EIP-AGRI Focus Group
Digital tools for sustainable nutrient management

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1. Executive summary

The EIP-AGRI Focus Group on Digital tools for sustainable nutrient management brought together 20 experts including researchers, advisors, civil servants, farmers and representatives of the industry. The aim was to discuss the available digital tools for nutrient management, reasons why farmers would or would not use them on the farm and needs for further digital nutrient management tools, which could be developed in the future.
The group identified four key topics to focus on:

- Requirements for sustainable nutrient management tools,
- Better data sharing: the need for better-trusted, more precise and valued nutrient management tools
- How can digital tools assist farmers in reducing the carbon footprint of plant nutrition, and
- What would encourage farmers to use these tools and what are the barriers limiting their uptake.

Although there are many digital tools for nutrient management available on the market, the uptake rate of these tools is still very low in Europe. Farmers need tools with the following properties and functions:

- User-friendly tools with straightforward user interfaces and advanced user experience
- Interoperability with other tools and data sources
- Flexibility with possibilities to customise for different farming environments and conditions
- Specific tools based on the local conditions
- Dynamic decision support, which considers the characteristics of the current cropping season (climatic, financial, etc.)
- Based on reliable methods and algorithms, scientifically sound and published.
- Able to access publicly available and relevant data.
- Offline versions for areas with limited network coverage.

Based on the examples collected by the Focus Group experts, farmers currently do not seem to consider data sharing and control as a priority when they decide on which digital nutrient management tools to use. In the near future this will be a key aspect, since the tools are getting more complex and require more data, which can create a heavy burden for the farmer due to the lack of data exchange across platforms and databases. The FG experts urgently recommend making more data available rapidly to power digital nutrient management tools. The tools cannot deliver smart nutrient management advice to farmers if there is no access to the necessary data sources. Moreover, farmers will not adopt tools that need manual input of data that could be easily imported automatically. And, most importantly, farmers want to stay in full control of their data.

Besides these key functions and properties, future digital tools for sustainable nutrient management should also focus on the environmental aspects of nutrient management. Agriculture’s climate impact is notable and evident, with significant consequences for the global climate. The primary sources of Green House Gas (GHG) emissions are land clearing and tilling, livestock breeding, application of fertilisers and fossil fuel use for production of inputs. Agriculture can also be a significant carbon sink. There are many possibilities to develop appropriate tools to reduce the carbon footprint of plant nutrition but more research and practical testing is needed. Currently, there is no tool on the market that would provide a complete solution, but some sustainable farm tools quantify emissions coming from nutrient management and they can support moving further to appropriate tools for reducing the carbon footprint of plant nutrition.

The Focus Group experts also provided ideas for EIP-AGRI Operational Groups and other innovative projects (see section 6.1. Ideas of Operational Groups) and identified new research needs (see section 6.2. Research needs from practice).

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The main topics for Operational Groups were:

- Grain and leaf nutrient benchmarking.
- Testing and sharing manure analysis. Combining different digital tools for more precise fertilisation (Variable Rate Application).
- Testing and sharing experiences in using different types of soil sensors in different types of soils.
- Accelerating nutrient data availability for better nutrient management tools.

Concerning the research needs identified, some to be highlighted are:

- The creation of better assessment methods of soil quality / health / properties in relation to nutrient management.
- More advanced, results-driven nutrient management tools, which can use soil sampling results pre- and post-harvest to evaluate the nutrient management programme and take this into consideration for the next planning phase.
- Development of decision support tools using digital technologies, which take available water content and subsurface compaction into consideration during the planning of nutrient applications and irrigation.
- Find ways to better measure and model GHG emissions, not only at regional level but at farm level with more specific and tailor-made models.
- Better, regularly updated nutrient management tools, which can incorporate the special needs of new crop varieties into the planning process. These tools should not only be crop-based but variety-based, using the response curves for nutrient efficacy of these varieties.
- N-requirements in legislation should be revised taking into account new plant varieties, new types of fertiliser, better efficiency in nutrient management, modern farming technology and higher yields.

As more requirements for digital tools for nutrient management are defined, more sophisticated and complex tools will be developed, which results in a need for more data and, eventually, the increase of the technical knowledge required for their operation. To engage farmers in the use of these tools a balance between a comprehensive approach and operational feasibility needs to be found. Tools need to focus on critical aspects, while equally respecting both environmental and economic ambition.

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2. Introduction

The **Farm to Fork strategy** under the **European Green Deal** identifies the excess of nutrients in the environment as a major source of air, soil and water pollution, negatively impacting biodiversity and climate. The European Commission aims to reduce nutrient losses by at least 50%, while ensuring there is no deterioration in soil fertility. This will reduce the use of fertilisers by at least 20% by 2030. Gross nitrogen balance is an important indicator for the quantified Green Deal target.

Improved nutrient management as part of more sustainable farming systems is included in the green architecture of the new Common Agriculture Policy 2023-27 (CAP), contributing to several specific objectives of the policy.

In particular, the new CAP Regulation[1] introduces the Farm Sustainability Tool for Nutrient Management (FaST) referring to digital application(s) that provide on-farm decision support on plant nutrition management, with focus on nitrogen and phosphate. The tool(s) will provide information on nutrient balance and soil at field scale, as well as relevant Integrated Administration and Control System data and legal requirements on nutrients.

Besides the FaST tool, several other options are available to farmers and advisors to assist decisions on sustainable nutrient management, based on different technologies, developed in research projects or by private companies. These developments provide an opportunity to speed up farmers' uptake of digital solutions going beyond the sphere of nutrient management, adding and connecting to other potential functionalities.

Despite the fact that these tools are based on advanced algorithms and methodology, using diverse sources of data and providing better decision support to farmers, the adoption rate is still low.

In this context, the EIP-AGRI Focus Group (FG) on 'Digital tools for sustainable nutrient management' aimed to identify good practices and inspiring initiatives developing, promoting and facilitating the use of digital applications for an enhanced sustainable farm nutrient management. To achieve the main goal of the FG the specific tasks performed during the work of the FG focused on the following subtopics:

- Map the digital farm tools already in place, or under development
- Assess the uptake level and usability of these tools among farmers
- Identify the data needs and gaps for an efficient and cost-effective use of these tools
- Address the main obstacles for farmers to start using these tools
- Highlight inspiring examples for tools integrating different datasets (both public and private domains)
- Explore which other technical and environmental aspects could be addressed by these tools (regardless of the current field of implementation)
- Propose potential innovative actions and ideas for Operational Groups to stimulate the development, improvement, uptake and use of these tools at farm level
- Identify needs from practice and possible gaps in knowledge

[1] **REGULATION (EU) 2021/2115 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013**

3. Brief description of the process

The Focus Group (FG) is a temporary group of 20 experts (**Annex 1**) with different professional backgrounds. The FG had one online meeting on 14-16 March 2022, one in-person meeting in Brussels, Belgium, on 15-16 June 2022 and a follow up online meeting, for the experts who could not participate in the in-person meeting, which was held on 28 June 2022.

Prior to the first meeting the experts were provided with a starting paper prepared by the Coordinating Expert and were requested to fill out a short survey on three topics:

- Identify digital tools used in nutrient management in their country that they consider most commonly used by farmers; provide criteria for assessing above-mentioned digital tools and assess the tools according to the proposed criteria;
- Propose possible barriers or obstacles for farmers to use these digital tools;
- Propose other technical, environmental or socioeconomic aspects (or functions) that these nutrient management tools could address or contribute to.

The information collected was used to feed the reflection during the 1st meeting of the Focus Group, where the main outcomes of the survey where presented.

The objectives of the first meeting were to establish a common understanding of the topic and organise the work of the FG. After the introduction, four different experiences from practice with digital tools were presented by four participants from different Member States. In addition, the Farm Sustainability Tool for nutrients (**FaST**) was presented by DG AGRI, European Commission. After the presentations the starting paper and the results of the online questionnaire were introduced. This was followed by an active reflection by experts.

Fig. 1. Participants of the 1st Focus Group meeting

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During the last sessions of the meeting the concept and purpose of mini-papers were presented. Different topics to be further analysed in mini-papers were then proposed by the experts. After clustering and prioritising, four mini-paper topics were selected (**Annex 2**).

During the second meeting the draft mini-papers were presented, followed by a discussion. During the second part of the day the FG visited two Flemish farms, which provided valuable insights on farmers´ views on the topic of the FG and allowing experts to see which nutrient management tools were being used or had been tested on the farms.

During the second day of the second meeting the experts discussed ideas for EIP-AGRI Operational Groups and other innovative projects as well as the needs from practice for further research.

A third meeting was organised – online - for the experts not present at the second meeting, focusing on the mini-papers, and identifying research needs from practice and ideas for potential Operational Groups' topics.

Fig. 2. Participants of the 2nd Focus Group meeting

4. State of Play

The European Green Deal

The European Green Deal (EGD)[2] is a plan to make Europe the first climate-neutral continent by 2050. The EGD is a package of measures that should enable European citizens and businesses to benefit from sustainable green transition. Different strategies and initiatives implementing the EGD are relevant for this Focus Group. In addition to the Farm to Fork strategy, the Biodiversity Strategy, the Forestry Strategy and the proposal for a new Regulation to curb EU-driven deforestation and forest degradation, the Zero pollution action plan and the Chemicals Strategy or the Circular Economy Action Plan are the most relevant.
Among them, the new **EU Soil Strategy for 2030** is a key deliverable of the EU Biodiversity Strategy, since healthy soils are the foundation for 95% of food, they host more than 25% of biodiversity and are the largest carbon pool on Earth.

The Farm to Fork Strategy and the Common Agricultural Policy (CAP)

At the heart of the EGD the **Farm to Fork Strategy**[3] aims to make food systems fair, healthy and environmentally friendly, accelerating our transition to a sustainable food system.
The Farm to Fork Strategy has a strong focus on nutrient management, aiming to reduce nutrient losses by at least 50%, while ensuring that there is no deterioration in soil fertility. This will reduce the use of fertilisers by at least 20% by 2030. To consolidate the role of European agriculture for the future, the CAP has evolved over the years to meet changing economic circumstances and citizens' requirements and needs. The new CAP supports agriculture in making a much stronger contribution to the goals of the EGD, with higher green ambitions by, among other aspects, an enhanced conditionality, stronger incentives for climate-and environment-friendly farming through the eco-schemes and a reinforced contribution of funds for measures to support climate, biodiversity, environment and animal welfare.
The Commission will also work with Member States to:

- extend the application of precision fertilisation techniques and sustainable agricultural practices, notably in hotspot areas of intensive livestock farming, and
- of recycling of organic waste into renewable fertilisers.

This will be done by measures such as the Farm Sustainability Tool for nutrient management, investments, advisory services and the EU space technologies (Copernicus, Galileo).

[2] COM/2019/640 final. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee Of The Regions. The European Green Deal

[3] COM/2020/381 final. Communication from the Commission to the European Parliament, The Council, the European Economic and Social Committee and the Committee of the Regions A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system

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The FaST Tool and FaST Navigator

The CAP regulation states that the Commission may provide support to the Member States in the design of the Farm Sustainability Tool for Nutrients. The main objective of FaST is a wider adoption of nutrient management plans, taking advantage of digital technologies. The Commission has been providing support to Member States for the implementation of a digital tool compliant with the minimum elements in the CAP regulation (FaST platform) and the development of new algorithms to provide advice about the use of fertilisers (FaST Navigator).

The FaST platform is an electronic tool for on-farm decision support about the use of fertilisers and the main functionalities can be extended to further sustainability objectives. Beyond the minimum requirements of the CAP, the FaST platform includes additional functionalities for the visualisation of space data (Copernicus) and the use of Galileo services like geotag photos. During the first two stages of the project the platform has been implemented in the following regions/countries: Andalucía (Spain), Castilla y Leon (Spain), Estonia, Piemonte (Italy), Wallonia (Belgium), Bulgaria, Greece, Romania and Slovakia.

The results of the FaST Navigator study were released in 2022 and provide a common framework for quantitative advice on crop nutrient requirements and greenhouse gas emissions and removal assessment at farm level. The main results of the study are the algorithms to assess crop nutrient requirements and fertilisation recommendations under different conditions of data requirements, ranging from the most basic approaches based on common farm data (crop, yield target, soil type, etc.) to advanced algorithms which use all relevant data for nutrient management (weather forecast, soil analyses, crop rotation, earth observation data, etc.). These algorithms facilitate the development of FaST as they provide a standardised reference for calculation procedures and are open access, to facilitate the adaptation of the methodologies in different environments.

The FaST tool is not unique, Member States can use this system developed by the Commission, or they can develop their own systems or make use of existing services if compliant with the minimum requirements and functionalities indicated in the CAP.

Horizon Europe

Horizon Europe, the EU framework programme for research and innovation for the period 2021-2027, is one of the tools to help achieve the goals of the EGD. It facilitates collaboration and strengthens the impact of research and innovation. In 2021 the EU launched 5 EU missions as part of Horizon Europe. One of these missions is the 'A Soil Deal for Europe', which contributes to the EGD targets on sustainable farming, climate resilience, biodiversity and zero-pollution. It is also a flagship initiative of the 'The long-term **Vision for the EU's Rural Areas'**. In addition, multiple **Horizon candidate partnerships** are connected to the topic of the FG.

Nutrient management in the EU

Fertiliser use has slightly increased in the last decade. Nitrogen application increased by 1.9% between 2008 and 2018, whereas phosphorous use declined by 1.2%.

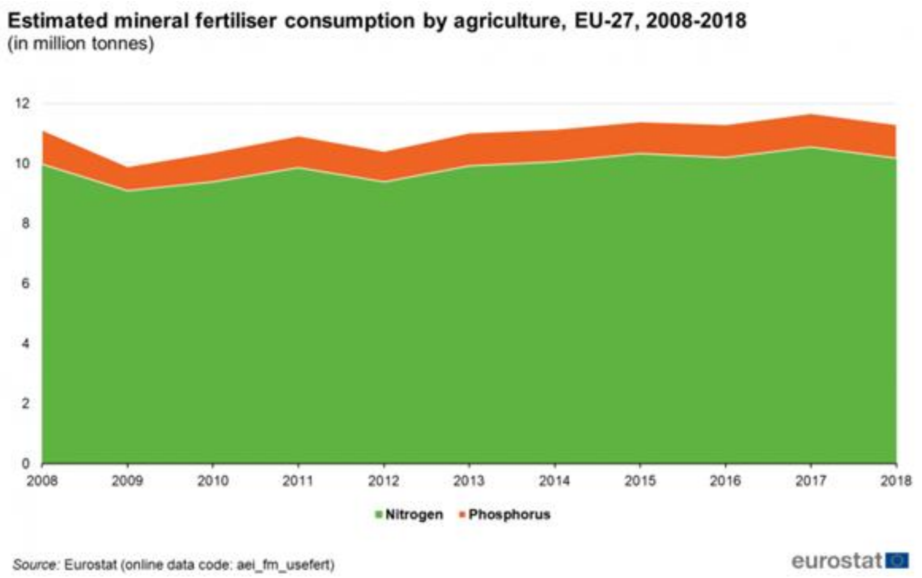

Fig.2. Estimated mineral fertiliser consumption by agriculture EU-27, 2008-2018 (Source: Eurostat)

In EU agriculture, a key challenge for nutrient management is to ensure that the necessary amount of nutrients is available at the right time, while reducing excess use of nutrients, and preventing nutrients leaching to waterbodies. In 2015, EU agriculture was responsible for 94% of ammonia emissions (Eurostat, 2017) and responsible from 22% to 99% of the total load of nitrogen into the environment, on average 77 %, being the most prominent source (EC, 2021). These come from several sources including the production of fertilisers, use of fertilisers and manure, livestock farming, among others. Climate impact is also notable, with over 2% of total EU greenhouse gas (GHG) emissions coming from the application of artificial fertilisers. This is around 20% of all GHG emissions from agriculture. Besides the environmental and climate effects, intensive agriculture and excessive fertiliser use has also affected soil health indicators and yield potential. Intensive agriculture reduces soil biodiversity through several mechanisms (e.g. physical disturbance, compaction, lethal and sub-lethal impacts of pesticides and herbicides on the soil biota, and inorganic fertilisers), making soils less efficient, more sensitive to weather events such as extreme drought and rainfall, and reducing organic matter (Tsiafouli et al., 2015). Although organic fertilisers can improve some soil health indicators, their excessive use is also a significant source of nitrogen and phosphorus emissions.

For these reasons, the EU has been controlling fertiliser use on arable land and grassland, using nutrient management plans (NMPs) as a monitoring and control tool. NMPs have been in use in the CAP for several years. For example, they have been supported in basic agri-environment schemes in the two previous programming periods, as well as forming part of the Statutory Management Requirements (SMR) of Cross Compliance (Regulation (EU) No 1306/2013) – notably SMR1 in relation to the Nitrates Directive (Council Directive 91/676/EEC) (ENRD, 2018).

5. Framing key issues

5.1. Tools to support sustainable nutrient management

Nutrient management tools can be focused on reducing impact on the environment, particularly of nitrogen and phosphorus, minimising losses of these nutrients, or on increasing nutrient and economic efficiency, particularly in plant production. Tools for the first purpose may have to be used by every farmer in a particular area, e.g. in nitrate vulnerable zones according to Nitrates Directive, and they should be easily applicable. On the other hand, tools for the second purpose should be mainstreamed among farmers if they intend to maximise the economic revenue of their business. However, those tools are usually only taken up by a small number of farmers. Either way crop nutrition planning should follow four main steps: (a) defining the appropriate amount of nutrients for the crop, (b) fertilising the crop accordingly, followed by (c) monitoring and (d) evaluation of the actual dosage of the whole nutrient management. These four steps could overlap in a virtuous circle:

a) Farmers traditionally **plan fertilisation** based on their experience and/or on simplified crop nutrient demand tables. Basic planning is done based on the yield expected at the beginning of the season. Several tools exist that calculate crop nutrient requirements based on a mass balance between inputs (fertiliser, manure, previous crop residues, atmospheric deposition, release from soil reserves) and outputs (crop harvest, with nutrient removal dependent on crop yield). Planning should be done with care, based on reliable targets and qualified models. Many different technologies, tools and techniques exist and are available to farmers to support decision making and assist optimised nutrient management. Although these tools are widely available in most EU countries, a widespread comparison of these tools, in terms of accuracy and suitability under different climatic, soil and environmental regions, hardly exists.

b) **Application of organic and inorganic fertilisers** is a key element in crop production. The machinery used for this purpose depends on the product and the crop. Any technology involved in the nutrient application process starts from the proper calibration of the equipment. The correct setting of the machine is determined by the physical properties of the fertiliser: particle size distribution and bulk density, if solid, and flow rate. With respect to organic fertilisers, e.g., Near Infrared Spectroscopy (NIRS) can determine the nutrients applied in real time and space, and link this data to other digital tools. Thus, digital tools can improve nutrient efficiency, but their use must be built on top of proper machine calibration.
Variable Rate Application (VRA): if the supporting data for variable rate planning is reliable and reflects the real field and environmental conditions, this can substantially improve the efficiency and sustainability of nutrient management, while reducing the environmental load of insufficient nutrient management. Although the technology can greatly improve nutrient management, unreliable, or low quality spatial information, if used for the planning of the VRA, can also decrease the efficiency and increase nutrient loss to the environment. Thus spatial information must be carefully selected and validated, before applying for VRA nutrient planning

c) To promote more efficient use of fertilisers (mineral or organic) and reduce their environmental impact, (1) **in-season monitoring tools** that allow adjustments to theoretical fertilisation plans should be promoted (e.g., N-sensors installed on tractors or operated from drones or by remote sensing from satellites; complex nutrient leaf analysis or grain harvest analysis); (2) **inter-season monitoring** – on the other hand – should be applied to evaluate the efficiency of the fertilisation process. Nutrient balance or budget can be interpreted as an *ex-post* monitoring-tool to evaluate the fertilisation process or even the nutrient management of a farm (farm gate budget).

d) New **tools for evaluation**/diagnosis should meet several requirements: be economical and simple to use, facilitate real-time diagnosis, measure the movement and availability of nutrients with special attention to leaching below the root zone, and should show an improvement compared to previous farming, economic, environmental conditions. They should also be practical to use, their results should be based on good science, they should allow new forms of economy of scale through sharing, while providing customised references for each farmer with indicators for both profitability and respect for the environment. The new digital tools must offer practical and satisfactory solutions for farmers, companies, cooperatives or agricultural consultants at a convincing cost/benefit ratio. It should also be possible to customise new digital tools to farm objectives, such as optimal yield, SOM increase, or complying with specific voluntary or mandatory production protocols

5.1.1. Criteria for digital nutrient management tools – farmers' perspective

Designing a successful digital tool for nutrient management is not as easy as it may seem, based on the main requirements discussed in the previous section. The barriers between farmers and digital tools are very diverse. Based on the findings of the FG, farmers are mainly looking for tools that are easy to use, have a proven cost benefit, can be customised to local conditions and allow them to share information with external advisors, lowering the administrative burden (Table 2.).

Table 2. Expert survey results, farmers' criteria towards digital tools

Criteria for digital tools	Importance (Rank)
Simple, user-friendly, accessible	1
Cost-benefit (preferably free)	2
Reliable, accurate, scientifically sound, regularly updated, effective	3
Advisor-connected, direct assistance	4
Adaptable to local conditions and practices	5
Administrative documents production/Historical data	6
Compliance with law, Data security	7
Integrated management (environment, nutrients)	8
Compatible with other programmes	9
Broaden network/experiences	10

Based on the points above, several different – mainly technical - aspects would make tools attractive to farmers, which could increase the adoption of digital technologies:

- Easy to use, user-friendly tools with straightforward user interfaces and advanced user experience.
- Interoperability with other tools, data sources, etc.
- Flexibility and customisation for different farming environments and conditions.
- Specific tools based on the local conditions.
- Dynamic decision support which takes the characteristics of the current vegetation period (climatic, financial etc.) into account.
- Reliability of the results through proven and scientifically sound and published methods.
- Access to publicly available and relevant data.
- Offline version for areas with limited network coverage.

5.1.2. Criteria for a digital nutrient management tool – experts' perspective

Besides evaluating a tool and its application from the farmer's point of view, it is also important to assess tools from a scientific viewpoint, even though this viewpoint is usually in line with farmers' needs. The most important criteria identified to evaluate a digital tool for sustainable nutrient management are:

- Ease of use
    - Minimise the manual data entry required from the user (farmer), automate data collection as much as possible, using public databases, machinery systems, etc.
    - Data import and export must be straightforward and compatible for different data formats and models.
    - Interpretation should be easy to understand, preferably visual and avoid providing raw uninterpreted data.
    - The system should be able to 'grow with the user', with more functionalities available to more experienced users, but still usable as a basic system those with less experience.
    - Live technical support, since often the problems encountered need to be solved immediately.
    - Low entry and exit cost (easiness of import and export data to and from the tool).
- Cost-benefit
    - Tools must provide a clear positive cost-benefit balance to the user, which can be measured in several ways, such as increased profitability through savings or increased yield. A reduction of office workload through efficient reporting can also be measured as a benefit.
    - Cost benefit balance is different depending on the farm priorities, as an example data gathering and integration can be an added value for some, while decision support is a minimum requirement for others.
    - The earnings through the use of the system must clearly exceed the investment cost.

- Multifunctionality
  - The tool should support different dimensions of nutrient management such as, production (i.e. fertilisation, irrigation, crop rotation, etc.), environment (i.e. nitrate leaching, phosphorus runoff, GHG and ammonia emissions, soil heath, etc.), economic aspects (cost of input material and application), compliance with reporting duties according to the local conditions, integrable in the supply chain (e.g. certification frameworks, traceability).
- Accuracy and robustness of data and models used by the tool, localisation
  - The tool must provide a properly validated, scientifically sound advice based on the information provided by the user.
  - The tool could also provide an indication on the reliability of the recommendation based on the user data quality, and the predictions of the used model.
  - Should be customisable to local conditions including farm type, environmental conditions, legal environment.
- Data access, transparency, and security
  - The tools should use data that is easily available and accessible to the farmer, both on- and off-site.
  - Farmers should be in control of which data they share and with whom. Different levels of connected users (stakeholders such as advisors, other farmers, public administration, etc.) must be defined with different data access levels, which the farmer should be able to customise.
  - Tool developers should communicate and provide information whether their models/algorithms are based on field trials, legislation, empirical data etc.

5.2. Commonly used digital tools

The most commonly used tool types (Table 3.) or recommended tools (**Annex 3.**), which were identified by the experts, frequently lack the complex requirements defined in the previous sections.
Based on the survey results, the most common digital tool seems to be different types of nutrient management applications. The use of these tools is expected to increase due to the spread of precision agriculture technologies or due to legal obligations imposed by the Nitrogen Action plan, when farming in Nitrate Vulnerable Zones.
In digital agriculture spreadsheets are a very popular and common application. Either in the form of a simple table or as a custom designed file provided by local authorities or developers.
Complex farm management applications, which can collect machinery data, provide more complex reporting functions and often monitoring and forecasting tools, are becoming more common in the farming community, partly owing to machinery providers with accompanying software solutions.
The use of satellite imagery, especially with the availability of Sentinel data from the European Spatial Agency (ESA), and the spread of precision agriculture is rapidly increasing and this is expected to continue in the future, due to the low cost, and now frequent and high-resolution data collection. Soil analysis is still an important part of nutrient management, and it is going through a transformation with the shift from wet chemistry-based methods towards proximal soil sensing and field soil scanners. These methods will help to significantly reduce the time between soil sampling and application of input materials. Variable rate application planners which are an important element of site-specific precision agriculture, can be very well connected to nutrient planning apps. In fact, they are often available as a more advanced version of the same application, or they can be connected to satellite imagery provider applications. In other cases though there is a disconnection between VRA applications and good nitrogen budgeting/planning algorithms, which can decrease the efficiency and scientific soundness of these applications. Other listed tools included weather forecasts, dairy management apps, leaf and grain analysis, etc.

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Table 3. Expert survey results, common digital tools and technologies used by farmers

Answer	Importance (Rank)
Nutrient monitoring and planning application	1
Spreadsheet (as it is or customised forms by local authorities, etc.)	2
Farm management system	3
Satellite image	4
Proximal soil sensing analysis	=
Variable rate application planner/Precision agriculture	=
Bookkeeping, financial management apps	5
Weather forecasts	6
Mandatory tools under the Nitrates directive	=
Dairy cow management apps	=
Leaf analysis sensors	=
Grain analysis sensors	=

5.2.1. Good examples of nutrient planning and management tools

Although tools that satisfy all the requirements discussed previously are hardly available on the market, there are available tools that can serve several of these functions, and many of these were developed by different scientific projects funded by the EU. Some examples, which are also implemented in the FaST tool, are listed below. For more tools available on the market the H2020 **Fairshare** project provides an inventory of existing Digital Advisory Tools and Services (DATS).

1. **Fertilicalc** (Villalobos and Fereres, 2016) allows the user to calculate the seasonal amounts of N, P and K needed and the most economic combination of commercial fertilisers for 149 crops. The tool also provides estimates of the Ca, Mg and S balances in the field and acidification balance (CaCO3, kg/ha). Fertilicalc is a free tool and the algorithm has been chosen by EC FAST Phase I and is the core of SATIVUM tool that includes all the parcel boundaries and crop information from the CAP Integrated Administration and Control System. Fertilicalc has different fertilisation strategies according to the user's needs:

- Sufficiency strategy: apply P or K only when the soil nutrient level is below the threshold.
- Accumulation and maintenance (minimum fertiliser): add fertiliser to compensate for the P and K exported from the farm and bring the soil nutrient level to the thresholds.
- Accumulation and maintenance (maximum yield): similar to the previous strategy, but now using the parameters that lead to maximum yield, preventing nutrient deficiency.

2. **AGROgestor** was developed in the LIFE+11 ENV/ES/641 sigAGROasesor project. It has two interconnected platforms with utilities and tools for advisory services on agricultural plots and for supporting collective crop management. The Decision Support Tools (DST) models allow integrating existing knowledge and the nutrient management (N, P and K) to the situation of each crop in each campaign in a specific plot, with its soil characteristics, type of management and weather conditions. Agrogestor/Agroasesor platform is managed by a consortium of public entities but the access is restricted to those authorised.

3. **FATIMA** was a H2020 project, with commercial versions of its tools in active use by **AgriSat** in the FertiMaps application and Ariespace. The FATIMA model works at different scales from plots to watersheds. The tool has five interconnected levels: a modular technology package (based on the integration of Earth observation and wireless sensor networks in a webGIS), a field work package (studying soil and resource improvement and management options), a set of tools for participatory processes, an integrated multi-scale economic analysis framework, and a set of policy analysis based on

indicators, accounting, and impact assessment. FATIMA provides irrigation and fertilisation maps, which can be included in precision machinery.

Other examples of digital tools with great potential

Recently (November 2021), the company Frutinter from Spain obtained the first nitrate footprint certification[1] after measuring the concentration of leaching nitrate at depth (4-8 m) following ad-hoc certification protocol established by the company Rina Services S.p.A. and the Wtech company. This achievement required advanced plant and soil monitoring equipment to improve irrigation and nutrition decisions[2]. The nitrate footprint measures what happens at depth, but it also has to measure "traceability" of nitrate in the soil in the agricultural area[3] (root and nearby drainage soil) and plant, climate, etc. so that the farmer can identify good practices to maintain or improve profitability while minimising nutrient pollution, based on his/her own experience.

Having a method for independent certification of nitrate contamination and being able to measure daily trends of nitrate in the soil (root zone and drainage) will provide new opportunities for collaborations between administrations, technicians, researchers, and cooperatives. It will require adapting these new technologies to generate experiences in different crops and areas in Europe to improve fertilisation plans for the most important crops in each area.

These Nutrient management tools can be focused on reducing impact on the environment, minimising losses of nitrate, or increasing nutrient and economic efficiency, particularly in intensive plant production, e.g., vegetable or fruit production.

1. https://www.fructidor.es/newsdetail.aspx?idn=57440
2. https://www.laverdad.es/nuestra-economia/wtech-metodologia-novedosa-0211106002328-ntvo.html?ref=https%3A%2F%2Fwww.laverdad.es%2Fnuestra-economia%2Fwtech-metodologia-novedosa20211106002328-ntvo.html
3. https://verdtech.es/la-sonda-nutrisens-ayuda-a-frutinter-s-l-a-conseguir-clementinas-certificadas-con-huella-denitrato-cero/

More on this topic can be found in **Mini Paper 3.**

5.3. Data, the bases of planning

The Focus Group experts noted that nutrient management tools need several improvements to increase adoption rate and the most crucial one is availability of data. Much effort is needed to feed these tools with precise, high quality data sets, since nutrient management tools become smarter and perform better when they are built on more precise and larger datasets. On-farm research can be used to create diverse sets of data. Although data availability is one of the main factors limiting adoption, data reliability and precision should also be considered for the nutrient planning process. Some of the basic information necessary for planning such as main and previous crop type, expected yield, fertiliser types, are straightforward, some others such as field boundaries, soil type, soil nutrient status, nutrient content of harvested cropland and of manure may be less reliable or not known. This can impair the sustainability of the applied nutrient management.

During the last decades many technological advances have been developed and presented to the market, which aim to perform better in cost, delivery time, precision, spatial distribution, information content or other aspects. In this intensively changing farming environment these tools should be reviewed and validated, and a roadmap should be drawn for farmers to achieve the environment-related goals while maintaining or increasing their profitability.

Soil sampling is a good example, where traditional surveying and sampling for nutrient status was followed for decades; in many parts of the world using grid-based soil sampling and wet chemistry. With the advances in technology, and the requirements for better spatial distribution and reliability, especially in precision farming, many new tools and survey methods were recently introduced. These technologies such as proximal sensing, soil scanning, and remote sensing are already used by consulting companies and farmers, despite the lack of standardisation and validation compared to traditional techniques, where comparability and repeatability are requirements and standards, often defined in legal bases. The rapid spread of these new technologies demands new standards, accelerated validation processes, and roadmaps for farmers working under different environmental and soil conditions. Since soil properties are the basis of calculation, this topic needs special attention, but the same problems apply for other data sources exposed to reliability issues.

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5.3.1. Data sharing

Most of the planning tools and NMTs require a diverse set of data, which are in the public domains or at private companies, and on the farm, to increase the speed of the adoption process, making planning and nutrient management tools better and more complex. Data sharing technology is currently so well advanced that there are no technical issues blocking the sharing of the data. Experts identified the types of already existing data that would make digital nutrient management tools more precise, valued and trusted by farmers, as well as typical (economic and social) barriers for data sharing.

The European Commission **Member State Geoportals** is a collection of information for relevant data offered by each Member State. The types and amount of data published varies a lot among Member States. For instance, some provide detailed information on fields, but some share no information at all. Very rarely this information can be downloaded in a format, which could feed into a nutrient management tool. The experts consider that these public registers do not see themselves having roles or tasks to provide farms or providers of nutrient management tool with the data they keep.

Further, on-farm research and data sharing could help make great steps in updating and differentiating the data required, e.g., on nutrient concentration in crops harvested, in (liquid and solid) manure. This could also assist in evaluating target data, e.g., target yields and qualities (raw protein concentration) in certain environments and climates or target concentration for plant analysis.

Some good examples can be found, such as in Flanders where the Department of Agriculture publishes the agricultural parcel information via the Flemish data sharing platforms DjustConnect.be. Apps that support the farmers in monitoring their crops and managing nutrients can directly use this information to automatically integrate the relevant farm data, such as the field boundaries, the crops or the ecosystem services. The platform is governed by a neutral party together with farmer cooperatives and is a non-profit initiative. This approach convinced the Flemish department of Agriculture to share data in a trusted environment.

Good examples: Latvia

Latvia provides publicly accessible information about each field via the online version of the land register, which allows the user to find LPIS information including crop, field boundaries, area, field number, block number, and the type of area support applied for. The data of the field register is updated several times a day, which means that the most current information is available to any user. The Rural Support Service also provides WMS and WFS services **free of charge,** which means users can have access to the geospatial data through WMS *(Web Map Service) an* WFS (*Web Feature Service)* services.

Denmark also has a good example where the Danish Veterinary and Food Administration (DVFA) is responsible for compliance with EU regulations on animal identification and registration. SEGES, the headquarters of the farm advisory service division of the Danish Farmers Council (farmer NGO / association), was subcontracted to perform this task. This collaboration resulted in the DVFA website where anyone is free to look up data about the livestock kept at any farm. The data is also accessible through an API (Application Programming Interface), which can be used by tool developers.

In Spain the whole FAST ecosystem is available for public use in interoperable ways. Parcel boundaries, crop and soil data is offered in OpenGIS formats as well as JSON with and without user authentication requirements depending on the data. The nutrient budgeting service that constitutes the SATIVUM tool is offered as an open and free API. Any tool can invoke the API with the crop and soil parameter to obtain a nutrition advice. Private and public Farm management Information Systems are taking advantage of this infrastructure to include nutrition advice in their functionality.

Public-private collaboration may be promoted by sharing successful experiences that combine profitability and sustainability using new technologies and serving as a reference for data sharing on these platforms. Demonstration projects can be customised for an important crop in an area where the recommendations of the "fertilisation plans" have been optimised using sensor registration and new technologies, in collaboration with advisors, researchers and farmers.

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5.3.2. To accelerate the adoption rate of these tools

Technology providers in the sector are showing good examples on data sharing and cloud-based applications to provide information and decision support to farmers using machinery data, satellite images, climate information and data entered by the users. These tools hardly use data coming from databases provided by public bodies and do not have the functionality to provide data towards these systems. To accelerate the adoption rate of these tools, public bodies should start providing information in a digital, machine-readable format. Unfortunately, public bodies are moving slowly in making data sets from public registers, machine readable and easily integrable in nutrient management tools. In many Member States this information is only available in pdf documents that are not fitted for such use, and the cost and workload to digitise it is the main reason that these public entities are lagging behind. Where there is an available digital version of information the provided formats differ from one Member State to another, and there is no standardised protocol for REST API's[4] for the data extraction at EU level, making EU-wide tool development hardly possible.

More on this topic can be found in **Mini Paper 2.** - Creating Trusted Nutrient Management tools through better data sharing

5.4. Other required functions for nutrient management tools

As nutrient management has significant effects on the environment, it is important to develop indicators to reflect how nutrient management affects its different aspects. Although the main function of nutrient management tools is supporting sustainable nutrient management, future applications should also be capable of serving other functions (Table 4.). These could include carbon, water and nitrogen footprints, different environmental indices reflecting on N and P content, leaching and runoff, biodiversity, different soil health indicators, and soil functions, which would enable better management and land use planning. Tools should also provide local CO_2 optimised fertilisation recommendations to address the GHG emissions related to farming, and circularity should be promoted by focusing more on nutrients than fertilisers and including nutrient budgeting in the algorithms/tools. Functions which are often missing in these tools should be promoted in future tools to guide farmers how to improve their GHG emissions, with outputs such as:

- Tailor-made fertilisation recommendation
- Nationally provided algorithms for local nutrient management optimisation
- Carbon balance and CO_2 emission information
- Clearly presented outputs

Increased efficiency is key to success from both the farmers` and the environmental perspective. Farmers mainly focus on applying the right product at the right rate, in the right place, but success is also dependent on the right time. Better timing can be supported by many digital technologies, such as on farm sensors, weather forecast, remote sensing, etc.

Since profitability is essential for farming tools, they must include economic calculations, modelling during the nutrient planning with possibly several model outputs. They should consider different annual weather scenarios while still meeting the regulatory needs, thus taking the local legal environment into consideration.
Tools should also promote co-learning through new tools and 'languages' to promote teamwork not only within companies but also within communities. Through the larger database this could reduce the time to achieve sustainability.
To increase the social acceptance of especially conventional farming, the tools could provide more traceability and transparency of the agricultural products, through the documentation of all farm activities, and use of inputs. This function could also partly serve as input for marketing and communication, helping farmers to directly reach out to consumers.

[4] Representational state transfer (REST) is a software architectural style that describes a uniform interface between physically separate components, often across the Internet in a Client-Server architecture (Wikipedia)

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Table 4 Expert survey results, on other technical, environmental or socio-economic aspects (or functions) the nutrient management tools should address or contribute to

Other aspects or functions	Importance (Rank)
Environmental aspects (leaching, runoff, emissions, carbon and nutrient cycling, irrigation, pollution, energy consumption, animal welfare, sustainability)	1
Better timing of fertiliser application/Increased efficiency	2
Need for a common basis in the EU and minimum requirements	3
Record keeping for comparison, future planning, stock buying	4
Combination of tools (pest advice, meteorological data)	5
Equipment management	6
Personnel management	7
Adjustable to many crops and treatments	=
Social acceptance	8
Dialogue link between farmer and administration	=

5.4.1. Measuring the carbon footprint of farming

A particularly important aspect to be addressed by the tools is the carbon footprint of nutrient management. Agriculture is seen as a net emitter of greenhouse gases. Nevertheless, agriculture sequesters carbon in soils and captures carbon in bioenergy and food products. With properly designed decision support tools carbon sequestration can be increased, while emittance can be reduced. Tools may support farmers in changing their management to:

- Increase the carbon content of soil – as a greenhouse gas (GHG) mitigation strategy, which also helps to improve soil quality and prevent erosion, with practices like:
    - Crop residue management.
    - Crop rotation and cover crops.
    - Use of organic fertilisers (manures and other recycled organic materials).
- Increase crop yield, since all measures to improve crop yield have a direct impact on the amount of CO2 captured from the atmosphere
- Improve the effectiveness of organic fertilisation (manure/slurry). These fertilisers must be applied at the right time (weather and crop conditions), in the right places (spreading techniques), and at the right rate according to crop requirements - this will improve the efficiency of nutrients supplied by the organic fertilisers and increase the productivity and biomass (net primary productivity).
- Reduce emissions. The main gases emitted by agricultural and livestock activities are CO_2, N_2O and CH_4. Emission sources can be directly (e.g. fertilisation, manure management and use, soil management) or indirectly linked to fertilisers leaching/runoff or volatilisation and atmospheric deposition.

5.4.2. Good examples

Although not many, some good nutrient management tool examples can be found which can cover many of the functions discussed in the subsection. Mostly they are local to countries (or regions) based but they can serve as good examples for future tool development:

Overseer: The tool uses science models to analyse the impact of farm management on the flow of nutrients through the farm system. It generates balanced nutrient budgets for seven key farm nutrients that estimate the amount of nitrogen (N) leaching at the root zone and phosphorus (P) surface run-off. It also models the amount of methane, nitrous oxide and carbon dioxide generated on-farm and the amount of carbon sequestered in trees.

Fasset: is a whole-farm dynamic model. The model distinguishes and links different farm components, including field (crops and soil), animals, housing and manure storages. The model allows different field and farm management options to be explored. This includes different crop rotations and crop management options as well as different livestock feeding practices and different technologies for managing manure. The model can be used for comparing with experimental data and for exploring consequences of environmental and management changes for farm productivity and environmental impacts.

Batfarm: The software has been developed as part of the European Batfarm project. The software makes it possible to simulate the effect of a range of strategies designed to mitigate pollution on livestock farms dedicated to pigs, laying hens and poultry meat, and dairy cows. The tool allows different scenarios on each farm to be compared and thus helps to select the most suitable environmental strategy in each case. The software covers all the phases in the production system: animal housing, storage, treatment and field application of manures and slurries.

5.4.3. Integrating carbon footprint considerations

Nutrient management tools should be able to assist users in optimising their carbon footprint, therefore these applications need to provide a set of output parameters to reach an improved CO_2 balance:

- Output parameters for farmers:
  - An appropriate fertilisation recommendation to optimise crop productivity and mitigate GHG emissions by sequestering carbon and/or by reducing N_2O, CO_2 and CH_4 emissions.
  - Algorithms that can be used by digital tools tailored to local conditions (algorithms need to be provided by national authorities)
  - Carbon balance to adopt fertilisation practices that favor soil C stocking.
  - Clustering the emissions to the different fertilisation actions, highlighting areas with high emissions.

FG experts also identified functions and properties which are still missing in the current tools and that would be necessary for properly integrating carbon footprint considerations –many of them also relevant for the integration of other type of aspects-. They are listed below:

- Algorithm integration.
- APIs that enable the connection with tools like farm management.
- APIs need to be standardised and easy to implement.
- Functions to compare alternative management options to improve the efficiency of nutrient by crops so as to optimise production and reduce the risk of adverse environmental impacts.
- Factors for emission reduction depending on the application technique of organic manure – standardised way for estimation of the factor available

More information is available on this topic in **Mini-paper 4.** - Digital tools for reducing the carbon footprint in plant nutrition.

5.5. Why farmers may adopt, or nor adopt digital tools

Although market trends and farm machinery sales indicate that smart farming uptake is increasing, it is still low. Studies show that in Europe there is a rapid adoption of GNSS (Global Navigation Satellite System) guidance, and slower adoption of VRT (Variable Rate Technology). Adoption of information gathering technologies like yield mapping and remote sensing which are used to inform VRT decisions has also been relatively slow. These patterns hold in Europe, as well as in the rest of the world. Variable rate fertiliser adoption is at the upper end of the worldwide range in parts of Europe. For example, the 31% adoption of VRT fertiliser on UK cereal farms is one of the highest VRT adoption estimates (Stafford et al 2019).

Whether a digital tool for nutrient management will be successful and will be adopted by many farmers is a complex question. As seen above, farmers have many requirements for such tools to be of real use to them. If these requirements are met and the barriers addressed, then the adoption speed can be accelerated.

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There are significant differences within the European farming community in terms of digital uptake. This diversity may depend on the region (some regions are front runners while others lag behind), sector (some sectors are more digitised, i.e. intensive horticulture), generation, farm size, etc. The combination of all these variables defines a range of farmer 'digital profile' and therefore of farm information needs.

5.5.1. The main reasons for/against the adoption of digital tools

Despite the fact that many of these technologies, especially the smart farming equipment, were more commonly used among large farms, with the technological advancement and the increasing competition among technology providers, technology prices have decreased, or smart functions are provided as default to the machines. In addition, the purchase of new machines is not always necessary to start smart applications, due to the upgrade kits available from different producers. This shows that in many countries financial barriers might not be the most common ones.

Besides cost, or cost-effectiveness being one of the main barriers for adoption, many farmers still need support to understand and take up new technologies and to make decisions on ICT use adapted to their specific needs. They may also need support to find out about and understand the digital-based solutions on offer to make the right choices for their farm. Many technologies are already available, but a lack of awareness, training, and education of farmers, and in some cases of advisers, hinder their adoption. Besides, farmers do not clearly see what the return on investment is when it comes to their specific situation. There is still much room for improvement of tools in terms of e.g.: user-friendliness, inter-operability, accuracy and relevance of the output, etc. Cost/benefit analysis is not available in many cases. At the same time, for some tools and technologies, basic infrastructures needed for operation are not in place, either at farm level (i.e. particular equipment) or in the area (i.e. no bandwidth or connectivity at all).

On a different level, those who are already aware of technologies and the opportunities they offer may lack trust, confidence or certainty about how and by whom the data will be used. Finally, getting extra added value from the use of those data poses some challenges and needs. For instance, some farmers could play a significant role during the development of new business models, applications, etc., but most of them lack the skills and/or the position within the ecosystem to get involved and directly benefit from that possibility. The results of the expert survey reflect very well most common adoption barriers as shown in Table 5.

Table 5. Expert survey results, identifying the main barriers for the adoption of digital tools (in order of importance)

Barriers	Importance (Rank)
Difficult and time-consuming/Complicated/Bureaucracy/Many inputs required	1
Farmers' age and lack of understanding/knowledge/skills/data interpretation	2
Cost-benefits/No funding/No financial data provided	3
Less benefits for the farmers than for the providers and the government bodies	4
Legal frameworks/Data security	5
Tools too general/Not for specific conditions	6
Tools new and unproven or unnecessary/Not a priority	7
Previous bad experience	8
Poor UI/UX (i.e., user experience/user interface)	9
Lack of smart phone version	=
Limited network coverage in agricultural areas	=
Poor interoperability	=

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5.5.2. Good examples and lessons learnt

The Focus Group experts noted an extremely low adoption rate of the number of tools developed in the last decade. One of the reasons for this is that many tools have been developed in a rather scientific context without directly involving the end user. Previous studies such as the one delivered in the Fairway project (Nicholson et al. 2020), tried to identify criteria for higher uptake of decision support systems:

- Identifying the user and their workflow (e.g., farmer or adviser)
- Asking whether, and how, the user would benefit.
- Investigating whether rural infrastructure is in place for the tool to be used.
- Testing, with actual users rather than colleagues, whether the system is easy to use.
- Adopting a good delivery plan, considering peer-to-peer networking and trusted advisory networks.
- Planning how the system will be maintained after release, otherwise it will quickly become obsolete (Rose et al., 2016).

It is difficult to define how to measure tool success, whether it is the number of users or intensity of use, or how the delivered nutrient management affects the environmental indicators. Still, there are many good examples and success stories, and probably just as many failed attempts, and lessons learnt during the adoption processes. Some common aspects can be identified, which could be of help for future tool developments.

Keys to success and the road to failure

As the example cases indicate, the key functions to a successful tool are quite universal in Europe, and are in line with the results collected during the expert survey. Almost all good examples list that compliance with legislation is a key as this will minimise the administrative burden for farmers. While this function is a key, tools need to be updated frequently to provide accurate and up to date information for farmers and advisors. Some examples showed that the lack of frequent updates can lead to abandonment of these tools by the users.

For many cases the involvement of a state institution (governmental or research) also helped in the adoption, since farmers trust these tools, possibly because of the provided compliance with the laws and the scientific soundness. However, farmers may have concerns regarding public agencies closely controlling their activities by accessing their data.

Other important point for adoption is the cost-benefit relation. Farmers need to see how they can improve their profitability using these tools. This may not only mean direct yield increase/input cost decrease, but also decreased working hours spent with administration, paperwork.

Available trainings, training materials (online videos, handbooks) and good customer service can also increase the use of these tools, since many farmers have limited knowledge at the early stages of adoption and learning curves can be steep at the start, so support is desirable for success.

Development of tools and new functions as technologies emerge and spread is also important, since many farmers are adopting new technologies such as Precision Agriculture and they need multi-purpose, or complex tools, because using multiple software can lead to the abandonment due to the increasing administrative burden.

Good examples: Mark-Online, Denmark

Denmark used to have serious problems with nutrient emissions to waters and since the beginning of the 1990s fertilisation rules have gradually become stricter. The Danish farmers` owned company SEGES reacted quite proactively by developing a nutrient management tool which was able to address current challenges in nutrient management (Mark Online). Development, maintenance and refining of the tool has been completely covered by software license fees without notable financial government support. Because of the private ownership of the tool, there have been no farmers' concern that the data fed into Mark Online could be used for other purposes than nutrient management planning.

Farm advisors were the key actors in spreading knowledge about the tool and implementing it in practice. Every advisor received intensive trainings by the tool developers and was supported by adequate information material such as detailed manuals.

After some time, the use of the tool become mandatory since the state imposed additional taxes on nitrogen fertilisers for farms which did not apply the sophisticated nutrient management tool. Currently, about 2.6 million ha in Denmark is being planned with Mark Online, either by the farmers themselves or by advisors on behalf of the farmers.

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Early adopters are also a key in how a tool will be adopted by farmers. If these pioneers fail in the process, or have bad experiences, followers are more likely to search for other tools, or the ones which have been successfully adopted by these experimenting farmers, since they lack the openness and resources for searching, and testing different tools. This perfectly represents how the good examples of neighbouring or widely recognised pioneer farmers can increase the adoption of new tools.

Data privacy, although recognised as a key issue on many levels, currently does not seem to be a key barrier for adoption. This may be the case because farmers have not yet recognised the value of the data they are sharing, or other benefits are more important than the ownership or control of the shared data. This will most likely change in the future, when farmers will share more and more information through the digitalised tools, machines and interconnected applications.

More tool examples and reasons for their (non) adoption discussed in detail can be found in **Mini-paper 1.**

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6. What can we do?

6.1. Ideas of Operational Groups

The FG experts developed ideas for EIP-AGRI Operational Groups and other innovative actions. Out of the 12[5] initial ideas, after some clustering, four main topics were further developed, which are detailed below. The other ideas can be found in **Annex 4**.

Idea 1. Grain and Leaf Nutrient Benchmarking

Addressed problem	Evaluating effectiveness of nutrient management
Research idea	Use grain (and leaf) analysis as indicator of nutrient status and the effectiveness of nutrient management
Research plan	The main goal is to develop a tool which uses grain nutrient analysis to reflect on the effectiveness of the nutrient management and the results can feed to the next nutrient application cycle. Farmers can share their results on the developed platform where they can get instant feedback interpreted on a clear and easy to understand way. The platform also serves for joint learnings and sharing experiences.
Activities to be performed	1. Soil survey and analysis for planning of nutrient management 2. Field trials with different nutrient management scenarios within field 3. Leaf analysis and monitoring of plants and environmental conditions 4. Grain analysis after harvest 5. Statistical analysis and algorithm development 6. Development of a digital platform for evaluation of tests and interpretation or results, co-designing useful outputs
Participating groups	The idea is a collaboration of all fields involved in the farming and advising process, including • Farmers • Laboratories • Advisors • Researchers • Producers/traders of fertilisers, seeds • Grain buyers • Food industry (mill industry)
Where it should be performed	All Members States where grain is produced

[5] Four more topics were proposed during the online meeting with those experts not involved in the 2nd face-to-face meeting in Brussels

Idea 2. Test & share in manure analysis. Combining different digital tools for more precise fertilisation (Variable Rate Application).

Addressed problem	Manure is a very diverse material and its properties can change depending on type of animal, animal feed, management, season…. For appropriate nutrient management there is a need to measure physical and chemical composition and pollutants – thus a need emerges for a tool for quick analysis, preferably on the go. In addition, Variable Rate Application for manure and organic fertilisers hardly exists, thus the basics of this should be developed, along with the corresponding machine controls.
Research idea	The main goal is to search and identify existing tools, which are capable of rapidly measuring different properties of manure, or capable of measuring similar materials and can be developed to serve the needs for manure characterisation. The identified, developed tools should also be able to feed into an application machine to perform variable rate application.
Activities to be performed	1. Literature review, market research and identification of available, or potential tools 2. Testing and calibration of available tools or research on potential tools in reliability, properties to be measured and customisation for the application on a manure spreader 3. VRA capability testing, calibration of application, quality controlling 4. Testing of survey techniques to support VR application of manure 5. Field research, with monitoring sites within field under different characteristics 6. Monitoring 7. Evaluation, publishing 8. Workshop for farmers on the advantages of on the go manure measurements and VRA application
Participating groups	• Farmers • Laboratories • Researchers • Machinery producers • Sensor technology companies
Where it should be performed	Member States where manure is produced and with special focus on organic farms

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Idea 3. Testing and sharing experiences in using different types of soil sensors, in different types of soils

Addressed problem	Laboratory soil testing takes a long time and is expensive, hampering the decision making in fertilisation
Research idea	Wet chemistry based laboratory measurements are time consuming an expensive, and also have a higher environmental load compared to proximal soil sensing technologies, which are rapidly emerging on the market, sold by several technology providers. Although these tools are rapidly spreading due to the easy data collection methods, their performance haven't been properly compared to standard survey/measuring methods. The research would compare each of these tools under different soil and climatic conditions to assess their performance and reliability to support sustainable nutrient management. The project outcome would be a guideline for advisors and farmers, which could help them identify the best available technologies under their conditions to support nutrient management.
Activities to be performed	• Identification of possible research fields with high variability either within field or within the selected fields • Identification of the survey tools and methods, planning of survey process • Field survey using the selected technologies and collection of independent validation points • GIS database building and statistical analysis of results • Comparison of nutrient plans based on the different survey techniques (and the combination of those) • Validation of tools • Guideline development, possibly a web based tool, where results are published and available to farmers/advisors, and recommendations are provide based on location
Participating groups	• Farmers • Laboratories • Advisors, soil surveyors • Researchers • Technology providers (sensing) • IT/GIS specialist
Where it should be performed	In Member States with the largest soil and climatic variability. Potentially existing OGs using such technologies could include more sensing/survey tools in the research and have a validation under their conditions.

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Idea 4. Accelerating nutrient data availability for better nutrient management tools

Addressed problem	Data stored in databases hosted by public bodies is hardly available, due to several issues. The data need of nutrient management applications could partly be fed from these databases, to decrease the frustrating manual data entry time, which could increase adoption rate among farmers and advisors.
Research idea	The research focuses on the data need of NMTs and whether these data can be found in databases hosted by public bodies. Identification of barriers, and potential solutions to make these data available to users to accelerate the adoption rate of digital tools among farmers and advisors with breaking down one of the main barriers, the frustration of data entry.
Activities to be performed	• Stakeholder analysis and involvement • Collection of data types stored by public bodies • Collection of nutrient management tool data needs • Evaluation of datasets for the purpose of using in NMTs • Finding the barriers limiting the availability of these datasets • Workshops to present good examples and current status, involving all stakeholders • Conception of barriers, possible solutions and potentially roadmaps to make more data available to NMTs on an easily readable format
Participating groups	• public bodies • farmers • advisors • researchers • business actors (tool developers)
Where it should be performed	All Member States

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6.2. Research needs from practice

The FG experts identified the following research needs from practice:

Create better assessment methods for soil quality / health / properties in relation to nutrient management. Not only chemical and physical parameters of the soil should be measured, but also biological and morphological parameters. Also most of the nutrient management tools only use topsoil characteristics, while limiting layers may occur below the sampled, characterised layer. New tools, survey techniques and equipment should be developed to enable the inclusion of such limiting layers into the planning process.

More advanced, result-driven NM tools which can use soil sampling results post-harvest to evaluate the nutrient management programme and consider these for the next planning phase. Tools should also be multidimensional and should be able to use several data sources for the planning (laboratory data, remote sensing, climate etc), which would also require improved modelling to calibrate satellite images to better assist nutrient management.

Development of decision support tools using digital technologies which takes available water content and subsurface compactions into consideration during the planning of nutrient applications and irrigation. Often the predicted yield cannot be attained because precipitation is lower than average (expected), but farmers continue fertilising according to the fertilisation plan, due to the lack of this information in most of the tools. Tools should better incorporate available weather information and forecasts into the decision advice process.

Measuring emissions. Several models are available to predict emissions, e.g. modelling nitrate leaching to ground water, but these models are often too general and do not predict emissions properly EU-wide. The estimates are sometimes valid for one area (mainly where the tool was developed), but research data linked with farmer data are needed to validate these model predictions. Basic and practical research regionally can help understand and fine-tune these prediction models for better results. Farmers are mainly said to be responsible for N leaching, but they need advice or a tool tuned to the local conditions.

More advanced tools for GHG emission measurements, prediction models. The way GHG emissions are measured in the farm or field level, is not reliable enough to summarise how much GHG a farm is producing, there is a need for more in depth data, to create better models and calculations. Also there is a need for the harmonisation of methods, protocols and models, to deliver comparable results. When these are done CO_2 tag and later price tag can be added to the farming technology/emission level.

Nutrient management tools are lagging behind plant breeding in development and there is a need for **more advanced, better updated nutrient management tools,** which are able to incorporate the special needs of the new crop varieties to the planning process. These tools should be **not only crop based but variety based**, using the response curves for nutrient efficacy of these varieties.

Revisiting the N-requirements in the legislation. With new varieties, new types of fertiliser, better efficiency in nutrient management, modern farming technology, higher yields, the N requirements in the legislation may need to be revised. This may require (field) testing the environmental and economic effects of legislation.

Better control and quality checking on new input products, especially those, which do not fall under strict regulations such as fertilisers. Especially products with plant growth promoting bacteria and other biological products.

Research on **how plant analysis can be incorporated into nutrient management tools and decision making** and how the results are comparable with soil analysis. This may also allow insight in yield quality of crops grown in different environments and under different soil, water, fertiliser and crop management.

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7. Conclusions and recommendations

Although there are many digital tools for nutrient management available on the market, the adoption rate of these tools is still very low in Europe. This can have diverse reasons, which experts tried to identify during the work of the Focus Group, while also defining requirements, needs for new tools, and for functions currently lacking in these tools. Clearly a need is defined for better, more complex and scientifically sound tools, that are user-friendly, easy to learn and efficient in data sharing.

The Focus Group experts identified a range of properties and functions needed in decision support tools for farmers and advisors such as:

- User friendliness
    - Minimise the manual data entry required from the user (farmer), automate data collection as much as possible, using public databases, machinery systems, etc.
    - Interpretation should be easy to understand, preferably visual and without raw uninterpreted data.
    - The system should be able to 'grow with the user', with more functionalities available to more experienced users, but still usable as a basic system for those with less experience.
    - Live technical support, since often the problems encountered need to be solved immediately.
- Cost-benefit
    - Tools must provide a clear positive cost-benefit balance to the user, which can be measured in several ways, such as increased profitability through input savings or increased yield. A reduction of office workload through efficient reporting can also be measured as a benefit.
    - The earnings through the use of the system must clearly exceed the investment cost.
- Multifunctionality
    - The tool should support different dimensions of nutrient management, such as production (fertilisation, irrigation, crop rotation, etc.), environment (i.e. nitrate leaching, phosphorus runoff, GHG and ammonia emissions, soil health, etc.), economic aspects (cost of input material and application), compliance with reporting duties according to the local conditions, integrable in the supply chain (e.g. certification frameworks, traceability).
- Accuracy and robustness of data and models used by the tool, localisation
    - The tool must provide a properly validated, scientifically sound advice based on the information provided by the user.
    - Should be customisable to local conditions including type of farm, environmental conditions, legal environment.

Based on the examples collected by the Focus Group experts, farmers currently do not seem to consider data sharing and control as a priority when they decide on which digital nutrient management tools to use. In the near future this will be a key aspect, since the tools are getting more complex and require more data, which can create a heavy burden for the farmer due to the lack of data exchange across platforms and databases. The FG experts urgently recommend making more data available rapidly to power digital nutrient management tools. The tools cannot deliver smart nutrient management advice to farmers if there is no access to the necessary data sources. Moreover, farmers will not adopt tools that need manual input of data that could be easily imported automatically. And, most importantly, farmers want to stay in full control of their data.

Recently emerging cooperative data platforms have helped to bring practical solutions to move data sharing forward and to deliver the necessary data sets for management and planning. They bring the ecosystem together around innovative technical solutions supported by a sustainable business model and an appropriate governance system.

Besides these key functions and properties, future digital tools for sustainable nutrient management should also focus on the environmental aspects of nutrient management. Agriculture's climate impact is notable and

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evident with significant consequences for the global climate. The primary sources of Green House Gas (GHG) emissions are land clearing and tilling, livestock breeding, application of fertilisers and fossil fuel use for production of inputs. Agriculture can also be a significant carbon sink. Using a systems approach to technology optimisation and fostering an innovation ecosystem that looks at a combination of technologies, agriculture can meet its critical societal function to provide food, feed, fibre, and fuel and support rural economics, all while generating significant environmental benefit for the public good. There are many possibilities to develop appropriate tools to reduce the carbon footprint of plant nutrition but more research and practical testing is needed. Currently, there is no tool on the market that would provide a complete solution, but some sustainable farm tools quantify emissions coming from nutrient management and they can support moving further to appropriate tools for reducing the carbon footprint of plant nutrition.

The requirements for digital tools for nutrient management are expected to increase, leading to more sophisticated and complex tools, which need more data and technical knowledge for their operation. To engage farmers in the use of these tools a balance between a comprehensive approach and operational feasibility needs to be found. Tools need to focus on critical aspects, while equally respecting both environmental and economic ambition.

Finally the Focus Group experts developed some recommendations to guide tool developers, to create better and more complex tools to support all aspects of nutrient management.

- Soil health, soil quality, and more complex soil properties (microbiology, morphology) should be considered in the planning
- Better monitoring of the results of the nutrient management during the cropping season with sensors, and post harvest soil samples to evaluate the nutrient management programme and take this into account for the next planning phase
- Tools should also be multidimensional and should be able to use several data sources for planning support (laboratory data, remote sensing, climate etc), which would also require an improved modelling to calibrate satellite images to better assist nutrient management.
- Decision support tools which take available water content and subsurface compactions into account during the planning of nutrient applications, irrigation.
- Measuring, and modelling emissions, and development of more advanced tools for GHG emission measurements, prediction models. The way GHG emissions are measured on the farm or field level, is not sufficiently reliable to summarise how much GHG a farm is producing, there is a need for more in depth data, to create better models and calculations.
- Nutrient management tools are lagging behind plant breeding in development and there is a need for more advanced, better updated nutrient management tools, which are able to incorporate the special needs of new crop varieties into the planning process. These tools should be not only crop based but variety based, using the response curves for nutrient efficacy of these varieties.
- Incorporating not only yield but also food quality in the nutrient management as an additional aspect.

While the FG members identified functions and properties for future tools, they also discussed some other aspects and proposed the following as important topics for further discussion:

- There is a need for validation of tools and methods which provide basic information for nutrient management. A good example is soil information, where new survey and laboratory technologies have been emerging in the past and widely used for nutrient planning. This has been the case especially in variable rate applications, but these new/trending methods and tools lack the validation and standardisation, which is common for standard laboratory measurements.
- With new varieties, new types of fertiliser, better efficiency in nutrient management, modern farming technology, higher yields, the N requirements in the legislation may need to be revised.
- Also there is a need for the harmonisation of methods, protocols and models, to deliver comparable results especially when measuring GHG emissions.
- Better control and quality checking on new input products, especially those which do not fall under strict regulations such as fertilisers. Especially products with plant growth promoting bacteria and other biological products.

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8. References

David C. Rose, William J. Sutherland, Caroline Parker, Matt Lobley, Michael Winter, Carol Morris, Susan Twining, Charles Ffoulkes, Tatsuya Amano, Lynn V. Dicks, Decision support tools for agriculture: Towards effective design and delivery, Agricultural Systems, Volume 149, 2016, Pages 165-174,ISSN 0308-521X, **https://doi.org/10.1016/j.agsy.2016.09.009**.

European Commission, 2021 REPORT FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT on the implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources based on Member State reports for the period 2016–2019. COM(2021) 1000 final

Eurostat, 2017. Agri-environmental indicator - ammonia emissions

ENRD, (2018). Improving soil and water management through management plans. ENRD Thematic Group (TG) on sustainable management of water and soils. Available at: **https://enrd.ec.europa.eu/sites/default/files/tg_water-soil_report_nutrient-management-plans.pdf**

John V. Stafford (ed.) (2019) Precision agriculture '19, Wageningen Academic Publishers.. DOI 10.3920/978-90-8686-888-9_106

Nicholson, F.; Krogshave Laursen, R.; Cassidy, R.; Farrow, L.; Tendler, L.; Williams, J.; Surdyk, N.; Velthof, G. (2020) How Can Decision Support Tools Help Reduce Nitrate and Pesticide Pollution from Agriculture? A Literature Review and Practical Insights from the EU FAIRWAY Project. Water,, 12, 768. https://www.mdpi.com/2073-4441/12/3/768/htm

Tsiafouli, M.A., Thébault, E., Sgardelis, S.P., de Ruiter, P.C., van der Putten, W.H., Birkhofer, K., Hemerik, L., de Vries, F.T., Bardgett, R.D., Brady, M.V., Bjornlund, L., Jørgensen, H.B., Christensen, S., Hertefeldt, T.D., Hotes, S., Gera Hol, W., Frouz, J., Liiri, M., Mortimer, S.R., Setälä, H., Tzanopoulos, J., Uteseny, K., Pižl, V., Stary, J., Wolters, V. and Hedlund, K. (2015), Intensive agriculture reduces soil biodiversity across Europe. Glob Change Biol, 21: 973-985. https://doi.org/10.1111/gcb.12752

Villalobos, F.J. and Fereres, E., Eds. (2016), Principles of Agronomy for Sustainable Agriculture, Springer, Cham.

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Annex 1: List of experts and facilitation team

Name of the expert	Professional background	Country
Rafael Álvarez Garrido	Farmer	Spain
Łukasz Czech	Farmer	Poland
Henning Foged	Researcher	Denmark
Padraig Foley	Adviser	Ireland
María Isabel García Pomar	Researcher	Spain
Franz Heinzlmaier	Industry	Austria
Mariya Hristova	Other	Bulgaria
Stephan Jung	Adviser	Germany
Zivan Karaman	Researcher	France
Daniel Kindred	Industry	United Kingdom
Susanne Klages	Researcher	Germany
Zita Kriauciuniene	Researcher	Lithuania
David Nafría	Civil Servant	Spain
Maria Doula	Researcher	Greece
Owen O'Driscoll	Adviser	Ireland
Peter Prankl	Farmer	Austria
Kieran Sullivan	Farmer	Ireland
Linda Tendler	Farmer	Germany
Jürgen Vangeyte	Researcher	Belgium
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Facilitation team		
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Quico Ónega Task manager, EIP-AGRI Support Facility	Task manager	EIP-AGRI Support Facility
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Katrien Dejongh Audenaert		EIP-AGRI Support Facility
Klavdija Ramsak-Noemi		DG AGRI
Marta Iglesias		DG AGRI

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Annex 2: List of mini-papers

MP	Mini-paper title	Core Team
MP1	Farmer (success) stories - drivers and barriers to adoption of nutrient management digital tools	Linda Tendler, Zita Kriauciuniene, Kieran Sullivan, Rafael Álvarez
MP2	Creating Trusted Nutrient Management tools through better data sharing	Jürgen Vangeyte, Daniel Kindred, Henning Foged, Stephan Jung, Zivan Karaman, Owen O'Driscoll
MP3	Minimum requirements towards digital tools for sustainable nutrient management	David Nafría , Susanne Klages , Rafael Álvarez, Daniel Kindred, Padraig Foley
MP4	Digital tools for reducing the carbon footprint in plant nutrition	Franz Heinzlmaier, Peter Prankl, Mariya Hristova, Maria Isabel García, Maria Doula

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Annex 3: Digital tools identified by FG experts

Tool	Description/Comment by farmer
MarkOnline	Full-scale GIS-based Danish Farm Management Information System. Always up to date, clear output, visualisation of output.
Weather forecast	Of high revolution. From agrometeorological station.
Fertilicalc	Application for calculating crop nutrient requirements and fertiliser amounts.
TUdi project	Tools to allow farmers, technicians, companies and government agents to carry out strategies at farm level.
cropmanager.eu	Support system for managing nutrients and crop production.
e-mission/Element	Industry online tool to plan and track emission testing programs and trend data.
FAST DSS	Decision-support system (mobile application and web based solution). Incorparates soil data from the entire Europe.
LIFE AGROStrat tools	Strategies for the improvement of seriously degraded agricultural areas.
Farmstar	Scalable, satellite and crop model based service that requires no investment.
N-tester/N-sensor	Quickly and easily measure the exact nitrogen requirements of developing plants, but hand-operated and thus not scalable.
Agricon/Agriport	Precision farming specialist for information-driven, knowledge-based and automated crop production.
Verde Smart Nutritional kit	Consultancy and software applications for efficient use of water, fertilizer and treatments.
Verde Smart Pro kit	Diagnosis of the concentration of N and K in the roots (and the leaching zone) and of balance of N and K in the plant.
Sativum	Computer development for farmers that allows access and management of information on agricultural plots.
NMP online	Online system for developing nutrient management plans for environment and regulatory purposes. Also available on phone.
Farm Eye	Nutrient monitoring and planning application.
Manner/PLANET	Software tool that provides farmers and advisers with an estimate of crop available N, P, K supply.
SigAGROasesor	Platform with GIS support to provide customised recommendations for the sustainable management of extensive crops.
Terrazo	Web portal with maps.
NutriGuide/NutriZones	Online fertilisation planner.
Farmdok	Farm management software and digital field index.
Agrosmart	Farm process management program.
WatchITgrow	Online platform to support growers to monitor arable crops and vegetables.
Excel/Spreadsheet	Very flexible, but demands larger IT experience than farmers usually have.
BESyD	Accounting and recommendation system for fertilisation.
SATAGRO	Flexible IT tool for nutrient management in area of export to machine terminals. However, with very poor UI/UX.
Duengeportal NRW	Management of operating data, individual specialist information, implementation of fertiliser regulations.
atfarm	Tool to monitor the crop growth and to create application charts for fertilisers.
Fertimaps	Site specific application planning with the use of remote sensing

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Overseer	OverseerFM is online software that connects farmers to information enabling sustainable farms that protect the environment
Batfarm	Batfarm software aims to assess the mitigation potential of nitrous oxide (N_2O), methane (CH_4) and ammonia (NH_3) losses as a consequence of different strategies and techniques implemented on intensive farms.

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Annex 4. Operational Group ideas

1. Independent advisory service/research - Which tool would be suitable for individual farms. Evaluation and validation of digital tools for nutrient management
2. Moving advisors: Advisors travel to/from another country and share their problems with farmers from an other country. Farmers may pay a visit back to the advisors' country and meet other farmers and advisors.
3. Experiencing and demonstrating for trust (digital tools for nutrient management)
4. Problem: CO2 emissions, nitrate leaching contamination
   Concept: fix carbon like a tropical forest reusing the biomass from the crop and improving soil texture (VRZ) and microobiota. Optimise fertilisation and irrigation decisions with new digital tools and get „nitrate footprint". Adopt to each countries' crops.
   Activities: practical works in the farm related to manure, biomass reuse, fertilisation (organic, mineral) and irrigation decisions. Adopt technologies to each case.
   Farmers + support in several countries
5. Facts about alternative nutrition products: There is an increasing number of biostimulator, bacterias for symbiosys, microelements. There is a need to do a proper scientific review of the facts promised by products, select the most appropriate for an area of interest and perform long term field trials open to the farmers.
6. Communities towards food self sustainability or making local communities food self sustain
7. Land management plans for securing fertile soils for food production
8. Incorporation of environmental outputs in digital nutrient management tools
9. Farmers of a region train each other in new technologies and „smart farming"
10. Leaf analysis to reduce target values for in-season establishment of a thermatic network, for nutrient evaluation/bench marking
11. Regional education of people on important plant nutrients
12. Nutrition on-farm experimentation, where farmers test fertiliser application and emission in zones, and asses the effect from fertilisers – measured by satellites, sensors, yield + grain analysis
13. Create an App/API to get variables such as climate, growth info and soil results to make informed decisions to apply optimum fertiliser at right time
14. Evaluation of On-site nutrient determination: Knowing the status of nutrient in the soil takes weeks from soil sampling until the result from the lab. There are alreadytechnologioes in place (mobile labs, Stenon,...) where a quickanalysis can be done. An evaluation and broad testing in practicewould be necessary in order to achieve a calibration of the tools
15. Impact of farmer actions on soil nutrients. Establish a baseline of nutrient levels on farms in a given area.Farmers in the OG then record their manure/fertiliser/lime applications and record soil nutrient levels over the space of 3-4years. The value or innovation would be in getting the basic data and in getting farmers familiar with the connection between their actions and the impact on the soil, rather than just the grass/crop grown
16. Communication/Dissemination: There is a wealth of research available which if implemented will contribute significantly to environment and climate. Mobile app devise delivering NMP's & fert programmes to farmers will help at farm level. Outcome: Mobile app granting access to NMP. Activities: Spec & develop app. Publish in IOS and android. Actors: Public/private advisors/farmers/developers

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EIP-AGRI Focus Group
Digital tools for sustainable nutrient management

MINI-PAPER Farmer (success) stories - drivers and barriers to adoption of nutrient management digital tools

Linda Tendler, Zita Kriaučiūnienė, Kieran Sullivan, Rafael Álvarez

(Examples have been provided by all Focus Group experts)

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1. Introduction

Digital nutrient tools bear potential to improve decision making in nutrient management. They can potentially help to increase yield and to reduce nutrient leaching or greenhouse gas (GHG) emissions. The bright promise is that tools can help to make decision on how, when and under which circumstances nutrients could be applied in a way that increases nutrient efficiency and even crop yield and quality in comparison to the status quo.

There is a high diversity of tools and models available which all aim to optimize nutrient application for the higher crop yield, moreover saving resources and environment. The technical requirements to work with very sophisticated tools especially on bigger farms are there - GNSS is present on almost every modern tractor.

However, the level of uptake of specific tools by farmers is still low. For instance, Focus Group experts are aware of countless examples of farms which are very much elaborated in terms of modern machinery, but on which nutrient management planning is still being conducted with pencil and paper or a simple Excel table calculation. This is remarkable, since many tools have been developed by spending considerable efforts and finances.

One of the main reasons might be that many tools have been developed in a rather scientific context without directly involving the target group, i.e. farmers. Results of the Horizon2020 project Fairway (2017-2021) showed in a striking way that there is almost no overlap of nutrient and pesticide management tools identified by scientific literature research and tools actually employed in 13 case studies all over Europe. Previous studies have tried to find the criteria that decision support systems should fulfil to have a higher potential of being uptaken (Fairway, Rose et al. 2016). However, even tools which have a comparatively high match with some of the criteria, remain of marginal importance. Aside from being uptaken, it is of particular interest if the use of the tools is limited to a certain period (e.g. the duration of a research or extension service project) or if its use continues independently of resources being allocated to it.

If a tool will be a success in practical farming, is quite hard to assess. It also depends on the definition of success. The number of users or intensity by which a tool is being used are strong indicators for a tool's success. In addition, there should be a measureable positive effect on nutrient efficiency by using the tool.

At any rate, we have to bear in mind that farms are complex ecosystems, where a whole bunch of impacts influences decisions. Farms are businesses, which might be driven very much by economic concerns. However, final decision makers are often human beings who do not act like *Homo economicus*.

Respecting that complexity, in this mini-paper we aim to identify examples where tool adoption has worked successfully. We assume that there are different scenarios, which might lead to success. Nevertheless, there might be some common aspects in the process of tool adoption, which are inherent.

We asked several experts who have been directly involved in the adoption process of tools to tell "the whole story". The following questions/keynotes could be seen as inspiration or nudging.

- How did farmers get to know about the tool?
- Which parties were involved? (government, advisors, companies, …)
- Individual motivation / benefits for farmers to use the tool
- How long did they think about implementation?
- What was the trigger?
- Did the farmer stick to the tool?
- How long have they already stayed with the tool? Will they continue using it?

The table below shows the cases gathered and analysed to draw up few conclusions on the adoption process.

Tool	Country, region
Mark Online	Denmark
Düngeplanung (="fertilization planner")	Germany, Lower Saxony
Variable rate fertilizer, Yara N-Sensor, N-tester	Lithuania - Kaunas, Joniškis, Šakiai
Tool box: Geodim, Verde Smart (e-verd2.0), Meteogrid (Simena), infocultivo (Scada software), Wtech	Spain-Andalucia
PastureBaseIreland	Ireland
Tool Box: geodim (web gis), Verde Smart (e-verd 2.0-Nutrisens, dendrometer Plantsens), Meteogrid (Simena), adcon (advantage PRO)	Spain - Andalucia
FARMDOK	Austria, Germany
GeoSCAN	Bulgaria, Romania, Ukraine
TerraZo	Austria
SATIVUM	Spain, Castilla y León
Cultivation Management Software	Greece, Region of ATTICA, Aegina island
PLANET	Great Britain (England, Wales & Scotland)
Tool box: Verde Smart (e-verd 2.0-Nutrisens, dendrometer Plantsens), Meteogrid (Simena), adcon (advantage PRO), Wtech (deep nitrate leaching control)	Spain-Murcia
MANNER-*NPK*	UK (England, Wales, Scotland and Northern Ireland)
Tool box: Geodim, Verde Smart (e-verd2.0-Nutrisens), Meteogrid (Simena), adcon (advantage PRO), Wtech	Spain-Comunidad Valenciana
Tool box: Geodim, Verde Smart (e-verd2.0), Meteogrid (Simena), adcon (advantage PRO), Cromoenos (Bioenos)	Spain-Comunidad Valenciana

2. Archetypical cases

Although diverse, the cases collected share some common patterns for adoption. Below we describe three of the cases collected in more detail as representation of three 'typical' adoption patterns that are successful: one about Mark Online, a Danish nutrient management tool developed and promoted by the advisory service, farmer's owned company, SEGES; a second one focusing on a VRA tool introduced and spread in the Lithuanian farming community by a farm technology provider; finally, an example in Spain where a farmer cooperative plays an important role upscaling the adoption of a very new approach.

a. Nutrient management in Denmark – A long-lasting success story

The most striking fact about the Danish nutrient management tool Mark Online is its long lasting success – though its maintenance and improvement it is being actively used by Danish farmers now for several decades already.

Denmark used to have serious problems with nutrient emissions to waters and thus already since beginning of the 1990s fertilization rules become gradually stricter. The Danish farmer's owned company SEGES reacted quite proactively by developing a nutrient management tool which should be able to address current challenges in nutrient management. Strikingly, both development, maintenance and refining of the tool has been completely covered by software license fees without notable financial government support. Because of the private ownership of the tool, there have been no farmer's concern that the data fed into Mark Online could be used for other purposes than nutrient management planning.

Farm advisors were the key actors in spreading knowledge about the tool and implementing it in practice. Every advisor received intensive trainings by the tool developers and was supported by adequate information material such as detailed manuals. In the course of time, experienced advisors were able to train other advisors or farmers for their part.

After some time, the use of the tool become mandatory since the state imposed additional taxes on nitrogen fertilizers for farms which did not apply the sophisticated nutrient management tool. Currently, about 2.6 million ha in Denmark is being planned with Mark Online, either by the farmers themselves or by advisors on behalf of the farmers.

There is a lot of effort to adapt the nutrient management software to recent changes in legislation and to integrate new technological advancements, such as e.g. precision farming modules. By successfully applying the tool, farmers can thus be sure that they comply with current legal requirements. If there is a discrepancy between planned management operations and legal obligation, Mark Online will specifically highlight such aspects. Because of such features and the useful user support, there have been almost no complaints by famers concerning the software use.

Challenges, however, can be identified from the tool administrator's perspective: Since growing conditions in Danish agriculture are diverse, the tool must reflect resulting specific management needs somehow. That is why local adaption of Mark Online is certainly one of the biggest challenges while most costly factor in tool refinement

Furthermore, as a historically developed software systems, its performance will gradually decrease on modern operating systems. That is why refactoring of software code will become essential in early future, which requires again considerable financial resources.

To sum up, it is important to realize that farming systems need time for adaptation. Mark Online is a particularly nice example to trace the implementation process over decades. In this case the conjunction of government enforcement, private software solution and active involvement of advisors certainly substantially contributed to the tool's implementation. The long-lasting success is achieved by continuous, solid and innovative tool's adaption to current challenges.

b. The increasing use of the variable rate fertilisation in farms of Lithuania

The international company providing tools for precision fertilisation in Lithuania is a leading provider of solutions for digital plant cultivation in Central and Eastern Europe since 1997. In Lithuania since 2011 Yara N-Sensors and N-testers for variable rate fertilization are successfully used in over 60 farms which are on average of 500-1000 ha size and in total area of 50000 ha. The main users of the tool are crop production farms.

Successful implementation and increase of the number of farmers and expansion of the area of using variable rate fertilisation tools are mostly due active promotion and advise for the farmers of the company providing the tools. It has been helping farmers use their machines, operating resources and work time more efficiently. As a result of this, the quality of plant cultivation decisions improves considerably. The trigger of using variable rate fertilisation application is usually financial. Another very important factor having major influence on tool users expansion is real life success stories of neighbour farmers using it. In some cases, innovativeness of the farmer, concern about the environment and climate change.

Farmers benefit from using this tool saving resources and at the same time soil and environment. Advantage of the using the tool includes more homogeneous fields, higher yields, better and more even quality parameters, and nitrogen savings. In some cases, the driver is curiosity of the farmers and willingness to adopt new advanced technologies also confirmation of the good results by saving resources without losing yield and profit. Some farmers are students studying in university, some are innovators, and some gaining experience from abroad by participating in international agricultural exhibitions. Half of the farmers have received funding from the government which was also important for the expanding of the use of the tool. The advantage of the tool is that it is easy to use, reliable, and profitable, which make farmers satisfied. It is attractive also because there no need to hire specially skilled personnel for tool usage, can be trained in farm already working any tractor operator.

Company providing these tools actively supports implementation of it in the farm by advising and helping farmers during tool adoption in agro-technologies. Tool is demonstrated in annual agricultural exhibitions, also seminars and field days are organised for the farmers and agricultural students. Company is continuously collaborating with researchers and farmers by doing experiments and disseminating results.

Main challenges during the adoption process of the tool are farmer and/or tractor operator age, motivation, and education. The most farmers that are using the tool is between 30-50 years old. The time for the implementation of the tool in the farm is very individual depending on the various circumstances, environment and character of the farmer himself. The farmers are already using the tools for 5-10 years and planning to continue using it. For the successful implementation is important to have possibility to use tool in national language, availability of the updates and maintenance after sale, training and customer support. Usually if the farmers see benefit in practice that tool is saving resources and increasing profit, also the advice is available, farmers are willing to use the tool continuously.

c. Producers organisations upscaling tool uptake – the example of a berries cooperative in Andalucía, Spain

Spanish farm cooperatives play a major role in all spheres of production in the fruits and vegetables sector. In many cases it is their role and performance what makes the sector so competitive despite the small average size of the farms. Producer organisations are commonly a key driver for innovation within the sector and it is also the case for digital tools for nutrient management.

One example of this is the Cooperative Costa Huelva located in Andalucía region in Spain. The cooperative is formed by around 250 berry growers involving 1.300 ha. It is close to the Doñana National Park in Andalusia, a UNESCO World Heritage Site and one of the most important in Europe, where there are problems of overexploitation of the 2.409 square kilometer aquifer because it is surrounded by an important irrigated area and there is also a high risk of nitrate contamination.

Since 2019, the cooperative has been immersed in a new project to improve the management and efficiency of crop nutrition among its farmers to achieve water and fertilizer savings while respecting the environment. The solution involved the uptake of a combination of new digital tools trying to have a minimum cost/ha and year per farmer, as there are some that can be shared by all. The new approach seeks to enable technicians to have real-time diagnoses at certain points to understand the principles of nutrition and nitrate leaching and to be able to extrapolate this learning to all farms[1]. Combining real-time nutritional status with extrapolation tools enables a better understanding of plant nutrient status, so that nutrient management is adjusted weekly throughout the season. The farmer's perspective is combined with the environmental one, working with the company Wtech and its digital tool to obtain a nitrate footprint certificate by measuring nitrate leaching in depth near the sensor points.

[1] In the sensor points, new Nutrisens nitrate probes are used in root and drainage zones with other sensors and learning to irrigate and fertilize without leaching nitrates (Scada de infocultivo or e-verd de Verde Smart), punctual intelligent predictions are used with spatial weather alerts (Meteogrid, Simena) and decisions are extrapolated with remote sensing (Geodim web gis) and with the basic nutrition kit, which allows an objective diagnosis of nutrition to be made on the same day as the technician's visit to the field.

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The cooperative's technical team is made up of more than 11 technicians with previous experience in managing digital tools for water management and had fertilization diagnostics only every 45-60 days. In that context, the cooperative's lead farmer began testing the technology on his own farm and then, based on the positive results, promoted it in the cooperative. Few more farmers joined the new development. They all together have set the example of using the tools on their own farms, even assuming the first investments on their own. They somehow generated a consensus and the need for a vision of change.

At the same time, the role of the technical staff at the cooperative, together with technological providers, has been very important. A lot of attention has been devoted by the technology providers to properly train technical staff of the cooperative. The goal was to develop their capacities to use the new precision farming tools and their ability to take preventive technical decisions with a new diagnosis system. This was considered a key aspect to ensure a good implementation and was present during the whole implementation phase, with training and support meetings every three weeks. Advisors at the cooperative become 'smart advisors', able to understand the limitations and advantages of each tool of the integrated system and advise farmers accordingly. The implementation of the system through the cooperative also allows the small farmers to share costs so that it does not represent a barrier.

As a result, the new tools of the basic nutrition kit (sap, suction probes) have been learned to be used with great success and in some cases nitrate consumption has been reduced by almost 70%, potassium inputs have been increased (30%) and yields and fruit quality have been improved. At the same time, a pool of success stories was created in the leading farms to promote within the cooperative and achieve the nitrate footprint in an environment of maximum environmental respect.

3. Drivers and barriers for adoption

a. Key stakeholders in the adoption process

The most important actors from the demand side, this is, within the farming community, are the innovative individual farmers – in some cases they are also leaders within their communities at certain level-, the 'front runners', who may be the most important disseminators of new ideas and tools. The advisory services, either public or private, appear to be the most relevant from the offer side; technology providers may also play a significant role.

Public agencies play a role especially when there is an environmental concern at stake, particularly on nutrient leaching (N) in nature sensitive areas or when pollution caused by nutrients becomes a generalized problem. However, farmers often have concerns regarding tools which are developed or controlled by public agencies since they fear the tool could be used to closely control all their activities.

Sometimes research institutions (via specific projects) are key partners developing the tool and, eventually, partnering with other organisations to make field trials and/or finding pilot farms; in some cases the tool scales up and gets used by an extended group of famers.

b. How does it start?

Typically, the innovative farmers look for inspiring, successful cases or experiences because they want to improve their farms or just because they are innovative and like to try new things. They are eager to travel even out of their area and visit other contexts. Sometimes, when the process starts at the offer side, advisors or the provider contact them first in a kind of pilot phase – those farmers who have a track on innovating or that are somehow open to learn and try new things.

Dissemination of knowledge on previous success cases is very important, particularly for the upscale of the tool-system. After the first farmers start using the tool, early followers look at their peers around and may try themselves.

Mandatory frameworks, if they are in place, also accelerate the uptake, particularly when the tool is recognized/accepted by public authorities for the sake of compliance with legal requirements. This may be due to the increasingly complexity of legal requirements that are framing daily operations so that the tool provides a check-up or even guarantee that those requirements are met, which could be a crucial driver for uptake.

Advisors play a key role to disseminate available tools. They can do it because they are in contact with many farmers and they have the time of engaging themselves with a specific tool, whereas mostly farmers suffer from a lack of time or are simply routine-blinded. However, even within the advisory services, the most innovative are the ones pushing and driving the process. To multiply the dissemination capacity, training of the rest of the advisory community becomes critical, so innovations and new tools become widespread.

c. Uptake conditions

In terms of skills, farmer tends to be self-sufficient in the long run with tools already well known and/or with simple and handy tools. More complex implementations (multi-tool or complex ones) require the direct and permanent intervention of well trained technicians. These technicians need to have a good understanding of the tool – to explain it properly and see how it fits within the farmer operations and very good understanding of farmer's main needs, expectations and wishes. In addition, they'd do much better when they have good communication skills and they speak an appropriate language. Mutual understanding becomes much easier when there is longstanding, trusted, relationship with the farmer.

Reliable and easily accessible support is very important in the starting phase. Previous relationships among farmers and key players at the offer side are also relevant; either with the advisor, provider, the farmer cooperative, etc., so there is already trust and pre-condition to further collaborate, try new things. Advisory services or providers may both offer this contextual environment for the introduction of new tools.

However, it is not clear if the scientific robustness of the tool affects the uptake compared with the trust that the farmers have on the messenger (which may not directly be related with the scientific accuracy of the message).

Good implementation very much benefits (or even needs) that the tool is adjusted to the farm environment-context, in the way that it connects with something that is already in the system: another tool or technology, or process, or know-how, or way of doing. The more isolated and/or distinct and/or standing alone the tool is, more attention and willingness by the farmer is needed: therefore, a much clear incentive should be there (economical, regulatory, etc.). In this sense, it might be more promising to build on already existing, well-functioning tools, than inventing a totally new one.

When aims are clear or issues at stake critical, there is margin for failure with one tool. Farmer may try another one anyway. But it may not be the case if reasons or potential gains are vague.

Cost of the tools is frequently referred to as a barrier. Nevertheless, considering the cases reviewed, frequently there are tools free of charge available for farmers. In addition, cost might not be a barrier when there is a clear cost/benefit ratio for the producer: i.e. with crops of high value and/or with a high ratio of input/ha, so there is a big margin for gaining efficiency and improving harvesting results, or in big farms when the cost/unit is low. Cost can also be affordable when there are economies of scale, for instance by sharing technologies and technical support among several farmers/hectares, which would lead to the scenario previously described. The direct involvement of farmer associations or cooperatives is, in that case, very important.

In first stages, data related issues seem not be a main barrier in many circumstances. It may be the case later in the adoption process, when farming technics get more digitalised and services interconnected. Besides, issues related to data privacy may be a constrain when there is a potential perception by the farmers of government accessing to too sensitive data as a means of intervention or control.

4. Cases collected

The following tables show the cases collected (except the ones already introduced). 15 cases from 10 countries have been surveyed by the focus groups experts.

a. Düngeplanung (="fertilization planner") - Germany, Lower Saxony

General info	
Country-Region of the farm(s)	Germany, Lower Saxony
Sector	Arable farming
Number of farmers involved	100-200
Average size of farm involved	From 5 to several hundred hectares
Age of the farmer(s)	Very diverse
Name of the tool	Düngeplanung (="fertilization planner")
For which functions is the tool used?	To design a plan on fertilizer distribution
Years in operation (the described tool)	About 8 years
Drivers and barriers for adoption	
Main driver for the adoption process	Agricultural advisors who run the tool with the data of the farmers. Farmers often contract the advisors to design the fertilization plans. In daily life, farmers usually provide all the information (fields, cropping history, soil and plant analyses, fertilization history, and so on) and ask the advisors to make the fertilization plan for them. This plan will usually be adopted several times during the growing season. Reasons: legal requirements and requirements for documentation. But it is also the concern about environmental pollution. And in recent times also the need to safe money, since prices for fertilizers doubled or even tripled.
Ways of identification, selection of potential tools	The tool has been adopted to the farmer's needs in terms of legal requirements for fertilization
Have several tools been tested?	To some extent. There are some very nice commercial solutions of tools, however, many of them lack comprehensiveness to over the complex fertilization requirements
If yes, which were the main	Issues with data privacy

properties upon selection?	Comprehensiveness of tool is not sufficient (does not need legal requirements)
External funding?	Yes, funded by the federal state of Lower Saxony
Challenges during the adoption process?	Changing legislation; not self-explanatory design of tool lack of maintenance of tool by IT
Were those successfully addressed or led to failing in the process	Partially. Some farmers dropped out because they were tired of delayed software updates
Which party was the main driver either way (farmer. Tech provider, advisor, farmers group or asoc., etc)	Agricultural advisors in public advisory service Some farmers in need to fulfill administrative documentation of fertilization
Main advantages of tool usage	A plan is designed beforehand by combing different data sources BEFOREHAND
How many personnel are trained at the farm to use the tool?	Sometimes only advisor, sometimes the head of the farm
If they failed with one tool (or adopted one but not satisfied fully), is there a willingness to try adopting another one?	Farmers tend to become tired when working with beta-versions of tools. They expect software which helps them to reduce work and d not want to work with tools which cause additional work

Adopted tool(s) basic information and technical details	
Cost (eg per ha)	About 2-5 EUR7ha and year but very variable; usage has been subsidized in the past
Regionality (languages and availability)	Only German
Platform (PC, Mobile)	PC version; app version would be preferable
Maintenance (updates, customer service)	Irregular updates; suggestions to improve the tool have been made bt it takes a lot of time until they are implemented
Training, customer support availability	Costumer support is poor but would be extremely helpful to support farmers in using the tool
Data needs of the tool	Fields (API to already existing data), soil analysis, fertilization history of field, crop rotation and yield information
Data sources of tool, API connection to other data sources	See question before
Visualization, interpretation	Visualization is poor; This is one of the crucial drawbacks. There would be may possibilities to nicely visualize the results

Transparency, scientific soundness	Evidence for specific numbers is not always provided. Clear data reference would surely help to make the tool more attractive
Comprehensiveness of tool	Tool is quite complex. However, it would be nice to integrate more data on non-mandatory basis (e.g. precision farming modules)
Data sharing, sovereignty, security	Full data sovereignity. The software runs offline.
Advisor connectivity, involvment	Support in using the tool is needed
Is the tool used is aligned with other tools and national declarations to transfer and share data for example to make reporting easier?	Partially. There are attempts to do so but it does not work properly yet.
Monitoring on sustainability, profitability provided?	Not known
Special skilled personnel should be hired/trained for tool usage?	Anyway, using the tools needs some extra training

b. PastureBaseIreland - Ireland

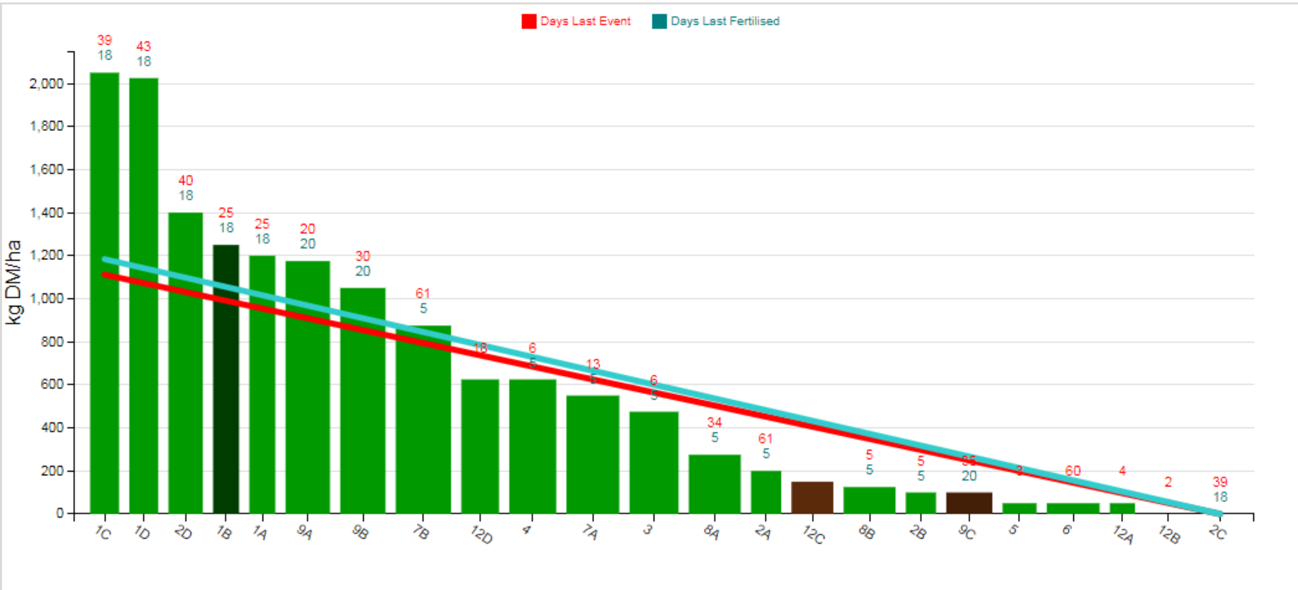
General info	
Country-Region of the farm(s)	Ireland
Sector	Available to all sectors but mostly used by dairy farmers
Number of farmers involved	3,000
Average size of farm involved	unavailable officially but average dairy farm in Ireland is 40 HA
Age of the farmer(s)	45-54
Name of the tool	PastureBaseIreland
For which functions is the tool used?	Main function: measure/record grass growth on a weekly basis; various reports are generated from this information including nitrogen/fertiliser use
Years in operation (the described tool)	8 years (started in 2014)
Drivers and barriers for adoption	
Main driver for the adoption process	Manage grass better to facilitate end of milk quota system in Ireland in 2015. For the most part, the need to grow more grass to carry more

	dairy cows when the milk quota scheme was removed.
Ways of identification, selection of potential tools	Nothing comparable available in Ireland. Advisors from Teagasc (tool developers/owners) and from other farmers in their discussion groups. There is also regular coverage of farmers using the tool, and their grass data, in the main farming newspaper (Irish Farmers Journal).
Have several tools been tested?	Unlikely but can't say for certain; there may have been some early competitors
If yes, which were the main properties upon selection?	N/A
External funding?	Free tool to farmers, but they contribute to the overall 'dairy levy' which part funded the original development of the tool
Challenges during the adoption process?	The usual: new tool = cost-benefit at farmer level; e.g. Why do I need a new tool to manage grass? I don't have time. Why are Teagasc (national advisory body) pushing this? Etc.
Were those successfully addressed or led to failing in the process	Farmers (adopters) have mostly overcome the challenges but each new user will have similar questions/challenges
Which party was the main driver either way (farmer. Tech provider, advisor, farmers group or asoc., etc)	Started with advisor (Teagasc) but may have been promoted thru farmers' peer discussion groups. Teagasc are the Government advisory body
Main advantages of tool usage	More efficient use of grass and silage crop
How many personnel are trained at the farm to use the tool?	Often just one: farm owner/manager, but maybe some staff as well
If they failed with one tool (or adopted one but not satisfied fully), is there a willingness to try adopting another one?	Unlikely

Adopted tool(s) basic information and technical details	
Cost (eg per ha)	App is free to download
Regionality (languages and availability)	Ireland
Platform (PC, Mobile)	PC, Mac, Android, iOS
Maintenance (updates, customer service)	Automatically by Teagasc developers
Training, customer support availability	Videos available online plus one-to-one available thru advisor

Data needs of the tool	Farm layout, location, paddock size
Data sources of tool, API connection to other data sources	Farmer enters data manually
Visualization, interpretation	"Wedge" shows bar chart with amount of grass in different paddocks with livestock demand superimposed on top (see example)

"Wedge" image example



c. VRA, Yara Sensor, N tester - Lithuania

General info	
Country-Region of the farm(s)	Lithuania - Kaunas, Joniškis, Šakiai
Sector	Crop production
Number of farmers involved	50
Average size of farm involved	500-1000 ha
Age of the farmer(s)	30-50
Name of the tool	Variable rate fertilizer, Yara N-Sensor, N-tester
For which functions is the tool used?	For variable rate Nitrogen, growth regulator and fungicide application
Years in operation (the described tool)	5-10

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Drivers and barriers for adoption	
Main driver for the adoption process	Easy to use, reliable, profitable, happy farmers
Ways of identification, selection of potential tools	Following precision farming recommendations
Have several tools been tested?	No
If yes, which were the main properties upon selection?	-
External funding?	Half of the farmers received funding from government
Challenges during the adoption process?	Tractor operator age, motivation, education
Were those successfully addressed or led to failing in the process	Yes
Which party was the main driver either way (farmer. Tech provider, advisor, farmers group or assoc., etc.)	Happy farmer influence to each other
Main advantages of tool usage	More homogeneous fields, higher yields, better and more even quality parameters, Nitrogen savings
How many personnel are trained at the farm to use the tool?	In average two
If they failed with one tool (or adopted one but not satisfied fully), is there a willingness to try adopting another one?	Yes, some of the farmers willing to make trials in the fields to test something new

Adopted tool(s) basic information and technical details	
Cost (eg per ha)	The sensor costs 40000-55000 Eur and saves 100-150 euros / ha / year Soil tests it is about 20 eur / ha / 4 years
Regionality (languages and availability)	Yes, available in local language (Lithuanian)
Platform (PC, Mobile)	PC
Maintenance (updates, customer service)	Yes, updates and maintenance provided

Training, customer support availability	Yes, customer support included
Data needs of the tool	Application maps, N-uptake maps
Data sources of tool, API connection to other data sources	All data collected online and sent to digital farming platform Agriport
Visualization, interpretation	Yes, maps of product application rates and N-uptake
Transparency, scientific soundness	Yes proven by many years of field trials OFR
Comprehensiveness of tool	Yes easy and simple to use
Data sharing, sovereignty, security	All data is protected by username and password
Advisor connectivity, involvment	Yes consultant can connect online and help customer
Is the tool used is aligned with other tools and national declarations to transfer and share data for example to make reporting easier?	Yes, all data can be used in standard,, shape,, or ,,iso.xml,, formats and sent to another digital farming platform
Monitoring on sustainability, profitability provided?	Provided information about fertilizer usage in each field for each crop
Special skilled personnel should be hired/trained for tool usage?	Not necessarily, can be trained in farm already exiting any tractor operator.

d. Tool Box – Andalucia, Spain

General info	
Country-Region of the farm(s)	Spain- Andalucía-Sevilla
Sector	Stone fruit production

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Number of farmers involved	Private company
Average size of farm involved	105 has
Age of the farmer(s)	Private company
Name of the tool	Different tools, from geodim (web gis), Verde Smart (e-verd 2.0-Nutrisens to measure nitrate and potassium in the soil and dendrometer Plantsens), Meteogrid (Simena), adcon (advantage PRO)
For which functions is the tool used?	Control Vegetative development, fruit growth, management to promote reserves of photoassimilates and nitrate in the tree for the following year to promote highest production with lowest inputs and nitrate environmental control to get nitrate footprint
Years in operation (the described tool)	Since August 2021
Drivers and barriers for adoption	
Main driver for the adoption process	It is a large company, with 3,000 ha of fruit trees, one of the leaders in Spain and they were looking for a customized solution to implement precision agriculture on a large scale in the company, especially everything related to the management of in-puts, fertilizers, and water, being aware of the potential savings of fertilizers, whose management involves more than 5 M€/year and potential improvement of production and quality (fruit-size). The fertilization plan is theoretical, based on experience, but there are no diagnostic tools available in real time during the execution of the plan, to know if there is a surplus or lack of nutrients, especially nitrates.
Ways of identification, selection of potential tools	visiting successful cases of this methodology in Spain and talking to similar cases abroad (Peru) on large farms.
Have several tools been tested?	Yes, The "smart method" includes GIS, remote sensing, monitoring points with sensors (plant-nitrate sensor Nutrisens from Verde Smart-soil moisture-weather), basic nutrition kit, training, intelligent forecasting and annual fee for on-line services and support. A nutrition methodology that combines weekly plant nutrition status, together with a daily nitrate and potassium sensor in the root zone and the drainage below roots to detect nitrate leaching to save nitrate.
If yes, which were the main properties upon selection?	Combining savings, teamwork, communication, know-how creation and sustainability. A tool was sought that facilitates the creation of a record of success stories and that the knowledge belongs to the company and facilitates the communication of the experience and enhances teamwork in an organization with more than 20 technicians and 30 different farms.
External funding?	no
Challenges during the adoption process?	Promote a process reengineering linked to the decision making of inputs throughout the organization where training for the use of new tools becomes one of the most important elements. It was necessary to look for technical leaders of change, open to technology and willing to learn, to create success

	stories to communicate to the rest of the organization, with the express support of the CEO and management, directly involved in the change. The company had already had failures in the implementation of other technologies and was reticent about new technologies.
Were those successfully addressed or led to failing in the process	They have been a success thanks to the fact that the objectives have been met: two technicians have been selected as leaders of change with a desire to learn, 2 different farms, weekly follow-up videoconferences have been held, including management representatives, to the technical direction that was initially reluctant to change and new precision agriculture technician, new position to help promote change. Decisions have been made from the first week of cultivation, with important changes in the nitrate and potassium supply plan. They have increased production in 15%, bigger fruit size, and the decision of increase 30% potassium. Same nitrate input, but it seems they could save next year.
Which party was the main driver either way (farmer? Tech provider, advisor, farmers group or asoc., etc)	A highly trusted prescriber of the property, based on the visit of success stories.
Main advantages of tool usage	With intelligent weather forecast to Irrigation and Nutrient decisions, checked, and adjusted daily with the performance of 2 "monitoring-Characterization" points with sensors from Verde Smart. Easy to use once training has been acquired by the technical department creation of traceability, development of internal capacity for preventive irrigation and fertilization decisions and creation of the company's know-how in an objective way to try to maintain quality and profitability every year together with sustainability.
How many personnel are trained at the farm to use the tool?	5
If they failed with one tool (or adopted one but not satisfied fully), is there a willingness to try adopting another one?	what is important in the training is to explain the advantages and limitations of each tool and that there is no "one tool that solves everything", but that the key is in the combination of all kinds of tools, respecting those that the technician himself is using currently, because it is necessary to find an optimal cost/benefit combination

Adopted tool(s) basic information and technical details	
Cost (eg per ha)	Economic cost/benefit ratio, €90/ha/year sharing basic infrastructure investments and annual expenses between 105 ha (€52/ha basic infrastructure) and €38/ha/year annual expenses).
Regionality (languages and availability)	Spanish language and is available to use it within the whole national territory
Platform (PC, Mobile)	PC, mobile and tablet and is supported for Apple iOS and Android OS devices.
Maintenance (updates,	Regular updates. Attention to users through support mail and by phone.

customer service)	
Training, customer support availability	Weekly meetings (videoconferences). Development of the internal capacities of the technical staff to use the new precision farming tools and their ability to take preventive technical decisions with new diagnosis.
Data needs of the tool	Personalized GIS with "fix data". Data from sensors, data from field data (quality, basic nutrition kit, app from leaf area, production forecast)
Data sources of tool, API connection to other data sources	Data from sensors are linked to all the different software's and have a common integration
Visualization, interpretation	Easy, with "red and green" easy interface once there are experience and easy diagnostic of plant problems. Customer is trained to create its own alerts based in their own experience and the focus is "preventive decisions" based in its own personalized alerts.
Transparency, scientific soundness	Private project.
Comprehensiveness of tool	Is a tool for technical staff, as it integrates different technologies they have to be trained to understand limitations and advantages of each one.
Data sharing, sovereignty, security	Data belong to the customer.
Advisor connectivity, involvment	Technical staff, advisors and owners can access to it.
Is the tool used is aligned with other tools and national declarations to transfer and share data for example to make reporting easier?	NO, it is a private solution, belongs to the customer
Monitoring on sustainability, profitability provided?	The farm is close to the Doñana National Park in Andalusia, a UNESCO World Heritage Site and one of the most important in Europe, where there are problems of overexploitation of the 2,409 square kilometer aquifer because it is surrounded by an important irrigated area and there is also a risk of nitrate contamination that could end up in 15 years like the Mar Menor. During the first six months, work has been done to understand the drainage dynamics and, in parallel, decisions have been taken from the outset to change the theoretical fertilization plan, which has led to a reduction in nitrate (10%) and increases in potassium inputs (30%) and has led to a record in production and fruit size (20% more production and 10% more fruit size). It is expected to start working with the nitrate footprint certificate this year.
Special skilled personnel should be hired/trained for tool usage?	Yes, they have hired on technical staff to be the specialist in precise agriculture and certifications.

e. FARDMOK – Austria and Germany

General info	
Country-Region of the farm(s)	Austria, Germany
Sector	All farming types
Number of farmers involved	>2000
Average size of farm involved	50 - 80
Age of the farmer(s)	20-60
Name of the tool	FARMDOK
For which functions is the tool used?	Documentation of farm activities, nutrient demand calculation, fertilization planning, organic manure management, creation of application maps
Years in operation (the described tool)	7
Drivers and barriers for adoption	
Main driver for the adoption process	Calculation, Optimization and documentation of fertilizer inputs. Fulfillment of legal requirements
Ways of identification, selection of potential tools	
Have several tools been tested?	Tool has been constantly improved during operation period.
If yes, which were the main properties upon selection?	User feedback, technology development.
External funding?	No
Challenges during the adoption process?	Both in Austria, but especially in Germany the legal framework around fertilization and allowed nutrient input in N and P is very complex. The development of all necessary functions was cumbersome and expensive. Changes of legal framework during the adoption process made the development even more challenging.
Were those successfully addressed or led to failing in the process	Challenges were addressed, testing with farmers and specialized advisors from German authorities done.
Which party was the main driver either way (farmer. Tech provider, advisor, farmers group or asoc., etc)	Farmers were the main drivers.

Main advantages of tool usage	Tailor-made nutrient demand calculation and automatic documentation of the fertilizer applications.
How many personnel are trained at the farm to use the tool?	Training online possible via youtube videos
If they failed with one tool (or adopted one but not satisfied fully), is there a willingness to try adopting another one?	n/a
Adopted tool(s) basic information and technical details	
Cost (eg per ha)	149 EUR/ha year up to 100 ha; version with precisión farming is more expensive
Regionality (languages and availability)	AT and DE with legal framework available; CZ,SK,HU without
Platform (PC, Mobile)	Web interface, mobile application (IOS and Android)
Maintenance (updates, customer service)	Updates when necessary; plant protection updates on daily base
Training, customer support availability	Dedicated customer support via phone or mail. Online and face to face trainings for groups upon demand.
Data needs of the tool	Digital field boundaries
Data sources of tool, API connection to other data sources	Own farm data.
Visualization, interpretation	Interactive map, charts, exports in various formats.
Transparency, scientific soundness	
Comprehensiveness of tool	Tool is to a large extent self explaining
Data sharing, sovereignty, security	Can only be determined by the user.
Advisor connectivity, involvment	
Is the tool used is aligned with other tools and national declarations to transfer and share data for example to make reporting easier?	Legally necessary reports can be created at fingertips when the documention of farm activities has been done earlier.
Monitoring on sustainability, profitability provided?	Cost- and earnings calculation possible on farm-, crop-, and hectar-level.
Special skilled personnel should be	Tool is intended for usage by farmers.

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hired/trained for tool usage?	

f. GeoSCAN - Bulgaria, Romania, Ukraine

General info	
Country-Region of the farm(s)	Bulgaria, Romania, Ukraine
Sector	Arable farming
Number of farmers involved	>200
Average size of farm involved	750 ha
Age of the farmer(s)	45-60
Name of the tool	GeoSCAN
For which functions is the tool used?	Management of entire process for soil sampling, results interpretation, fertilization recommendation and variable rate application maps generation.
Years in operation (the described tool)	5
Drivers and barriers for adoption	
Main driver for the adoption process	Optimization of fertilizer inputs for medium and big size farms.
Ways of identification, selection of potential tools	
Have several tools been tested?	Tool has been constantly improved during operation period.
If yes, which were the main properties upon selection?	User feedback, technology development.
External funding?	No
Challenges during the adoption process?	Main challenge for Variable Rate of Application is the farmers' doubts about the real benefits of the solution. Next comes the technological obstacles in implementation of the recommendations/digital maps for fertilization on the field – suitable equipment, trained personnel.
Were those successfully addressed or led to failing in the process	Challenges were addressed with number of trials and demonstrations on farmers' fields, exhaustive training and technical support at field level.
Which party was the main driver	Main driver is the technology and advisory provider – NIK Agro Service

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either way (farmer. Tech provider, advisor, farmers group or asoc., etc)	Ltd. which operates in both countries.
Main advantages of tool usage	Significant reduce of application of Phosphorous fertilizers, Nitrogen application and especially VRA is still in trial phase.
How many personnel are trained at the farm to use the tool?	Depending on the farm size – between 2 and 5.
If they failed with one tool (or adopted one but not satisfied fully), is there a willingness to try adopting another one?	n/a

Adopted tool(s) basic information and technical details	
Cost (eg per ha)	n/a
Regionality (languages and availability)	EN,BG, RO, Ukraine, Russian, Italian, Spanish. Currently in the countries above.
Platform (PC, Mobile)	Web SaaS, mobile application (IOS and Android)
Maintenance (updates, customer service)	2-3 weeks update cycle. Specialized tools for user onboarding and updates notifications.
Training, customer support availability	Dedicated customer support, field visits by advisors, specialized training facility – NIK Academy with training halls, hardware equipment and test fields.
Data needs of the tool	Digital field boundaries, Sentinel 2 images, weather monitoring hardware (weather stations and soil sensors), weather forecast API by third party provider.
Data sources of tool, API connection to other data sources	Integrations with 3rd party API's – navigation displays data connections.
Visualization, interpretation	Interactive map, charts, exports in various formats. Highly customizable interpretations and recommendations algorithms.
Transparency, scientific soundness	Partnership with leading universities in EU and USA, ISO certification for IT security, quality and soil sampling procedure.
Comprehensiveness of tool	n/a – nor sure what's about
Data sharing, sovereignty, security	Via API and files export.
Advisor connectivity, involvment	Full integration with advisory service.
Is the tool used is aligned with other tools and national declarations to transfer and share	Partialy for PPP documentation and record keeping.

data for example to make reporting easier?	
Monitoring on sustainability, profitability provided?	Expenses calculation and planning is core functionality of the system.
Special skilled personnel should be hired/trained for tool usage?	Tool is intended for usage by farm managers and agronomists.

g. TerraZo – Austria

General info	
Country-Region of the farm(s)	Austria
Sector	Currently for cereals
Number of farmers involved	>500
Average size of farm involved	15 - 200
Age of the farmer(s)	20-60
Name of the tool	TerraZo
For which functions is the tool used?	Creation of application maps including fertilization advice
Years in operation (the described tool)	2
Drivers and barriers for adoption	
Main driver for the adoption process	Fulfilling F2F requirement – increasing of nitrogen efficiency
Ways of identification, selection of potential tools	Tool was created newly – basis for the recommended nitrogen amounts in the different zones of a field are field trial results over 5 years; differences of humid or dry regions are taken into account.
Have several tools been tested?	Tool has been constantly improved during operation period.
If yes, which were the main properties upon selection?	The knowledge of how to improve nitrogen efficiency in a scientifically proven way was the driver for creating the tool.
External funding?	yes
Challenges during the adoption process?	The correct interpretation of different crop development in parts of the field and how to react best with fertilization (also the quantity difference between zones)

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Were those successfully addressed or led to failing in the process	Testing with 20 pilot farms and advisors from the agricultural chambers done.
Which party was the main driver either way (farmer. Tech provider, advisor, farmers group or asoc., etc)	Ministry of Agriculture, agricultural chambers, Josephinum Research.
Main advantages of tool usage	No costs, completely easy to use and enhanced fertilization; less nitrogen necessary for the same yield
How many personnel are trained at the farm to use the tool?	Tool is basically self-explaining. Regular trainings for groups of farmers are organized.
If they failed with one tool (or adopted one but not satisfied fully), is there a willingness to try adopting another one?	n/a

Adopted tool(s) basic information and technical details	
Cost (eg per ha)	For free
Regionality (languages and availability)	AT
Platform (PC, Mobile)	Web application + mobile application (IOS and Android)
Maintenance (updates, customer service)	Constant updates/improvements/new features
Training, customer support availability	Customer support via agricultural chambers and Josephinum Research. Group trainings are organized
Data needs of the tool	Only internet
Data sources of tool, API connection to other data sources	Any company or institution can use the algorithm via API. Currently existing API with Borealis L.A.T GmbH
Visualization, interpretation	Interactive map, can be used on mobile pone during fertilizer sopreading process
Transparency, scientific soundness	Hundreds of scientifically proven field trials over 5 years are building the base.
Comprehensiveness of tool	Tool is to a large extent self explaining
Data sharing, sovereignty, security	Can only be determined by the user.
Advisor connectivity, involvment	

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Is the tool used is aligned with other tools and national declarations to transfer and share data for example to make reporting easier?	Legally necessary reports can be created at fingertips when the documentation of farm activities has been done earlier.
Monitoring on sustainability, profitability provided?	Cost- and earnings calculation possible on farm-, crop-, and hectar-level.
Special skilled personnel should be hired/trained for tool usage?	Tool is intended for usage by farmers.

h. SATIVUM – Spain, Castilla y León

General info	
Country-Region of the farm(s)	Spain-Castilla y León
Sector	Grain crops, mosly cereals rainfed or irrigated.
Number of farmers involved	5
Average size of farm involved	150 ha
Age of the farmer(s)	40 years
Name of the tool	SATIVUM (www.sativum.es)
For which functions is the tool used?	Nutrient plan for current season, crop monitoring by remote sensing images (Sentinel-2); log the tasks carried out on the plots (tillage, phytosanitary treatments, fertilizer applications, etc); check weather forecast and observe historical meteorological data.
Years in operation (the described tool)	Since March 2021
Drivers and barriers for adoption	
Main driver for the adoption process	Presence in workshops and farmer associations meetings. Also regulation changes accepted specifically SATIVUM as a tool for nutrient balance in the Nitrate Vulnerable Zones and in the permission for new animal farms.
Ways of identification, selection of potential tools	Free
Have several tools been tested?	Yes
If yes, which were the main properties upon selection?	Handy and simple application, and it should be an easy-to-use and intuitive tool. He highlights that it must be possible to use it without the need to invest a lot of hours in training.

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External funding?	Yes, the tool is a fork of EU FAST platform in the nutrition side
Challenges during the adoption process?	The main challenge was getting them used to the tool and using it on a regular basis. Also that they trust the recommendations offered by the nutrient module. We dare to say that maybe this is the most difficult challenge. The tool has been developed together with data sources to assure that most data required is already preloaded
Were those successfully addressed or led to failing in the process	He got used to the application easily, so was successfully addressed. But about the fertilization issue, he is in process to adopt the recommendations…
Which party was the main driver either way (farmer. Tech provider, advisor, farmers group or asoc., etc)	ITACyL technicians and collaborating farmers
Main advantages of tool usage	It is easy to use with a little training
How many personnel are trained at the farm to use the tool?	One
If they failed with one tool (or adopted one but not satisfied fully), is there a willingness to try adopting another one?	Yes

Adopted tool(s) basic information and technical details	
Cost (eg per ha)	Totally free available at www.sativum.es
Regionality (languages and availability)	Spanish language and is available to use it within the whole national territory
Platform (PC, Mobile)	PC, mobile and tablet and is supported for Apple iOS and Android OS devices.
Maintenance (updates, customer service)	Regular updates. Attention to users through support mail (soporte-sativum@itacyl.es) and by phone.
Training, customer support availability	Workshops and training sessions on local demand. There are also short videos uploaded on the website to help users learn the app usage (https://www.sativum.es/web/sativum/tutorials).

Data needs of the tool	There are several application levels. In order to ease the application usage, a plethora of data have been previously uploaded to the platform through several source of information (soil database, meteorological data network, LPIS information, crop information on basis of CAP declarations or an own crop classification map annually generated. Thus, on the basic level users do not need to enter any data. Nevertheless, as the users want a more advanced answer, they have the chance to enter their own soil analysis data, for example, in order to obtain a personalized fertilization plan.
Data sources of tool, API connection to other data sources	For nutrition there is an API to get soil information from the parcel based on large soil samples database from the government. There are several other REST services developed and published such as LPIS parcels and crop, nitrate on ground water and so on. (https://www.sativum.es/web/sativum/services).
Visualization, interpretation	Sativum has a data viewer to ease the user interpret better the data.
Transparency, scientific soundness	High level of transparency. All the REST services developed have been made publicly available to third parties. The algorithm (FERTILICALC) is published in scientific papers and the code is available in the FAST platform.
Comprehensiveness of tool	Regarding nutrition covers the planification at multiples stages accepting changes in yield expectations along the season. It also covers VRA zones delineation and there is a version in progress to link VRA with nutrient balance.
Data sharing, sovereignty, security	The app offers the chance to download the geographical borders of the plots in a geocsv format and the nutrition plans in excel file. The API developed allow third parties to use them. For instance, the farmers Parcells (geometry) and crop are available.
Advisor connectivity, involvment	No specific role for advisor. It was considered from the beginning linked to FAST platform advisers but it is not further developed.
Is the tool used is aligned with other tools and national declarations to transfer and share data for example to make reporting easier?	Yes, it is connected with the Geo-Spatial Aid Application, GSAA in order to let farmers to download their graphical declarations for the CAP subsides. It also allows farmers to send georeferenced photos to accomplish some requirements for the CAP.
Monitoring on sustainability, profitability provided?	It is possible to introduce price of fertilizer and perform a cost per parcels but is not very much developed.
Special skilled personnel should be hired/trained for tool usage?	It is designed for farmers use, nevertheless, if wanted, the advanced parametrization would require a good agronomic background.

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i. Cultivation Management Software - Greece, Region of ATTICA, Aegina Island

General info	
Country-Region of the farm(s)	Greece, Region of ATTICA, Aegina island
Sector	Pistachio trees cultivation
Number of farmers involved	30
Average size of farm involved	Small holdings of ca 0,1 ha for each farmer involved
Age of the farmer(s)	30-60
Name of the tool	Cultivation Management Software
For which functions is the tool used?	A GIS tool designed to provide: 1. soil, water and organic waste (solid and wastewater) assessment in terms of their physicochemical properties and especially for waste the appropriateness of use according to law restrictions 2. fertilization consultancy 3. soil suitability for waste reuse 4. amount of waste to be reused in fields in relation to trees requirements, soil composition and law restrictions. 5. information archiving and monitoring at field level, either by the producer or by the association and the Region Wastes considered are: pistachio waste, olive mill waste, wine-making waste, manures.
Years in operation (the described tool)	10
Drivers and barriers for adoption	
Main driver for the adoption process	Limited digital skill of the farmers
Ways of identification, selection of potential tools	The tool was the only one used since it was developed during the LIFE-AgroStrat project and was one of the project objectives.
Have several tools been tested?	See pls the previous answer
If yes, which were the main properties upon selection?	
External funding?	LIFE+
Challenges during the adoption process?	Older farmers face difficulties to use such tools.
Were those successfully	We organized a series of training courses for all farmers.

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addressed or led to failing in the process	
Which party was the main driver either way (farmer. Tech provider, advisor, farmers group or asoc., etc)	Farmers and their association.
Main advantages of tool usage	1. There are two ways of using the tool. The one way is for farmers who have recent soil, and waste chemical analysis. They insert the results and receive consultancy. The second way is for farmers who have not analyses of the resources. In this case, the software retrieves soil data from soil thematic maps created for the whole area of interest through soil samplings and mapping. The farmer finds its field on the map and the background soil data is retrieved and used for the consultancy. In the same way, preexisted data for the different waste streams (retrieved from literature) is also used. 2. The entire area was characterized in terms of its suitability for waste distribution and reuse, by considering specific criteria of suitability, from highly suitable to absolute unsuitable.
How many personnel are trained at the farm to use the tool?	All farmers of the association
If they failed with one tool (or adopted one but not satisfied fully), is there a willingness to try adopting another one?	

Adopted tool(s) basic information and technical details	
Cost (eg per ha)	No cost
Regionality (languages and availability)	English, Greek
Platform (PC, Mobile)	pc
Maintenance (updates, customer service)	Partners of the LIFE Project are responsable for this
Training, customer support availability	Yes, on demand
Data needs of the tool	Chemical analysis of soil, water and waste Age of the trees Field coordinates
Data sources of tool, API connection to other data sources	
Visualization, interpretation	Outputs are included in tables and are pdf extractable

	For archives we use also graphs
Transparency, scientific soundness	The algorithms behind the tool are based on crops needs and the legislation, while the estimation for fertilizers/waste application is performed using a nutrients balance approach. Land suitability evaluation is performed according to FAO methodology
Comprehensiveness of tool	
Data sharing, sovereignty, security	Each Farmer has credentials and can retrieve information of his/her own fields. It is also possible, as it was done for another association in central Greece which also uses the tool, for an association or the regional authority to have access to all fields data, however with the consent of the farmers.
Advisor connectivity, involvement	No, but it is possible. It depends on how the professionals would like to exploit the tool
Is the tool used is aligned with other tools and national declarations to transfer and share data for example to make reporting easier?	No for the moment. We have discussed for upgrading the tool in order to be used by the Ministry of Agricultural Development and Food, for monitoring and keeping records from fields that accept sewage sludge, In such a case reporting will be included.,
Monitoring on sustainability, profitability provided?	No
Special skilled personnel should be hired/trained for tool usage?	No. The tool is user friendly and understandable by all, because it was developed to be used by farmers,

j. PLANET - Great Britain (England, Wales & Scotland)

General info	
Country-Region of the farm(s)	Great Britain (England, Wales & Scotland)
Sector	All open field agriculture (arable, grassland, horticulture)
Number of farmers involved	Over 22,000 registered users
Average size of farm involved	Information not collected
Age of the farmer(s)	Information not collected
Name of the tool	PLANET (**Pl**anning **L**and **A**pplications of **N**utrients for **E**fficiency and the environmen**T**)

For which functions is the tool used?	PLANET is a nutrient management decision support tool for use by farmers and advisers in England/Wales and Scotland for field level nutrient planning and for assessing and demonstrating compliance with the Nitrate Vulnerable Zone (NVZ) rules.
Years in operation (the described tool)	17 years. The first version of PLANET was released in 2005. The last version (v.3.3) was released in 2013.
Drivers and barriers for adoption	
Main driver for the adoption process	Nutrient management planning and assessing/demonstrating compliance with Nitrate Vulnerable Zone (NVZ) rules.
Ways of identification, selection of potential tools	PLANET is well known by farmers within the UK. Links to the tool are included in Defra and SRUC guidance to farmers on nutrient management and NVZ rule.
Have several tools been tested?	No. PLANET has been developed to fulfill a specific function (nutrient management planning and assessing/demonstrating compliance with NVZ rules).
If yes, which were the main properties upon selection?	Not applicable
External funding?	PLANET has been developed by ADAS with funding and support from Defra and Scottish Government.
Challenges during the adoption process?	Some users, especially those who are less confident with software tools, find the tool complicated to use.
Were those successfully addressed or led to failing in the process	User feedback has been sought before each of the main updates. Information notes are included in the software, written help guides and video tutorials are also available from within the software.
Which party was the main driver either way (farmer. Tech provider, advisor, farmers group or asoc., etc)	The funders (Defra and Scottish Government) were the key drivers in development and updating of the tool. The tool provides nutrient management guidance to farmers which help deliver Defra/Scottish Government objectives of supporting farmers to achieve good nutrient management and to assess/demonstrate compliance with NVZ rules.
Main advantages of tool usage	PLANET helps farmers plan their nutrient use and demonstrate compliance with NVZ rules. PLANET gives fertiliser recommendations for all major nutrients and lime. Fertiliser recommendations take account of the crop nutrient requirement, the soil nitrogen supply, laboratory soil analysis results, and the nutrients supplied from any organic material applications (calculated using the MANNER-*NPK* 'calculation engine'). A nutrient application plan can be developed and updated during the season. Detailed field records can be kept of cropping, soil analyses, and fertiliser and organic material applications.
How many personnel are trained at the farm to use the tool?	Help guides and video tutorials are available in the software.

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If they failed with one tool (or adopted one but not satisfied fully), is there a willingness to try adopting another one?	Farmers who are not comfortable with software decision support tools can access the information provided by PLANET in written nutrient management/NVZ compliance guidance documents.

Adopted tool(s) basic information and technical details	
Cost (eg per ha)	Free. Available to download from the website.
Regionality (languages and availability)	English. Fertiliser recommendations and NVZ rules used by PLANET are specific to England, Wales and Scotland.
Platform (PC, Mobile)	PC (Windows based)
Maintenance (updates, customer service)	The software is maintained and supported by ADAS. The last update was in 2013.
Training, customer support availability	Information notes are available within the software. Help guides and video tutorials are also available.
Data needs of the tool	Farm and field details including location (postcode to retrieve location specific rainfall data), soil type, past cropping, soil analysis, planned cropping and planned manure use. NVZ N loading module requires data on farm area, livestock type and numbers and imports/exports of organic manures. NVZ Organic manures inventory requires entry of livestock type and numbers, manure system (solid or liquid) and when the livestock are housed.
Data sources of tool, API connection to other data sources	DST uses postcode specific long term average (30 year) climate data. This climate data is included within the model.
Visualization, interpretation	Fertiliser recommendations are given in grids displayed on screen and also available in printable reports. Visualization is clear, but may be considered dated (last update 2013).
Transparency, scientific soundness	PLANET gives fertiliser recommendations for all major nutrients and lime based on Defra's "Fertiliser Manual (RB209)" (8th Edition) in England/Wales and on SRUC "Technical Notes" in Scotland.
Comprehensiveness of tool	PLANET is a nutrient management decision support tool for use by farmers and advisers in England/Wales and Scotland for field level nutrient planning and for assessing and demonstrating compliance with the Nitrate Vulnerable Zone (NVZ) rules.
Data sharing, sovereignty, security	PLANET is a Windows based tool. There is no data sharing with any other tolos. Data input is owned and retained by the Farmer.
Advisor connectivity, involvment	Feedback on the usability and functionality of the tool has been actively sought from users on three occassions – during tool development (prior to the reléase of v1), and then again prior to the reléase of v2 and v3.

Is the tool used is aligned with other tools and national declarations to transfer and share data for example to make reporting easier?	PLANET gives fertiliser recommendations for all major nutrients and lime based on Defra's "Fertiliser Manual (RB209)" (8th Edition) in England/Wales and on SRUC "Technical Notes" in Scotland. The PLANET 'calculation engine' is available as a Dynamic Link Library (DLL) free of charge to commercial software companies to integrate into their own tools. The PLANET DLL has been integrated into commercial tools produced in the UK by Farmplan, Muddyboots and Pear Agri.
Monitoring on sustainability, profitability provided?	Not applicable – the software tool is available free of charge.
Special skilled personnel should be hired/trained for tool usage?	Not required. Help guides and video tutorials are available from within the software.

k. Tool Box – Murcia, Spain

General info	
Country-Region of the farm(s)	Spain-Murcia
Sector	lemon production
Number of farmers involved	Private company, Finca Fontes C.B
Average size of farm involved	100 has
Age of the farmer(s)	Private company
Name of the tool	Different tools, Verde Smart (e-verd 2.0-Nutrisens to measure nitrate and potassium in the soil and dendrometer Plantsens), Meteogrid (Simena), adcon (advantage PRO), Wtech (deep nitrate leaching control)
For which functions is the tool used?	It is a demonstration project, called RIS3MUR in one of the most sensitive nitrate vulnerable zones in Spain, the Mar Menor, with recent major pollution problems and a priority for the regional and national government due to the significant media coverage of this problem. The aim is to characterize the usual practices of farmers and demonstrate that it is possible to save water and fertilizers while maintaining or increasing the profitability of the farmer but respecting the environment using digital tools for nutrition management.
Years in operation (the described tool)	Since March 2021
Drivers and barriers for adoption	
Main driver for the	The problem of nitrate pollution in the Mar Menor and its important

adoption process	environmental repercussions that affect tourism, agriculture and the future of the entire environment has been the priority to find solutions. The Government of the Autonomous Community of Murcia itself, with its Department of Innovation, is participating in the project.
Ways of identification, selection of potential tools	They were looking for digital fertigation management tools that have been successful in practical agriculture combining the farmer and environmental perspective.
Have several tools been tested?	Yes
If yes, which were the main properties upon selection?	The previous successful experience of the company Frutinter in Castellón was considered, with the possibility of achieving the world's first nitrate footprint (in the end it succeeded). Previous success stories and scientific and technical reliability of the technology (15 years).
External funding?	RIS3 MUR "SUSTAINABLE AGRICULTURE WITH ZERO NITRATE LEACHING IN THE MENOR SEA". The project was financed by the Department of Innovation of the Government of Murcia and the partners of this project, WTECH, S.L., Finca Fontes C.B., Karma Produce, S.L., IBERMED INGENIERIA, S.L., CEBAS-CSIC and the Polytechnic University of Cartagena. There are other activities in the project other than monitoring and control points for nitrate drainage with the nitrate footprint, which are not discussed in this document.
Challenges during the adoption process?	Convince the owners that it is necessary to change the way of managing the fertigation of the farm, and that it is possible to do so by reducing the use of water and fertilizers.
Were those successfully addressed or led to failing in the process	The actual experience of water and fertilizer management on the farm during 2021 has been recorded and from this experience of the impact of nitrate in the leaching area the owners have been convinced that it must be managed with digital tools and decisions in 2022 are being made with great success in environmental impact, compared to last year's results.
Which party was the main driver either way (farmer? Tech provider, advisor, farmers group or asoc., etc)	Tech provider Wtech and advisor.
Main advantages of tool usage	By combining these tools, the farmer can understand how his fertilizer and water management can be optimized, because more inputs are being provided than the plant needs, and that means significant cost savings, and it also means a lower environmental impact, which can be certified as a nitrate footprint and commercially help the marketing of his fruit by its environmentally friendly seal. With intelligent weather forecast to Irrigation and Nutrient decisions, checked and adjusted daily with the performance of 2 "monitoring-Characterization" points with sensors from Verde Smart and two monitoring "nitrate leaching" points at 6-8 m by Wtech. Creation of traceability, development of internal capacity for preventive irrigation and fertilization decisions and creation of the company's know-how.
How many personnel are	2, Easy to use once training has been acquired by the technical department

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trained at the farm to use the tool?	
If they failed with one tool (or adopted one but not satisfied fully), is there a willingness to try adopting another one?	Yes

Adopted tool(s) basic information and technical details	
Cost (eg per ha)	Economic cost/benefit ratio, annual cost of water + fertilizers + energy is 2000€ /ha. Saving 5% is enough to be profitable. The cost of this services as a commercial perspective will be 100€/ha/year sharing basic infrastructure investments and annual expenses between 100 ha (€50/ha basic infrastructure) and €50/ha/year annual expenses).
Regionality (languages and availability)	Spanish language and is available to use it within the whole national territory
Platform (PC, Mobile)	PC, mobile and tablet and is supported for Apple iOS and Android OS devices.
Maintenance (updates, customer service)	Regular updates. Attention to users through support mail and by phone.
Training, customer support availability	One year with weekly meetings (videoconferences). Development of the internal capacities of the technical staff to use the new precision farming tools and their ability to take preventive technical decisions with new diagnosis.
Data needs of the tool	Data from sensors, data from field data (quality, basic nutrition kit, app from leaf area, production forecast), control of nitrate leaching at 3-8 m below roots.
Data sources of tool, API connection to other data sources	Data from sensors are linked to all the different software's and have a common integration, including on-line control of leaching with Wtech.
Visualization, interpretation	Easy, with "red and green" easy interface once there are experience and easy diagnostic of plant problems. Customer is trained to create its own alerts based in their own experience and the focus is "preventive decisions" based in its own personalized alerts.
Transparency, scientific soundness	The project, which began in March 2021, included work for a doctoral thesis, special support from the nitrate footprint company, Wtech, and support from CEBAS-CSIC and the Polytechnic University of Cartagena and technical advisor for citrus from Finca Fontes
Comprehensiveness of tool	Is a tool for technical staff, as it integrates different technologies they have to be trained to understand limitations and advantages of each one.
Data sharing, sovereignty, security	Data can be shared as is a demo-project
Advisor connectivity,	Technical staff, advisors and growers can access to it.

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involvment	
Is the tool used is aligned with other tools and national declarations to transfer and share data for example to make reporting easier?	NO, it is a private solution, belongs to the customer
Monitoring on sustainability, profitability provided?	It has already been demonstrated since the beginning of this 2022, that with the new fertigation management, there are fertilizer savings of 40% during 2022 compared with 2021 and zero nitrate impact in depth (in 6 months of cultivation with the new management).
Special skilled personnel should be hired/trained for tool usage?	Yes, the advisor has been involved and trained during the first year.

l. MANNER-NPK - UK (England, Wales, Scotland and Northern Ireland)

General info	
Country-Region of the farm(s)	UK (England, Wales, Scotland and Northern Ireland)
Sector	All open field agriculture (arable, grassland, horticulture)
Number of farmers involved	Over 5,000 registered users
Average size of farm involved	Information not collected
Age of the farmer(s)	Information not collected
Name of the tool	MANNER-*NPK* (**MAN**ure **N**utrient **E**valuation **R**outine)
For which functions is the tool used?	MANNER-*NPK* is a software decision support tool for calculating crop available nutrient supply from applications of organic materials to land.
Years in operation (the described tool)	22 years. The first MANNER software tool was released to farmers on CD in 2000. The MANNER-*NPK* calculations were updated in 2004 and 2010 to incorporate advances in our understanding of nitrogen transformation and loss processes following the land application of organic materials. The latest version – MANNER-*NPK* includes additional improvements to usability and functionality and was released to farmers in 2013.
Drivers and barriers for adoption	
Main driver for the adoption process	Improving nutrient management from organic materials. Organic materials are a valuable source of plant available nutrients that can be

	used to meet crop nutrient needs reducing the requirement for manufactured fertiliser. However, farmers do not always make adequate allowance for the contribution of organic materials to crop requirements, potentially resulting in nutrient oversupply and environmental pollution. MANNER-*NPK* is a practical software tool for use by farmers to quantify the crop available nutrient supply from organic materials (nitrogen, phosphate and potash).
Ways of identification, selection of potential tools	MANNER-*NPK* is well known by farmers within the UK. Links to the tool are included in Defra and AHDB guidance to farmers on good nutrient management.
Have several tools been tested?	No. MANNER-*NPK* has been developed to fulfill a specific function (calculation of nutrient supply from organic materials).
If yes, which were the main properties upon selection?	Not applicable
External funding?	MANNER-*NPK* has been developed by ADAS with funding and support from AHDB, CSF, DARD, Defra, Environment Agency, Natural England, Scottish Government, Tried and Tested and WRAP. The software is maintained and supported by ADAS.
Challenges during the adoption process?	The main challenge is to provide guidance on the nutrient supply from organic materials which is accessible in a range of formats to maximize its uptake and impact. In our experience, whilst some farmers like to use the standalone version of MANNER-*NPK* because it is simple and easy to use, others prefer to access the information via their main nutrient planning system. Farmers and agronomists prefer not to have to enter the same information into multiple software tools.
Were those successfully addressed or led to failing in the process	This challenge has been addressed through integration of the MANNER-*NPK* calculations into the PLANET nutrient management software and in turn into commercial software tools produced by Farmplan, Muddyboots & Pear Agri. This enables farmers to access the MANNER-*NPK* calculations via other software decision support tools.
Which party was the main driver either way (farmer. Tech provider, advisor, farmers group or asoc., etc)	The funders (mainly Defra and Environment Agency) were key drivers in development and updating of the tool. The tool provides nutrient management guidance to farmers which help deliver Defra/EA objectives of supporting farmers to achieve good nutrient management.
Main advantages of tool usage	MANNER-*NPK* provides an estimate of crop available nutrient supply from applications of organic material. This information can be used by farmers to improve their nutrient use. This has the potential to improve farm profitability and reducing diffuse pollution (by maximizing nutrient use efficiency)
How many personnel are trained at the farm to use the tool?	MANNER-*NPK* is simple to use. A help guide is available in the software. External training is not required.
If they failed with one tool (or adopted one but not satisfied fully), is there a willingness to try	In addition to the standalone MANNER-*NPK* software tool, the MANNER-*NPK* calculations are available within a number of other written and software tools. MANNER-*NPK* was used to produce the

adopting another one?	organic material crop available nitrogen 'look-up tables' in national written nutrient management guidance in the 'AHDB Nutrient Management Guide' Chapter 2 in England and Wales (AHDB 2021) and the SRUC Technical Note on 'Optimising the application of livestock farmyard manure and slurries TN736' in Scotland (SRUC, 2020).

Adopted tool(s) basic information and technical details	
Cost (eg per ha)	Free. Available to download from the website.
Regionality (languages and availability)	English. Specific to the UK (England, Wales, Scotland & Northern Ireland). The model has been developed and tested using UK field experimental results. The model uses UK climate data (based on user entered postcode).
Platform (PC, Mobile)	PC (Windows based)
Maintenance (updates, customer service)	The software is maintained and supported by ADAS. The last update was in 2013.
Training, customer support availability	The majority of farmers and farm advisors with a basic level of computer literacy should be able to use MANNER without any training or additional support. A help guide is available from within the software. The software is maintained and supported by ADAS.
Data needs of the tool	Farm and field details (location from postcode, crop type and soil type). Details of the organic manure application including manure type, application data, application rate, method of application and manure analysis if available).
Data sources of tool, API connection to other data sources	DST uses postcode specific long term average (30 year) climate data. This climate data is included within the model.
Visualization, interpretation	Results are provided in a 'results' tab in the software and in a printable report. Visualization is clear, but may be considered dated (last update 2013).
Transparency, scientific soundness	A detailed explanation of the science and algorithms underpinning the MANNER-*NPK* tool are given in the peer-reviewed scientific paper by Nicholson et al. (2013). This information is also provided to users in a 'Technical Guide' available from the 'Help' menu within the software. Nicholson, F.A., Bhogal, A., Chadwick, D., Gill, E., Gooday, R.D., Lord, E., Misselbrook, T., Rollett, A.J., Sagoo, E., Smith, K.A., Thorman, R.E., Williams, J.R. and Chambers, B.J. (2013). An enhanced software tool to support better use of manure nutrients: MANNER-NPK. Soil Use and Management 29 (4) 473-484. Available from http://onlinelibrary.wiley.com/doi/10.1111/sum.12078/abstract
Comprehensiveness of tool	MANNER-*NPK* is a software decision support tool for calculating crop available nutrient supply from applications of a wide range of organic materials to land. It can be used by farmers in the UK.

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Data sharing, sovereignty, security	MANNER-*NPK* is a Windows based tool. There is no data sharing with any other tolos. Data input is owned and retained by the Farmer.
Advisor connectivity, involvment	Feedback on the usability and functionality of the tool has been actively sought from users on two occasions – following the release of MANNER in 2000 and prior to release of MANNER-NPK in 2013.
Is the tool used is aligned with other tools and national declarations to transfer and share data for example to make reporting easier?	In addition to the standalone MANNER-*NPK* software tool, the MANNER-*NPK* calculations are available within a number of other written and software tools. MANNER-*NPK* was used to produce the organic material crop available nitrogen 'look-up tables' in national written nutrient management guidance in the 'AHDB Nutrient Management Guide' Chapter 2 in England and Wales (AHDB 2021) and the SRUC Technical Note on 'Optimising the application of livestock farmyard manure and slurries TN736' in Scotland (SRUC, 2020).
Monitoring on sustainability, profitability provided?	Not applicable – the software tool is available free of charge.
Special skilled personnel should be hired/trained for tool usage?	Not required. The majority of farmers and farm advisors with a basic level of computer literacy should be able to use MANNER without any training or additional support. A help guide is available from within the software.

m. Tool box - Spain-Comunidad Valenciana

General info	
Country-Region of the farm(s)	Spain-Comunidad Valenciana
Sector	Citrus production
Number of farmers involved	Private company, Frutinter
Average size of farm involved	120 has
Age of the farmer(s)	Private company
Name of the tool	Different tools, from geodim (web gis), Verde Smart (e-verd 2.0-Nutrisens to measure nitrate and potassium in the soil and dendrometer Plantsens), Meteogrid (Simena), adcon (advantage PRO), wtech (deep nitrate leaching control)
For which functions is the tool used?	Control Vegetative development, fruit set and fruit growth to promote highest production with lowest inputs and nitrate environmental control to get nitrate footprint
Years in operation (the described tool)	Since July 2018

Drivers and barriers for adoption	
Main driver for the adoption process	Saving fertilizers and water and reduce nitrate leaching. The intention of testing the possibility of meeting the requirements of the nitrate footprint while saving fertilizers and water and maintaining or improving the profitability of the farmer.
Ways of identification, selection of potential tools	The "Frutinter Chair" made an exhaustive review of existing technologies worldwide with a clear idea: to use innovative technologies, but in an operational context. The Smart method, from Verde Smart and its partners, was selected by the Universidad Polytechnic de Valencia as the best commercial diagnostic method with digital tools for the improvement of fertigation diagnostics. Wtech technology was selected to control nitrate leaching in the 3-8 m lithologic profile.
Have several tools been tested?	Yes, The "smart method" includes GIS, remote sensing, monitoring points with sensors (plant-nitrate sensor Nutrisens from Verde Smart-soil moisture-weather), basic nutrition kit, training, intelligent forecasting and annual fee for on-line services and support. Nitrate leaching control with Wtech company to get the nitrate footprint certification by Certificación Food Rina España y Portugal
If yes, which were the main properties upon selection?	Previous success stories and scientific and technical reliability (15 years). We had the first nutrition methodology that combines weekly plant nutrition status, together with a nitrate and potassium sensor in the root zone and the drainage are of the soil to detect nitrate leaching.
External funding?	The project was financed by the Frutinter Chair of the UPV, created in 2018 with the aim of promoting the sustainable development of the farms that the company owns in the north of the province of Castellón, is the joint work of the Universitat Politècnica de València (UPV) and the company Frutinter
Challenges during the adoption process?	To tell the grower, during the monitoring process, to stop applying nitrate for 7 months base of the combination of diagnostic.
Were those successfully addressed or led to failing in the process	After two years we were able to save 65% of nitrate, increase potassium 66%, increase production (5%) and increase fruit size a 8% and they were able to get the first world certification of "nitrate footprint", from RINA.
Which party was the main driver either way (farmer? Tech provider, advisor, farmers group or asoc., etc)	The university recommendation.
Main advantages of tool usage	With intelligent weather forecast to Irrigation and Nutrient decisions, checked and adjusted daily with the performance of 2 "monitoring-Characterization" points with sensors from Verde Smart and two monitoring "nitrate leaching" points at 6-8 m by Wtech. Combining this tools grower can understand how their fertilizer management to

	promote profits impacts in deep leaching. Easy to use once training has been acquired by the technical department creation of traceability, development of internal capacity for preventive irrigation and fertilization decisions and creation of the company's know-how in an objective way to try to maintain quality and profitability every year together with sustainability.
How many personnel are trained at the farm to use the tool?	3
If they failed with one tool (or adopted one but not satisfied fully), is there a willingness to try adopting another one?	Yes

Adopted tool(s) basic information and technical details	
Cost (eg per ha)	160,000 euros have been invested in 3 years in training, sensor points, GIS, intelligent forecasts, nitrate footprint, which means 18 €/ha/year and annual service expenses (software, sap analysis, etc.) of 15 €/ha/year, totaling 33 €/ha/year, with annual expenses of 1500-2000 €/ha between water, fertilizers and energy.
Regionality (languages and availability)	Spanish language and is available to use it within the whole national territory
Platform (PC, Mobile)	PC, mobile and tablet and is supported for Apple iOS and Android OS devices.
Maintenance (updates, customer service)	Regular updates. Attention to users through support mail and by phone.
Training, customer support availability	As it was a pilot project combining nitrate leaching certification it took 2,5 years with weekly meetings (videoconferences). Development of the internal capacities of the technical staff to use the new precision farming tools and their ability to take preventive technical decisions with new diagnosis.
Data needs of the tool	Personalized GIS with "fix data". Data from sensors, data from field data (quality, basic nutrition kit, app from leaf area, production forecast)
Data sources of tool, API connection to other data sources	Data from sensors are linked to all the different software's and have a common integration
Visualization, interpretation	Easy, with "red and green" easy interface once there are experience and easy diagnostic of plant problems. Customer is trained to create its own alerts based in their own experience and the focus is "preventive decisions" based in its own personalized alerts.
Transparency, scientific	The project, which began in May 2019, included, under the

soundness	coordination of the professor of the School of Agricultural Engineering and Natural Environment (ETSIAMN-UPV), and director of the Frutinter Chair, Pedro Beltrán, a pilot experience in a farm located in Onda (Castellón) for the implementation of the SMART methodology
Comprehensiveness of tool	Is a tool for technical staff, as it integrates different technologies they have to be trained to understand limitations and advantages of each one.
Data sharing, sovereignty, security	Data belong to the customer.
Advisor connectivity, involvment	Technical staff, advisors and growers can access to it.
Is the tool used is aligned with other tools and national declarations to transfer and share data for example to make reporting easier?	NO, it is a private solution, belongs to the customer
Monitoring on sustainability, profitability provided?	They got the first "nitrate footprint" of the world. https://frutinter.com/nitrato-cero-nuestra-huella-para-un-mundo-mejor/. At the same time they reduce by half the water needed for the cultivation of citrus fruits and up to 60% the amount of nitrate used. The project has allowed, in turn, to increase the yield of the plot, producing between 8,000 and 10,000 kg of oranges more per hectare, and improve the size of the fruit, which is more uniform, facilitating its commercial output.
Special skilled personnel should be hired/trained for tool usage?	Yes, they have hired on technical staff to be the specialist in precise agriculture and certifications.

n. Tool box – Spain, Comunidad Valenciana

General info	
Country-Region of the farm(s)	Spain-Comunidad Valenciana
Sector	Viticulture and wine production
Number of farmers involved	Cooperative with 320 farmers
Average size of farm involved	1000 ha
Age of the farmer(s)	Around 50 years
Name of the tool	Different tools, from geodim (web gis), verde smart (e-verd2.0), Meteogrid (Simena), adcon (advantage PRO), Cromoenos (Bioenos)

For which functions is the tool used?	Vegetative development and stress control to promote quality with intelligent weather forecast to Irrigation and Nutrient decisions, checked and adjusted daily with the performance of 5 "monitoring-Characterization" points with sensors (weather, plant, humidity and nitrate and potassium in the soil) in representative varieties and extrapolated using remote sensing images (Sentinel-2) and sap nutrition control. Study of fixed factors and vigor results of recent years for point location and semivariogram of variability for sampling points. The tasks carried out on the plots (sap sampling, quality, leaf area with app, production in the monitoring points and in sampling points to create maps of production, plant balance, quality, etc). Proprietary plant indicators of stress
Years in operation (the described tool)	Since September 2020
Drivers and barriers for adoption	
Main driver for the adoption process	to create a traceability to understand the control of the plant with the management of in-puts (water and fertilizers) to record good practices between viticulture and enology and to communicate and promote them among the growers through the new "languages" linked to technologies and to design new forms of quality payment for the grapes that promote them to try to repeat good practices and avoid bad ones. Sustainability marketing.
Ways of identification, selection of potential tools	Investment for basic infrastructure (GIS, remote sensing, monitoring points with sensors, basic nutrition kit, training, intelligent forecasting of the 4 microclimates tested) and annual fee for on-line services and support
Have several tools been tested?	Yes
If yes, which were the main properties upon selection?	Previous success stories, visiting 2 customers in viticulture and scientific and technical reliability. Previous success stories and scientific and technical reliability (15 years). Integration of technologies for a solution to customers' problems. Training technical staff and promote the change together with farmers who are leaders of change and management supporting them.
External funding?	Yes, the tool is supported by fundings from Generalitat Valenciana for precise agriculture
Challenges during the adoption process?	Training the technical staff, convince the growers leading the farms "of the change" to change the standard use of irrigation and fertilizers practices.
Were those successfully addressed or led to failing in the process	Being a cooperative, where you have to work with over 300 farmers has created several levels of farmer involvement and a lot of new communication work, but it is proving to be a success with the farmers leading the change and changing the irrigation and nutrition advisory system on a large scale.
Which party was the main driver	This is an example where "human resources" are critical to generate a

either way (farmer. Tech provider, advisor, farmers group or asoc., etc)	change and there is consensus and the need for a vision of change between viticulture, enology, presidency, and management. Training is key.
Main advantages of tool usage	Easy to use once training has been acquired by the technical department Solves the most important customer problems such as quality improvement (wine PH, tannin ripening, wine freshness, etc.), creation of traceability, development of internal capacity for preventive irrigation and fertilization decisions and creation of the company's know-how in an objective way to try to maintain quality and profitability every year.
How many personnel are trained at the farm to use the tool?	two
If they failed with one tool (or adopted one but not satisfied fully), is there a willingness to try adopting another one?	Yes

Adopted tool(s) basic information and technical details	
Cost (eg per ha)	Economic cost/benefit ratio, €25/ha/year thanks to sharing basic infrastructure investments and annual expenses between 1000 ha (€15/ha basic infrastructure) and €10/ha/year annual expenses).
Regionality (languages and availability)	Spanish language and is available to use it within the whole national territory
Platform (PC, Mobile)	PC, mobile and tablet and is supported for Apple iOS and Android OS devices.
Maintenance (updates, customer service)	Regular updates. Attention to users through support mail and by phone.
Training, customer support availability	1 year with weekly meetings (videoconferences). Development of the internal capacities of the technical staff to use the new precision farming tools and their ability to take preventive technical decisions with new diagnosis.
Data needs of the tool	Personalized GIS with "fix data". Data from sensors, data from field data (quality, basic nutrition kit, app from leaf area, production forecast)
Data sources of tool, API connection to other data sources	Data from sensors are linked to all the different software's and have a common integration
Visualization, interpretation	Easy, with "red and green" easy interface once there are experience and easy diagnostic of plant problems. Customer is trained to create its own alerts based in their own experience and the focus is

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	"preventive decisions" based in its own personalized alerts.
Transparency, scientific soundness	Private development for last 17 years. Several patents. More than 15 research projects where have been involved more than 30 different private companies and more than 15 research centers. Some scientific publications.
Comprehensiveness of tool	Is a tool for technical staff, as it integrates different technologies they have to be trained to understand limitations and advantages of each one.
Data sharing, sovereignty, security	Data belong to the customer.
Advisor connectivity, involvment	Technical staff, advisors and growers can access to it.
Is the tool used is aligned with other tools and national declarations to transfer and share data for example to make reporting easier?	NO, it is a private solution, belongs to the customer
Monitoring on sustainability, profitability provided?	Yes, its management is linked to get the "nitrate footprint"
Special skilled personnel should be hired/trained for tool usage?	Yes, they have hired on technical staff to be the specialist in precise agriculture and certifications.

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EIP-AGRI Focus Group
Digital tools for sustainable nutrient management

MINI-PAPER Creating Trusted Nutrient Management tools through better data sharing

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1. Introduction

The adoption of digital nutrient management tools (DNMTs), seen in a European crop production perspective, is rather low, judged on own experience and based on exchange with farmers and the related farm business. One reason for this is that farmers and advisors are not convinced whether the existing tools can bring the necessary added value. To increase the value of the tools several improvements are needed but the most crucial one is the availability of the high-quality data, needed for as well a smooth and efficient operation of the tool as for well-founded data-driven nutrient management decisions at farm level. Currently, many farmers consider that the added value of the tools does not match the efforts required to provide input data to the tools, largely due to unexploited possibilities for trustworthy interoperability and portability of specific farm data and other required information.

Due to the ongoing digitalization effort in agriculture, farmers and agribusiness are not only producing food, but more and more also an enormous mass of data. Dairy companies have data on the milk composition. Potatoes processing companies have data on the yield and the quality. Also, governments are holding valuable data sets, such as registers of fields, seeds and commercial fertilisers. And last but not least the farmers themselves have a lot of data available, like the amount of fertiliser applied or maps of soil conditions. But surprisingly this creation of unlimited data sets did not yet bring a breakthrough to unleash the full potential of management tools. Up till now the increase in data availability did not trigger an increased adoption of digital technologies.

This mini paper seeks to clarify the type of already existing data (see annex) that would make the use of digital nutrient management tools more precise, valued and trusted by farmers, as well as typical barriers but also possible drivers for making the data available, interoperable and portable for farmers, businesses and governments. Some good examples to build upon will be highlighted and recommendations given.

2. Powered by data

A first prerequisite to create valued and trusted DNMTs is qualitative data. The necessary data to power DNMTs is available in the complex network between the farmers, IoT and service providers, public or semi-public organisations and businesses including the supply and processing industry. Different types of data are relevant: data related to invoices and documents sent between different actors, government data, like the Integrated Administration and Control System (IACS) and the animal identification and registration system (I&R), satellite data and IoT data from sensors and machines. More concrete, data sources available at public authorities are for instance field boundaries, soil information, topographic data and digital elevation models. But, also information about the authorisations of plant protection products, fertilisers, soil improving agents and sludge is hosted by public entities. Private actors can offer data on crop yields or application rates of inputs via the machinery used by farmers. Service providers can deliver satellite and weather data.

The major part of these farm data although owned by the farmer, as agreed the EU code of conduct on agricultural data sharing, is actually not hosted on the local computer of the farmer, but on IT infrastructure outside the farm. Why is the data not flowing into the DNMT?

3. Unlock data sharing

Unfortunately, currently the potential for data sharing and interoperability is largely unexploited, despite the benefits being clear. (1) First of all, data sharing would avoid farmers from spending time on registration of data that is necessary for use of DNMTs, but which is already registered elsewhere, for instance information about the farm's own fields, which already exists in the public Land Parcel Identification System (LPIS) public register, or about the number of manure-producing livestock that are kept on the farm, which is already reported to the public animal register according EUs regulations[1]. (2) By making more data available, the DNMT's will become smarter and perform better as they are built on more precise data. More data from the farming process can flow into the DNMT of the farmers, but also, more

[1] Central EU regulations concerning animal identification and registration are EU regulation 1760/2000, Council Directive 2008/71/EC, EU Regulation 21/2004.

data between the tools could be shared to validate and improve the DNMT. (3) An additional advantage may come from extra revenue that can be earned when farm data is collected and shared with other actors in the supply chain. Examples are farmers receiving better payment when delivering their product to the factories with extra information on the production process, the amount or the quality. While on the one hand the benefits of data sharing are clear, on the other hand some first operational platforms are showing that data sharing technology is at the current stage so well advanced that there are no technical issues blocking the sharing of the data. So, what are the current hurdles?

Most urgent challenges to be solved are situated in the business to government data sharing. Indeed, public bodies are moving slow in making data on legislations that are in public registers, machine readable and easily integrable in the DNMTs.

In most cases the information is available in complicated, elaborated pdf documents that are not fitted for the use in digital tools. Manual integration of the information from these pdf files into the DNMT is just too complex and too time consuming both for the farmers and the developers of the tools. In some European regions research centres or farmer organisations are putting effort in translating the PDF files to machine readable open data sets, but only for very specific tools, that they are supporting for local farmers. In addition, where public data is made available in digital format, the data formats differ from one Member State to another, and standardised protocol for REST API's for the data extraction on EU level is not existing. Actually, the overall interoperability between the different tools, apps and software used in the farm is still lacking. The data is available in different format and is not easily portable from one tool to another. In reality, farmers will have to input the data several times manually in order to provide all the information. The **huge workload and the technical complexity** to further digitalize the information and the related costs are the main reasons that public entities are lagging behind.

In Government to Business (G2B) data sharing another challenge is to create **trust between the different actors.** Considering reporting to authorities, it cannot be emphasized enough that farmers do not wish to share all DNMT data with the authorities, but alone the part that are checkpoints for public control according EU-based regulations, for instance national provisions based on EU's Nitrates Directive, including Cross Compliance criteria[2]. On the other hand, nutrient management planning comprises a wealth of issues that are not regulated, but deals with the farms' crop production business management. Farmers wish to limit the shared information to the minimum required to be reported to the authorities. In line with this, tools that are developed, managed and maintained by authorities, who cannot guarantee that the famers stays in full control of the DNMT data are not trusted and will not be used in reality. The **governance of the tools** is of key importance to convince farmers to use DNMTs. Important steps in data sharing between government, business and farmers need to be taken especially on governance aspect and the related business model.

Actors like research institutes, farmer organisations and business are working hard to identify the right public entities that can make more data available. It takes time to explain the opportunities for all actors involved and to convince the governmental actors to invest in G2B data sharing taking into account data sovereignty.

4. Show cases/ best practices

In general, the webpage https://agridata.ec.europa.eu/extensions/iacs/iacs.html provides an overview of data offered by Member States. From the webpage it can at least be concluded:

(1) There is a wide difference among Member States concerning the type of data that are published. Latvia, for example, provides publicly accessible information about each field via https://karte.lad.gov.lv/?q=13561205, where you can see/view LPIS information, including crop code, crop, field boundaries, field number, block number, and the type of area support applied for.

[2] This includes eg. the Nitrates Directive (EU/91/676) - see https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/income-support/cross-compliance_en

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A contrast to this are Member States that do not publish data that could be connected to specific farms or fields, or Member States that do not publish anything at all.

(2) It is very seldom that data is made available in a machine-readable format, and there is no EU-wide standard for REST-APIs. Most public actors at this moment are not yet taking action to service farms or their DNMT providers with the data they are governing.

Despite the big challenges ahead, there are already a few show cases and good examples to be followed:

a. Show case in Flanders

In Flanders the department of Agriculture publishes the agricultural parcel information via the Flemish data sharing platform DjustConnect. Apps that support the farmers in monitoring their crops and managing the nutrients can directly use this information to automatically integrate the relevant farm data, like e.g. the field boundaries, the crops or the ecosystem services.
How does it work in practice? An API is exposed on the data platform. Any interested actor can ask access to the data via the API. Then the platform takes care of the consents. First the department of agriculture is informed about the data demand. If they agree, the platform will ask consent to each of the addressed farmers. Only when the consent by the farmer is given, the data platform will allow the data to flow to the data user.
How was this achieved? The platform is governed by a neutral party together with farmer cooperatives and it is a non-profit initiative. This approach made it possible to convince the Flemish department of Agriculture to share data in a trusted environment. The cost to build APIs and the technical support are shared by the research institute and the department of agriculture. The data set is provided for free.

b. Show case in Germany

Data of field boundaries (parcel information) are publicly available on websites hosted by every federal state. This includes only the data about the field boundaries. There is no public information about the crops or the fertilization practise on these fields. The farmers have to give the information every year about their field's location and about the crops on each field under the cross-compliance framework to receive EU income support. The farmers themselves can download their own data for their electronic farm management programs. Probably from next year, farmers have to calculate and provide the fertilizer requirements for every field. This field nutrient management data will include field specific details of N and P nutrient application details, and also the date, type of fertilizer, total and plant available nutrient contents. Famers will have to put the information into a database for the federal government to report overall fertilization statistics to the EU.
There is (nearly) no mechanism to make this data available to third parties in an automated way. Downloading the files and then send them via email is possible, but this work then needs to be done manually for each document by the farmer himself. No automatic consent system is implemented. In Germany farmer data is regarded as private data, at least by farmers. There is a high lack of trust to share the data as farmers feel that other actors like to get access to this data to be able to monitor the activities of the farmers.
The German weather service (a public authority) provides weather information specially for farmers (soil temperatures, soil moisture, forecast). This service is just free for farmers. They have to login with a special account. However, this service is not known very well among farmers, since farm management software and mobile apps do not use the api much yet.

c. Show case in Poland

In Poland, the Ministry of Digital Affairs created and maintain a national data portal (https://dane.gov.pl/en) providing a source of reliable and updated data that is made available for re-use free of charge. The data, coming from over 200 providers including public administration and private entities, is classified in different categories depending on their topic. In the category of agriculture, fisheries, forestry and food, there are almost 100 public datasets.

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The national eDWIN initiative is building the decision support platform for farmers in Poland, starting from integrated plant protection aspects, and it integrates several data sources from different actors and institutions, some of which are coming from the national data portal. Additionally, the platform is producing and making available data, from the over 500 agro meteo stations (infrastructure created in eDWIN project) or from results of the prediction models. The relevant data like field boundaries are being imported from the Funding Agency for Agriculture (can be imported by each farmer separately). The platform is also integrated with the Polish governmental geoportal, that is one of the main sources of the data, and is starting to connect data with standard vocabularies like AGROVOC. Poznań Supercomputing and Networking Center (PSNC) is also in parallel testing the publication and sharing of some dataset as linked data.

How does it work in practice? An API is exposed on the eDWIN platform. Any interested actor can ask access to the data via the API. There is separate API for the massive/bulk requests. Users are provided with different kind of the client applications. Farmers data are not being exposed. How was this achieved? The platform has been developed within the Digital Poland programme, and it is a public platform, open for the farmers. The platform is operated by WODR - Wielkopolska Agriculture Advisory Center in collaboration with PSNC, but all 16 regional agriculture advisory centers are involved. The platform is run under the governmental domain and it is under patronage of Ministry of Agriculture. Wider opening of the data towards companies will be further developed in the starting EC projects like DATAMITE.

d. Show case in France

In France two interesting data sets that are useful for nutrient management digital tools are publicly available data.

The field boundaries are publicly available from the French National Geographic Institute Geoservices Web site. They correspond to the CAP declarations by the farmers. Data can be downloaded as compressed ESRI Shape files by year and by administrative regions and is available from 2010 (https://geoservices.ign.fr/rpg#telechargement). The same data is also available through API using the OGC (Open Geospatial Consortium) Web Feature Service (WFS) or Web Map Service (WMS) standards, and can be readily integrated to Web sites or GIS tools like ArcGIS or QGIS. (WMS: https://wxs.ign.fr/agriculture/geoportail/r/wms?SERVICE=WMS&VERSION=1.3.0&REQUEST=GetCapabilities)(WFS:https://wxs.ign.fr/agriculture/geoportail/wfs?SERVICE=WFS&VERSION=2.0.0&REQUEST=GetCapabilities).

The data is freely available to everyone. But, unfortunately the data has two major shortcomings: (1) The data is made available with a delay of one or two years. For example, as of June 2022, the latest available data is for the year 2020. The data is anonymous, there is no administrative (like the associated farm) or agronomic (like the planting date, irrigation status, etc.) information attached to it, except for the major crop.

Detailed topographical data are publicly available from the French National Geographic Institute Geoservices Web site. (https://geoservices.ign.fr/rgealti) The data were derived from the airborne LIDAR measures. The data are available at 1 meter and 5 meters spatial resolutions. These are very high resolutions, compared for example with the Sentinel satellite imagery 10-meter resolution. Data can be downloaded as compressed collection of raster ".asc" files by French "departement". These files can be easily transformed into a single GeoTIFF raster file by GIS tools like GDAL, which is more practical to work with. The same data is also available through API, both as a raster or as a vector layer, using the OGC (Open Geospatial Consortium) the Web Map Service (WMS) standard, and can be integrated to Web sites or GIS tools like ArcGIS or QGIS.

URL to access data as a raster layer through WMS:
https://wxs.ign.fr/altimetrie/geoportail/r/wms?SERVICE=WMS&VERSION=1.3.0&REQUEST=GetCapabilities
URL to access data as a vector layer through WMS:

https://wxs.ign.fr/altimetrie/geoportail/v/wms?SERVICE=WMS&VERSION=1.3.0&REQUEST=GetCapabilities

e. Show case in Denmark

The Danish Veterinary and Food Administration (DVFA)[3] is officially responsible for compliance with EU regulations on animal identification and registration. They have subcontracted SEGES, the headquarters of the farm advisory service division of the Danish Farmers Council (farmer NGO / association) to maintain the register.

On the DVFA webpage, anyone can freely look up data about the livestock kept at any farm. It requires you enter a herd number or the address of the farm, to see how many animals of which type the farm is keeping, the animals official ID's, their birthdate, etc. In line with this, the Danish understanding is that data that businesses, including farms are legally required to report to authorities are public owned data, and the question about publicity of the data is alone a question about the ease of accessibility: Shall it alike the herd and animal identification data be possible to view on a web page, shall data be found in an annual report issued by the competent authority, or shall it for instance alone be available upon specific requests for insight to the authorities?

However, for accessing the data in machine-readable format, you have to contact SEGES with a request, including a signed consent of the farmer that wants to use the data for own management tools. Currently the start-up fee for a tool provider is app. € 1,350, and the farmer must pay an annual fee per animal for the data handling in the level of 0.1 € per animal. SEGES has developed a REST-API, and the data access is a fully automated procedure that does not require negotiation or extra administrative burdens.

The REST-API allows in fact a wealth of data, because SEGES within the same database keeps information about e.g. genomic tests, herd books, inseminations, milk recording, etc. Having once established the connection, the digital tool provider can decide to alone extract data, or also develop a tool so that the farmer also can register data to SEGES' animal database.

When looking at data like field boundaries or animal information, the concern of data ownerships comes into play. When the public actors that host the data want to respect the data sovereignty of the farmer, they can only share the data to be used in DNMTs if the farmers give consent. However, the process of giving consent can be very simple and handled in different ways. For instance, it is in Denmark only a formality to get access to data from the animal register in a machine-readable format. There is a standard start-up payment and a requirement of the tool provided to deliver a signed form with the consent of the farmer for importing the data so that the farmer can base the use of the digital tool on this. In addition, the farmer pays an annual fee per animal for the data handling.

5. Solutions and Recommendations

Based on the reflections, experience and cases described above we can overall recommend an **urgent acceleration in making more data available** to power digital nutrient management tools. The tools cannot deliver smart nutrient management advice to farmers if there is no access to the necessary data sources. Moreover, farmers will not adopt tools that need manual input of data, that could be easily imported automatically. So the data has to flow automatically into the tools using APIs and interoperable data formats. And, most important the farmers want to stay in full control of his data.

Clearly, the strongest win here can be made by **governmental actors** investing time and effort in making public registries and documents available in a machine-readable format. Based on cases seen in Denmark and Flanders, **public private cooperation** between research institutes and farmer cooperatives can help to facilitate this process in member state that did not yet start the process of government to business data sharing in farming. Their role is to guarantee a **governance of the shared data** in a way that creates trust with the farmers., i.e. to guarantee that their data is not shared beyond their clear consent. Here it is

[3] https://www.foedevarestyrelsen.dk/english/Pages/default.aspx

recommended to build on the already existing EU code of conduct on agricultural data sharing, but also other existing European frameworks that support **data sovereignty**. Research institutes and farmer cooperatives are well placed to explain the win-win strategy behind governance to business data sharing.
Recently emerging **cooperatives data platforms** have proven to be able to bring practical solutions to move data sharing forward and to deliverable the necessary data sets for. They bring the digital ecosystem together around innovative technical solutions supported with a sustainable business model and a suited governance system. In this ecosystem farmers, advisors, business actors, researchers and governmental actors can work together to co-create useful applications with the available data and additional support on digitals skills and cost benefits analysis can be provided.

Finally we call on a European initiative to invite public bodies to make the data available and create a European Data Space with EU-wide standard for data exchange.

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Annex

The table below shows just some examples of data that is relevant and needed for operation of DNMT's and currently existing, but seen in European perspective, not made available by Member States in machine-readable format.

Table 1

Data	**Data holder/type**
Registered fertilisers	IACS
Registered seeds	IACS
Registered plant protection products	IACS
Crop codes	IACS
Animal codes	IACS
Maximal allowed fertilisation rates for different crops, (in some cases also given as recommendations)	Legislation
Crops environmental focus area coefficient	Legislation
Crop related subsidy qualification	Legislation
Standard manure figures for different livestock types (animal codes)	Legislation
Correction coefficients for soil analyses	Legislation
Field and block boundaries	LPIS
Land status (Nature 2000, etc.), no tillage zones, streams etc	
Crops grown the last three years on specific fields	IACS
Number of animals of different types (animal codes) AND methode of production	IACS
Weather data collected from a private weather station	Crop producer
Yield mapping by combiner	Crop producer

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Digital tools for sustainable nutrient management

MINI-PAPER Minimum requirements towards digital tools for sustainable nutrient management

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1. Introduction

Nutrient management tools can be focused on (A) reducing impact on the environment (water and atmosphere), particularly of nitrogen and phosphorus, minimising losses of these nutrients, or (B) increasing nutrient and economic efficiency, particularly in plant production. The further specialized the production process and the higher the possible income from agricultural production, the more elaborated a nutrient management tool may be. Of particular relevance is the nutrient management in livestock and

dairy farming due to added complexity of manure management, in particular when balancing technic, economic and environmental aspects all along the year.

Tools for purpose (A) may have to be used by every farmer in a particular area, e.g., in nitrate vulnerable zones according to Nitrates Directive. Tools for this general use have to be either easily applicable. On the other hand, tools for purpose (B) should be mainstreamed among farmers as long as they pretend to maximise the economic revenue of their business, but usually are interesting only for a small number of farmers. There is, however, an overlap between both approaches as long as nutrient loss represents a clear penalty in both cases.

From the beginning of the Focus Group meetings the idea of classifying the nutrition operations and tools according to different steps has been recurrent. It is very helpful in terms of setting up requirements.

Four steps have been identified in the nutrient management process in a farm. All those steps are linked normally in a sequence: nutrition planning is necessary to define the appropriate amount of nutrients, next the fertilisation operation itself, followed by monitoring and evaluation of the actual dosage. Planning, monitoring and actual fertilization could overlap in a virtuous circle. New technologies should provide real time monitoring capacities to improve the planning and the execution.

1.1. Soil survey and analysis

Soil sampling still remains an important basis for nutrient management. Although new technologies are advancing also at the level of soil analysis, the truth is that in many farming systems and regions, traditional soil sampling appears to be a critical cornerstone which co-exists and supports the use of digital tools all along the nutrient management cycle.

The core reason for carrying out soil sampling is to determine the average nutrient status of a given area to measure the available nutrients in the soil.

A sample generally consists of 0.25 – 0.5 kg of soil and this is taken to represent the entire area or field. Research shows that land contains in the region of 2,000 tonnes of soil per ha to a depth of 100 mm and it is important to take a sample that represents the management area. Soil analysis are only as good as the sample that has been taken. It is always wise to consult with extension services prior to taking soil samples. Based on soil maps for the farm region, policy, cropping history and future plans additional analysis may be recommended.

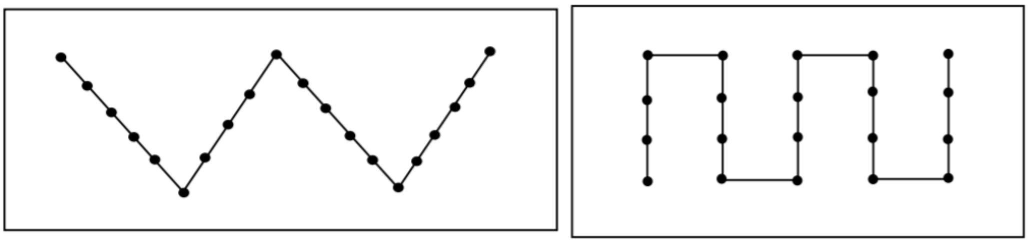
Below we present some recommendations for taking soil samples which will be used for P, K and pH analysis[1].

- It is common practice to base fertiliser advice on soil tests for up to four years and in some instances beyond. This is due to soil nutrient levels being slow to change under the majority of cropping systems. On lighter soils or where P or K fixation is known to occur, three years would be more ideal. Equally more frequent soil sampling may be beneficial to manage the balance between offtakes and inputs of nutrients to support various farming practices.
- When taking a soil sample it is essential to have a suitable soil corer, screw auger, etc. that will facilitate taking a soil sample to the desired sampling depth. Ensure that all samples are taken to a uniform depth.
- Ensure all soil sampling equipment is clean and free of rust or old soil residues to avoid contaminating the soil sample. Galvanised, brass or bronze sampling tools should not be used to collect soil samples that will be tested for micronutrients, e.g. for Zn.
- Divide the farm into fields or areas and as a guide, take one sample to represent the planned or legally defined area. Draw a plan of the farm showing all fields and giving each a permanent number e.g. Field No. 1, No. 2, etc. match the field numbers to the samples taken. Keep the farm plan safely for future use.
- Take separate samples from areas that are different in soil type, previous cropping history, slope, drainage or persistent poor yields..
- Avoid any unusual spots such as old fences, ditches, drinking troughs, dung or urine patches or where fertilizer/manures or lime has been heaped or spilled in the past.
- Do not sample a field until 3 to 6 months after the last application of P and K. Where lime has been applied allow a time lag of up to 2 years before sampling for lime requirements, and 6 month after the last application of manure.
- Take a representative soil sample from the field either by walking in a W shaped pattern. Alternatively, a grid pattern may also be used; this is more representative of the area. See fig 1 and 2 below.
- Where possible take a minimum of 20 soil cores. If taking samples in a W shape as per fig 1. Below, take approximately 5 soil cores per arm of the W. Mix them together, and take a representative sub-sample for analysis, making sure the sample size is enough for the laboratory analysis..
- When taking a sample, avoid walking in the lines of normal fertilizer and lime spreading operations on the field.
- It the crop rotation enables, sample at the same time of the year to aid comparisons of soil sample results (this is not possible in many crop rotations with fall and spring crops with different fertilization times, though).
- Avoid sampling under extremes of soil conditions e.g. waterlogged or very dry soils.
- Place the soil sample in a soil box / container to avoid contamination and write the sample number on the soil box/ container with a permanent marker.

[1] Teagasc, 2020. Major & Micro Nutrient Advice For Productive Agricultural Crops. **Available here**

Soil sampling patterns

Figure 1. Sampling using a W shaped (or M shaped) path is most convenient (Left). Sampling using a grid pattern better represents the field area (Right)



The farmers' details and spatial and agronomic information about the soil sample is required by the laboratory before analysis can be performed.

Although the basic principles of soil sampling are the same for different sampling schemes, with the spreading of site specific application of input materials, other sampling strategies emerged in the last decades, along with survey techniques, which can aid the sampling with the delineation of homogenous areas within fields. When validated and used by professionals during the survey and post processing, these techniques can improve the accuracy/validity of the soil sample, representing the sampled area.. These survey methods, and supporting datasets, include, among others:

- Soil scanning using contact and non contact sensors measuring:
  - Electrical conductivity
  - Electromagnetic induction
  - Reflectance
  - pH
- Soil scanning using gamma radiation-based sensor data
- Remote sensing using optical sensors (satellite, airborne, UAVs)
- Digital soil mapping techniques supported by guided soil sampling
- Digital terrain models

It is also important to note that not only survey and mapping technologies are developing in the last decade, but also laboratory measurement methods are advancing, with the development of proximal soil sensing equipment and post processing methods. The technology enables the fast measurement of soil samples without the use of chemicals like traditional wet-chemistry methods, thus being more environmental friendly. Besides these noted advantages, the technology is approaching the same accuracy as the tradition methods, and not only in laboratory environment, but also on the field with handheld soil scanners.

While modern technologies are booming recently, tradition soil surveying (mapping) with the usage of soil pits is also experiencing a renaissance. While the traditional method was the standard until the middle of the last century, it became less and less spread due to the increasing cost and the time needed for such a survey, compared to simple topsoil samplings. However, the increasing data and knowledge needs of precision agriculture and the new generation of farmers created a new demand for detailed, in depth surveys.

2. Requirements for nutrient management tools

2.1. Components and metrics of nutrient management

In order to usefully support decisions on nutrient management (eg. whether to apply a nutrient, how much to apply, when, recording what has been applied and calculating nutrient balances) DNMTs need more than just data, they need a framework on which the decision is based. This could be purely empirical (eg. based from past experimental responses), purely based on principles (eg. matching nutrient balances) or a combination of empirical and principle (see text box for example of Ireland). In either case there is a core set of data that is likely to be needed to be able to effectively support decisions, and further data that is useful for administrative purposes.

Important components & metrics of nutrient management:

- How much nutrient does the crop need? (crop nutrient demand)
- How much nutrient is supplied from the soil? (soil nutrient supply)
- How much nutrient is available from manures applied?
- What proportion of fertiliser applied will get into the crop? (fertiliser recovery)
- How much nutrient is in a crop at this time? (can be inferred from LAI /GAI, N uptake, biomass, NDVI)
- What is the current nutrient status of a crop? (deficiency or sufficiency)
- How much nutrient goes into the harvested portion of the crop (nutrient offtake)
- How much nutrient did the crop take up in total (nutrient uptake)
- What is the nutrient balance (ie nutrient applied – nutrient removed)
- How much nutrient was lost to the environment through leaching, run-off, volatilisation etc?
- How much nutrient to apply as fertiliser (Fertiliser requirement)
- Nutrient Use Efficiency – many definitions including:
    - Kg yield achieved per kg nutrient available (soil + fertiliser)
    - Kg yield achieved per kg nutrient fertiliser applied
    - Kg nutrient taken up by crop per kg nutrient available (soil + fertiliser) (N Uptake efficiency)
    - Kg nutrient taken up by crop per kg nutrient applied in fertiliser (fertiliser recovery, if soil nutrient accounted for)
    - Kg nutrient in harvested crop per kg nutrient available, or per kg in fertiliser

In Ireland the Green Book “Major & micro nutrient advice for productive agricultural crops" encompasses decades of soil & crop research. It defines crop requirements on various soil types and soil fertility levels. It outlines requirements, offtakes, etc. This data is then included in the digital tool NMP Online in naturally complex algorithms in order for farms to be mapped, soil samples to be matched to maps and to crops. The system then provides the fertilizer & lime recommendations for each parcel and each crop. Based on manures produced on the farm, e.g. if there are a lot of livestock and there is winter storage, this organic manure can be taken into consideration in any advice provided.

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Data of some sort is required to calculate, estimate or predict each of the above:

Crop nutrient demand requires an empirical estimate by crop in a given environment/situation which has been shown to avoid deficiency, or it can be calculated from **expected Crop Yield** multiplied by an expected crop nutrient content (accounting for grain nutrient %, straw or residue nutrient % and harvest index – these are normally assumed (eg 23 kg N/t for wheat)). Nutrient plant demand changes during the vegetation period.

Estimation of **Soil Nutrient Supply** varies by nutrient. For nitrogen in the UK it is most commonly estimated empirically using the field assessment method (RB209) from knowledge of **previous crop** (hence likely N residues), **soil type** and over winter rainfall (hence likely losses to leaching). Some nutrients can be measured by laboratory soil analyses, but it can be challenging to interpret how much will be available to the crop, rather than fixed or mineralised. P K & Mg are routinely measured in the top soil (23cm). Nitrogen as ammonium and nitrate can be measured to depth, but only gives a snapshot as it may be leached, immobilised or mineralised. Estimating crop nitrogen in spring gives a useful indicator of N available from soil, especially for oilseed rape.

Broad empirically based estimates of nutrient availability from manures can be used but nutrient content varies substantially by manure type, age, storage and application method. Analysis of dry matter % and nutrient content is recommended (by lab, NIRS, hydrometer, quantofix). MANNER-NPK is a digital tool that estimates nutrient contents and availabilities. There are models based on simple mass balance. Those models relay on the averaged values of extraction on NPK in the harvest organ and in the residues coupled with some soil thresholds to modify the pure crop extraction balance. They include as well as elements of N fixation by atmosferic deposition and symbiosis in legume crops. Examples of this approach could be found in tools like Ferticalc, SATIVUM, and Navigator F3. All those tools have been included in the FAST platform as API.

Empirical estimates of fertiliser recovery can be used based on **soil types** and **fertiliser type** - in the UK a standard value of 60% is assumed for Ammonium Nitrate fertiliser on medium soils, 50% for chalky soils and 70% for sandy soils. Urea has a lower fertiliser recovery due to greater ammonia losses through volatilisation.

Several digital tools estimate crop N uptake at a given time using reflectance properties of the canopy to infer its size (eg ground cover/GAI by digital photos, NDVI, N Sensor, Satellite data). Such estimates are rarely absolute, but are indicative and allow empirical comparisons.

Nutrient status can be detectable visually if deficiencies are showing or by plant analysis. For nitrogen, leaf chlorophyll content gives a good indication of N status and can be estimated from spectral reflectance (sensors, multi-spectral cameras, satellite imagery) or transmission (SPAD / N Tester). Because critical N concentrations reduce with development, the best approach to judge N deficiency/sufficiency can be the Nitrogen Nutrition Index, which uses an estimate of biomass as well as N concentration, together with an empirically derived critical N dilution curve.

Nutrient offtakes can be estimated from measured (or estimated) yield at harvest, usually with an assumed nutrient content of harvested product, but ideally with measured grain nutrient analyses.

Nutrient uptake can be estimated from nutrient offtake with assumed nutrient harvest indices (ie to estimate nutrient remaining in residues).

Nutrient balances can be calculated from **records of fertiliser & manures** applied and the estimated nutrient offtake.

Various **models** can be used to estimate nutrient losses with sufficient information on **soil** characteristics, **weather,** topology (slope), hydrology and fertiliser type, timings and application methods.

There are many methods used to calculate or adjust recommendations of **fertiliser requirement** based on one or more of the measures above. Records are required for fertiliser applications (date, rate, what). When variable rate fertiliser is applied, ideally an as applied map should be recorded.

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To calculate NUE, it is critical to first be clear of the definition you are using. With measured yield, recorded nutrient inputs and estimated soili supplies it should be possible to calculate NUE.

Data likely to be needed by digital tools to effectively assist nutrient management decisions:

- Crop grown
- Previous crop
- Expected yield
- Soil type (multiple ways of characterising soil type)
- Soil nutrient measures (& pH and SOM%)
- Location (latitude and longitude) - gives access to soil estimates, weather data & satellite data
- Manure use – type & rate, (ideally DM% & nutrient analysis, date of application & application method)
- Fertiliser type
- Fertiliser applied
- Yield achieved
- (Grain nutrient analysis)

2.2. Requirements for nutrient planning

Nutrient balance is considered the main planning tool. The nutrient balance is defined (e.g., Villalobos and Ferreres, 2016) as the difference between the nutrient inputs entering a field (fertiliser, manure and amendments) and the nutrient outputs leaving the field. Farmers have traditionally performed that balance based on their experience or on simplified tables of extraction from different crops. Basic planning is done based on yield expectancy at the beginning of the season. Good agricultural practices recommend to split the fertiliser application in several doses according to the crop demands in order to avoid over fertilisation if yield does not fulfil the desired level due to water stress, pests, etc. That means that the nutrient balance could be performed several times during the growing season.

According to the Nitrates Directive, farmers are only obliged to do fertilization planning and make some record on the applied fertilizer on Nitrogen vulnerable Zones or connected to certain subsidy programs. Legislation does not require neither monitoring nor evaluation. Same applies in some member states that have regulation regarding the registration of every fertilizer application such as Spain. Therefore planning tools represent the essential and key element able to cover all the agricultural sector. Planning should be done with care, based on reliable targets and qualified models. Monitoring and evaluation of the fertilization process is generally a voluntarily aspect for farmers nevertheless some countries imposed monitoring and evaluation obligations (such as Nmin-analysis and N and P budgets).

In some rainfed crop production systems, farmers are used to apply fertilizers in one single base application. In this case, fertilizer planning should be as realistic as possible. However, particularly in purely rainfed plant production systems, conditions may change considerably within one vegetation/cropping period; additional monitoring and evaluation rounds within a cropping period would enable the farmer to adjust fertilizer amounts to the actual demand. This would however require the splitting of fertilization (at least for N).

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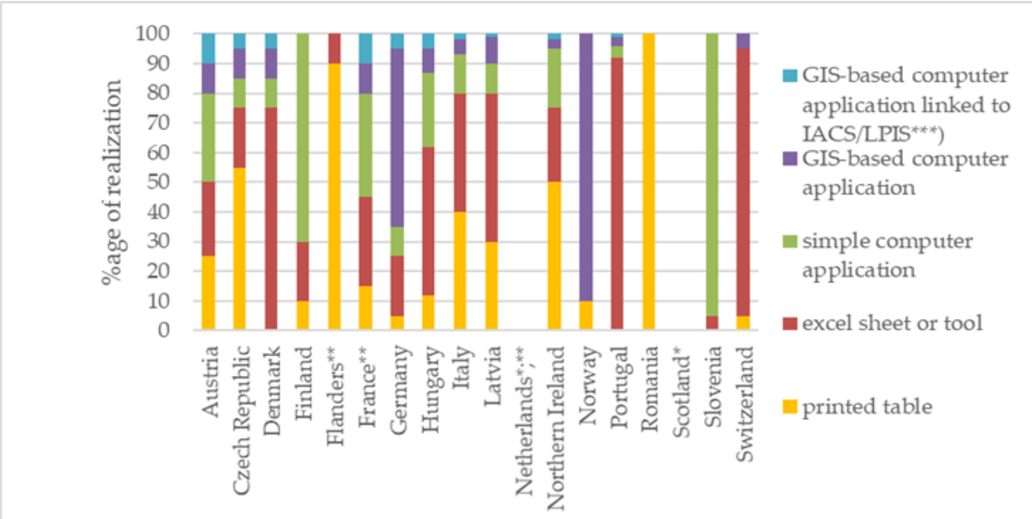

Figure. Estimates on share of technical realization of fertilization planning (Klages, S., et al, 2022)[2]

Crop nutrient demand is deduced from data on nutrient demand (N, P, K, others) depending on crop (species, variety), target yield and target quality. Target yields are deduced farm- or site-specific from previous years or standard (table) data are used. For target qualities, standard (table) data or farm performance of previous years are used, but also farm advice and analytics of harvested crops. Standard (table) data are compiled and updated by governmental or federal research institutes, the ministry in charge, or institution closely linked to it.

Fertilizer demand is calculated from crop demand by deducing plant available nutrient supply in soil where crop shall be cultivated. On site nutrient supply is affected by soil type, previous organic fertilization, nutrient supply from preceding crop (main crop, catch- or cover crop), current soil mineral nitrogen concentration, irrigation (fertilizing and watering aspect). Climate plays a major role as it affects plant growth as well as mineralisation and thus nutrient supply of crop.

Main challenge for determination of N fertilizer demand is that an often large amount of N is bound in soil organic substance (some 1000 kg/ha N) is accompanied by a small amount of readily plant available, mineral N (few 10 kg/ha N). Changes in weather conditions (precipitation, temperature) and mechanical influence (soil tillage) may influence mineralization and increase or reduce the supply of N (and other nutrients). The higher the concentration of organic matter in soil, the stronger the uncertainty to predict N supply during vegetation period.

Main challenge for determination of P fertilizer demand is that legacy P is bound in soil in mineral and organic form. The plant availability of soil P depends not only on external factors but also on the plant (e.g., root growth). An oversupply of soils with manure in the past decades has led to high concentrations of soil-P in areas with intensive animal production. Where legal limit values are reached, Fertilization planning has to take into account limitations for manure and other organic fertilizers containing P.

Linking planning with execution is particularly challenging when manure or other organic fertilizers are in place, given that nutrient availabilities in those materials are variable and not accurately known in advance –and very frequently nor at the moment of disposal either-. In fertilization planning manure to be applied has to be quantified according to general calculation data, whereas in the execution of fertilization, nutrient should ideally be recorded on-site (e.g., via NIRS).

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[2] Susanne Klages, Claudia Heidecke, Eke Buis, Lyske Elings, Vera Eory, Karolin D'Haene, Suzanne Higgins, George Hofman, Sari Luostarinen, Ingrid Nesheim, Georgio Provolo, Tapio Salo, Adelheid Spiegel, Nicolas Surdyk (2022). Aspects of implementing Farm to Fork nitrogen targets with tools, measures and policy instruments across Europe. *International Interdisciplinary Conference on Land Use and Water Quality. Agriculture and the Environment.* Maastricht, the Netherlands, 12-15 September 2022

2.3. Requirements for execution

Application of organic and inorganic nutrients is a key element in crop production. It takes place with diverse machinery depending on the product and the crop. It is not the target of this document to cover all the technology involved in the fertilisation application machines such as spreaders, sprayers and tanks, but to consider those aspects more related to the use of ICT.

Nevertheless any technology involved in the nutrient application process starts from the proper calibration of the equipment. The correct setting of the machine is determined by the physical properties of the fertiliser: particle size distribution and bulk density if solid and flow rate. Different kinds of fertiliser and manure may require different settings. Machine manufacturer produces tables with the correct settings according to the product to be applied. These tables are based on tests under ideal conditions and give information on how to set the spreader for optimum even spreading at the desired application rate (kg/ha) and at a specific working width. Digital tools can provide improvements on nutrients efficiency, but this has to be built on top of the proper machine calibration.

2.3.1. Fertilisation records

- **ISOBUS SOLUTION AND VRA**

ISO 11783, known as Tractors and machinery for agriculture and forestry—Serial control and communications data network (commonly referred to as "ISO Bus" or "ISOBUS") is a communication protocol for the agriculture industry based on the SAE J1939 protocol (which includes CANbus)

ISOBUS, Task Controller (TC) is the component of the standard that automates commands for the Electronic Controlled Unit (ECU) of the application machines such as spreaders. There are three subprotocols: Basic (TC-BAS), Section (TC-SC), and Geo (TC-GEO).

TC-BAS describes the documentation of total values that are relevant for the work performed. The implement provides the values. For the exchange of data between farm management system and Task Controller the ISO-XML data format is used. Jobs can easily be imported to the task controller and/or the finished documentation can be exported later.

TC-SC allows automatic switching of sections of a fertiliser spreader, sprayer and the manure application devices, based on GPS position and desired degree of overlap.

TC-GEO provides capability of acquiring location based data – or planning of location-based

jobs, as for example by means of application maps. It is the core element for the automatic execution of Variable Rate Applications (VRA). Each parcel is divided in several areas, denominated management zones, that are stored using vector geometries.

VRA can be performed based on pre-elaborated maps or on the go using crop/soil sensors. Farmers or advisors elaborate management zones based on previous yield maps (obtained from combine harvesters with yield monitor), soil maps (obtained commonly from electrical conductivity sensors complemented with individual soil samples test) and satellite/proximal sensors from current or previous seasons like Greenseeker. Adobe all those sources Satellite image is the more common input for zone delineation as could be seen in applications such as CropSat, Terrazo, Satagro, Onesoil.ai, Fieldview, Graniot, Agrisat, Sativum and many more. All those tools take advantage of the free Copernicus Sentinel-2 Satellite imaginary. Almost all of them are based on simple Normalized Diferenced Vegetation Index. Tools that accept yield monitor input data are reserved mostly to agricultural machinery and yield monitor manufacturers such as FarmTRX.

Those management zones are assigned with a proper nutrient dose according to farmer/adviser expertise or a general nutrient balance for an average expected yield. VRA is generally quite disconnected from nutrient balances and the common practice does not apply nutrient budgeting at each management zone. The common use of the technology still lacks agronomic background and is reproducing the business as usual strategy to determine the fertiliser dose with the single difference of determining a dose for each zone instead of the whole agricultural parcel.

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There is an important remark that nutrition should accommodate crop needs based on yield expectations. VRA allows farmers to decide to apply more or less fertiliser according to the yield on every designated area. Farmer strategy could focus more on providing more nutrients to low productive areas in order to level the general production of the plot. It is important to remind that nutrition principles are based on Liebig's Law of the Minimum as well on Mitscherlich's Law of Diminishing Returns. Therefore nutrition should always be considered from a cost/benefit approach, avoiding over-fertilisation on areas where probably there are other limiting factors (abiotic stress or lack of other nutrients).

VRA as other PA domains needs smooth data sharing between machines. Although claims for standarization and efforts in that direction have been increasing during the last years, it is frequently a challenge, particularly considering the relatively high number of machine manufacturers (and providers) in Europe. Platforms like Agrirouter aim to address that gap.

- **MANUAL APPLICATION ASSISTANT**

Traditionally farmers have been varying the fertilisers dose according to their experience managing the tractor speed. Depending on the strategy, farmers had increased or decreased the speed of the vehicle changing the average rate set for the parcel. This practice is based on the experience and the knowledge of every parcel and comes from inductive reasoning along decades of farming, long ago with low powered machines or animals that allowed them to have a slower understanding of the crop growing process. As farms grow in area under management, machines in power and harvest operations are subcontracted, this knowledge is getting lost.

Nevertheless there are digital tools to assist farmers on VRA without having an implement compatible with ISOBUS TC-GEO (or any other standard) that provides visual and voice advice to the farmer about the dosis to apply according to a preloaded VRA map or specified rate.

Examples of this technique could be found on the Austrian GIS-ELA tool from Josephinum Research and SATIVUM tool from ITACyL that show and read the dose to apply on an android device. Another example is the Spanish platform AgroXControl from AgroIntelligence that assists the tractor driver on the speed according to the desired rate of manure to apply on the field. AgroXControl includes as well as a continuous measurement of manure electrical conductivity to estimate N content and accommodate the actual N rate instead of just manure rare.

2.3.2. Fertiliser declaration. Field Book

As mineral fertilisers are generally the most expensive input of the farm, all the Farm Management Information Systems (FMIS) keep records on fertiliser applications and its economical aspects. Manure applications are covered as well but as a secondary aspect as long as generally manure is provided free or at a low cost to the agricultural farmer from the animal farms. In intensive animal breeding regions, the costs for disposal of manure is a relevant economic factor. Fertilization planning in this respect also includes the record-keeping to prove good agricultural practice in line with Nitrates Directive and other legislation.

As mentioned before ISOBUS TC-BAS provides automatic records to feed FMIS in the cloud and is a common flow in modern tractors and implements.

According to regulation (EC) No 1107/2009 Professional users of plant protection products shall, for at least 3 years, keep records of the plant protection products they use, containing the name of the plant protection product, the time and the dose of application, the area and the crop where the plant protection product was used. Good Agricultural and Environmental Conditions (GAEC) established for many contrived the obligation to keep those records as Cross-Compliance for the eligibility of the land for Common Agricultural Policy (CAP) subsidies. Even Though fertilisers and manure are not covered by Regulation (EC) No 1107/2009, the recording of fertiliser and manure application has been made mandatory in areas designated as Nitrogen Vulnerable Zones (NVZ). Under these circumstances farmers must provide to the authorities those records. With the new CAP post 2020, several Member States such as Spain are considering the digitalization of those field books and the inclusion of that information in the Integrated Administration and Control System (IACS) of the CAP in a routine manner, including all the aspects related to fertilisation inside or outside NVZ.

2.4. Requirements for Monitoring

To promote a more efficient use of fertilizers (mineral or organic) and reduce the environmental impact of fertilizers, diagnostic tools that allow technicians and farmers to make adjustments to the theoretical fertilization plan in those crops in which several applications are made during the campaign must be promoted. A new approach should be introduced in fertilization decision making, which facilitate personalized learning for each farmer for his crop, soil type and microclimate, in such a way that the practical experience during the campaign is considered as a recurrent logic of "planning-execution-diagnosis-adjusted execution-new diagnosis, etc." that ends up having an impact on the fertilization plan itself. It can be done up to 50 times in intensive fertigation crops in the south or twice in herbaceous crops in northern Europe, but it may always provide an improvement to the current situation of only executing a plan without measuring anything during the campaign, since the climatic factor is a determining factor in mismatching the needs of plants to the theoretical plan and this mismatch has a high economic and environmental impact.

The new diagnostic tools should meet several requirements: be economical and simple to use, facilitate real-time diagnosis and improve the previous situation, have a scientific basis of practical utility, enable new forms of economy of scale to be shared and allow the creation of customized references for each farmer with indicators that express the dual perspective of profitability and environmental respect.

The problem is holistic, so there is no digital tool that will solve it. However, the solution can be addressed by the integration of different technologies based on a thorough knowledge of each problem and the advantages and disadvantages of each available tool. The training of technicians will be a determining factor.

The improvement in the diagnosis is facilitated if the data are available "in real time", otherwise the passage of time makes it difficult to make decisions, because after the diagnosis it is necessary to implement the action of adjustment of the theoretical plan, which can take several days to execute it.

The new digital tools must offer a solution to the diagnosis of fertilization in its evolution in "time" and "space" according to the problem posed to the farmer, company, cooperative or agricultural consultant in order to offer a satisfactory solution from the perspective of profitability and sustainability and at a cost/benefit that is convincing.

Diagnostic improvement has to differentiate plant indicators from factors affecting the plant. Plant indicators are integrative and will allow to create personalized references for each farmer to try to repeat experiences and make preventive decisions if there are diagnostics before each application. Plant indicators can measure plant processes impacted by nutrition (such as vegetative development measurable with app's or remote sensing, vigour trends with a dendrometer) or directly measure a nutritional status in the plant (with sap analysis). Indicators of factors affecting plant nutrition are climate and soil conditions (moisture, nitrate and potassium, microbiota, salinity and temperature).

To improve temporal and spatial resolution we can consider different digital tools to be combined in each customized approach.

2.4.1. Continuous indicators

They are installed in the field and facilitate the "nutritional characterization" of the crop and continuous recording of data in configurable minutes. They are used to understand the interaction of climate and fertilization on the plant and soil in a microclimate and to know if there is a lack or excess of nutrients.

Their location, in order to be representative, must be studied with some tool or method to be representativeness of their area of influence. The characterization point should have plant, climate and soil sensors that allow to understand the nutrition and its factors in a few m^2. Earth observation and different GIS layers can provide useful information to identify the locations more characteristic according to the target needs.

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· **Climate:** they influence the physiological functioning of the plant (transpiration, stomatal closure, photosynthesis, etc.) and help to understand nutrient uptake and water and nitrate dynamics in roots and drainage. Each microclimate should have temperature, relative humidity and rainfall, sensors that can be shared (either in a cooperative, company, etc.).

· **Plant:** interests that express nutritional trends and physiological states of the plant (photosynthesis, stomatal conductance) combined with climate data. For instance, the company Verde Smart offers the Plantsens dendrometer with mechanistic models[3] that expresses these values on a daily basis, useful to understand the impact of climate on nutrient uptake with SaS everd 2.0 software (for trees and shrubs). With stress or low photosynthetic activity the plant does not take up nitrate and this is washed away if it is not absorbed.

· **Soil:** Moisture, temperature (and salinity if of interest) sensors are needed in the root zone and drainage (below roots) of the soil and irrigation control if irrigation is present. There are already selective sensors that measure nitrate and potassium trends in the soil that can be very useful to understand root and drainage dynamics in combination with the other sensors[4]. In this regard, selective probes appear to be more precise than indirect measurement probes (from salinity). In that sense, this type of selective probes (Nutrisens from Verde Smart) is included in the certification of the first nitrate footprint obtained by the company Frutinter in 2021.

2.4.2. Discontinuous indicators

They provide "punctual" measurements (every week, fortnight, month) and can be of manual component (analytical, app measurements) or can be "automatic" (satellite images, drone, etc). These tools offer a solution to spatial diagnostics, as they make it easier to measure at the sensor point and also to have data available at other points where there are no sensor points. The speed in the availability of the results is very important, since we can have measurements that facilitate a diagnosis on the same day of data collection or we can wait several days. They can be manual or automatic

- **Manuals**: facilitate the change in the diagnosis as they allow to have, on the same day of the field visit, the nutritional status of nitrate and potassium of the plant (based on its weekly or biweekly balance) and the nitrate and potassium in the irrigation water and in the soil (in the root and drainage zone). Inexpensive equipment is used and sampling can be done by the farmer or the technician during his visit to the field. They should be complementary to traditional foliar analysis.
    - **Macroelement analyzers**: facilitate the change by measuring macroelements in real time in aqueous solution (irrigation water, dripper, suction probe solution in soil in root zone or drainage, or in sap). For instance, according to some studies, the *Horiba LAQUAtwin* analyzer measures nitrate and potassium with a resolution similar to a laboratory (Fernández, M.M. et al, 2013)[5]
    - **Suction probes**: facilitate the extraction of water in the macropores, around the roots and drainage after rainfall or irrigation and analyze the concentration of the most important macroelements. They are cheap and some can extract aqueous solution in a short time (one hour), like *Rhizon probes,* or in 24 hours with porcelain capsules such as *Irrometer extraction probes.*

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[3] The company is leading a European project, IRRIWELL, with 5 research centers to improve mechanistic models

[4] In this regard, a recent study by Bellosta, A. (2022), from Public University of Navarra-UPN, analyses the performance of three probes in a sandy soil in Spain. Study available **here**

[5] Manejo de sondas de extracción de solución de suelo y métodos rápidos de determinación de nitratos. / [Fernández, M.M.; Cánovas, G.; Martín, E.]. – Almería. Consejería de Agricultura, Pesca y Desarrollo Rural, Instituto de Investigación y Formación Agraria y Pesquera, 2013. 1-21 pp. Formato digital (ebook) - (Producción Agraria).

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- **Vigor measurements:** It is necessary to be able to measure the evolution of vigour and stress trends at the point of the sensors and in all the farms in the area with objective measurements that allow them to be related to nutrition and other factors. There are free and very simple apps to measure plant leaf area, both in horticulture (for instance, *Canopeo*) and trees (like *Viticanopy*). As another example, the company *Geodim* offers an *IMAX* algorithm, based on remote sensing images, that correlates with leaf area and a stress indicator (*ISTRES).*
- **Sap**: Plant petiole sap analysis allows to know if the plant takes more nitrate or potassium than it consumes, it facilitates the diagnosis of nutrition at the sensor point and the result can be compared with other sap measurements in other plots of the same crops in nearby areas, thus facilitating a spatial management of nutrition in "farmer groups", cooperatives or companies. It is obtained from petioles and there are sap extractors of different types and costs. At the point of sensor characterization, sap testing together with other vigour measurements (such as the Viticanopy or Canopeo apps or the remote sensing IMAX index), allows linking nutritional states with plant growth, nitrate washout detection, physiological states, etc., and defining reference values for the farmer, cooperative, etc., as well as defining reference values for the farmer or cooperative itself. The novelty lies in measuring it in real time with the Horiba analyzer on the same day of the field visit, with low-cost equipment that can be shared among several farmers. The availability of sap analysis (nitrate, potassium, º brix) with a certain periodicity (7-15-30 days) changes the perspective of nutrition diagnosis.
- **Microbiota:** analyses of soil microbial species (offered in the market by facilitate to know their evolution during the campaign (3-4 analyses) and the services they offer to the soil from the point of view of quality, biodiversity, resistance and functionality. It is recommended to be taken at the sensor point to understand its impact in plant nutrition.

2.4.3. Embedded and shared solutions

An integrated solution to improve the diagnosis during crop nutrition (and irrigation) management would entail the deployment of a 'basic infrastructure', understood as a combination of both a set of equipment and services. An example with maximum services could include:

- Training: "technical staff" trained to work with all the new digital tools and provide better diagnostic support to the farmer and facilitate adjustments to the FERTILIZATION (and irrigation) PLAN during the season
- Annual GIS and remote sensing service with customized weekly vigour and stress images.
- Network of quality weather points in the area in strategic crops and microclimates.
- Intelligent Weather Forecasting (IWF) Service
- Basic nutrition kit services (sap analysis, Horiba, suction probes, etc.)

The basic infrastructure can be shared by the farmers to lower their cost and make those new technologies affordable, which depending on the type of crop and its value should be customized.

Therefore it is important to know the suitability of the tools to be shared and integrated into a common solution. One option could be to derive an annual cost (i.e. per ha) including the amortization of the investment of the service set-up and the annual support that can be shared among different farmers of an association, cooperative, or a large company with different farms. Design in this way, such a basic infrastructure allows to offer a set of services to farmers who sign up to the system that can be scaled up, and whose annual cost can be very economical for large areas (500-2000 ha). It can be complemented with characterization points on concrete farms/fields which would allow to adjust the fertilization plan of strategic crops, and as a result the new insights can be radiated to the rest of the other crops with basic or manual intake services. Different types of producers can benefit of the basic infrastructure depending on how they engage in the services of the new tools, with different cost per ha/year.

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EIP-AGRI Focus Group

Digital tools for sustainable nutrient management

MINI-PAPER Digital tools for reducing the carbon footprint in plant nutrition

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1 Introduction

The constant demand for resources from an ever-growing population is placing enormous pressure on the biodiversity, threatening our future well-being and, ultimately, raising temperatures. The issue of climate change is still one of the most significant problems facing the world at present.

In a way, agriculture, our primary source of food, and by extension, life, releases up to one-quarter of the world's annual Green House Gas (GHG) emissions. However, agriculture only contributes three percent to the world's Gross Domestic Product (GDP), which suggests that agriculture is highly GHG heavy.

Agriculture's climate implications are notable and evident with significant consequences for the global climate. The primary sources of Green House Gas (GHG) emissions are land clearing and tilling, livestock breeding, and fossil fuel usage for inputs and farm equipment like fertilizers. Agriculture is seen as a net emitter of greenhouse gases. Nevertheless, agriculture sequesters carbon in soils and captures carbon in bioenergy and food products. The purpose of agriculture is to produce food and feed, where the use of plant nutrients plays an essential role for food security. Nutrients applied in the right dose at the right time account for carbon capturing as an additional benefit.

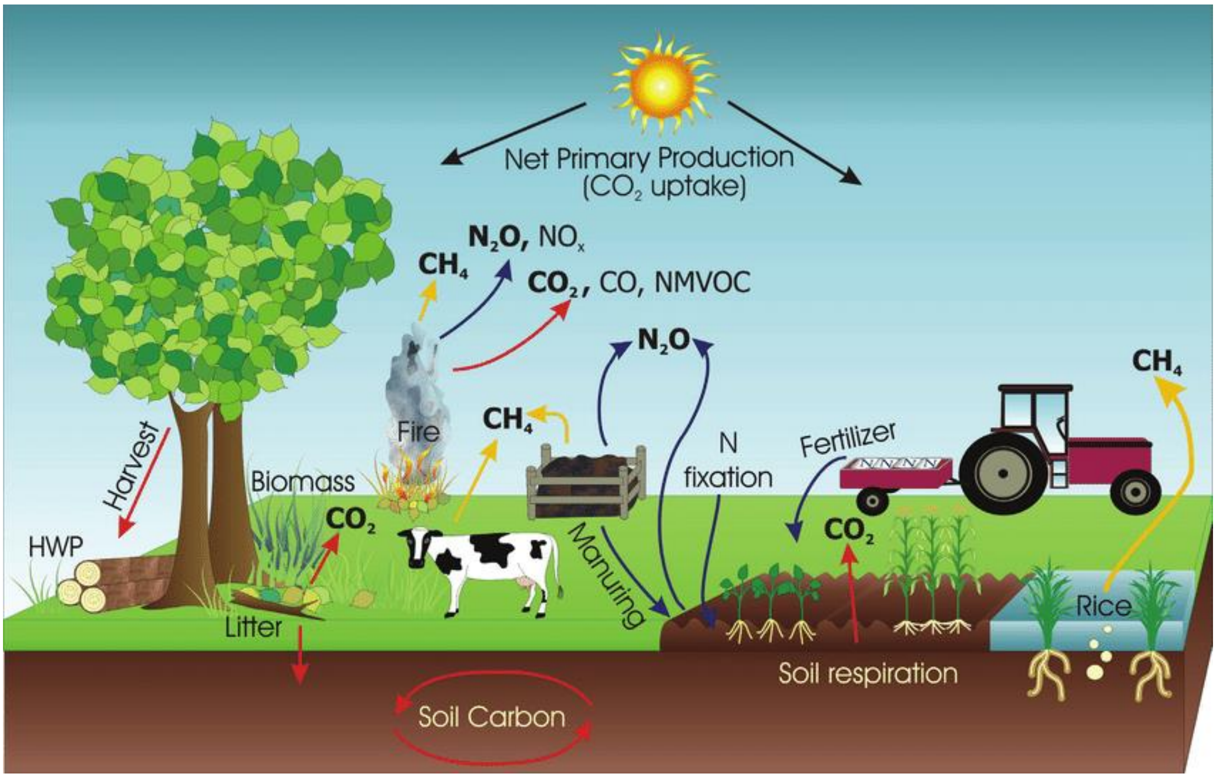

Figure 1. The main greenhouse gas emission sources/removals and processes in managed ecosystems. (Paustian *et al.*, 2006)

2 It's in the farmer's hand: management practices for improving the CO2 balance in plant nutrition

2.1 Optimization of soil organic carbon (SOC)

Increasing the carbon content of soil is a greenhouse gas (GHG) mitigation strategy, which also helps to improve soil quality and prevent erosion.

As plants grow, they take carbon from the atmosphere, and some of this carbon is apportioned into their roots. The majority is then released into the atmosphere when the plants die and decompose. Nonetheless, if left undisturbed, and depending on the climate, rainfall, soil microbial community, management and many other variables, some of the carbon in these roots (rhizodeposition) and plant litter may eventually incorporate into more stable compounds in the soil, therefore constituting a net removal of carbon from the atmosphere.

Land management practices aiming to increase SOC look to improve productivity and to increase biomass (net primary productivity) that is highly influenced by fertilization, and also look to use sources of organic matter.

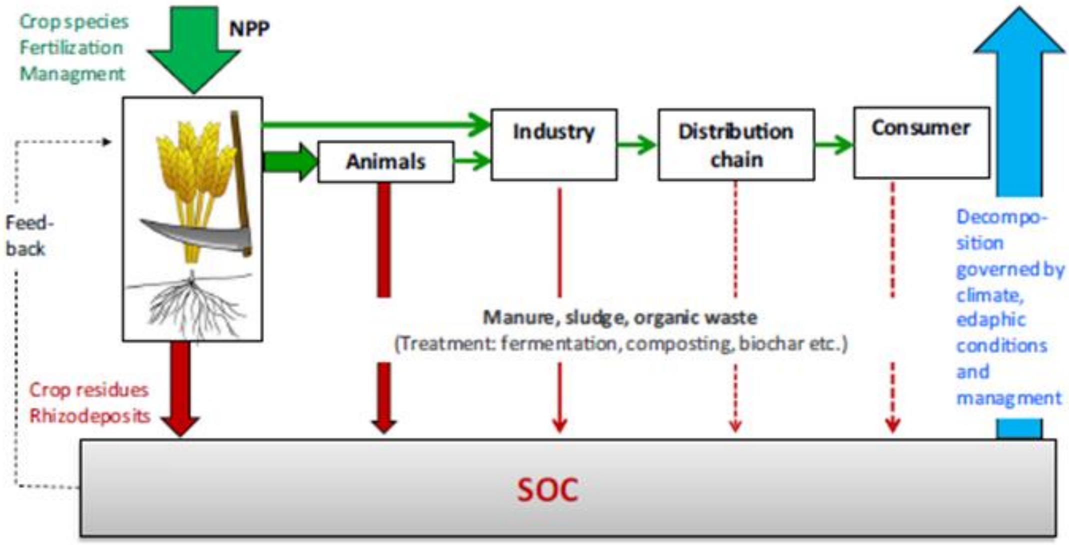

Fig. 1 The major fluxes of carbon in the food chain affecting the soil organic carbon (SOC) balance for agroecosystems are net primary productivity (NPP) and CO_2 release from soil through decomposition. Measures that stimulate NPP, decrease decomposition of SOC, or increase recycling of products will favor carbon sequestration. SOC stocks are in equilibrium when the C inputs are equal to the outputs

(Bolinder *et al.*, 2020)

Some practices related to plant nutrition include:

1) Crop residue management.

A proper fertilization leads to a higher net primary productivity, that implies more crop residues, with the resulting positive impact of crop residues being used to induce C sequestration, which is estimated at around 15% (Lal, 1997) or 30% (Angers *et al.* 1995) of the total input. C sequestration depends on the crop type, growth conditions and agricultural techniques used. Generally, there is a linear relationship between the organic matter in the first 15 cm of soil and the quantity of crop residues applied (FAO, 2001).

2) Crop rotation and cover crops.

These management practices provide biomass residues and protect against erosion.

Crop rotations enhance C sequestration in long-term rotations of over 15 years (Sanz Cobena *et al.*, 2017) depending on the type of crops and their management. Perennial crops in rotation have resulted beneficial for C sequestration. In general, crop rotations imply a reduction of fertilizers, an improved crop yield, and an additional reduction of emissions.

Cover crops may be used as winter cash crops or green manure in arable farms, or as cover crops in orchards and vineyards. Cover crops enhance soil organic matter and labile C by incorporating plant material into the soil (Veenstra *et al.*, 2007).

3) Use of organic fertilizers (manures and other recycled organic materials).

The effect varies depending on the quantity applied and the quality of the materials, and this depends on the proportions of organic materials that are converted to more resistant SOC (Bolinder *et al.*, 2020). Solid manures have a positive effect on SOC, but this effect is not contrasted sufficiently with liquid manures (Bolinder *et al.*, 2020).

Sewage sludge has labile organic matter forms and the high amounts that tend to be applied may increase CO_2 emissions due to increased soil respiration (Sanz-Cobena *et al.*, 2017).

It is also necessary to consider that the use of these fertilizers closes the nutrient cycle, with the associated reduction of mineral fertilizers.

2.2 Increase of crop yield

Carbon enters into plants by assimilating CO_2 into leaves from the atmosphere using light energy from the sun. Carbon is primarily fixed into sugars for the synthesis of plant tissue. The conversion of atmospheric CO_2 into crop biomass through photosynthesis (biological CO_2 fixation) is the process by which CO_2 can be removed from the atmosphere by agriculture. The fraction of carbon fixed by photosynthesis into biomass is the most important step of capturing carbon from the atmosphere (Kirchmann *et al.*, 2014). Therefore, all measure that farmers can take to improve crop yield, have a direct impact on the amount of CO_2 captured from the atmosphere:

2.2.a Liming

Liming, or more in general the correction of soil pH, is a well-established practice that can increase crop yield, and consequently the crop residue production. It is applied to crops and to grassland when the excessive acidity, or excessive alkalinity, cause a decrease in productivity due to toxicity or scarce nutrient unavailability. This practice is effective in increasing plant growth, although its effects on GHG emissions and C stocking are variable (Abdalla *et al.*, 2022; Goulding, 2016).

2.2.b Irrigation

Irrigation is one of the most influent factors of plant production in Southern Europe, and an increase in its adoption is also expected in the future due to climate change adaptation (Zhao *et al.*, 2022).

2.2.c Improve of nitrogen use efficiency

The nutrient use efficiency of mineral and organic fertilisers is a key issue in plant production as well as in environmental protection. In particular, as N is the most influent element on biomass production, a special attention should be devoted to N use efficiency, defined as the quota of N fertiliser that is effectively used by the crop (Xie *et al.*, 2022)

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2.2.d Improving the effectiveness of organic fertilizer (manure/slurry).

In the EU-27 more than 1400 million tons of slurry is produced yearly, most of which is reused on agricultural soils (Fangueiro et al., 2016; Danish Ministry of Energy, 2017). To ensure a good organic fertilizer management, the fertilizers must be applied at the right time (weather and crop conditions), in the right places (spreading techniques), and at the right rate according to crop requirements, as this will improve the efficiency of the nutrients that are supplied by organic fertilizers and increase the productivity and biomass (net primary productivity).

Studies show that up to 12% of applied N was utilized by plants; up to 45-47% is lost to atmospheric emissions, and the rest is directed to groundwater, through leaching (Ma *et al.*, 2010; Webb *et al.*, 2010). Therefore, reducing losses of nitrogen during slurry application on soil is of crucial importance.

a. Distribution time depending on the weather.

It is important to avoid applying fertilizers when there is a high-risk of surface runoff (winter with wet or frozen soils), when it is expected that there will be heavy rain in the next few days, when there is a high-risk of rapid percolation (wet soils), or when there is no crop to use the added N. Applying fertilizers at said times would reduce manure N use efficiency and increase NO_3 leaching and indirect N_2O emissions

(Price *et al.*, 2011).

b. Models for mineralization

The release of nitrogen as a result of the mineralization of organic matter is influenced by soil type and uncontrollable factors such as rainfall and temperature and which is difficult to monitor. Models for mineralization is a mean to provide an understanding of nitrogen dynamics and allow to adjust nitrogen supply to crop demand (Van der Burgt *et al.*, 2006).

c. Using low emission slurry spreading (LESS) techniques (dribble bar, trailing shoe or injection)

Applying organic fertilizers through band spreading reduces NH_3 emissions (55%) when compared to surface application, incorporation (70%) and injection (80%), by minimizing the surface area to which slurry is applied and consequently the slurry exposured to air, which in turn results in lower indirect GHG emissions and in the reduction of the production costs.

The effects of slurry injection or incorporation into the soil on N_2O emissions varies considerably and it is related to many factors (manure types and application rates), soil properties (texture, moisture content), vegetation and climate (Velthof *et al.*, 2003).

d. Quick on-site methods for estimating manure/ slurry nutrient content

To optimize the use of manure/slurry it is important to know its nutrient content. Manure/slurry nutrient content is highly variable across farms and seasonally within the same farm. By more accurately determining the nutrient content of the slurry in a quick and easy way prior to application it is possible to adjust fertilization rates and increase nutrient efficiency. There are a number of different approaches for rapid on-farm analysis (density, conductivity, hand-held NIRS,…). These measurements are facilitated by the use of calculations, which are specific to regional conditions and/or to the specific type of equipment used.

e. Slurry treatments.

Raw slurry is separated into liquid slurry and solid fraction. Separation enables greater flexibility in manure management and application timing. Following field application, lower NH_3 emissions (18%) were found for separated liquid fraction than for raw slurry; however, this did not have an effect on N_2O emissions. The N_2O emissions from field applied solid fractions were 46% lower than those from field applied untreated manure (Hou *et al.*, 2015).

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2.3 Reduction of emissions

The gases that are mainly released from agricultural and livestock activities are CO_2, N_2O and CH_4. Emission sources can be direct (e.g. fertilization, manure management and use, soil management) or indirect due to fertilizers leaching/runoff or volatilization and atmospheric deposition.

2.3.a Reduction of nitrogen emissions

Nitrogen fertilizers (inorganic and organic) and soil organic carbon mineralization are the main sources of N_2O emissions. Organic (peat) soils that have been drained and cultivated can also give rise to particularly high N_2O fluxes (Kasimir-Klemedtsson *et al.*, 1997).

Nevertheless, there is still considerable scope for reducing synthetic fertilizers use. In this light, the application of the required amount of nitrogen, taking into account the soil nitrogen content and crops' requirements at the different growing stages, is one of the most important improvements in terms of lowering production costs, improving fertilizers efficacy, and reducing N_2O emissions.

In addition, the use of split applications of nitrogen fertilizers could increase the efficiency of use by plants, allowing less nitrogen to be lost to the atmosphere or leach. The symbiotic fixation of atmospheric nitrogen by grain legumes in crop rotations or legumes in grassland implies a low use of mineral nitrogen fertilizers and less use in the subsequent crop due to the presence of nitrogen rich residues in soil, mainly when legumes are used as green manures. The adoption of legumes, as well as nitrification inhibitors to limit nitrification could be effective measures against N_2O generation and emission.

Research contacted so far, revealed that up to 80% of N_2O emissions occurred in the first two months after fertilizers application (Chantigny *et al.*, 2010; Escobar *et al.*, 2010), while emission increases exponentially with soil temperature (Dinsmore *et al.*, 2009). Moreover, the nitrogen not retained by plants, remaining in the soil after fertilization can be transformed by nitrification to nitrates and then to N_2O. This process is triggered by anoxic soil conditions, which prevail under high soil moisture content. Therefore, intense rainfall after fertilization causes high N_2O fluxes due to O_2 reduction in soil pores, induced by elevated levels of pores saturation with water (Smith *et al.*, 2003).

Although N_2O is emitted in significantly smaller quantities than CO_2, nevertheless, its global warming potential is 265 times higher than that of CO_2, meaning that 1 kg of N_2O impacts as 265 kg of CO_2 on the planet warming.

It is therefore urgently important to limit N_2O emission, however, without causing crop malnutrition. This is a particularly big challenge, considering that the reduction of nitrogen fertilizers may cause reduced yields and, in turn, socio-economic consequences.

2.3.b Reduction of methane emission.

Methane emission is mainly related to animals' enteric fermentation, manure storage and management, rice cultivation, and field burning.

Efficient methods for the reduction of CH_4 emissions from rice fields are midseason drainage, intermittent irrigation, and avoidance of organic fertilizers inputs as long as fields remain flooded (Wassmann *et al.*, 2020).

The most effective approach for CH_4 reduction is capturing carbon in soils, in other words, carbon sequestration, as for example, the use of organic fertilizers, composting and reuse on soils, selection of high-quality feed that reduce methane emissions from enteric fermentation, return crop residues in soil avoiding burning, manure management (manure covering at storage areas, optimization of manure use by developing a manure management plan).

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2.3.c Reduction of carbon dioxide emissions

The main sources of CO_2 from agricultural activities are the application of lime and urea, field burning, land use (e.g. tillage), and land-use change. Fuels for agricultural machinery and electricity use from the network are also sources of CO_2 emissions.

The different tillage practices distinguished are conventional; conservation; and zero tillage. In general, after each soil disturbance by ploughing and disc harrowing, CO_2 fluxes almost doubled compared to undisturbed soil. This is mainly due to the mineralization of the spontaneous vegetation incorporated into the soil and to the decomposition of soil organic matter associated with soil aggregates which are destroyed by tillage (La Scala *et al.*, 2006). Studies confirmed that increased CO_2 emissions from tilled soils lasted for approximately 70 days (Rochette, 2008; Rochette *et al.*, 2009). Moreover, Kristensen *at al.* (2020) stated that the decomposition of soil organic matter due to tillage increases the mineralization of soil nitrogen and consequently the potential production and emission of N_2O. Reduction of tillage that consumes fossil fuel also helps reduce CO_2 emissions.

3 The outputs of digital tools need to guide farmers to improve their CO_2 balance

3.1 Tailor-made fertilization recommendation

According to Kirchman et al., 2014, the most effective farmers' practices are those that can increase net primary production through fertilization with regards to mitigation of CO_2 losses. A proper fertilization recommendation is the basis to plan the crop production in a way that yields can be optimized taking into consideration local soil-, climate- and farming conditions. Not only nitrogen, but also the supply with P and K as well as with secondary and trace elements increase nutrient efficiency. The application of organic manure bears potential to reduce emissions as described in the chapter above.

3.2 Nationally provided algorithms to take care for local nutrient management optimization

The legal framework for nutrient quantities to be applied differ between the EU member states. The conditions for crop production differ even more within the countries. Outputs of digital tools need to take care both of the agronomic and legal premises. Local field trials commissioned by national authorities are necessary for finding the best nutrient management strategies under national conditions. Out of the scientifically proven trial data, algorithms can be developed which will give – once implemented in digital tools – fertilization recommendations for low-emission fertilization strategies.
Algorithms derived from public field trial data should be accessible for the public; through proper APIs an implementation into any farm management system or other digital tools can be possible.

3.3 Carbon balance and emission information

In any grown and harvested product, the carbon content can be determined. Official figures for CO_2 emissions of fertilizer production, transport and application are available. Therefore an immediate output on the carbon balance depending on fertilization and expected (or harvested) can be made visible as an output parameter of the digital tool. Referring to existing fertilization practises, e.g. high organic manure input, areas of high emission potential should be highlighted in order to use future nutrient management strategies for lowering the emission potential.

Necessary input parameters in order to reach the desired outputs need to cover:

- Weather conditions
- Local soil classification
- Cropping system (crops, crops rotation, residues management)
- Fertilizer type

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- Land use and land use change
- Expected crop yield or alternatively, model for biomass development
- Mineralization models
- Energy -fuel and electricity- consumption (transport and application).

3.4 Proper presentation of outputs by digital tools

In order to assure actions from farmers side to improve their nutrient management with digital tools, the outputs of such tools need to be provided and visualized in an easy and understandable way. This can be

- in the form of application maps
- infographics that show the emission potential of the fertilization activities for creating awareness on the emissions through the different farm works and for identifying "hot spots" of emissions.
- indicators that show the efficiency in nutrient use at the same time of showing the emissions, in order to modify management according to yield and carbon footprint criteria. Nitrogen footprint could be included, too.

In general we recommend that digital tools for nutrient management should be connected to a common, national algorithm, which brings the scientific knowledge directly to the farm. Free APIs that enable any digital tool using national algorithms will help to reach the aim to make farmers work into the same direction for a better nutrient management all together.

4 Examples of current digital tools for nutrient management

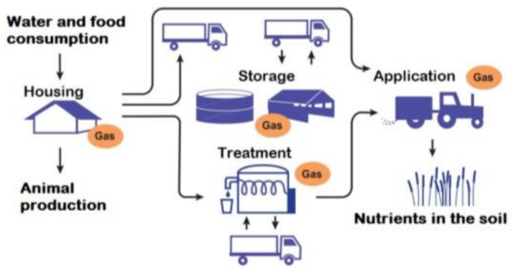
Nutrient management affects GHG emissions, but in general current nutrient management digital tools have no modules for estimation of emissions. However, there are a range of tools that help farmers, researchers or policy makers to implement measures to increase farm sustainability, and which estimate farm emissions and help reduce them. These tools quantify, in different sections, emissions coming from nutrient management and therefore they are proposed as examples to support moving further to appropriate tools for reducing the carbon footprint in plant nutrition.

4.1 BATFARM (European project)

Scope: BATFARM has been developed as part of the European BATFARM project, funded by the IIIB-Atlantic Area Interreg Programme and entitled "Assessing the best techniques available for cutting air and water pollution on livestock farms".

It enables farmers to make an accurate environmental assessment of their farms. BATFARM makes it possible to simulate the effect of a range of strategies designed to mitigate gaseous losses (NH_3, N_2O, CH_4) and nutrient balance (N, P, K) on livestock farms dedicated to pigs, laying hens and poultry meat, and dairy cows. The tool allows different scenarios on each farm to be compared and thus helps to select the most suitable environmental strategy in each case. The software covers all the phases in the production system: animal housing, storage, treatment and field application of manures and slurries.

It is a tool for advisors and farmers.



Batfarm submodules and its interactions

Inputs: Type and number of animals, diets, nutrition strategies (adjusting of protein and phosphorus, feeding in phases), the design of housing (types of housing, flooring and deep ditch), and the management of manure and slurry storage (emptying system, type of cover, additives). Upgrading treatments (drying, separating of solids from liquids, aerobic treatment, methanization, composting), systems for field application (injection, incorporation) and other good practices specified by the users themselves are added to these components.

Outputs: The main calculations made by the computing tool are feed, water and energy consumption (kWh and CO_2 equivalents) considering only the direct energy consumed on the farm due to electricity, fuel and biogas consumption (when there is anaerobic digestion with combustion/cogeneration); animal production (live weight, eggs, meat, milk); ammonia, nitrous oxide and methane emissions; the production and composition of manures and slurries; and the nutrients applied to the soil (pastures or agricultural soils). These measurements offer the possibility of comparing different situations.

The total emissions output is made up of several graphs showing the emissions of ammonia, methane and nitrous oxide in each phase and in the whole farm, on a monthly and annual basis

To make these calculations, BATFARM uses default and regionalised values- adapted to national conditions in the Atlantic region (Spain, Portugal, France, UK, Ireland) - relating to zootechnical and climate data and emission factors. Enteric CH_4 emissions from animals are obtained from literature review and national inventories. IPCC Tier 2 default values are used to estimate N_2O and CH_4 emissions from manure management.

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Website: https://www.intiasa.es/es/batfarm-software.html

4.2 Cool Farm Tool

Scope: The Coolfarm tool quantifies on-farm greenhouse gas emissions, water, biodiversity and soil carbon sequestration

COOLFARM is a whole-farm dynamic calculator, which can be used as a tool to evaluate on-farm greenhouse gas emissions, water, biodiversity and soil carbon sequestration.

The model distinguishes and links different farm components, including field (crops and soil), animals, housing and manure storages. The Cool Farm Tool allows farmers to find out how their fields respond to the management options of interest.

Inputs: Harvested yield and marketable yield product weights, Growing area, Fertiliser applications: type and rate, rate & active ingredient of pesticide applications, Energy use (kWh and fuel use) and (optionally) transport: mode, weight of product and distance. For livestock, calculations are built from herd size, manure management, grazing time, feed and energy use., general information about crop protection management, green manure crops and soil cultivation, area (ha), OR length and width (m), of small or linear habitats including: Grassy verges along roads or tracks, Field corners and margins managed for wildlife, Hedgerows, Solitary trees, widely spaced avenues of trees or woodland patches, water courses (including ditches, field drains, streams), Ponds and pools, Area (ha) of any larger pieces of semi-natural habitat managed for nature conservation (woodland, grassland or heath, or wetland areas greater than 1 ha).

Outputs: The tool comprise of three modules – greenhouse gases (field level assessment including nutrients, energy and land use measuring carbon), biodiversity (quantitative scoring of the whole farm management) and water (crop irrigation requirements and blue and green water footprints). The Cool Farm Tool is a GHG calculator at farm level – this means related emissions coming from agricultural production of a specific product (crop or livestock).

The GHG Protocol defines three different scopes:

Scope 1: Direct emissions at your farm (e.g. combustion of diesel, N_2O emissions from your field, CH_4 emissions from your cattle)

Scope 2: Indirect emissions from purchased energy/electricity (Emissions are produced someplace else, but the energy is used at the farm)

Scope 3: Other indirect emissions (Emissions from another company that provide products or services for your operations.)

The Cool Farm Tool is taking the scope 3 approach for many aspects, such as fertilisers, pesticides, and transportation of goods to and from the farm. However, there are also areas, which are only partly covered such as seed production (only for potatoes) or not covered at all such as the production of machinery or build infrastructure. The latter are not covered to ease the use of the CFT and also because the emissions may have only a minor impact on the overall result.For crops, the Cool Farm Tool incorporates Tier 1, Tier 2 and when it comes to N_2O emissions and soil carbon sequestration, a "simple Tier 3" model – as described by Prof. Pete Smith – as it is a multi-factoral empirical model based on Bouwman 2002, which is widely acknowledged in the public domain. The Cool Farm Tool is moving towards Tier 3 whenever possible. Also for livestock it considers Tier 1 and 2 as in dairy and beef. For example manure on pasture is modelled using Tier 1 (1% of N applied becomes N_2O), while gross energy demand is Tier 2. There is only some unclarity for other livestock like camels & goats, and we have prepared methodology to update models for pigs & poultry which are not deployed, but would bring that along.

Website: https://coolfarmtool.org/

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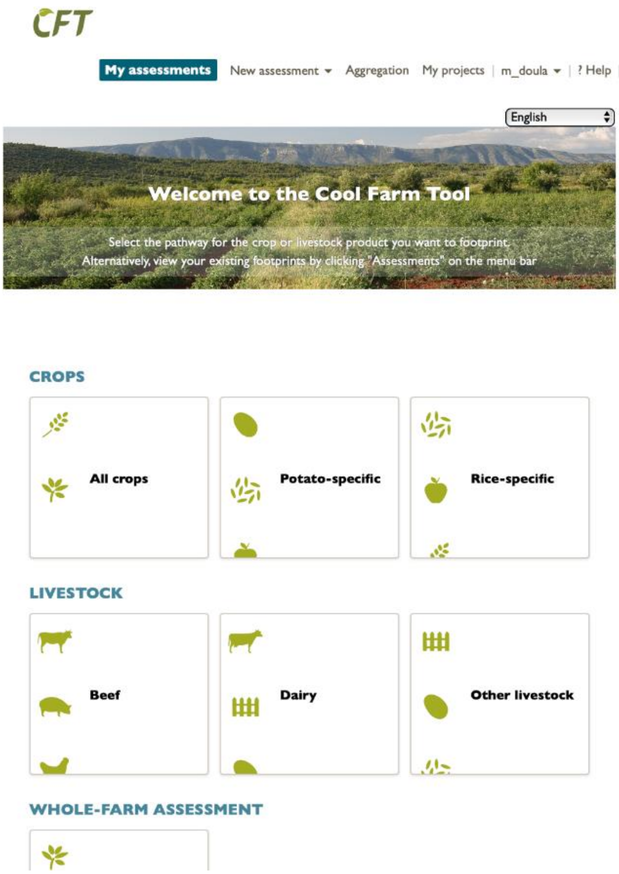


4.3 DAYCENT (United States)

Scope: The DayCent model is the flagship ecosystem model deployed by Soil Metrics via **Greenhouse Gas Inventory Tool (GGIT)**. **First published in 1998**, the DayCent model is a daily time-step version of CENTURY, one of the first ecosystem research models developed and deployed to access carbon and nitrogen cycling for research and applied uses. DayCent is the **U.S. Environmental Protection Agency** and the **U.S. Department of Agriculture**'s model of choice for assessing soil organic carbon and direct soil nitrous oxide emissions in the annual greenhouse gas inventory completed for the **U.N. Framework Convention on Climate Change (UNFCCC)**.

DAYCENT simulates fluxes of C and N among the atmosphere, vegetation, and soil. Key submodels include soil water content and temperature by layer, plant production and allocation of net primary production (NPP), decomposition of litter and soil organic matter, mineralization of nutrients, N gas emissions from nitrification and denitrification, and CH4 oxidation in non-saturated soils. Flows of C and N between the different soil organic matter pools are controlled by the size of the pools, C/N ratio and lignin content of material, and abiotic water/temperature factors. Plant production is a function of genetic potential, phenology, nutrient availability, water/temperature stress, and solar radiation. NPP is allocated to plant components (e.g., roots vs. shoots) based on vegetation type, phenology, and water/nutrient stress. Nutrient concentrations of plant components vary within specified limits, depending on vegetation type, and nutrient availability relative to plant demand. Decomposition of litter and soil organic matter and nutrient mineralization are functions of substrate availability, substrate quality (lignin %, C/N ratio), and water/temperature stress. N gas fluxes from nitrification and denitrification are driven by soil NH4 and NO3 concentrations, water content, temperature, texture, and labile C availability.

Inputs: daily maximum/minimum air temperature and precipitation, surface soil texture class, and land cover/use data (e.g., vegetation type, cultivation/planting schedules, amount and timing of nutrient amendments).

Outputs: daily N-gas flux (N_2O, NO_x, N_2), CO_2 flux from heterotrophic soil respiration, soil organic C and N, NPP, H_2O and NO_3 leaching, and other ecosystem parameters.

Recent improvements to the model include the ability to schedule management events daily and the option of making crop germination a function of soil temperature and harvest date a function of accumulated growing degree days. The ability of DAYCENT to simulate NPP, soil organic carbon, N_2O emissions, and NO3 leaching has been tested with data from various native and managed systems(Del Grosso et al., 2001b; 2002; 2005).

The model simulates all major processes that affect soil C and N dynamics, including plant production, water flow, heat transport, SOC decomposition, N mineralization and immobilization, nitrification, denitrification, and methane oxidation under a variety of agricultural management practices. In addition, DAYCENT is able to specify the effects of elevated [CO_2] (atmospheric CO_2 concentration) and other global changes (e.g., N deposition) on net primary production, transpiration rate, and C: N ratio for biomass.

DAYCENT model was successful at predicting direct soil GHG emissions of different alternative management systems in California, but a sound error analysis must accompany the predictions to understand the risks and potentials of GHG mitigation through adoption of alternative practices (De Gryze et al. 2010).

DAYCENT is also included in the international AgMIP model inter-comparison project.

Website: https://www.quantitative-plant.org/model/DayCent

https://www2.nrel.colostate.edu/projects/daycent-downloads.html

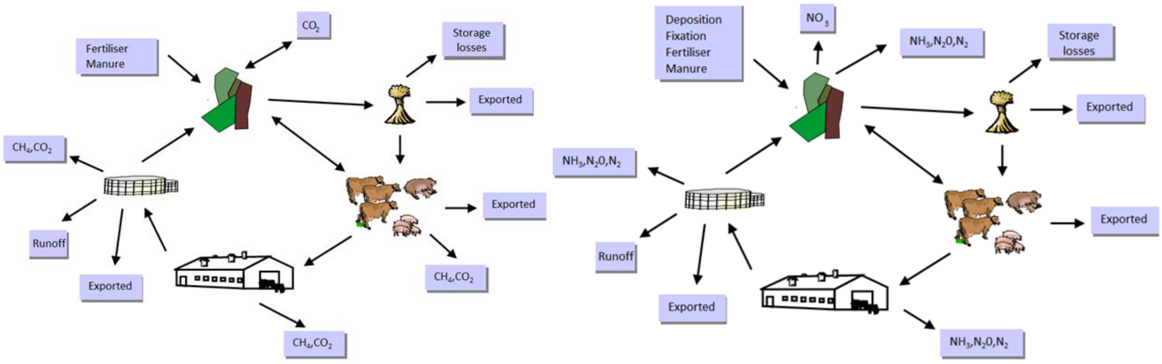
4.4 FARM AC (Denmark)

Scope: The FarmAC model was developed as part of the EU AnimalChange project.

It simulates the flows of carbon (C) and nitrogen (N) on arable and livestock farms, enabling the quantification of greenhouse gas emissions, soil C sequestration and N losses to the environment. It also simulates crop and livestock production.

The model can be used to investigate a range of farm management options on production, greenhouse gas emissions and C or N flows. It can also be used to investigate management options to compensate for negative effects of climate change or take advantage of positive effects. This is achieved by the user designing a baseline scenario and then one or more additional management scenarios.

The tool is helpful for educators, competent farmers or farm advisors.



Farm carbon and nitrogen flows - FARM AC

Inputs: Farm type, agroecological zone, bought manure, cropping sequences (area, soil type, irrigation, crops, primary and secondary crop products), potential yield, fate of secondary crop products, types and number of animals, feed ration (type and dry matter intakes), housing and manure storage type, manure and fertilizer applications (types, amount and application technique).

Parameters are specific to a particular agro-ecological zone (AEZ); default values are available for a range of AEZs or location-specific values can be used, if local expert knowledge is available.

Outputs: Actual crop yields, milk/meat production, nitrogen and carbon flows, NH_3 emissions and greenhouse global warming potentials (kg CO_2 equivalents): N_2O emissions from manure, field and indirect emissions from leaching, enteric CH_4 emissions, CH_4 emissions from manure and field excreta and change in C stored in soils.

Outputs are at farm level or per unit area (ha) on annual basis

The model uses Tier 2 methodologies that describe flows in livestock and manure management and Tier 3 methodologies for crops and soil.

Website: https://www.farmac.dk/

4.5 FARMSCOPER (United Kingdom)

Scope: FARMSCOPER (FARM Scale Optimisation of Pollutant Emission Reduction) was developed by ADAS (UK) under Defra projects WQ0106 and SCF0104, to allow the assessment of the cost and effectiveness of mitigation methods against multiple pollutants (nitrate, phosphorus, sediment, ammonia, methane, nitrous oxide, FIOs, pesticides) and multiple targets (carbon dioxide from energy use, soil carbon stocks and agricultural production). The farms systems within the tool can be customised to reflect management and environmental conditions representative of farming across England and Wales. The tool contains over 100 mitigation method classified in 9 management groups among those are manufactured fertilizer and organic manure. The tool allows for the creation of unique farming systems, based on livestock, cropping and manure management. The tool works at farm scale, but can be scaled up to catchment, regional and national level.

The intended end users are advisers, catchment managers or policy makers.

Inputs: Rainfall zone, soil type, drainage status, farm type, livestock numbers, cropping, manure management, details of field operations, pollutants and mitigation methods to be tested.

Outputs: Graphs and reports produced which specify the relative importance of each pollutants and reductions achieved for each mitigation method. Pollutant losses are showed as kg or t lost from the whole farm or apportioned by land use, with an annual resolution. Graphs show a apportionment by source: animal, fertilizer and soil, by pathway: runoff, preferential, leaching or direct and by location: arable, grass, rough, fords and trucks, housing and steading and manure storage.

Methane and direct nitrous oxide emissions are calculated according to either the equations used in the UK Agricultural Ammonia and GHG inventory or using a coefficient-based approach derived from the Scenario Management Tool which summaries the output of the GHG inventory. The indirect emissions from nitrate leaching were calculated from the results of the nitrate output. Energy use -emissions in kg of CO_2- are calculated for the major processes on farms (field operations, manure management, milking, livestock housing,...), as are the embedded emissions resulting from the production of fertilisers and pesticides. The soil C approach uses an enhanced IPCC Tier 1 methodology and the total C stock (t ha^{-1}) is calculated assuming that the land is in equilibrium (both for the baseline situation and any mitigation scenario). A rate of change can thus be found by differencing the baseline and a mitigation scenario and estimating the length of time required to reach the new equilibrium under the mitigation scenario.

Website: https://adas.co.uk/services/farmscoper/

funded by European Commission

4.6 FASSET (Denmark)

Scope: FASSET was developed in Denmark under the research project "Sustainable Strategies in Agriculture".

FASSET (FarmASSEssmentTool) is a whole-farm dynamic model, which can be used as a tool to evaluate consequences of changes in regulations, management, prices and subsidies on a range of indicators for sustainability at the farm level, e.g. farm profitability, production, nitrogen losses, energy consumption and greenhouse gas emissions. The tool can simulate arable, pig and dairy farms.

The model distinguishes and links different farm components, including field (crops and soil), animals, housing and manure storages. Optionally, it includes a module for the economic optimization of the farm. The model allows different field and farm management options to be explored. This includes different crop rotations and crop management options as well as different livestock feeding practices and different technologies for managing manures. The model can be used for comparing with observed experimental data and for exploring consequences of environmental and management changes for farm productivity and environmental impacts.

It is a tool for researchers.

Inputs: Cropping systems, crops, crop management: fertilization, crop residue management and others, buildings and stores, machinery and labour, type and number of animals, feed ration, grazing, soil and weather data.

Outputs: Economic and productive indicators (yield and quality of crops and milk/meat) and environmental (leaching and volatilization of N, greenhouse gas emissions) and N and C balances at farm level. The tool incorporates a deterministic component for the economic optimization of the farm.

Environmental calculations are made on a daily basis.

The N_2O emission submodel in FASSET is based on the 'Hole-in-the-Pipe' scheme, where the N intermediates from the nitrification and denitrification processes are assumed to be the sources for N_2O production. FASSET has a Soil Organic Matter model that gives changes in soil C and soil CO_2 budget. CH_4 emissions from enteric fermentation in cattle are included.

Website: https://fasset.dk/

4.7 FAST tool (European project)

Scope: The FAST tool is a web GIS application, developed for agribusinesses supported by the European Commission's DG Agriculture and Rural Development, by the EU Space Programme (DG DEFIS) and by the EU ISA2 Programme (DG DIGIT), the FaST digital service platform will make available capabilities for agriculture, environment and sustainability to EU farmers, Member State Paying Agencies, farm advisors and developers of digital solutions. It provides visual information through integrated maps overlaying farm data on GIS layers, Copernicus/Sentinel imagery: RGB+NDVI, campaign management with import of IACS/GSAA farmer data, fertilization recommendation, Geo-tagged photos, two-way communications, weather/climate information.

The main elements are related to relevant farm information based on LPIS (Land Parcel Identification System) and IACS (Integrated Administration and Control System), Information from the soil sampling, on an appropriate spatial and temporal scale, Information on relevant management practices, crop history, and yield goals, indications regarding legal limits and requirements relevant to farm nutrients management, and a complete nutrient budget.

funded by European Commission

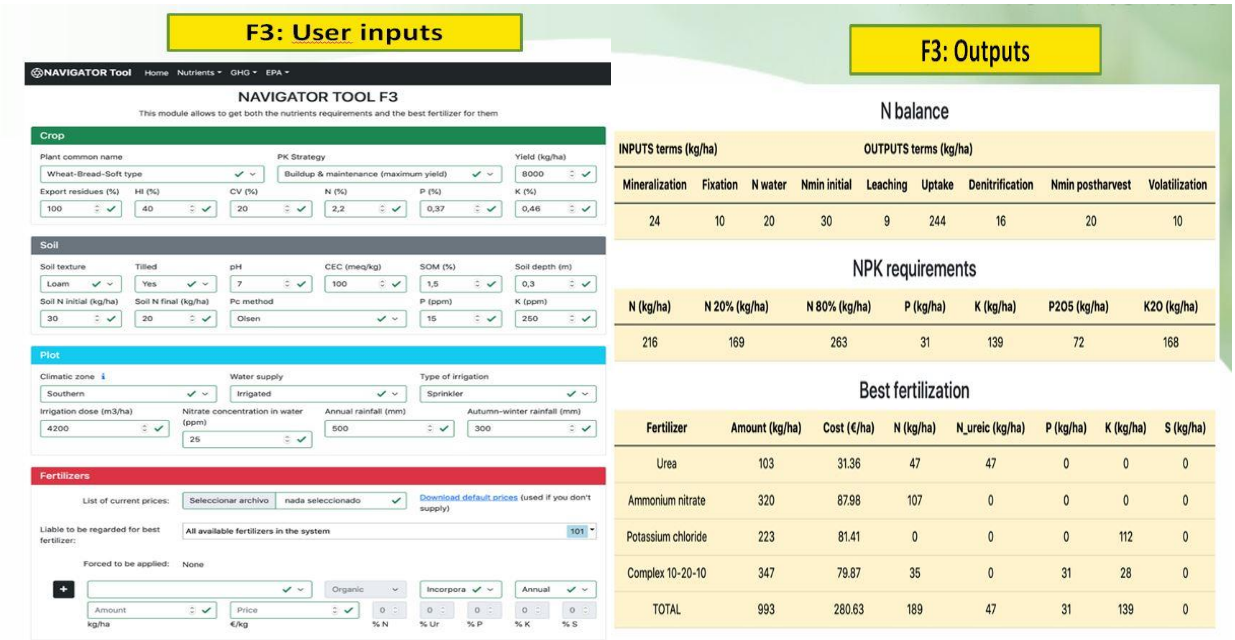
The tool is based on the Navigator tool (European project) – integrated to Fast open digital tool, accessible via web, capable of:

calculating the recommendation of nutrients at field scale

assessing the greenhouse gas emissions / removals and

economic performance at farm scale.

The tool would be helpful for individual farmers and their associations, groups of farmers, agribusinesses, entrepreneurs, farm advisors, consultants.



The GHG module provides opportunity for calculation of the GHG emissions for crops at plot and farm level, livestock, carbon cycle, energy. For the calculation of the GHG emissions for crops, the input information requests for crop, area, yield, export residues, SOM, tillage, drain rate, organic matter spread, cover crops, seeds, pesticides, nitrogen, type of climate, temperature regime, moisture regime and soil. For the calculation of GHG emissions concerning livestock the input information requests information on the dairy cattle, sheep (milk and meat), pigs, type of diet, meat cattle, feed data, manure data, etc. For the calculation of the carbon cycle the module requires information on the natural infrastructure, land use change, forests etc.

Website: https://tool.fastnavigator.eu/index.html

4.8 OVERSEER (New Zealand)

Scope: OVERSEER provides a way to estimate how nutrients are cycled within a farm system (dairy, beef, sheep, deer, goats, outdoor pigs, fruits, seeds, grains, vegetables). This allows the user to better understand how they are using nutrients, annual average nutrient requirements and the likely effects of changing management practices on the farm's overall nutrient inputs and losses (N, P, K, Ca, Mg, S).

To achieve this, OVERSEER is made up of a set of science models (animal, climate, hidrology, irrigation, block N, urine patch, wetlands, methane, nitrous oxide) and components (supplements, crops, dry matter intakes, pastures, inter-block(area), effluent management, soils) that work together to model nutrient flows including greenhouse gas emissions for a farm system. Farmers, advisors and policy makers are able to estimate nutrient loss from scenarios with limited training in model use.

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Inputs: Structures, effluent systems, animals and their production (milk/meat), animal supplements, animal distribution, pasture type and management, fertilizer applications, fuel, transport, electricity use, fruits and management, crops and management, climate data, irrigation system, soil type, soil tests, drainage system, wetland characteristics.

Outputs: N pool graphs (estimated nitrogen in the soil pool each month: soil mineral N, plant N, residue N and processes and applications that add or remove from the soil nitrogen pool: plant uptake, fertilization, leaching, fixation, immobilization, mineralization, volatilization and denitrification), nutrient budgets (nutrients added, nutrients removed and changes in pool), effluent reports (nutrients from effluent applied to blocks), animal reports (farm level metabolizable energy intake, dry matter intake and nutrient intake, nutrient distribution as excreta, pasture dry matter consumption by block) and GHG reports. GHG reports show the estimations of CH4, N2O and CO2 emissions for the farm by source e.g. N2O from excreta, effluent, fertilizer, crops and indirect. This allows to understand where emissions are coming from and how much is being generated by different sources. The New Zealand greenhouse gas emissions national inventory emissions factors are used. The estimated values for each gas are show as kg of CO2eq per hectare per year so they can be compared with each other and other GHG reporting.

Website: https://www.overseer.org.nz/our-model

4.9 ROAD tool (European project)

Scope: The ROAD tool is a web GIS application, developed for agribusinesses in the framework of the INTERREG BALKAN-MED project entitled "Towards farms with zero carbon-, waste- and water-footprint. Roadmap for sustainable management strategies for Balkan agricultural sector-BalkanROAD".

It provides visual information on greenhouse gas emissions at each stage of the production i.e., cultivation, harvesting, processing, bottling, packaging, and distribution, making it easy to identify those stages that can be further improved. Therefore, it can be used at farm and at agribusiness level, covering the entire production chain, from field to the market. The tool also provides the potential for estimating the waste and the water footprint of all processes.

The tool would be helpful for individual farmers and their associations, groups of farmers to form local value chains, agribusinesses, entrepreneurs, farm advisors, consultants.

Inputs: Materials used during cultivation (amount of mineral and organic fertilizers, manure, compost, sewage sludge, urea, lime), materials for crops processing and packaging (e.g. quantity of pallets, bottles, corks, tapes, label, cartons, etc.), soil management practices (e.g. tillage type), cultivation practices (amount of crop residues, field burning, prunnings burning), energy and fuels consumption, gas used for refrigerators, cooling systems, air conditions and heat pumps (type of gas and amount for recharging), number of animals at field, amount of composted organic waste.

Outputs: Total, direct and indirect, CO2eq, and also total CO2, direct and indirect N2O and CH4, emitted per unit of product or area. Emissions originated from each production stage, from all types of materials used and resources consumed, as well as fugitive emissions from refrigerators, cooling systems, air conditions, heat pumps. LULUCF emissions and avoided emitted carbon due to composting are also calculated.

Some of the outputs for Greece, Cyprus, Bulgaria, Albania, and the Republic of North Macedonia are of Tier 2 as the tool applies the emission factors found in the National Inventory Reports-UNFCCC (NIR).

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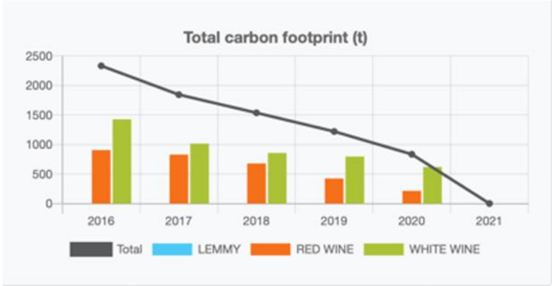
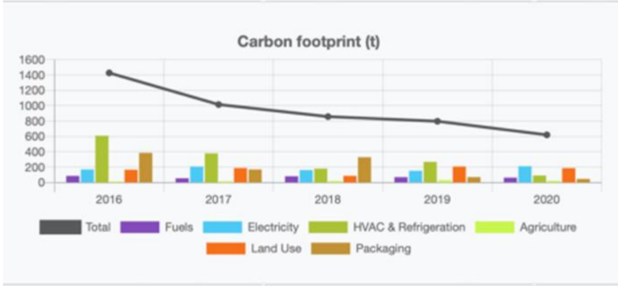
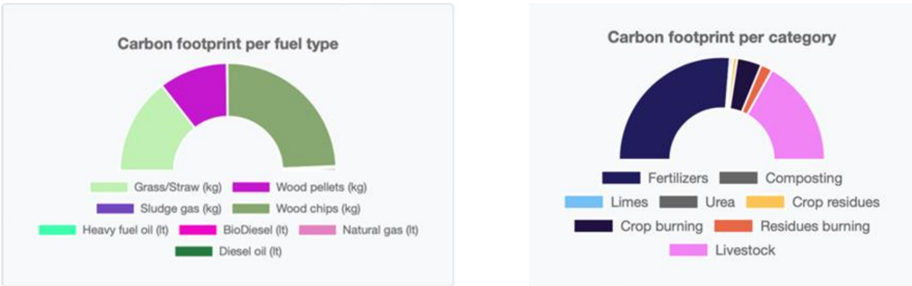
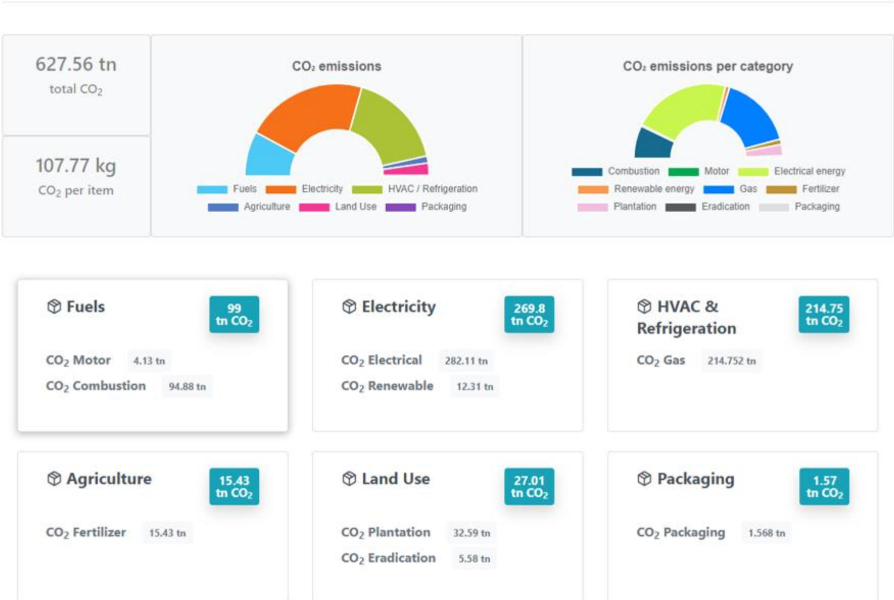




For the case of nonexistent national emission factors or for other countries than the above, the tool applies the emission factors provided by the IPCC for Europe or the global ones, and therefore, for these cases, is of Tier 1 level.

Website: https://roadtool.balkanroad.eu





4.10 TERRAZO (Austria)

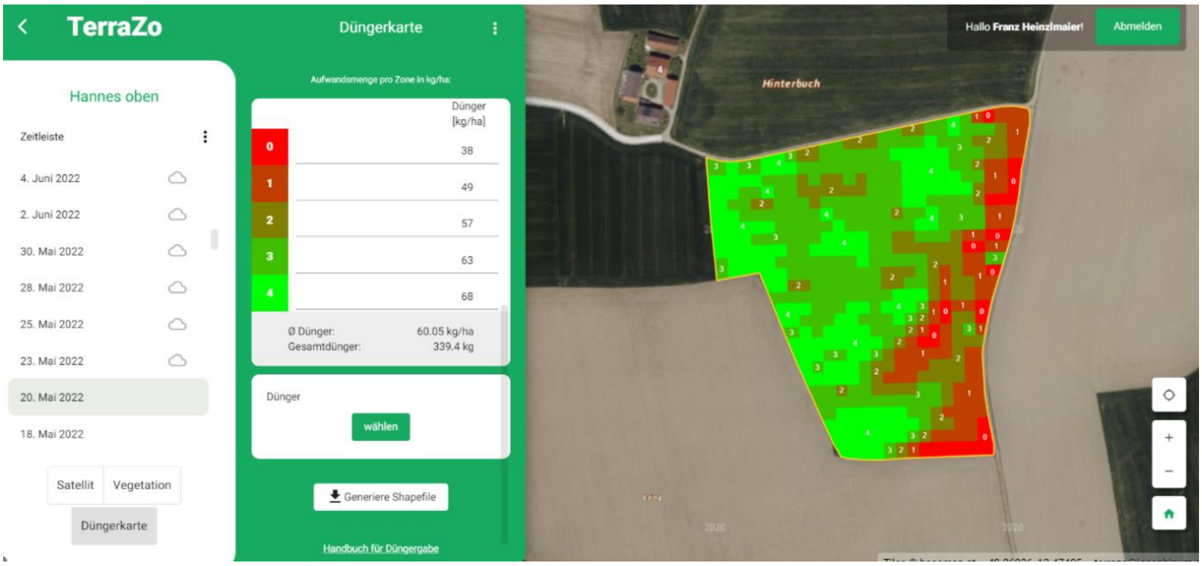
Scope: Terrazo is a Web-Service for the generation of variable rate application maps based on satellite imagery from Copernicus and ESA-program. For cereals, a fertilization model allows the creation of individual and adaptable variable rate fertilization maps. Fields can be drawn manually or selected by clicking on them. Satellite view and vegetation view (based on NDVI) are possible.

The application maps can be downloaded and used via tractor- or spreader terminals as well as via mobile Apps (GIS-ELA and NutriZones®) for manual adjustment of the quantities to apply during the spreading process.

Inputs: Region, N-quantity for the first (proposal by default available) and second application. Yield- and protein target as well as quantity of first and second application for N-recommendation for the third application.

Outputs: fertilization map for download, showing average N-quantity or fertilizer quantity (a range of fertilizers can be selected).

Website: https://terrazo.josephinum.at



5 Looking forward

5.1 Under which conditions farmers would use such a tool in practice?

The need for an individualized plan highlights a significant social barrier to adoption of new technologies for reducing the carbon footprint in nutrients. Producers will need information to adopt new practices, and while many of these technologies represent low emission "drop-in" inputs (e.g., green ammonia) others require new management practices. Other technical barriers that may prevent adoption include access to broadband internet and data management platforms and expertise.

Technical solutions such as edge computing will address some data management issues, but they highlight the need for additional skillsets to realize the technical potential. Broad adoption of low-emission production will require agricultural consultants, and educators to provide local knowledge for deploying novel technologies. Furthermore, any trade-offs, including higher food prices or reduced yields, need to be considered in optimizing for the environmental footprint.

5.2 What is still missing in the current tools that have been defined as potentially suitable?

The main aspects that we consider as not sufficiently developed in the existing tools are:

- Algorithm development: data from scientifically proven field trials are basis to develop national algorithms that can be used by farmers for an improved nutrient management.

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- Proper APIs for the connection with tools like farm management systems need to be provided in order to use the algorithms
- Those APIs need to be standardized and easy to implement
- Digital tools could provide a comparison between alternative management options to improve the nutrient use efficiency so as to optimise production and reduce the risk of adverse environmental impacts
- Tools should provide details of gaseous emission reduction after the adoption of manure management techniques. To our knowledge, there is no standard assessment method or list of Emission Factors for improved techniques

5.3 What next steps are necessary to be taken?

There are many possibilities to develop the appropriate tools for reducing the carbon footprint in plant nutrition and more research/work is needed. Currently, there is no tool in the market that would provide complete solution, but some sustainable farms tools quantify, in different sections, emissions coming from nutrient management and they can support moving further to appropriate tools for reducing the carbon footprint in plant nutrition.

Some other actions to consider:

- The tools must highlight areas of the farm work where emissions seem high and must allow comparison between similar farms (benchmarking like for like) as well as within the farm over years and should be a GIS based tool.
- Subsidies need to be provided for a common algorithm development that is broken down to national legislation.
- Digital measured data should be integrated with the models.
- Recording successful stories which leads to reducing emissions as improving productivity and returns.

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6 Conclusion

One of society's greatest challenges is sequestering vast amounts of carbon to avoid dangerous climate change without driving competition for land and resources. Every sector will chart its own path to net negative emissions to address climate change. For agriculture to succeed, all need to understand practical matters of technology adoption to engage producers, attract investors, and inspire technology developers.

The inclusion of measures for support and the implementation of strategies for removing the farmer's barriers for application of digital tools for sustainable nutrient management as an obligation for every member state are crucial for carbon capturing. Using a systems approach to technology optimization and fostering an innovation ecosystem that looks at a combination of technologies, agriculture can meet its critical societal function to provide food, feed, fiber, and fuel and support rural economics, all while generating significant environmental benefit for the public good.

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7 References

Angers DA, Carter MR, Gregorich EG, Bolinder MA, Donald RG, Voroney RP, Drury DF, Liang BC, Simard RR, Beyaert RP (1995). Agriculture management effects on soil carbon sequestration in Eastern Canada, pp 253-264. In Berna MA (Eds) Carbon Sequestration in the Biosphere, NATO ASI Series 1, 33. Springer-Verlan. Berlin and Heidelberg.

Bolinder MA, Crotty F, Elsen A, Frac M, Kismányoky T, Lipied J, Tits M, Tóth Z, Kätterer T (2020). The effect of crop residues, cover crops, manures and nitrogen fertilization on soil organic carbon changes in agroecosystems: a synthesis of reviews. Mitigation and Adaptation Strategies for Global Change 25, 929-952.

Bouwman AF, Boumans LJM, Batjes NH (2002) Modeling global annual N2O and NO emissions from fertilized fields. Global Biogeochem Cycles 16(4):1080

Chantigny MH, Rochette P, Angers DA, Bittman S, Buckley K, Massé D, Bélanger G, Eriksen-Hamel NS, Gasser MO (2010). Soil nitrous oxide emissions following band-incorporation of fertilizer nitrogen and swine manure. Journal of Environmental Quality 39, 1545-1553.

Danish Ministry of Energy; Utilities and Climate. Denmark's Seventh National Communication and Third Biennial Report: Under the United Nations Framework Convention on Climate Change. 2017. Available online: https://unfccc.int/sites/default/files/resource/8057126_Denmark-NC7-BR3-2-NC7-DNK-Denmarks- NC7-and-BR3_1January2018-12MB.pdf (accessed in June 2022).

Dinsmore KJ, Skiba UM, Billett MF, Rees RM, Drewer J (2009). Spatial and temporal variability in CH4 and N2O fluxes from a Scottish ombrotrophic peatland: implications for modelling and up-scaling. Soil Biology & Biochemistry 41, 1315-1323.

Escobar LF, Amado TJC, Bayer C, Chaves LE, Zanatta JA, Fiorin JE (2010). Postharvest nitrous oxide emissions from a subtropical Oxisol as influenced by summer crop residues and their management. Revista Brasileira de Ciência do Solo 34, 507-516.

FAO (2001). Soil carbon sequestration for improved land management. World Soil Resources Report, 96. Rome (Italy).

Fangueiro D, Surgy S, Fraga I, Monteiro FG, Cabral F, Coutinho J (2016). Acidification of animal slurry and nitrogen dynamics after soil application. Geoderma, 281, 30-38.

Foray S, Loges R, Nadeau E, García Pomar MI, Howatson S,Debruyne L, Andersen T (2019). Eurodairy Technical Leaflets on Resource Efficiency. Eurodairy Project. 51 pp.

Hou Y, Velthof GL, Oenema O (2015). Mitigation of ammonia, nitrous oxide and methane emissions from manure management chains: a meta-analysis and integrated assessment. Global Change Biology 21, 1293-1312.

Kirchmann H, Kätterer T, Börjesson G, (2014) Changes in organic carbon in topsoil and subsoil and microbial community composition caused by repeated additions of organic amendments and N fertilisation in a long-term field experiment in Sweden. Agriculture, Ecosystems and Environment 189: 110-118.

Lal R (1997). Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO2 enrichment. Soil and Tillage Research43, 81-107.

Northrup LD, Basso B, Wang MQ, Morgan CLS, N. Benfey PN (2021). Novel technologies for emission reduction complement conservation agriculture to achieve negative emissions from row-crop production. Edited by Edward S. Buckler, Agricultural Research Service, US Department of Agriculture, Ithaca, NY, https://www.pnas.org/doi/10.1073/pnas.2022666118

Paustian K, Ravindranath NH, Amstel A, Gytarsky M. (2006). Chapter 1 -Introduction. In Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K (Eds). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhoues Gas Inventories Programme. Japan: IGES:

Price N, Harris JP, Taylor M, Williams JR, Anthony SG, Duethmann D, Gooday RD, Lord EI, Chambers BJ, Chadwick DR, Misselbrook TH (2011). An inventory of mitigation methods and guide to their effects on diffuse water pollution,greenhouse gas emissions and ammonia emissions from agriculture. Part of Defra Project WQ0106. 158 pp.

Sanz-Cobena A et al (2017). Strategies for greenhouse gas emissions mitigation in Mediterranean agriculture: A review. Agriculture, Ecosystems and Environment 238, 5-24.

Van der Burgt GJHM, Oomen GJM, Habets ASJ, Rossing WAH (2006). The NDICEA model, a tool to improve nitrogen use efficiency in cropping systems. Nutrient Cycling in Agorecosystems 74, 275-294.

Veenstraa JJ, Horwath WR, Mitchell JP (2007). Tillage and cover cropping effects on aggregate-protected carbon in cotton and tomato. Soil Science Society of America Journal 71, 362-371.

Velthof GL, Kuikman P, Oenema O (2003). Nitrous oxide emission from animal manures applied to soil under controlled conditions. Biology and Fertility of Soils, 37, 221-230.

The European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI) is one of five EIPs launched by the European Commission in a bid to promote rapid modernisation by stepping up innovation efforts.

The **EIP-AGRI** aims to catalyse the innovation process in the **agricultural and forestry sectors** by bringing **research and practice closer together** – in research and innovation projects as well as *through* the EIP-AGRI network.

EIPs aim to streamline, simplify and better coordinate existing instruments and initiatives and complement them with actions where necessary. Two specific funding sources are particularly important for the EIP-AGRI:

- ✓ the EU Research and Innovation framework, Horizon 2020,
- ✓ the EU Rural Development Policy.

An EIP AGRI Focus Group* is one of several different building blocks of the EIP-AGRI network, which is funded under the EU Rural Development policy. Working on a narrowly defined issue, Focus Groups temporarily bring together around 20 experts (such as farmers, advisers, researchers, up- and downstream businesses and NGOs) to map and develop solutions within their field.

The concrete objectives of a Focus Group are:

- ✓ to take stock of the state of art of practice and research in its field, listing problems and opportunities;
- ✓ to identify needs from practice and propose directions for further research;
- ✓ to propose priorities for innovative actions by suggesting potential projects for Operational Groups working under Rural Development or other project formats to test solutions and opportunities, including ways to disseminate the practical knowledge gathered.

Results are normally published in a report within 12-18 months of the launch of a given Focus Group.

Experts are selected based on an open call for interest. Each expert is appointed based on his or her personal knowledge and experience in the particular field and therefore does not represent an organisation or a Member State.

*More details on EIP-AGRI Focus Group aims and process are given in its charter on:
http://ec.europa.eu/agriculture/eip/focus-groups/charter_en.pdf

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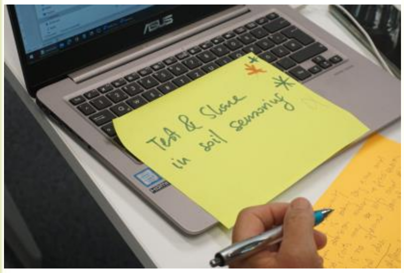

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