of SFTs, based on reading and interpreting the SFTs in the current version of the inventory.

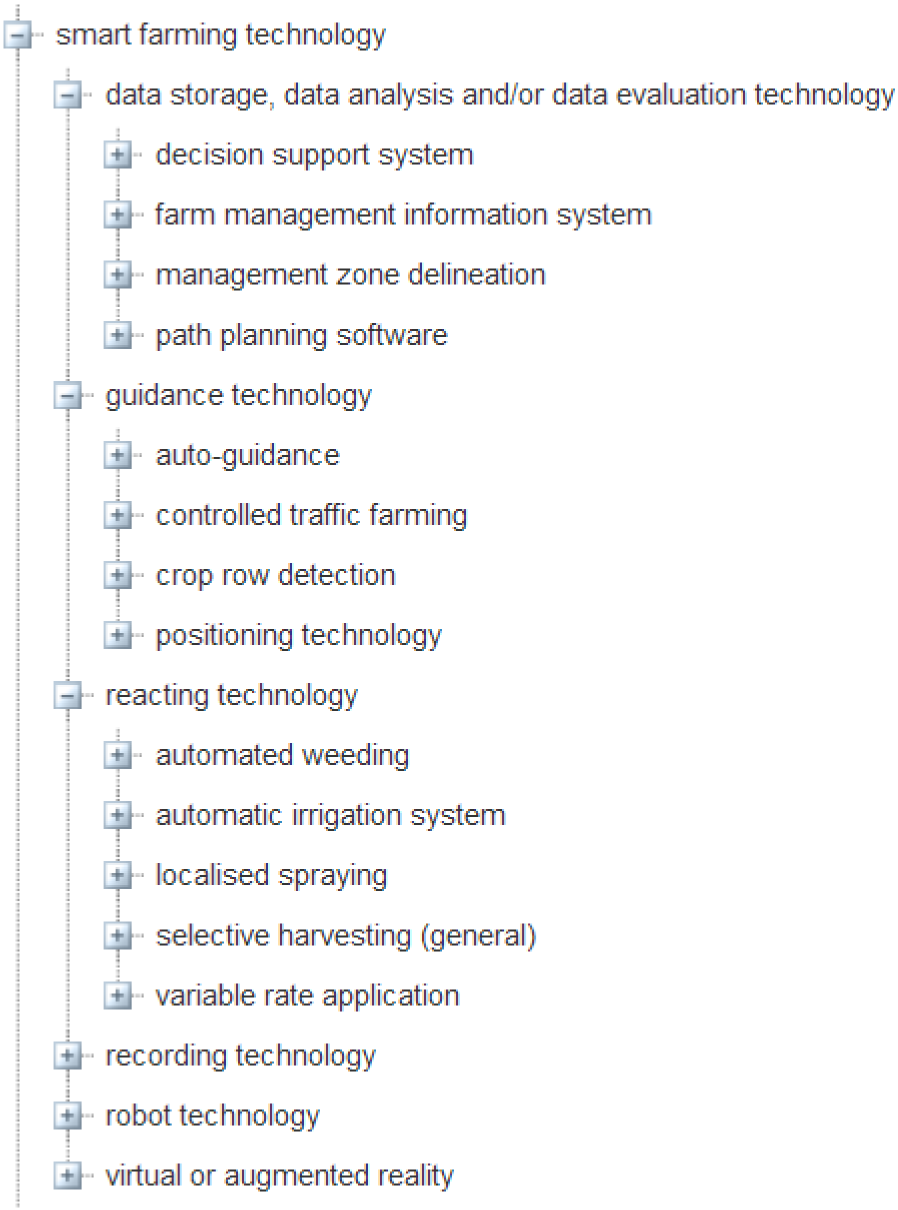


Figure 58. Screenshot of the "smart farming technology" part of the VALERIE ontology. Note that some concepts are hidden in this view and can be made visible in the online version by clicking on the "+" icons.

With the VALERIE ontology in hand, we revisited the list of SFTs and determined for each SFT the ontology concept (in some cases: concepts) that best describes that SFT. An attempt was made to be as specific as possible. This can be illustrated by an example. A part of the ontology reads as follows (each indent level indicates an is-a relationship):

smart farming technology
- reacting technology
  - variable rate technology
    - variable rate fertilizer application
      - variable rate nitrogen application
    - variable rate pesticide application

Using this part of the ontology, we can classify the SFT "SmartCONTROL CAN to ISOBUS bridge module for section and rate control"[17] as a variable rate technology. The SFT "Variable rate nitrogen fertilizer response in wheat using remote sensing"[18] is also a variable rate technology, but can in addition more precisely be described as “variable rate nitrogen application”. Because we know from the ontology that variable rate nitrogen application is just a special case of variable rate fertilizer application in general, we lose nothing. In fact we can aggregate the number of SFTs at each level in the tree using an automated procedure.

In Figure 59a the number of SFTs is shown in each category where only the first level below “smart farming technology” is taken into account. When the number of SFTs in each category is divided over the second level below “smart farming technology”, the result is Figure 59b. Finally, Figure 59c three levels are used. This example demonstrates that, as more and more detail is added in plotting the figure, the original figure is not changed.

[17] https://smart-akis.com/SFCPPortal/#/app-h/technologies?techid=1210

[18] https://smart-akis.com/SFCPPortal/#/app-h/technologies?techid=250

4.16 Using the ontology to understand SFTs

Figure 59. Tree maps showing the number of SFTs that are described by each concept in the ontology. A (top left): one hierarchical level (the first level below "smart farming technology") is used. B (top right): two hierarchical levels used. C (bottom): three hierarchical levels used.

4.17 Trends

We have collected information about a large number of SFTs. Research papers and research projects have a time reference and they can thus be used to analyze trends. But precision agriculture (smart farming, high-tech farming) has been around for at least two decades. Let's look at the hopes and promises that were expressed some time ago (Zhang et al., 2002)

Twenty years ago it was thought that SFTs would have a positive impact on profitability and decrease the negative impact of agriculture on the environment (Zhang et al., 2002). We can safely say that this has indeed happened, although many SFTs improve either profitability or environment, rather than both.

Zhang et al. also expressed the opinion that many sensors would be developed, to measure yields, crop and soil characteristics, and anomalous conditions such as the presence of weeds, pests and diseases. For example, VIS/NIR spectroscopy to measure soil organic matter and other soil properties is now becoming mainstream technology. Overall, Zhang et al. have been proven correct by the large inventory of SFTs that we have been able to compile in this report.

The same authors foresaw that actuators ("controls" in their terminology) would be developed. VRT applicators for agro-chemicals and guidance systems are certainly available now. But robotic harvesting has not been realized yet, even robotic weed control is still largely an unfulfilled potential.

In terms of data infrastructure, a lot still needs to be achieved. Many farmers use an FMIS now, but data interchange between different brands of FMIS and between FMIS on the one hand and agricultural machinery on the other hand is often difficult to realize in practice.

From our work we have learned that research is slowly shifting from recording and mapping technologies to work on actuation technologies. This will address some of the gaps noted above. The share of research papers that work on robotics has increased (albeit from a low base), but the focus of robotics researchers is not necessarily on harvesting robots

New (types of) sensors and measurement methods can be found in our inventory. These include VIS/NIR spectroscopy to measure soil organic matter and other soil properties, ground penetrating radar (GPR), and radar and passive microwave remote sensing for crop biomass and soil water content.

Finally, augmented reality is a completely new technology that may well prove to be useful as an SFT. The first tentative applications are close to market entry[19,20].

5 Assessment of practical value of SFTs

The survey with which information about SFTs is collected contains questions about the effect that technologies have. For example, the survey contains a statement "The SFT has the following effect on productivity (crop yield per ha)" and respondents are given a choice between "Large increase", "Some increase", "No effect", "Some decrease" and "Large decrease". This is useful information and it is presented in the Smart-AKIS platform. However, these answers are qualitative as well as subjective. While this is fine when one is exploring the SFTs, it is likely that practitioners will need quantitative, evidence-based information about technology benefits when they start considering adopting a particular technology. The demand for quantitative information is expected to be strongest for those technologies that deliver a benefit directly to the farmer: either recording/mapping technologies or actuation (reacting / guiding / robotic) technologies. We reviewed the literature in order to collect this quantitative information. In this review we considered the entire body of literature, i.e. we did not limit ourselves to the period starting in 2012.

Recording/mapping technologies provide a measurement of a certain variable; this measurement can then be used to make decisions. Thus, for recording technologies, it is of interest how precise (how much do repeated measurements of the same thing deviate from each other) and how accurate (how close is the measurement to the true value) can a variable be measured. We reviewed the literature to assess how accurate and precise the technologies are.

Actuation technologies have the potential to reduce the cost of field operations or help to achieve a reduction in input use. For actuation technologies it is of interest how large the benefit is. This

[19] https://www.realagriculture.com/2016/09/virtual-reality-crop-scouting-coming-to-a-field-near-you/

[20] https://www.space-of-innovation.com/farmar-helping-farmers-making-sustainable-decisions-based-satellite-data/

benefit can sometimes be measured in terms of input saved and sometimes in terms of increased yield or quality. We reviewed the literature to collect quantitative evidence about the benefits. In cases where this evidence is not available, we attempt to quantify the theoretical maximum value of the benefit.

An FMIS is often the connecting tissue between recording and actuation. FMIS are thus very important in realizing practical benefits, but we attribute this benefit to the actuation technologies. In this review, we do not attempt to determine the benefit of FMIS.

5.1 Recording technologies

5.1.1 Soil recording and mapping technologies

5.1.1.1 Electrical Conductivity by Electrical Resistivity and Elecotromagnetic Induction (ECa)

The electrical conductivity (EC) of soil is influenced by the amount of water in the soil, by chargeable soil particles such as clay and organic matter, by the presence of salts or salinity and temperature. Bulk density and pore size distribution influence soil water content. Soil properties that can be measured (indirectly) via EC therefore include clay content, organic matter content, bulk density and pore size distribution (Adamchuk et al., 2017, Knotters et al., 2017, Triantafilis and Lesch, 2005). Related soil properties can sometimes be approximated locally using that relationship (Heil and Schmidhalter, 2017). Since soil moisture, clay content and organic matter content all cause a higher EC one can argue that EC itself is an indicative measure of soil water availability.

EC can be measured as electrical resistivity with galvanic probes or coulters in direct contact with the soil. A current is inserted into the soil by one (set of) coulters and the transmissivity is measured by another set of coulters (Veris, Geophilius Electricus). EC can also be measured by electromagnetic induction using two or more coils. One coil creates an electromagnetic field and the other(s) measures the resulting secondary electromagnetic field which is a measure for the apparent electrical conductivity of the soil (Geonics, Dualem, GF Instruments, Geoprospectors). Electrical resistivity is invasive and needs to be in contact with the soil at all times. It can therefore not be used on frozen or rocky soils. Electromagnetic induction is non-invasive but is more sensitive to the presence of metallic objects nearby (fences etc). Measured patterns tend to be relatively stable over time, but absolute values may differ due to temperature and moisture. Calibration models are therefore usually inferred locally (field/farm/regional scale).

Measurement of soil properties via EC is most likely to be successful if one property is responsible for most of the variation in the signal. In that case it is possible to calibrate the EC signal to that property using soil samples. Precision and accuracy of the measurement depend on the instrument, the precision and accuracy of the calibration measurements and contribution of the property to variation in EC. Because the EC signal is influenced by multiple soil properties, exact estimations of the precision and capability to predict a (range of) soil properties at a certain location is hard to specify. In general, texture classes, (larger) differences in soil moisture or saline versus normal conditions can be measured (Corwin and Lesch, 2005, Doolittle and Brevik, 2014). Other properties can only be measured when the aforementioned are homogeneous and with sufficient calibration data (Doolittle and Brevik, 2014). Measurement depth is dependent on the distance between coils, multiple depths can be measured by an array of coils. By inversion of the (multiple) signals a EC soil profile with depth can be measured. Typical depth ranges vary between 0-50 cm up to 6 meter.

Instruments

Each instrument on the market has a different coil configuration and therefore different depth range and resolution. Important to note when looking at the specifications of a system is that the depth range is indicative. For instance a coil spacing of 50 cm means the signal will be influenced by soil properties between 0 and 80 cm depth but primarily at 20 – 30 cm depth. More coils within the desired measurement depth means a better depth resolution. Suitable systems for agriculture include the Dualem 21S, Geonics EM38, Veris MSP3, GF Instruments CMD mini explorer, Geoprospectors Topsoil Mapper. Some instruments now come with a built-in calibration procedure whereas others need a manual calibration procedure per field and measurement. Most handheld systems can be carried over the field while walking or towed on a sled behind a quadbike, car, tractor or gator at max 10-15 km/hr.

The interpolated point readings of EC are often used to delineate (topsoil) management zones for which it is assumed that soil texture and nutrient content are homogeneous. The amount of allowed variation within each zone and the minimum size per zone depends on the SFT application (eg.

sensitivity of the crop for the soil property variation and working width of the equipment) (Frogbrook and Oliver, 2007, Hedley, 2004, Van Meirvenne et al., 2013). EC is also used for measuring depths and thicknesses of soil layers for instance for simulating soil water dynamics, thus providing soil profiles (De Smedt et al., 2013, Saey et al., 2011) and for improving the delineation and detail of traditional soil maps (Doolittle and Brevik, 2014, Vitharana et al., 2008).

An indication of the accuracy with which soil properties can be measured using EC is given in Table 14.

Table 14. Accuracy of measurement of soil properties using EC.

EMI	Correlation (R^2) / RMSE
Clay content/ soil texture	0.72[a] - 0.77[c] – 0.2-0.9[n] / 5.06%[c] - (differentiate between texture classes clay, sandy loam, loamy sand, clay loam, sand, fine clay)
Soil Organic Matter	+/- 5 percentage points[d]
Soil moisture	0.42[a] – 0.65[b] – 0.37-0.99[e] / 0.046 m3m-3[b] - rough classes of wet and dry
pH	0.23[a] – (0.17-0.76[e]) / - - Depends on link to soil texture
CEC	0.53[a] - (0.18-0.76[e])/ -
Salinity	0.5-0.98[e] / -

[a] (Hedley, 2004)

[b] (Martinez et al., 2018)

[c] (Triantafilis and Lesch, 2005)

[d] (Martinez et al., 2009)

[e] (Mahmood, 2013)

5.1.1.2 VIS/NIR spectroscopy

The reflectance of light incident on a soil is influenced by the constituents of the soil. Different chemical bonds or mineralogical properties absorb radiation at specific wavelengths (e.g. chlorophyll, cellulose, lignin, kaolinite, carbonates). If the spectrum is measured at those wavelengths, the amount present can be quantified after calibration with samples. Relevant wavelengths for soil are located in the near (NIR) and the mid infrared (MIR). For field measurements at present only NIR tools are commercially available. However, the influence of varying soil moisture and granularity of the samples limits the accuracy of measurements in the field. Therefore the calibration of spectra with soil properties (joined in spectral libraries) is performed on relevant lab-measured samples and then applied to field measurements. Precision and uncertainty of predictions depend on the instrument, measurement conditions and protocol, quality and relevance of the spectral library used and modelling algorythms.

Soil properties that can usually be measured reasonably well (R^2 of 0.7 or 0.9 if a suitable and good quality library is available), are soil organic carbon (SOC), organic matter, total carbon, clay content, carbonate content, pH and CEC. Other properties such as clay type and nutrients can be predicted too, but tend to have a higher uncertainty (R^2 0.6 or lower in lab conditions). Penetration depth is small, a few millimetres or centimetre. It is therefore mainly used as (point) surface tool or dragged through the soil up to 5 cm depth. Once the calibration to soil properties is established it can be also be used to classify areal (UAV, plane) or satellite imagery in areas without vegetation or cloud cover.

Instruments

Spectrometers differ in spectral range and spectral resolution and generally cover part of the infrared spectrum, so a choice may depend on the properties that need to be measured. There are multi-spectral systems and hyperspectral systems. The multi-spectral is typically designed to measure a few properties well and has bands at the absorption features of that property (eg leaf greenness has bands in red and near infrared for NDVI calculation). Hyperspectral systems have spectral bands of typically 2 to 4 nm wide that cover the entire spectral range of the instrument. This provides more possibilities for prediction of properties but is usually more expensive. Most multi-spectral systems are designed for plant tissue analysis and not for soils, so for measuring soils a hyperspectral camera is often needed. Some sensors are designed for use in the lab, others for the field. Typically, instruments in the lab yield better results while field measurements may allow SFT applications. Sensors are typically expensive (30-100 k€) but over the last 5 years more low end tools are becoming available (Scio, Tellspec, Ocean Optics; 300 – 2000 €).

Measurements can be performed in the field on point basis either handheld (ASD, Soilcares) or driving (Veris MSP3). Also aerial images can be taken by an UAV (currently still expensive but improving), an airplane (most common method now) or by satellite (hyperspectral satellites are expected before 2022). All types are then calibrated using a spectral library derived in the lab. There are several libraries available, but not all are open. At present a few systems worldwide allow hyperspectral sensing of a soil core, either retrieved by an hydraulic soil auger and air-dried (Hedley et al., 2014, Lobsey and Viscarra Rossel, 2016, Roudier et al., 2015) or in situ in the borehole (Ackerson et al., 2017, Poggio et al., 2017).

The applications at present mainly focus at soil organic carbon monitoring for climate, updating soil maps, in field measurement of SOC for precision agriculture and more extensive soil property measurement using NIR and MIR in the lab. Other properties are still often mapped by other instruments or lab analysis. NIR or MIR systems are typically part of a multi-sensor setup for for instance fertilser advice (Lab-in-a-box – SoilCares) (Ackerson et al., 2017, Lobsey and Viscarra Rossel, 2016, Roudier et al., 2015).

An indication of the accuracy with which soil properties can be measured using VIS/NIR spectroscopy is given in Table 15.

Table 15. Accuracy of measurement of soil properties using VIS/NIR spectroscopy.

Vis-NIR/NIR	In situ: Correlation (R^2) / RMSE	Lab: Correlation (R^2) / RMSE
Soil Organic Carbon	0.38-0.47[g] – 0.39[l] /- 0.66%[l]	0.76[a] - 0.86[b] – 0.80[l] – 0.46-0.98[n] /- - 0.27%[b] -0.37%[l] – 0.06-2.9%[n]
Total Carbon	0.92[h] / 0.38%[g] – 0.15[h]	0.91[a]/-
Soil Organic Matter	0.8[h] – 0.19-0.61[i]– 0.66[m] / 0.4%[h] – 0.27-0.38%[i] – 0.3-0.5%[j] – 10.33%[m]	0.83[c] - 0.92[d] / - - 7.6%[d]

Clay content	0.29-0.59[f] - 0.65-0.71[k] – 0.7[m] / 252-418 g kg^{-1}[f] -5.6%[j] – 14.73%[m]	0.7[a] – 0.78[e] - 0.15-0.91[n] /- - 7.9 %[e] – 0.79-6.1 %[n]
pH	0.68[h] – 0.33-0.71[i] - 0.67[m] / 0.46[h] – 0.58-1.1[i] - 0.41[m]	0.63[a] – 0.5-0.97[n] / 0.04-1.43[n]
CEC	0.77[m] / 16.54 meq $(100g)^{-1}$[m]	0.78[a] – 0.13-0.9[n] / 1.22-10.43 cmol kg^{-1}[n]
$CaCO_3$		0.7[a] – 0.89[d] – 0.07-0.95[n] / - 6.5 gkg^{-1}[d] – 0.66-52.9 cmol Ca kg^{-1}[n]
Sand content	0.5[m] / 10-11%[j] – 18.29%[m]	0.70[a] /-
Soil moisture	/ 2.8%[h]	0.9 / 5.3 gkg^{-1}[d]

[a] (Stenberg et al., 2010)

[b] (Viscarra Rossel et al., 2016)

[c] (Shonk, 1991)

[d] (Ben-Dor et al., 2008)

[e] (Viscarra Rossel et al., 2009)

[f] (Ackerson et al., 2017)

[g] (Roudier et al., 2015)

[h] (Christy, 2008)

[i] (Schirrmann et al., 2013)

[j] (Wetterlind et al., 2015)

[k] (Poggio et al., 2017)

[l] (Hedley et al., 2014)

[m] (Zhang et al., 2017)

[n] (Mahmood, 2013)

5.1.1.3 Gamma-ray

Gamma-ray spectrometry or radiometry is based on the passive measurement of naturally occurring radioactivity in the Earth's surface with a scintillation crystal. Radiation is emitted by nuclides (^{40}K, ^{238}U, ^{232}Th) with long half-life times that are present in minerals in rocks and soils or emitted by nuclear testing or accidents such as Chernobyl (^{137}Cs). The spatial distribution of the latter is dependent on rainfall patterns at the time, geographic location and soil relocation (eg erosion/sedimentation and mixing (ploughing, plant growth). Because of the short half-life time of 30 years the concentrations of ^{137}Cs are decreasing. The composition of minerals in a soil is dependent on geological provenance (and therefore parent material) and soil texture. Measuring the nuclide composition of soil can therefore be an indicator for parent material and soil (textural) properties. The signal originates from the top 30 cm of the soil (it is a exponential decline function where 85 % comes from 0-20 cm, 90 % comes from 0-40 cm and a very low amount can come from 50 cm depth). The main radiation emitting nuclides (^{40}K, ^{238}U, ^{232}Th) occur in the clay fraction (0-2 µm) and some (mainly ^{40}K) in the sand fraction. Therefore ^{232}Th is usually a good predictor of clay content (Van Der Klooster et al., 2011) and ^{40}K of median grain size (van Egmond et al., 2010). A small percentage (^{137}Cs) is taken up by plants and hence is included in organic matter. The method is therefore suitable to measure clay percentage of soils with more than 5 % clay and to measure medium grain size on sandy soils (Coulouma et al., 2016, Mahmood et al., 2013, Pracilio et al., 2006, Van Der Klooster et al., 2011, Viscarra Rossel et al., 2007). Calibration is performed within provenance regions for soil properties or across provenance regions for parent material classes. Calibration methods vary from linear regression to machine learning algorithms based on a spectral library. The accuracy depends on the accuracy of the lab, the size of the sensor, spectral analysis and the predicted property. Clay can usually be predicted with a 2-5 percentage point accuracy. Local calibration performs better than regional calibration but regional is still ok for most applications. Also texture derived properties can be mapped if a relation is present between the property and texture (eg Mg content and clay). Larger differences (2-10 percentage points) in soil organic matter can be mapped due to the absence of minerals and uptake of nuclides by plants. Moisture content has an attenuating effect on the signal, but when measuring on agricultural fields the effect is usually small (0% increase in soil moisture results in 10% decrease of signal intensity without effecting spectral shape; in field driving conditions usually 10% is not exceeded, this may be different in airborne applications).

Application in hilly terrain requires correction for the varying vicinity of the hillslopes and valleys. The footprint increases exponentially with flying altitude.

Instruments

Gammaspectrometers can be differentiated to type of scintillation crystal, standalone capacity and (calibration and) software tools for spectral analysis. CsI (more efficient, therefore smaller) and NaI crystals are cheaper and often used for agricultural applications. BGO crystals have a higher spectral resolution and are more expensive. (Hendriks, 2001) Some instruments are now designed as standalone, with less need for a separate laptop and GPS (Medusa Sensing), on a sled (Radiation Solutions Inc., GF Instruments), or tractor mount (the Mole). The methods for spectral analysis are Windows Analysis or Full Spectrum Analysis (Hendriks, 2001) of which the latter requires calibration of the sensor but is then more robust and efficient than Windows analysis. Most companies supply one or both of these analyses in the accompanying software.

Different sizes of gammaspectrometers exist for various platforms; handheld for point measurements, mounted on a quadbike, car, tractor, gator, mounted on a UAV, airplane or helicopter (80 m). Due to laws of physics it cannot be mounted on a satellite. Choice of platform depends on required accuracy and resolution, costs (walking < vehicle < UAV < airplane) and accessibility of the terrain (van Egmond, 2018).

Tillage layer soil texture maps are used in (precision) agriculture to define management zones or for applications such as variable planting distance, variable compost etc. Soil moisture sensors can be better positioned using the maps resulting in extrapolations of soil hydraulic properties and moisture. Correlations to yield maps are made (Mahmood et al., 2013, Van Meirvenne et al., 2013). In mining, gammaspectrometry is a standard technique to help delineate parent material classes. It is also used in road analysis to identify differences in crushed stone types.

Advantages of this technique are the quantitative, robust measurement of texture, especially clay and loam content, a depth range that equals the tillage layer, and a relative insensitivity to moisture.

An indication of the accuracy with which soil properties can be measured using gammay-ray is given in Table 16.

Table 16. Accuracy of measurement of soil properties using gamma-ray.

	Indication	Correlation (R^2) / RMSE
Clay content	2-5 percentage point	0.6[a] - 0.65-0.73[b] - 0.6-0.95[c] – 0.85 - 0.76-0.63[e] / 4.2 dagkg-1[a] - 0.96-0.81% [b] - 2-6 %[c] – 3.1%[d] – 5.34-6.56 dagkg^{-1}[e]
Soil organic matter	2-10 percentage point	0.4-0.9[b] - 0.51-0.88[d] / 0.41-0.24%cal.[d]
total organic carbon		0.45-0.17 [b] / 0.027-0.078 dagkg-1 [b]
Median grain size (M0)	30 % point	0.84[d] / 13.3 mu[d]
Silt fraction		0.8[c] - 0.4-0.44[e] / 5.4%[d] - 2.46-1.83 dag kg^{-1}[e]
Loam content	10 % point	0.82[d] / 8.7%[d]
Coarse sand fraction		0.73-0.76[e] / 8.28-6.25 dag kg^{-1}[e]
EC		0.6-0.31[e] / 27.96-31.58 mS m^{-1}[e]
Magnesium content		0.65-0.9[d] / 15.2-4.5 mg kg-^{1}cal[d]
pH		0.4[e] / 0.48-0.72[e]
Other nutrients, pH, CEC	Only possible when relation with texture is present	

[a] (Coulouma et al., 2016)

[b] (Mahmood et al., 2013)

[c] (Van Der Klooster et al., 2011)

d (van Egmond et al., 2010)

e (Viscarra Rossel et al., 2007)

5.1.1.4 Ground penetrating radar (GPR)

A Ground Penetrating Radar (GPR) consists of a sending and a receiving antenna. (Huisman, 2003) The sending antenna emits radio signals between 100 MHz and 2 GHz in a downward direction. The signal is reflected on layer transitions between layers of different (physical) properties such as clay to sand, peat, brick, metal, asphalt etc. Discernibility depends on layer thickness (> 5 cm with low frequency and >1 cm with high frequency systems), the sharpness of the layer transition (<5 - 8 cm with low frequency systems; gradual transitions are less easily detected), difference in physical properties (e.g. roughly > 8 percentage point clay, > 100 mu median grain size, > 8 percentage point organic matter). Due to differences in porosity and water content layers with different densities can also be seen if strong enough (e.g. man-made during road construction) and in otherwise homogeneous material. A low frequency GPR (300 MHz) has a penetration of 1-3 m in clayey soils and 4-6 m in sandy soils with penetration being less in moist soils. Depth resolution will be about 5-10 cm. A high frequency GPR of 2 GHz has a penetration of 20-40 cm in dry soils but has a depth resolution of 1-2 cm. Data analysis is either manually by visual image interpretation, semi-automated image pattern recognition or semi-quantitatively per time-slice (depth-slice) to the amount of reflection over depth. A GPR is suitable for measuring changes in soil profiles with depth, either natural or man-made.

How to choose an instrument?

There are many different GPR systems on the market for different applications. (GSSI, ZOND, 3D Radar, IDS, MALA, USRADAR, etc.) GPR systems differentiate mainly in frequency, and therefore depth range and resolution. The next difference is between ground-coupled and air-coupled antennas, the first need to be within vicinity of the soil (0-20 cm), the other should be positioned further from the soil (>20 cm). Depending on measurement speed (Hz) and software systems can be suitable for high speeds (highway) or not. Different brands may have different spectral quality or distinctiveness (Huisman, 2003).

Platforms

GPR surveys are conducted by walking the survey lines with the GPR mounted on a push-cart, or driving with the GPR towed behind or mounted on the vehicle. Recent applications show preliminary reasonable results with a GPR flown by airplane or helicopter although signal quality and resolution are less.

GPR has many applications. For agriculture, presence, thickness and depth of distinct texturally different layers are mapped and several studies are performed to evaluate the potential to measure soil moisture, the groundwater table and soil compaction. Some results show the localisation of drains in saturated soil. The results of these studies vary depending soil profile, instrument and complexity. GPR is successfully used in agriculture, archaeology and planning to determine peat thickness and starting depth. GPR does not have widespread SFT applications (Liu et al., 2016) due to its semi-quantitative nature and low automisation of analysis, but can for sure have added value in areas with significant texture differences with depth. Results of GPR analysis are used as input for (hydrological) models.

Outside of agriculture GPR is also used to map depth to bedrock under glaciers or soil, the surface geology of an area, landfills (extent and cover), utility (cables and pipes), road construction and quality, localisation of e.g. graves and buried objects, archaeology (walls, canals, larger structures), non-exploded ordnance and tunnels.

Advantages of GPR are its high depth resolution and precision, measurement range and depth application across sectors, ability to measure soil profiles and artefacts.

An indication of the accuracy with which soil properties can be measured using GPR is given in Table 17.

Table 17. Accuracy of measurement of soil properties using ground penetrating radar.

	Correlation (R^2) / RMSE
Texture/topsoil depth	0.55-0.85[a] / -
Water content	0.57-0.95[a] / -
Salinity	0.6-0.85[a] / -
Compaction	0.45-0.7[a] / -

[a] (Mahmood, 2013)

5.1.1.5 pH sensor

Usually, pH sensors are electrodes that are operated as handheld point measurements. One sensor features an on-the-go sensor for pH analysis (Veris). Tests in the Netherlands show systematically higher values than meaured in the lab with pH-KCl (Schans and Berg, 2013). The correlation was on average 0.73. Accuracy is often 0.1 – 0.2 pH point.

Other techniques used to estimate pH are NIR/MIR.

5.1.2 Crop recording and mapping technologies

5.1.2.1 Canopy reflectance (visual; remote and proximal)

The reflectance of incident light by a crop canopy is influenced by the amount of biomass, by the N content (kg/m^2 ground area), chlorophyll concentration (µg/cm^2 leaf), and to a lesser extent by canopy structure. Compared to destructive sampling, measuring crop reflectance is quick, cheap, and can be used to measure a large area at high resolution. Reflectance is commonly measured with cameras on board of satellites, airplanes, and drones. It is also measured with non-imaging devices that are hand-held or mounted on tractors.

In those cases where reflectance has been measured from two or more platforms, there was usually good agreement between reflectance measured from satellites, airplanes, drones and on the ground. The farmer can select a method based on availability and cost.

There are three major ways of interpreting reflectance measurements, namely (i) using vegetation indices, (ii) using statistics, and (iii) using inverse modelling.

(i) A vegetation index (VI) is a combination of reflectance measured in two or more narrow spectral bands (Hatfield et al., 2008). Commonly used VIs include Normalised Difference Vegetation Index (NDVI), Normalized Difference Red Edge (NDRE) and Chlorophyll index (CI). VIs can be used with the relatively cheap (multispectral) instruments that measure reflectance in only a few wavebands.

(ii) Hyperspectral instruments measure reflectance in dozens or hundreds of wavebands. Several statistical methods are available to interpret this kind of measurement, notably Partial Least Squares (PLS).

(iii) Inverse modelling is a method in which a model of canopy reflectance is used to simulate reflectance. The parameters describing the canopy (biomass, LAI, chlorophyll content, and so on) are then systematically varied until the simulated reflectance spectrum matches the measured reflectance spectrum.

The accuracy and precision of determination of biomass or N uptake using a VI are often not as high as one might desire. For potato, N uptake using Weighted Difference Vegetation Index (WDVI) was measured +/- 30 kg ha^{-1} (Van Evert et al., 2012). Also for potato, but using the chlorophyll index (CI) and the Meris terrestrial chlorophyll index (MTCI), canopy nitrogen content was estimated with a RMSE of 16 kg m^{-2} (Clevers and Gitelson, 2013). The same authors found similar accuracies for maize, soybean and grassland.

LAI and ground cover of potato was estimated using WDVI with an absolute error of less than 6 percentage points (Bouman et al., 1992).

Reflectance sensors need to be properly calibrated in order to give good measurements. The calibration of satellite and airborne sensors is obviously beyond the reach of the farmer. For the calibration of drone-mounted sensors detailed procedures are given. For tractor-mounted sensors the issue is less clear. For the Greenseeker, no calibration procedure is available, and no method to check the calibration is given by the manufacturer, other than returning the sensor. When six Greenseekers were tested side-by-side, they showed great variability (Van der Schans et al., 2012). For the N-Sensor a calibration procedure is available that can be done on-farm. The manufacturer of the CropCircle recommends returning the instrument to the factory for recalibration.

The differences between the commercially available proximal sensors mean that some sensors are more suitable for a given task than others. For example, the Greenseeker measures NDVI. In potatoes, this VI is capable of detecting the differences in crop senescence that are important for VRA haulm killing. In the same crop, however, NDVI is not sensitive to the differences in N uptake that exist in June/July when nitrogen sidedress is applied.

5.1.2.2 Remote sensing of crop biomass using radar

Satellite-based measurement of canopy reflectance in the optical part of the spectrum is easily disturbed by cloud cover. Low-frequency microwaves (1-10 GHz) penetrate cloud cover. In addition, they allow night-time measurements. The possibility of measuring crop biomass and/or LAI using radar was mentioned decades ago (e.g. Luciani et al., 1994, Ulaby et al., 1984).

Backscatter of microwaves is influenced by characteristics of the canopy and of the soil. Canopy characteristics include amount of biomass, geometry of the canopy, LAI, water content of the canopy (Steele-Dunne et al., 2017). Soil characteristics include soil surface roughness and soil water content (Steele-Dunne et al., 2017). This means that in order to interpret the radar data, it is necessary to have a model of the backscattering processes. Information about crop and soil is then obtained from the measurement by inverting the model. Uncertainties in the model and noise in the data lead to the result that some information about the crop can be extracted, but at present this information is not accurate enough to be of interest to farmers.

This situation is set to improve in large part due to the launch by the European Space Agency of Sentinel-1A in in 2014 and Sentinel-1B in 2016. These satellites carry a radar instrument with high resolution. Using Sentinel-1 data and random forest regression, it was possible to estimate LAI of wheat in India with a RMSE of 0.3 and dry biomass with a RMSE of approx. 1 t ha^{-1} (Kumar et al., 2018). Also for wheat in Denmark good results are reported but quantitative results for this work-in-progress are not yet available (Christiansen et al., 2018).

5.2 Actuation (reacting / guiding / robotic) technologies

For actuation technologies, the benefit for farmers is sometimes measured in terms of inputs saved and sometimes in terms of increased yield or quality. We attempt to collect quantitative evidence about the benefits. In cases where this evidence is not available, we attempt to quantify the theoretical maximum value of the benefit.

The financial benefit of using an SFT can be determined if sufficient information is available about the costs of inputs, outputs, and buying, operating and maintaining the SFT.

5.2.1 VRA fertilizing

Our survey results indicate that VRA fertilizer reduces input use. It may also increase the quality of the product. For example, the quality of bread wheat and malting barley may be increased by more closely approaching a target N protein content. Taken together, VRA fertilizer may increase profit.

There is quantitative evidence for a number of crops. In potato in The Netherlands, canopy reflectance-based sidedress N leads to a reduction in N use of 15% (Van Evert et al., 2012); however, profitability is increased only slightly (Van Evert et al., 2017). In potato in Argentina, experiments show that canopy reflectance in mid-season can indicate when N is needed, but the authors do not quantify N savings (Giletto and Echeverría, 2016).

In potato, crop quality can be increased by using VRA N because homogeneous application of N typically results in overapplication of N in some areas. In areas with excess N the crop stays green longer, ripening of the rubers (including skin hardening) is delayed, and damage to the tubers during harvest is likely (Kempenaar and Struijk, 2008). VRA N can be used to grow a homogeneous crop which ripens evenly across the entire field field .

For an experiment with maize in Italy, the standard N rate was 240 kg N ha^{-1}. Variable rate determined with a crop growth simulation was almost 40 kg N less and increased net income by 12 euro ha^{-1} (Basso et al., 2016). For maize in the USA trials were conducted on commercial farms over a period of 5 years (55 plot-years). Adopting sensor-based variable rate sidedress N reduced the average application rate from 194 to 179 (-16) kg N ha^{-1}. Yield remained the same and partial profit increased marginally from 1672 to 1714 (+42) USD ha^{-1} (Scharf et al., 2011). In another on-farm maize experiment, the producer chose a uniform rate 105 kg N ha^{-1} (preplant + sidedress) and the sensor-based rate (fixed preplant + variable rate sidedress) was 90 kg N ha^{-1}; again, yields were the same (Li et al., 2016).

An experiment in winter wheat in Italy makes clear that appropriate variable rate N increases NUE but the paper doesn't quantify N savings (Basso et al., 2016). For an experiment in the USA, several comparisons between treatments can be made. For example, a single application of 45 kg N ha^{-1} gives 1562 kg grain ha^{-1} whereas the sensor-based variable N rate was 43.1 kg N and yielded 1835 kg grain (much higher NUE). Or 45 kg N ha^{-1} pre-plant + 45 kg N ha^{-1} mid-season gives 2105 kg grain ha^{-1} whereas 45 kg N ha^{-1} pre-plant + variable N rate (62.5 kg N ha^{-1}) gives 2292 kg grain ha^{-1} (higher yield, same NUE) (Raun et al., 2002).

For wheat in Greece, VRA N using the Crop Circle ACS-430, a revenue increase of €100 ha-1 was reported excluding the cost of the sensor (Stamatiadis et al., 2017).

For maize in Canada, VRA N using Greenseeker sensors resulted in reduced N use while yield was unaffected (Ma et al., 2014).

For olive in Greece, zone-based P fertilization and application of lime resulted in large reductions in use (Fountas et al., 2011). The large reductions were likely a result, at least in part, of unfavourable farmer practices.

It has been noted that an important limitation to the widespread use of sensors for VRA N is the availability of algorithms that are reliable in a variety of soil and weather conditions (Samborski et al., 2009). Perhaps for that reason, many reports focus on a specific sensor and the proprietary algorithm that is built into it.

For the N-Sensor, it was reported that VRA N increased wheat yield in Germany by 8% (Leithold and Traphan, 2006) compared to uniform application. Wheat yield was increased by an average of 3.2% when data from a number of trials around the world were pooled (Jasper et al., 2004). Also, VRA N resulted in a more homogeneous ripening and drying of the crop and therefore better harvesting (Jasper et al., 2004). Again for the N-Sensor, it was reported for winter wheat in Germany that combine performance was increased by 9 to 33% because there was less green leaf and green straw biomass and the separability of kernels was higher (Feiffer et al., 2007).

On the other hand, for maize in Brazil it has been reported that N-Sensor-based VRA N increased N uptake compared to a single-rate application of N only when rainfall was sufficient to support enhanced crop growth (Bragagnolo et al., 2013). Also, the increase in N uptake did not lead to higher maize yield (Bragagnolo et al., 2013).

In summary, in many crops a 15% reduction in N use relative to current practice is within reach. Also in many cases, once the sensors and other investments needed to realize this reduction in N have been paid, there is at most a small increase in profit.

It could be argued that when a farmer uses his or her knowledge of the field to vary N rate, the effect might be the same as with a sensor-based variable N rate (Obenauf et al., 2014). The literature mentioned above supports that view. However, sensors are especially useful when a farmer relies on hired labour, works with rented land (with which he or she is not familiar), or manages a farm which is so large that a single person cannot know it well enough to optimize N fertilization without resorting to SFTs.

5.2.2 VRA pesticides

In recent years, variable rate pesticide application (VRPA) technologies have appeared aiming in differentiating the application rate according to the actual or potential pest stress avoiding over-application of plant protection products (PPPs) where is not needed and reduce overlapping or under-coverage (Batte and Ehsani, 2006, Karkee et al., 2013). VRPA have found several applications, but weed control received the greatest attention due to their immobility (Swinton, 2003).

There are two types of VRPA technologies, namely (i) map-based systems and (ii) real-time sensor based systems. The first is a dual-mode application, since primarily a prescription or application map derived by previous in-field monitoring need to be extracted and secondly this map is loaded to the sprayer to adjust the application rate based on it. This system accuracy is based on the positioning of the sprayer in the field using GNSS receivers so that prescription map dose is mirrored in reality (Grisso et al., 2011). To avoid this dual-mode, there are systems based on real-time sensors that sense the current pest stress and canopy characteristics. It should be noted that the same rate and nozzle control systems can be implemented in both VRPA technology types.

A technology that is auxiliary to VRPA, but extremely important for the reduction of PPP use, is spray drift reduction systems that use environmental information (i.e. temperature, wind speed and direction) to change the sprayer settings (spray pressure, nozzle type) based on the sprayer location in relation to vulnerable areas using GNSS receivers (Doruchowski et al., 2009).

Finally, boom height control is another auxiliary technology that minimizes under- or over-application of PPPs due to sprayer boom oscillation above its horizontal axis and improves PPP application uniformity (Karkee et al., 2013).

5.2.2.1 Map-based VRPA systems

There are two main categories of map-based VRPA systems, i.e. (i) rate control, including flow-based control systems, direct chemical injection systems, and chemical injection systems with carrier control, and (ii) nozzle control, including modulated spraying nozzle control systems.

Flow-based rate control system. These systems vary the nozzle flow rate in direct proportion to the ground speed in order to keep the application rate steady (Hloben, 2007). The flow rate is regulated by adjusting the nozzle pressure. To do so, the system has a flow meter, a ground speed sensor, and a regulating valve with an electronic controller that determines the application rate. Having in mind the width of application and the forward speed, a microprocessor calculates the quantity of PPP mix per hectare and then the system opens or closes the valve so that the flow meter matches the calculated flow rate. It has the advantage of quick PPP mix rate changes, because its control system has quite fast response to a new rate command (Humburg, 2003). However, the system has the drawback of large changes in spray droplet size and potential problems with spray drift due to the fact that its working principle allows variable pressure rates that do not always cope with the optimum operating range of the nozzles in use (Humburg, 2003).

Direct chemical injection rate control systems. These systems have a completely different approach, since the alleged controller regulates the flow of the PPP into a stream of the carrier (water) rather than the flow rate of a PPP-water mix. The applied PPP(s) and the carrier are stored in separate tanks (Hloben, 2007) and each tank has an independently controlled injection pump (Ess et al., 2001). It should be noted that the system maintains the carrier flow rate constant, while the PPP injection rate varies according to the commanded application rate (Humburg, 2003). There are systems with injection upstream (suction) or downstream (discharge) side of the carrier pump depending on the location of the injection point. In addition, the injection of the PPP(s) can be either executed to the whole boom, only one section, or directly to each nozzles, while the PPP can be delivered continuously or discontinuously (Hloben, 2007).

The advantages of this system are multiple. The carrier circuit has no disposal of chemicals, eliminating the need for leftover PPP mix management (Humburg, 2003), for hydraulic agitation system and for protection against aggressive chemicals (Hloben, 2007). Moreover, the constant flow of carrier allows operating nozzles in their optimum pressure rate to provide droplets of desirable size and distribution. However, such systems show long transport delay between the PPP injection pump and the discharge nozzles at the end of the line (Humburg, 2003).

Rate control via chemical injection and carrier control. These systems are an evolution of the latter; where there are two controllers regulating both the PPP injection rate and the carrier rate to respond to the application rate changes. This system maintains the advantages of the previous system regarding the disposal of chemicals in the system, but the problem of delivering varying amounts of liquid to the spray nozzles as rate changes, resulting in changes in droplet size distribution and spray pattern, reappears (Humburg, 2003). The most significant advantage is that as the rate change of both PPP and carrier controller is very fast, the concentration variations within dynamic response differences between the two subsystems is also rapid, thus reducing the effect of transport delays (Yang et al., 2015). Nevertheless, the addition of more hardware in the system makes it more complex increasing its initial cost (Humburg, 2003).

Nozzle control systems. In modulated spraying nozzle control systems, the outlet of the nozzles (conventional types) opens/closes rapidly using direct-acting, in-line solenoid valves. The system provides two flow conditions, full flow and zero flow, and the perception is to vary the time that the valve stays open to variate the flow rate, and thus the application rate, without changing the droplet and spray characteristics. Even if the system is designed to have very short cycles between the two stages (10 Hz) to minimize under-coverage of field parts when a nozzle valve is closed, phase shift of adjacent nozzles is used (when zero flow is applied to one nozzle, full flow is used for the nozzles adjacent to it). Another mean to reduce under-coverage effect is the use of wide spray angle nozzles (110°) (Ess et al., 2001).

Another way to control the flow rate on a nozzle basis is the use of air flow to be fused into the PPP reducing the flow by half. In addition, varying the nozzles orifice can be achieved by a moving, steerable component within each nozzle or by combining several nozzles into one holder and switching between them (Weis et al., 2012).

If patches or subfields are to be treated, section division and control can be used (Christensen et al., 2009). However, as the patch size reduces to a single plant level, sections are not enough and the process is called microspraying because the PPP application is reduced so much that soil is almost not contaminated at all and the PPP residues on the harvested crops is negligible (Midtiby et al., 2011). Another evolution of micro-sprayers is the ones with single drop applications that have shown some development (Lund et al., 2006, Urdal et al., 2014).

5.2.2.2 Real-time sensor based VRPA

These systems control the application rate based on the current situation of pest stress or canopy characteristics, involving both contact and noncontact sensing to identify either pests that need to be controlled or the crop that needs to be protected. According to the type of pest, different sensor types can be used, such as photodetectors, laser scanners, ultrasonic sensors, but also cameras (RGB, multispectral, hyperspectral, thermal) that determine variables such as reflectance, shape, size, texture, colour and temperature of pests. This data is processed, transformed into information and transferred within seconds to actuators to apply the correct PPP dose (Karkee et al., 2013).

5.2.2.3 Spray Drift Reduction Systems

Spray drift reduction systems receive information on environmental parameters (i.e. temperature, wind speed and direction) from weather stations covering the area of interest to change the sprayer settings (spray pressure, nozzle type) based on the sprayer location in relation to vulnerable areas using GNSS receivers (Doruchowski et al., 2009).

5.2.2.4 Boom height control

This system is not a direct VRPA technology, but as it eliminates streaks and improper overlaps and thus improves coverage (Grisso et al., 2011) we consider it in this section. It is a reality that boom sprayers' oscillation above its horizontal axis is very common due to ground speed variation, tyre pressure changes, and ground unevenness. Boom oscillations and vibrations are disastrous for the homogeneity of the spray liquid distribution on the crop, resulting in under- and over-applications of PPPs with, respectively, a missed treatment effect and remaining residues (Hostens et al., 2000). These results could be eliminated by boom height control that improve the uniformity of chemical application (Karkee et al., 2013). To do so, the distance to the ground needs to be measured continuously so that height can be adjusted simultaneously. This is done using utrasonic sensors that are directed to the soil measuring 40 times per second the distance to the ground and have shown quality results even when spraying at 29 km h^{-1}. Except boom sprayers, similar systems can also be used for maintaining the appropriate distance from the crop canopy in orchards and ornamental nurseries (Karkee et al., 2013).

5.2.2.5 Economic Impact of VRPA

It should be noticed that map-based VRPA systems decrease costs mainly due to reduced PPP use, but have increased costs due to operations that conventional spraying does not comply, such as mapping, data processing, decision making, and VRPA technology. However, (Swinton, 2003) pointed out that most research work, up until then, seemed to ignore this fact. Timmermann et al. (2003) explained that VRPA should consider the extra cost of equipment, though it could be considered lower, as most of this gear will be useful for all other precision agriculture activities within a farm. They also explained that more savings are possible from reduced volumes needed per hectare that allow less costs (labour, fuel, machine maintenance) due to less filling and carrying time requirement. Regarding real-time sensor based VRPA, cost reduction can be achieved again from savings on PPP use, but in contrast to map-based VRPA, there is no need for prescription map generation, meaning that cost like powerful computers and GIS software are not included in the investment. On the other hand, the sensors required could be very expensive.

One of the first research attempts on VRPA effect was by Oriade et al. (1996) who worked on weed control using simulation tools. It was found that VRPA could show tangible economic and environmental results only when weed population and level of patchiness were significant. In corn and soybean, they showed cost reduction of 17-33 €/ha and pointed out that in order to shift from conventional weed control practice to VRPA, the cost reduction has to be at least 14 €/ha. However, this simulation model did not take into account costs related to information collection, time effects, and human capital, meaning that the above mentioned benefits would be lower. Gerhards et al. (1999) showed cost potential reduction up to 70% using VRPA for weed control in comparison to conventional sprayers depending on operating conditions. Gerhards and Sökefeld (2003) estimated that weed control using a direct injection system in sugar beet, maize, winter wheat and winter barley, excluding the cost of the sprayer itself, would cost 3.9 €/ha. They also estimated the cost of a camera system for weed detection to 40000 €, showing the increased budget required to go for sensor based VRPA systems. Another part of this work was the economic evaluation of a real-time VRPA weed control system in comparison to conventional spraying, where it was seen that even if the VRPA equipment cost reached 9.56 €/ha and conventional sprayer 5.20 €/ha, the average weed control cost was reduced significantly due to herbicide savings. In winter wheat and barley, the difference was 32 €/ha vs. 68 €/ha, while in sugar beet and maize the change was 69 €/ha vs. 148 €/ha and 96 €/ha vs. 103 €/ha respectively. Furthermore, Timmermann et al. (2003) showed that VRPA for weed control reduced cost of herbicides in many crop types (maize, winter wheat, winter barley and sugar beet, savings of respectively 42 €/ha, 32 €/ha, 27 €/ha, and 20 €/ha). The different level of cost reduction was based on the herbicide price and amount. (Schwarz and Schlauderer, 2004) used an online VRPA system for both herbicide and fungicide application. They used a CROP-meter sensor (cost of about 5000 €) and an ijet gear box (cost of about 25000€) on a modified regular sprayer in wheat and achieved up to 40% and 25% less herbicide and fungicide respectively compared to the standard application rate. This PPP use reduction was translated in an average of 13.2 €/ha and 7.4 €/ha after subtracting the ijet gear box investment cost that need to cover the sensor cost.

Batte and Ehsani (2006) pointed out that mapping of field boundaries including waterways and other physical features increase cost of spraying by 4.5–9.0 €/ha. However, they estimated spray material savings of about 4 €/ha for a map-based spraying system compared to a self-propelled sprayer without any form of guidance system or sprayer control. They also calculated the cost for a precision controlled sprayer, reaching 8000€, pointing out that since most of the costs is related to the fixed investment, when the farm size increase this costs are reduced significantly in a land surface basis. In addition, it was discussed that the price of pesticide, the number of spraying applications and the over-application due to overlapping can increase the profit of VRPA use in comparison to conventional systems. Dammer and Wartenberg (2007) worked on weed detection using an optoelectronic sensor of low cost (about 2000 €) with good results only for operations within the tramline, as the sensor could not separate crops from weeds and they commented that investing in VRPA would be higher if appropriate sensors would be available and cheap. In a study of Vasileiadis et al. (2011) on maize-based cropping systems, experts within Europe evaluated that precision spraying using GPS spray maps can result in a net profit within a time frame of 3-4 years.

From simulations performed by Ramon et al. (1997), it was concluded that both rolling motions and horizontal vibrations of the boom can severely disturb the spray deposition pattern. Local under- and over-applications caused by boom rolling varied between zero and 10 times the desired dose. Horizontal boom vibrations caused variations between 0.3 and 4.0 times the prescribed dose. In practice, this uneven distribution may results in yield losses or in additional pesticide costs, however, no studies were found that calculated these economic effects.

5.2.2.6 Environmental Impact of VRPA

VRPA ecological advantages come mainly from PPP use reduction that decreases the risk of ground and surface water contamination with possible biodiversity increase. Vasileiadis et al. (2013) pointed out that limiting PPP use and providing floral resources and shelter habitats could be a way to increase abundance and diversity of natural enemies, decrease pest damage and increase crop yield and farmer's profit. (Gerhards et al., 1999) reduced herbicide use by about 70% using boom section control of 3m. Heisel et al. (1999) achieved a 54% herbicide reduction in spring cereals, while in winter cereals there was a 50 to 61% reduction (Berge et al., 2007). An average herbicide saving of 54% for weed control in many crop types (maize, winter wheat, winter barley and sugar beet) was reported by (Timmermann et al., 2003). In particular, PPP savings for grass weed control was found to be 90% in winter cereals, 78% in maize, and 36% in sugar beet, while PPP savings for broadleaf weed control were 60% in winter cereals, 11% in maize, and 41% in sugar beet. (Schwarz and Schlauderer, 2004) conducted an analysis based on their trials (see above) and showed significant savings for both VRPA in herbicide and fungicide application respectively of primary energy consumption (0.268 and 0.162 GJ/ha), the greenhouse effect (21.035 and 0.053 kg CO_2eq/ha), the acidification effect (0.011 and 4.19 kg SO_2eq/ha) and the eutrophication effect (0.084 and 0.002 PO_4eq/ha).

Solanelles et al. (2006) prepared a prototype electronic control system for air-assisted sprayers to achieve VRPA on tree crops (olive, pear and apple orchards). It had ultrasonic sensors and proportional solenoid valves and the flow rate adjustment was based on the relationship between the actual tree width measured by the ultrasonic sensors and the maximum tree width in each orchard. Spray volume savings of 70%, 28% and 39% in comparison to conventional spraying were recorded in the olive, pear and apple orchard respectively, combined with better application efficiency. Gil et al. (2007) worked also in permanent crops (vineyards) and used ultrasonic sensors and electro-valves to modify the flow rate from the nozzles in real-time in relation to the variability of the crop width. They concluded in less spray volume of about 58% compared to constant rate application, while coverage and penetration rates remained at the same levels. Llorens et al. (2010)

used the same system as Gil et al. (2007) in three vine varieties at different crop stages and achieved the same average spray volume reduction showing the stability of the system. Chen et al. (2013) used laser scanning to convert an air-assisted sprayer for VRPA in an apple orchard based on the principle of applying PPP according to various tree-canopy characteristics. The VRPA sprayer achieved adequate spray canopy coverage by consuming 27-53% of the spray mixture in comparison to the conventional sprayer. Dammer and Wartenberg (2007) used a reflectance based weed sensor and a multiple nozzle body with four nozzle types for flow rate adjustment and managed to have average herbicide savings of 22.8% and 27.9% in cereals and pea respectively. Dammer and Adamek (2012) used the same multiple nozzle body and a CROP-meter sensor for insect control and achieved average insecticide saving of 13.4% compared to a conventional spraying.

The amount of soil herbicides used in crops can be reduced by adjusting the dosage to the local soil condition. In particular, soil herbicides are more effective in zones where soil organic matter and/or lutum content content are low. The application rate of soil herbicides can be lowered in those zones without affecting their efficacy. Reductions in herbicide use in The Netherlands are reported of between 20 and 40% (Heijting and Kempenaar, 2013, Kempenaar et al., 2018, Kempenaar et al., 2014).

Detection of weeds with cameras allows usage reduction of 6-81% for herbicides against broad leaved weeds and 20-79% for herbicide against grass weeds (Gerhards and Oebel, 2006).

Finally, it is worth noting that the reduction in pesticide usage is in part dependent on the spatial scale at which the weed or pest occurs, the scale at which detection takes place, and the scale at which application takes place. For potato haulm killing in The Netherlands, it was demonstrated that 3 L ha^{-1} of haulm killing agent was needed when the field was treated uniformly, 2.2 L ha^{-1} was needed when decisions were made for blocks of 30×30 m^2 (full sprayer width), and 1.8 L ha^{-1} was needed when blocks of 15 × 15 m^2 were used (sprayer with section control) (Van Evert et al., 2012).

5.2.2.7 Social Impact of VRPA

Operator exposure to the applied PP can be reduced using VRPA with separate chemical tank due to avoidance of preparing the PPP mix with the carrier (Humburg, 2003). In addition, operators can reduce field working hours due to lower tank filling time, as the volume needed per hectare is reduced with VRPA technologies (Timmermann et al., 2003). However, using map-based technologies increase desk labour to prepare the prescription maps.

Regarding the public concern about extensive PPP use, VRPA can make a big difference (Dammer and Wartenberg, 2007), something that was proven by European experts in terms of social awareness of their environmental and health impact, and safety of agricultural products (Vasileiadis et al., 2011). Society may also benefit through reduced cost of food and fiber due to reduced PPP use (Batte and Ehsani, 2006) and through providing the consumer with information regarding PPP applications, for example for PPP-free products (Swinton, 2003).

5.2.3 VRA irrigation

Irrigation have been in practice for centuries, however the efficiency of water use in most cases is not as high as it could be. If this is combined with the fact that over 70% of global water use is due to agriculture (OECD, 2018), then the need of high-efficiency irrigation systems becomes a social demand.

The most frequently used irrigation systems are self-propelled systems and micro-irrigation systems. The first category comprises centre pivot and lateral move systems that apply water to crops using sprinklers, in principle from above their canopy (Berne, 2015). (Colaizzi et al., 2009) reported that 72% of the irrigation systems installed in the USA during 2000 used sprinklers. The second category comes in three types, namely (i) drip and tickle emitters, (ii) micro-sprinkling and micro-spray and (iii) subsurface irrigation. It is mainly directed to areas with water scarcity, because they have a better water use efficiency, as irrigation is applied on the soil surface and water drift and evaporation are excluded from the action. In addition, according to (Camp, 1998) micro-irrigation can provide higher yields and lower pesticide use due to no contact of irrigation water with the crop canopy and due to warmer soil temperature (with subsurface systems) compared to sprinkler systems. However, these systems have higher investment costs and they are mainly useful for high-value crops, such as orchards and vineyards.

5.2.3.1 Technology

Variable rate irrigation (VRI) is defined as the ability to spatially vary water irrigation application quantities within a field to address specific soil, crop, and/or other conditions. Regular centre pivot and linear-move systems are ideal platforms upon which site-specific irrigation management technologies could be applied by differentiating speed and sprinklers water quantity. The opportunity is even higher due to their current and increasing usage, large area of coverage, and relatively high degree of automation (King et al., 2005).

A common technology used to assess the water quantity to be applied in a field is to assess plant water stress by using sensors that can monitor thermal part of the spectrum. In particular, by measuring the thermal radiation of the plants it is possible to inversely correlate between plant leaf temperature and stomatal opening and identify the stress. Other technology advancements that can be used in VRI systems are wireless networks with low-voltage sensor and radio frequency data communications that can provide clear view of the in-field water status and offer tremendous opportunities for the development and application of real-time management systems for agriculture (Evans et al., 2013).

Research and development have been focused on optimising centre pivot systems control by varying water quantity to different field parts using soil water and plant sensors and incorporating GNSS technology. Data from sensors can be transformed into information of spatial and temporal in-field variation resulting in automatic site-specific irrigation scheduling. This enhancement provides better water use efficiency and possible higher yield and quality, but increasing cost significantly. It should be noted that such a distributed in-field sensor-based site-specific irrigation system requires the seamless integration of sensor fusion, irrigation control, data interface, software design, and communication that can be highly challenging. In addition, irrigation quantity accuracy according to what the system prescribes is critical to convince about the quality of VRI systems (O'Shaughnessy et al., 2013).

There are commercial variable rate irrigation (VRI) systems that can be retrofitted onto existing moving sprinkler systems. Variable water quantities can be delivered along the lateral by either using parallel sprinkler control (King et al., 1999, McCann et al., 1997) or multiple manifolds that are valved separately (Omary et al., 1997, Stone et al., 2006). Another way to regulate water site-specifically is to change the flow of each sprinkler drop hose by placing a hydraulic valve above each hose and controlling their on/off cycle (Chávez et al., 2010, Dukes and Perry, 2006, Han et al., 2009). Finally, a third technology was designed and tested by King and Kincaid (2004) that use cycling of a retractable pin in and out of the nozzle to change the cross-sectional area of a sprinkler nozzle.

Regarding micro-irrigation, most orchards planted within the past 15 years use micro-irrigation for both water and nutrient delivery, and many older orchards that currently use flood or sprinkler irrigation are being converted to micro-sprinklers to reduce costs, because both water use efficiency and leaching of nutrients reduction can be achieved by this irrigation method. However, to convert these systems into VRI there is a need to primarily assess the distance between emitters and their flow rates according to the soil's water capacity and status in combination with the crop's water needs. This was not extensively investigated and (Thorburn et al., 2003) have identified the need for site-specific soil information to design efficient micro-irrigation systems.

Coates et al. (2006) designed a variable rate micro-sprinkling system in an orchard to irrigate individual trees for specific durations or to apply a specific volume of water at each tree. The system used a micro-sprinkler sensor and a control system combined with a valve with individually addressable micro-sprinkler nodes, located at every tree to provide spatially variable delivery of water. Each node was commanded by a drip line controller that was fed by the information given in the stored irrigation schedule. Lateral line pressure feedback was provided by installing pressure sensors connected to selected nodes. A series of parameters that affect orchard yield were taken into account, such as tree stress, soil type, topography, water and nutrient availability, diseases and pests, tree size and age, alternate bearing, and individual tree genetics. In order to quantify the impact of these parameters, remote sensing techniques were used (e.g., normalized difference vegetation index), combined with soil sampling, yield monitoring, and growth measurements.

McClymont et al. (2012) have worked on a zonal irrigation system with emitters in a Shiraz vineyard in Australia. Primarily, data was collected under uniform irrigation management to identify spatial variation in canopy cover, yield and fruit composition across the vineyard and using NDVI and canopy temperature data three irrigation management zones were delineated and the irrigation strategy was decided. Water use efficiency and yield improvements were achieved by implementing site-specific irrigation, but the impact on quality parameters remained unclear.

Sams et al. (2015) have proposed a modular irrigation system for drip emitters in vineyards of California, USA that is fed with information regarding topography (aspect, elevation and slope), chemical and physical properties, soil texture, water holding capacity, pH, and nutrient content. Based on the fact that significant correlations were found between yield and grape quality and these parameters, a variable rate irrigation system with drip hoses was installed in a cabernet sauvignon vineyard in 2012 and it was consisted of two master valves to separate the field in two parts, flow meters in the start of each irrigation line and a series of solenoid valves in between the line. The irrigation scheduling was calculated using input from the visible and infrared sensors of Landsat satellite and weather data from a meteorological station to measure the evapotranspiration. The results were encouraging as the system was technically even, while in the first season VRI decreased vineyard variability and increased water use efficiency and in the second season VRI increased yield in low yielding vines and maintained high water use efficiency

Nadav and Schweitzer (2017) performed VRI at a semi-arid Israeli Syrah vineyard with precipitation only during the winter that used to be irrigated by a single on-surface dripper-line located in the vine row. Certain parameters were measured for 2 years before the VRI system was installed, namely stem water potential (SWP), leaf area index (LAI) and normalized difference vegetation index (NDVI). The vineyard was split in 12 zones and the VRI system was consisted of one electric valve for each zone and a main controller. After its deployment, total yield increased by 17% and water consumption fell by 20% compared to conventional single zone irrigation, due to the variable allocation of water across the different irrigation zones.

5.2.3.2 Economic Impact of VRI

Amosson et al. 2011 worked on the economic results of irrigation systems, analysing the economic impact of the techniques described above, but VRI was included in their work. Lambert and Lowenberg-De Boer (2000) reported that VRI had a positive economic impact on corn production through higher yields and lower water use, but it was not described numerically. There is a series of research work, where VRI high costs together with higher yield, lower water and pesticide use are mentioned especially in climatic unfavourable years, but again comparable figures were not given (Booker et al., 2015, Colaizzi et al., 2009, Evans et al., 2013, Sadler et al., 2005).

5.2.3.3 Environmental Impact of VRI

Evans and King (2010) have simulated a centre pivot system run with zone control in comparison to a conventional one and reported water saving of 0 - 26%. They pointed out that water savings depend on the soil type, with light soils producing better results in water saving compared to heavy soils. Another environmental parameter that VRI could provide significant positive impact would be soil N_2O emission. A review by Trost et al. (2013) compared irrigated and non-irrigated fields and showed that availability of reactive nitrogen compounds controls increased N_2O emissions under irrigation, ranging between 50% and 140%.

5.2.3.4 Social Impact of VRI

The main motive for VRI adoption is the reduction in work load. Therefore, the latest and most expensive and knowledge demanding site-specific controllers and sensors are currently not much used. This might change when water supply is more scarce or when the efficient use is licensed.

5.2.4 Auto-steer and GPS-based application of seed, chemicals, manure, fertilizer

The main advantages of auto-steer are that it reduces worker fatigue and avoids overlapping trajectories in the field. Less overlap means that less driving is needed and fuel is saved. Less overlap also means a reduction in fertilizer and pesticide use and it leads to a more even crop or more even crop protection. These advantages are easily understood and have been docuemented to some extent. Reductions in overlap between 2.3 and 6% have been reported (Bora et al., 2012, Ehsani et al., 2001, Shannon and Ellis, 2012, Shinners et al., 2012). It has been reported that the cost of a GPS-based guidance system could be recovered by considering fuel savings alone (Shannon and Ellis, 2012).

When automatic route planning is used in addition to GPS guidance, 8% energy saving was reported (Rodias et al., 2017).

Automatic guidance is also an enabling technology for controlled traffic farming (CTF) (Pedersen and Lind, 2015).

5.2.5 (Semi-) autonomous, non-chemical weed control

Development of autonomous systems for weed control, including weed detection and removal, has been one of the major fields of research in agricultural robotics in the last few decades (e.g. Choi et al., 2015, Gonzalez-de-Soto et al., 2016, Midtiby et al., 2016, Oberti et al., 2016, Pantazi et al., 2016, Perez et al., 2000, Thompson et al., 1991, Torres-Sospedra and Nebot, 2014, Van Evert et al., 2011). Many of these systems have been evaluated in realistic field conditions with results reported in the scientific literature

Despite the above, to date only a few (semi-)autonomous robotic weed control systems have been commercialized. To our knowledge, only a few systems are currently commercial, e.g. Steketee IC weeder (Steketee, 2017), Robovator (Poulsen, 2017) and Robocrop (Garford, 2017), while the "lettuce bot" is used for thinning rather than weeding (Blue River Tech, 2017). Several more robotic weed control systems are under development (Deepfield Robotics, 2017, Ecorobotix, 2017, Naïo Technologies, 2017) .

Currently, many (semi-)autonomous weed control systems have significant drawbacks in terms of flexibility, efficiency, robustness, operator cost and capital investment. For example, they are typically unable to operate on fields containing bed-planted or full-cover crops. The Ecorobotix solution uses (microdose) herbicide application and does not offer a solution for organic farmers, while Deepfield Robotics' mechanical stamping actuator ("puncher") to control weeds suffers from limitations regarding speed, robustness, reliability, and permitted location of the weeds. Current systems are not completely autonomous, as has been pointed out in a critical review (Merfield, 2016).

The technology of (semi-)autonomous non-chemical weed control is not yet fully mature, but the prospective advantages are huge. In crops where currently hand-weeding is used, these systems are poised to enable a large reduction in labour and the associated costs. In the UK, the typical costs of hand-weeding lettuce is £350 ha^{-1} for each pass or up to £2,200 ha^{-1} over the full cropping cycle.

In The Netherlands, new weed control systems are needed, for example, in onions. Onion is a relatively slow growing crop where the foliage stays open for quite a long time. Consequently, many weeds develop more quickly than the onion. Weed control between the rows can be done quite effectively by using harrows and finger and torsion weeders but the main issue is the weed control in the row: weeding by hand to remove only the weeds in the row takes on average 135 hours per ha per year, but in bad situations this number may reach 200 hours per ha per year.

In dairy farming, broad-leaved dock (*Rumex obtusifolius* L.) is an important weed which will overgrow large parts of the pasture if left uncontrolled. Conventional farmers use a selective herbicide once every few years to control this weed but organic dairy farmers need to rely on hand-weeding. Some organic dairy farmers report that they will switch back to conventional farming if they cannot find a solution for broad-leaved dock (Van Evert et al., 2011).

5.3 Summary

Sections 5.1 and 5.2 contain a large amount of information that may easily overwhelm the first-time reader. Therefore we present the information from these Sections in condensed form in three tables below. Soil recording and mapping technologies are summarized in Table 18, crop recording and mapping technologies are summarized in Table 19, and actuation technologies are summarized in

Table 20.

Table 18. Summary of soil recording and mapping technologies. Entries are summarized from the literature cited in the main text.

SFT	Soil property	Accuracy
EC	Clay content/soil texture	5 percentage points (differentiate between texture classes clay, sandy loam, loamy sand, clay loam, sand, fine clay)
	Organic matter content	5 percentage points
	Soil moisture	0.05 m^3 m^{-3}
	pH	Depends on link to soil texture
	CEC	Depends on link to soil texture
	Salinity	Depends on link to soil texture
VIS/NIR spectroscopy	SOC	0.7 percentage points (in situ)
	SOM	Between 0.3 and 10 percentage points
	Clay	5 percentage points
	pH	0.5 unit
	CEC	16 meq per 100 g
	Sand	10-20 percentage points
	Soil moisture	2.8 percentage points
Gamma-ray	Clay	2-5 percentage points
	SOM	2-10 percentage points
	Median grain size	30 percentage points
	Loam content	10 percentage points
	Other nutrients, pH, CEC	Only possible when relation with texture is present
Ground penetrating radar	Texture/topsoil depth	Insufficient information available
	Water content	Insufficient information available
	Salinity	Insufficient information available
	Compaction	Insufficient information available
pH-sensor	pH	0.2 unit
Remote sensing	Soil moisture content	Insufficient information available

Table 19. Summary of crop recording and mapping technologies. Entries are summarized from the literature cited in the main text

SFT	Crop property	Accuracy
Canopy reflectance	N uptake	15-30 kg N m^{-2}
	LAI	5 percentage points
	Ground cover	5 percentage points
Remote sensing radar	Biomass	1 t ha^{-1}
	LAI	0.3 units

Table 20. Summary of actuation technologies. Entries are summarized from the literature cited in the main text.

SFT	Crop	Input use reduction	Effect on yield and/or quality	Effect on profitability
Fertilizer				
VRA N	Wheat and maize. Europe and US	15%	More even ripening and crop drying results in better harvesting	Slightly positive effect
VRA N	Potato	15%	More even ripening results in less tuber damage at harvest	No significant effect
Pesticide				
VRA soil herbicide (pre-emergence)	Potato, onion	20-40%	Some yield increase if herbicide damage to the crop is reduced	Large positivev effect if the pesticide is expensive
Herbicide (post-emergence, map-based)	Many crops	10-80%	No significant effect	Positive effect
Herbicide (post-emergence, on-the-go)	Many crops	10-80%	No significant effect	Positive effect
Potato haulm killing herbicide	Potato	20-47%	No significant effect	Positive effect
Fungicide	Late blight in potato in The Netherlands	20-30%	No significant effect	Positive effect
Irrigation				
VRA irrigation		Up to 26%	Possible increase	Positive effect
Auto-steer and guidance systems				
Auto-steer		5% (fuel, fertilizer, pesticides)	More even crop	Positive effect
(Semi-)autonomous non-chemical weed control				
Weed control systems		100%	Organic farming within reach	No reliable information available

6 Factsheets

The Smart-AKIS platform displays information about SFTs in the form of “technology cards”: visually attractive pages with a summary description of the technology and a few key performance indicators. We have created for each SFT an additional web page and pdf document where all the information from the survey is given. These detail pages (“factsheets”) can be reached from the technology cards. An example is given in base. Factsheets can be downloaded, stored and distributed. If they are distributed, they will advertise the existence of Smart-AKIS, because each page/pdf document contains a hyperlink to the SFT’s main entry point on the Smart-AKIS platform.

7 Discussion and conclusions

In this report information is given about the inventory of SFTs and an analysis of the results. We have identified 1064 SFTs. The majority of these are scientific papers.

The analysis of the collected research and commercial SFTs revealed that the majority of the SFTs in academic research are focused on monitoring and mapping of crops and soils. In the commercial sector, this is more balanced, probably because users are more likely to buy solutions which can be put into practice. This seems to indicate that there is a knowledge gap between measuring the status of crop and soils on the one hand, and using that information to make practical decisions in farming on the other hand. Therefore, research is needed to provide the knowledge that will allow recording and mapping SFTs to be applied in practice. In particular, more research is needed to provide algorithms for variable rate pesticides, variable rate fertilizers, as well as variable rate seeding and tillage. It is expected that robots for weed control and other field operations will deliver large benefits in terms of reducing labour demand and input use. But at present, few SFTs can be classified as “robotic”. The share of research papers focusing on robotics is increasing but is at the moment still small.

The majority of commercially available SFTs lead to higher productivity and profitability, sometimes with reduced emissions as a side-effect. There are few SFTs directly improving sustainability (e.g. biodiversity, soil compaction). Commercially available SFTs often target larger farms, while SFTs investigated in applied research projects are applicable on smaller farms, as well as larger farms.

From the work in other work packages of this project, we know that issues related to data management, such as ownership, transfer, sharing, security, privacy and exploitation, are of high importance to the stakeholders. Few SFTs explicitly address these issues. This is not surprising because these issues are for a large part organizational issues that cannot be solved by technology alone.

When we take a broad view, it is clear that technical, social and legal barriers related to collecting, storing and transferring data hinder farmers' transition to digital agriculture. Farmers do not always have access to effective tools and approaches for "letting the data flow" from the point where it is collected, to data storage, to decision making, and then send a prescription map to the tractor or farm implement for actuation.

Data access and transfer associated to the use of FMIS and decision software is one of the technical barriers faced by farmers. Interoperability is another technical barrier frequently encountered by farmers. Connections between machines typically use the worldwide ISO 11783 (ISOBUS) standard which defines the communication between agricultural machinery and also the data transfer between these machines and farm software applications. Files in ISO-XML format are used to deliver data to or export data from an ISOBUS system. Unfortunately, the standard leaves room for interpretation so that in practice many incompatibilities arise when farmers buy equipment from different manufacturers.

The above issues are technical, but legal and social issues related to agricultural data, such as data ownership, access, control, security, etc. have been enumerated (Kritikos, 2017). Farmers' personal data is protected by current personal data regulations but the ownership of equipment-generated data raise concerns among farmers and other agricultural stakeholders. Data security in agriculture, and privacy implications resulting from a security breach, are a major concern for the digitization process of agriculture (Ferris, 2017). In recent years many data breaches have targeted governments, businesses, and individuals. The large number of devices and connections used in precision agriculture renders the complete system vulnerable.

Data-based decision tools can bring benefits to farming but ethical questions must be asked about the consequences of changes in power relations that may follow the introduction of big data SFTs in agriculture and food production. Mepham's ethical matrix (Mepham, 2005) has been used to systematically examine ethical questions in agriculture and biomedical practice. An ethical issue is that in some cases data is provided by citizens (farmers), yet the information is primarily benefiting commercial actors. Another ethical issue is that farmers with limited resources, such as rural smallholder farmers, may not be able to make the investments that are necessary to reap the benefits of data-based tools.

Farmers are willing to exchange their data if they see the benefit on it and they understand the risks. Data sharing agreements already exist, such as the New Zealand Farm Data Code of Practice[21], the Privacy and Security Principles for Farm Data published by American Farm Bureau Federation and underwritten by dozens of companies[22], and the code of conduct drawn up by farmers' cooperatives and processors of potatoes and sugar beet in The Netherlands[23]. In Europe, a European Code of Conduct as a result from a consensus among Copa-Cogeca, CEMA, agricultural contractors and "Fertilisers Europe" will be published early 2018. This Code of Conduct will include guidelines and areas for improvement contributing to the building of an EU data economy.

We conclude that the inventory of SFTs described in this report is important in the sense that it provides farmers with an opportunity to acquaint themselves with the SFTs that are available, but that this is not enough. A follow-up to the present work is needed in which an inventory is created of data-related technologies, practices, standards, and agreements.

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9 APPENDIX I Queries

9.1 Projects selection query

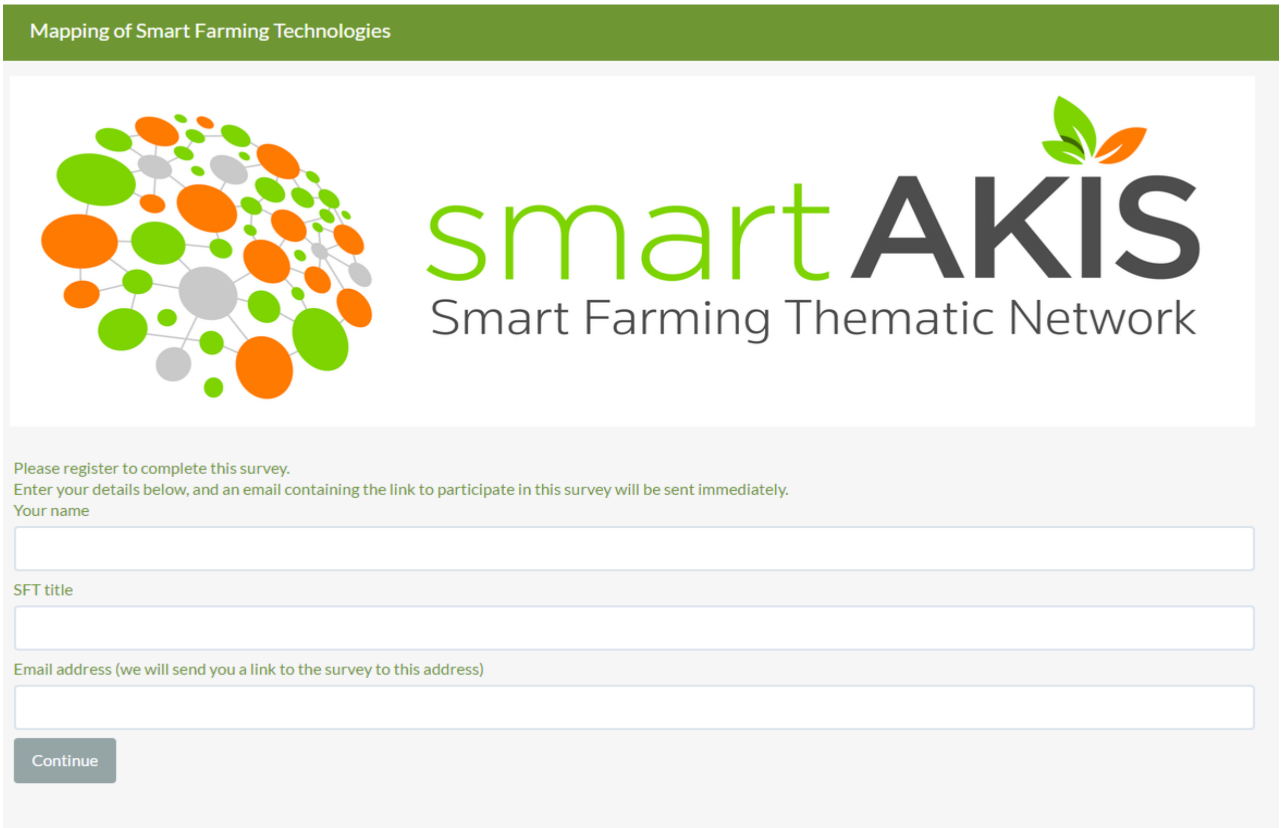
SELECT * FROM eu_projects

WHERE (lower(eu_projects.objective) ~~ '%sensor%'::text OR lower(eu_projects.objective) ~~ '%automat%'::text OR lower(eu_projects.objective) ~~ '%decision-support%'::text OR eu_projects.objective ~~ '%dss%'::text OR lower(eu_projects.objective) ~~ '%database%'::text OR lower(eu_projects.objective) ~~ '%ict%'::text OR lower(eu_projects.objective) ~~ '%autonom%'::text OR lower(eu_projects.objective) ~~ '%robot%'::text OR lower(eu_projects.objective) ~~ '%gps%'::text OR lower(eu_projects.objective) ~~ '%gnss%'::text OR lower(eu_projects.objective) ~~ '%information system%'::text OR lower(eu_projects.objective) ~~ '%image analysis%'::text OR lower(eu_projects.objective) ~~ '%image processing%'::text OR lower(eu_projects.objective) ~~ '%precision agriculture%'::text OR lower(eu_projects.objective) ~~ '%smart farming%'::text OR lower(eu_projects.objective) ~~ '%precision farming%'::text) AND (lower(eu_projects.title) ~~ '%agricult%'::text OR lower(eu_projects.title) ~~ '%crop%'::text OR lower(eu_projects.title) ~~ '%arabl%'::text OR lower(eu_projects.title) ~~ '%farm%'::text OR lower(eu_projects.title) ~~ '%vineyard%'::text OR lower(eu_projects.title) ~~ '%orchard%'::text OR lower(eu_projects.title) ~~ '%horticult%'::text OR lower(eu_projects.title) ~~ '%vegetabl%'::text);

9.2 Scopus query

(TITLE-ABS-KEY(sensor or decision-support or dss or database or ict or automat* or autonom* or robot* or gps or gnss or "information system" or "image analysis" or "image processing" or "precision agriculture" or "smart farming" or "precision farming")) and (TITLE-ABS-KEY(agricult* or crop* or arabl* or farm* or vineyard or orchard or horticult* or vegetabl*)) AND (LIMIT-TO(PUBYEAR,2001)) AND (LIMIT-TO(DOCTYPE,"ar") OR LIMIT-TO(DOCTYPE,"re")) AND (LIMIT-TO(SUBJAREA,"AGRI") OR LIMIT-TO(SUBJAREA,"ENGI"))

10 APPENDIX II Survey



Mapping of Smart Farming Technologies

smart AKIS
Smart Farming Thematic Network

Please register to complete this survey.
Enter your details below, and an email containing the link to participate in this survey will be sent immediately.

Your name

SFT title

Email address (we will send you a link to the survey to this address)

Continue


Mapping of Smart Farming Technologies
Exit and clear survey
smart AKIS
Smart Farming Thematic Network
Mapping of Smart Farming Technologies
Aim of Smart AKIS:
Smart-AKIS is a European Network mainstreaming Smart Farming Technologies among the European farmer community. The project will collect existing knowledge related to Smart Farming Technologies and will produce easily accessible end-user material under the EIP-Agri common format. The project will also integrate the socio-economic aspects involved in the innovation processes and will bridge the gap between practitioners and research on the identification and delivery of new Smart Farming solutions fit to the farmers' needs.
Goal of this survey:
The goal of the project is mapping of relevant existing research results, projects and products all across Europe whose scope are Smart Farming Technologies. The Inventory of all collected Smart Farming Technologies will allow searching available categories of solutions, so the end-users can easily find and implement them in their working routine.
Next

Mapping of Smart Farming Technologies

Resume later   Exit and clear survey   Question index

smart AKIS
Smart Farming Thematic Network

General - Identity

*** What is your SFT?**

- (•) Product
- ( ) Project
- ( ) Article

*** Is this the first time you are filling in this questionaire?**

[Yes] [No]

*** Company name**

*** Legal name of the company**

*** Street name and number**

* Postal code

* City

* Country

Please choose...

* Number of employees

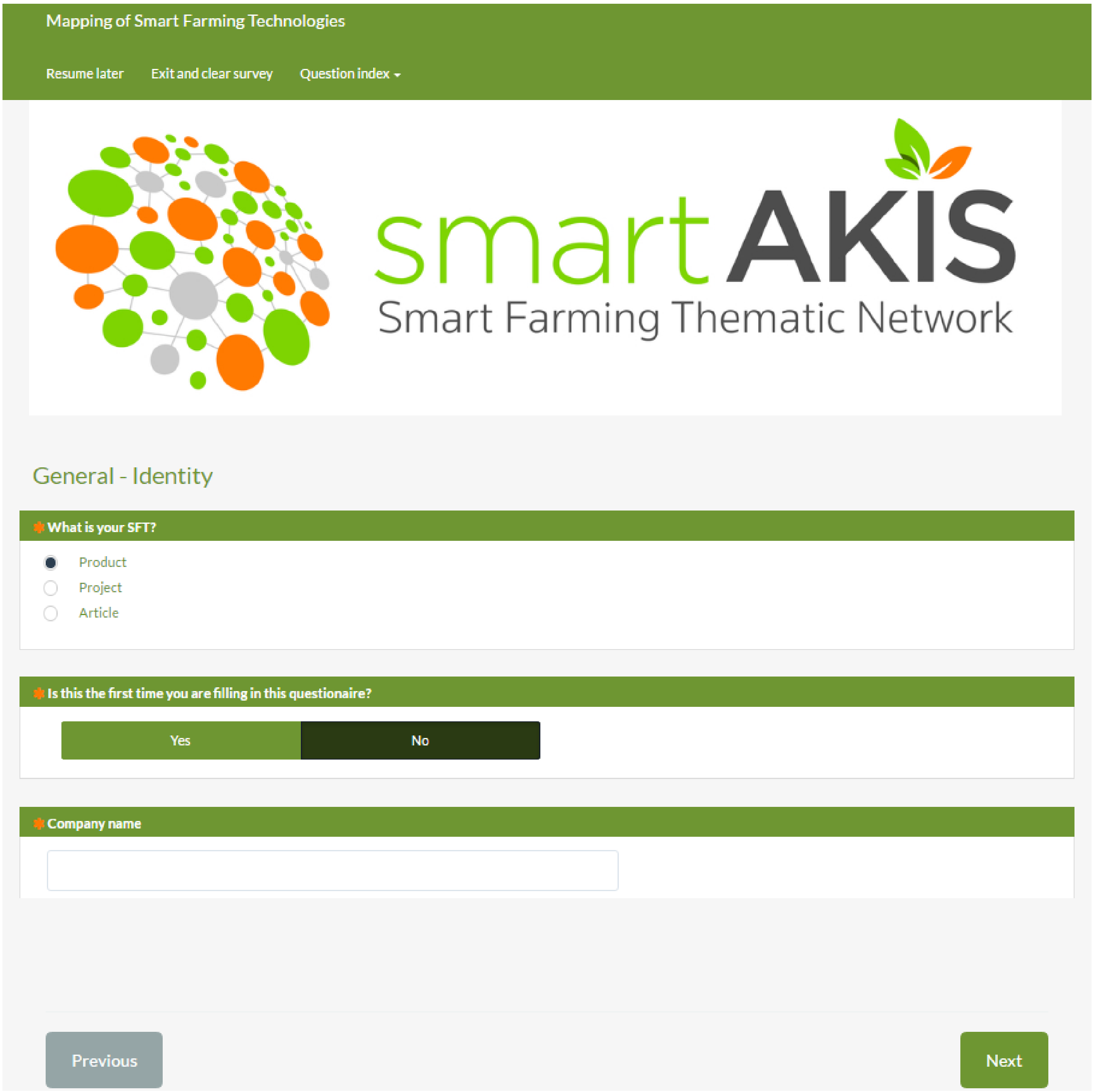
- 1 - 10
- 11 - 50
- 51 - 100
- 101 - 500
- 501 - 1000
- 1001 - 10000
- 10000+

* Establishment (month, year)

* Value proposition/ Unique selling points

Previous

Next


Mapping of Smart Farming Technologies

Resume later | Exit and clear survey | Question index

smartAKIS
Smart Farming Thematic Network

General - Identity

* What is your SFT?

- (•) Product
- ( ) Project
- ( ) Article

* Is this the first time you are filling in this questionaire?

Yes | No

* Company name

Previous | Next

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smartAKIS Smart Farming Thematic Network

General - Identity

*** What is your SFT?**

- ○ Product
- ● Project
- ○ Article

*** Project name**

*** Project coordinator**

Coordinator's email address

Project partners

Enter no more than 90 partners. Once you fill in the existing field, a new empty field will appear. Please enter one partner per field.

*** Project period**

Start of the project (year)

End of the project (year)

Project status

- ongoing
- finished

Funding source

- EU - H2020
- EU - FP7
- EU (other)
- National
- Industry
- Self-funded
- Other:

Total budget
Only numbers may be entered in this field.

Final report

Please provide a link to the final report.

Objective of the project (native language)

Please enter up to 300 words.

Objective of the project (in English)

Please enter up to 300 words.

Description of the context

Please enter up to 300 words.

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General - Identity

What is your SFT?

- Product
- Project
- Article

Title of the article

* Author(s)

* Source (Journal / proceeding)

* Year of publication

Your answer must be between 1950 and 2017

Only an integer value may be entered in this field.

DOI (Digital Object identifier)

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SFT basic information

Name of the SFT (native language)

*** Name of the SFT (in English)**

*** Please check the keywords that describe your SFT?**
This question is mandatory
Please check at least one item.

- ☐ Agricultural production system
- ☐ Farming practice
- ☐ Farming equipment and machinery
- ☐ Plant production and horticulture
- ☐ Fertilisation and nutrients management
- ☐ Soil management / functionality
- ☐ Water management
- ☐ Climate and climate change
- ☐ Energy management
- ☐ Waste, by-products and residues management
- ☐ Biodiversity and nature management
- ☐ Farming/forestry competitiveness and diversification

Please give up to 5 additional keywords that describe your SFT

*** Please refer to the Eurostat NUTS classification to indicate where this SFT is intended to be used.**

Please visit Eurostat NUTS classification website.
Structure your answer using the following examples:
EU = SFT is used in all or most of Europe
FR = SFT is used in all of France
FR5 = SFT is used in France NUTS-1 region 5 ("Ouest")
FR52 = SFT is used in France NUTS-2 region 52 ("Bretagne")
FR524 = SFT is used in France NUTS-3 region 524 ("Morbihan")
Two or more regions may be indicated as follows:
FR, NL22, NL321

Other geographical location

If your SFT is specific to one or more cropping systems, please specify which one(s)?

- ☐ Arable crops
- ☐ Tree crops
- ☐ Open field vegetables
- ☐ Vineyards
- ☐ Grassland systems

If your SFT is specific to one or more crops, please specify which one(s)?

- ☐ arable crop
- ☐ grassland crop
- ☐ horticulture crop
- ☐ perennial crop

*** In what kind of field operations is this SFT meant to be used?**

This question is mandatory
Please check at least one item.
If you choose 'Other:' please also specify your choice in the accompanying text field.

- ☐ tillage
- ☐ sowing
- ☐ transplanting
- ☐ fertilization
- ☐ pesticide application
- ☐ weed control
- ☐ pest and disease control
- ☐ irrigation
- ☐ harvesting
- ☐ post-harvest storage
- ☐ scouting of crop and/or soil
- ☐ Other:

*** Who will use the SFT?**

This question is mandatory
Please check at least one item.

- ☐ Farmer
- ☐ Contractor
- ☐ Supplier
- ☐ Buyer of farm products
- ☐ Processor of farm products

*** How close to the market is this technology? (TRL - Technology Readiness Level)**

Please choose...

Patent status

no patent

Links to other websites

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SFT details

Description of the SFT (native language)

Please enter up to 300 words.

*** Description of the SFT (in English)**

Please enter up to 300 words.

*** Objective of the SFT**

Please enter up to 300 words.

Audio/visual material

- ○ The material is online, I would like to provide a link.
- ● I would like to upload material
- ○ No material available

Audio/Visual material (upload)

Please upload at most one file

Upload files

Website (company, article)

Website for this SFT

Please estimate the total area in Europe (ha) on which this SFT is being used.

This SFT has the following effect on:

	Large decrease	Some decrease	No effect	Some increase	Large increase	If possible, please quantify percentage of change
Productivity (crop yield per ha)	○	○	●	○	○	
Quality of product	○	○	●	○	○	
Revenue, profit, farm income	○	○	●	○	○	
Soil biodiversity	○	○	●	○	○	
Biodiversity (other than soil)	○	○	●	○	○	
Input costs	○	○	●	○	○	
Variable costs	○	○	●	○	○	
Post-harvest crop wastage	○	○	●	○	○	
Energy use	○	○	●	○	○	
CH4 (methane) emission	○	○	●	○	○	
CO2 (carbon dioxide) emission	○	○	●	○	○	

N2O (nitrous oxide) emission	○	○	●	○	○	
NH3 (ammonia) emission	○	○	●	○	○	
NO3 (nitrate) leaching	○	○	●	○	○	
Fertilizer use	○	○	●	○	○	
Pesticide use	○	○	●	○	○	
Irrigation water use	○	○	●	○	○	
Labor time	○	○	●	○	○	
Stress or fatigue for farmer	○	○	●	○	○	
Amount of heavy physical labour	○	○	●	○	○	
Number and/or severity of personal injury accidents	○	○	●	○	○	
Number and/or severity of accidents resulting in spills, property damage, incorrect application of fertiliser/pesticides, etc.	○	○	●	○	○	
Pesticide residue on product	○	○	●	○	○	
Weed pressure	○	○	●	○	○	
Pest pressure (insects etc.)	○	○	●	○	○	
Disease pressure (bacterial, fungal, viral etc.)	○	○	●	○	○	

*** This SFT is a:**

	Yes	No
Recording or mapping technology	○	○
Reacting or variable rate technology	○	○
Guidance or Controlled Traffic Farming technology	○	○
Farm Management Information System application or App	○	○
Robotic system or smart machine	○	○

Please indicate the price of this SFT (in local currency; please indicate currency)

In case the price is not defined, write NA.

	strongly disagree	disagree	no opinion	agree	strongly agree
This SFT replaces a tool or technology that is currently used. The SFT is better than the current tool.	○	○	●	○	○
The SFT can be used without making major changes to the existing system	○	○	●	○	○
The SFT does not require significant learning before the farmer can use it	○	○	●	○	○
The SFT can be used in other useful ways than intended by the inventor	○	○	●	○	○
The SFT has effects that can be directly observed by the farmer	○	○	●	○	○
Using the SFT requires a large time investment by farmer	○	○	●	○	○
The SFT produces information that can be interpreted directly (example of the opposite: the SFT produces a vegetation index but nobody knows what to do with it)	○	○	●	○	○

Who will use this SFT?

- ☐ all farmers
- ☐ Farmers with primary education
- ☐ Farmers with secondary education ("high school")
- ☐ Farmers with apprenticeship and/or technical school
- ☐ Farmers with university education
- ☐ Other:

On what size farm do you think this SFT will be used?

- ☐ < 2 ha
- ☐ 2 - 10 ha
- ☐ 11 - 50 ha
- ☐ 51 - 100 ha
- ☐ 101 - 200 ha
- ☐ 201 - 500 ha
- ☐ > 500 ha

Additional information

Additional comments

11 APPENDIX III Example factsheet

THIS PROJECT HAS RECEIVED FUNDING FROM THE **EUROPEAN UNION'S HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME** UNDER GRANT AGREEMENT N. 696294

biosensors as monitoring tools to assess soil restoration

Title	biosensors as monitoring tools to assess soil restoration
Title (native language)	
Category	• Farm Management Information System
Short summary for practitioners (Practice abstract) in English)	isotope techniques for process and performance assessment of nutrient treatment in bioreactor and land drainage systems. Developing novel farm-scale bioreactor and nutrient recycling technologies for resource (N, P) recovery/re-use and mitigating point source and diffuse C, N and P emissions may apply considerable savings in fertiliser usage and therefore costs.
Short summary for practitioners	
Website	
Audiovisual material	
Links to other websites	
Additional comments	
Keywords	Soil management / functionality | Water management | Climate and climate change | Waste, by-products and residues management
Additional keywords	low input lab method, soil analysis, water analysis
Geographical location (NUTS)	EU
Other geographical location	

Cropping systems	
Field operations	
SFT users	Farmer | Contractor
Education level of users	
Farm size (ha)	0-2 | 2-10 | 10-50 | 50-100 | 100-200 | 200-500 | >500

Project info

Project name	INSPIRATION: Managing soil and groundwater impacts from agriculture for sustainable intensification
Project coordinator	THE UNIVERSITY OF SHEFFIELD (UK)
Project partners	IWW RHEINISCH-WESTFALISCHES INSTITUT FUER WASSER BERATUNGS-UND ENTWICKLUNGSGESELLSCHAFT MBH | UNIVERSITE DE LIEGE | EIDGENOESSISCHE ANSTALT FUER WASSERVERSORGUNG ABWASSERREINIGUNG UND GEWAESSERSCHUTZ | WAGENINGEN UNIVERSITY | POLITECHNIKA WARSZAWSKA | GEOLYS | HELMHOLTZ-ZENTRUM FUER UMWELTFORSCHUNG GMBH - UFZ | T.E. LABORATORIES LIMITED | TEAGASC - AGRICULTURE AND FOOD DEVELOPMENT AUTHORITY | VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK N.V.
Project period	2016 - 2020
Project status	ongoing
Objective of the project (native language)	The intensification of agricultural production has led to food safety uncertainty. The project aims to train highly qualified professional in sustainable approaches. Develop: 1) smart monitoring techniques and multi-suite stable isotope methods to determine C, N and organic pollutant flux dynamics, 2) sustainable management practices and pollution mitigation concepts, 3) biosensor biotechnology to restore degradation, 4) decision-making tools for performance assessment by linking lab-scale studies with field-scale evaluation of the above. An extensive training agenda and knowledge transfer activities will provide the skills for the sustainable management of soil/water resources.
Objective of the project (in English)	The intensification of agricultural production has led to food safety uncertainty. The project aims to train highly qualified professional in sustainable approaches. Develop: 1) smart monitoring techniques and multi-suite stable isotope methods to determine C, N and organic pollutant flux dynamics, 2) sustainable management practices and pollution mitigation concepts, 3) biosensor biotechnology to restore degradation, 4) decision-making tools for performance assessment by linking lab-scale studies with field-scale evaluation of the above. An extensive training agenda and knowledge transfer activities will provide the skills for the sustainable management of soil/water resources.

Effects of this SFT

Productivity (crop yield per ha)	No effect
Quality of product	No effect
Revenue profit farm income	No effect
Soil biodiversity	Large increase
Biodiversity (other than soil)	Some increase
Input costs	No effect
Variable costs	Some increase
Post-harvest crop wastage	No effect
Energy use	No effect
CH4 (methane) emission	Large decrease
CO2 (carbon dioxide) emission	Large decrease
N2O (nitrous oxide) emission	Large decrease
NH3 (ammonia) emission	Large decrease
NO3 (nitrate) leaching	Large decrease
Fertilizer use	No effect
Pesticide use	No effect
Irrigation water use	No effect
Labor time	No effect
Stress or fatigue for farmer	No effect
Amount of heavy physical labour	No effect
Number and/or severity of personal injury accidents	No effect
Number and/or severity of accidents resulting in spills property damage incorrect application of fertiliser/pesticides etc.	No effect
Pesticide residue on product	No effect

Weed pressure	No effect
Pest pressure (insects etc.)	No effect
Disease pressure (bacterial fungal viral etc.)	No effect

Information related to how easy it is to start using the SFT

This SFT replaces a tool or technology that is currently used. The SFT is better than the current tool	no opinion
The SFT can be used without making major changes to the existing system	no opinion
The SFT does not require significant learning before the farmer can use it	disagree
The SFT can be used in other useful ways than intended by the inventor	agree
The SFT has effects that can be directly observed by the farmer	disagree
Using the SFT requires a large time investment by farmer	no opinion
The SFT produces information that can be interpreted directly	disagree

View this technology on the Smart-AKIS platform

SMART AKIS PARTNERS:

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SMART AKIS PARTNERS: