EIP-AGRI Focus Group

Protecting agricultural soils from contamination

MINIPAPER: **Precision Agriculture as a tool to reduce and prevent soil contamination**

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1. Introduction

Unsustainable agriculture practices are responsible for soil and water pollution worldwide. The widely used pesticides (i.e., plant protection products to prevent disease and infestation of crops) are a major contributor to agricultural pollution. The other main contributor is the fertilizers (either mineral or organic) that are used to supply one or more nutrients essential to the growth of plants. Other major pollutants are potentially toxic trace elements (PTEs), persistent organic pollutants (POPs, industrial xenobiotics, and by-products), plastics debris, pharmaceuticals (e.g., antibiotics, hormones, anti-inflammatory substances), including veterinary products, and personnel care products (PCPs). The contaminants or residues from the overuse or misuse of agrochemicals in agriculture, such as pesticides and fertilizers, can enter the soil, surface and underground water via leaching and run-off. They affect habitats, insect population, and biological activities in soil and water, resulting in biodiversity loss (Ewald, 2015 and Hallmann, 2017). The latest research confirmed that pesticide residues are found in over 80% of the investigated samples of European agriculture soils (Silva et al. 2019). Reports from drinking water monitoring stations showed that about 7% of the groundwater contains excessive levels of pesticides (one or more out of the 31 parameters) in 2013 (Eurostat).

These problems cause deterioration of soil and water quality, as well as fodder and food contamination, posing risks to human health in either a direct (e.g., drinking water) or indirect (e.g., food consumption) way. The European Union (EU) set an objective by 2020 that the use of plant protection products should not have any harmful effects on human health or unacceptable influence on the environment. To this end, adequate and sustainable use of pesticides and chemical fertilizers are vital for achieving this goal (Directive 2009/128/EC on the sustainable use of pesticides (2017/2284(INI))).

Despite the ambitious goal, the total sales of the pesticides remained constant during 2011-2016 (Figure 1); the use of chemical fertilizers in the EU countries has even shown a slight increasing trend over the past decade and it is also expected to further grow until 2029, by 0.9 % (NPK combined) (Fertilizer Europe, 2019). Although there is insufficient evidence on the direct causal relationship between the increasing usage of agrichemicals and human health issues, it is still advisable to explore new technologies to identify potential solutions to decrease the usage of these agrochemicals.

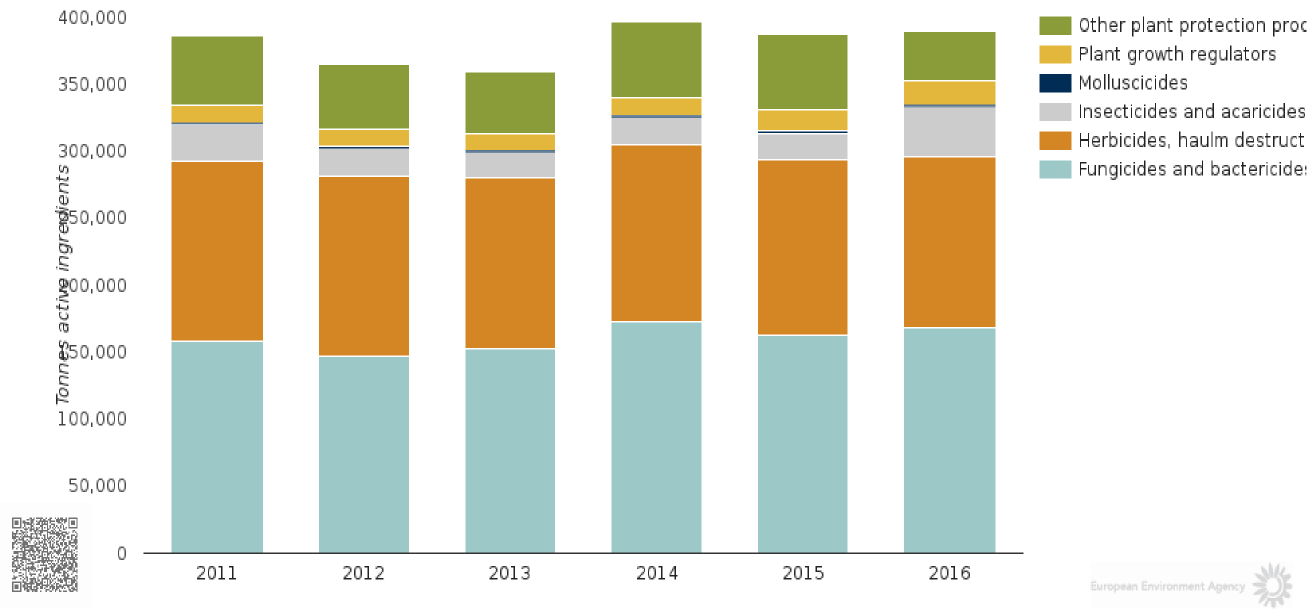

Figure 1. Total sales of pesticides in the EU countries 2011-2016 (Source: https://www.eea.europa.eu/airs/2018/environment-and-health/pesticides-sales**)**

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To feed the projected population, feasible solutions are needed to double our current food production. One of the possible ways is to intensify our agricultural production, but more sustainably without harmful impacts on soil and water resources. Precision agriculture (PA) with the assistance of smart technology is an emerging concept to achieve the sustainable intensification of agriculture. PA uses affordable, high-resolution information technologies, such as sensor, mapping, and low-cost remote sensing techniques, to develop fine-scale or site-specific agricultural management, highlighting a promising form of sustainable intensification to improve production efficiency, productivity, and profitability while minimizing environmental impacts. With the help of advanced technologies, the demands of a certain crop for agricultural inputs can be identified and quantified over time and space; agrichemicals can be applied in more precise amounts at the right time and the right spatial distribution (e.g., within-field variability). Such tailored applications offer the potential to optimize the relationship between inputs and outputs, thereby increasing the sustainability of agricultural production. In this paper, available technologies and best practices for PA are described and a discussion about how to optimize agrichemical use and enhance sustainability on farms by addressing benefits for farmers and the environment is included.

2. Development and technology of precision agriculture

Precision Agriculture (PA), which has emerged in the 1980s in the USA, assists the farmers in decision making for efficient farm management. PA has proven to be a cost-effective and environmentally sustainable approach for farming practices. It is recognised as a management concept that aims to monitor and control the variability in farm operations to achieve better yields. The use of wireless communication and GPS in the equipment of PA enables auto-steering of vehicles, variable rate application of fertilizers, controlled operations of planters, seeders, sprayers, and so on. These technologies also help farmers in evaluating the crop production cycle with yield monitoring. A growing emphasis on input costs has triggered the need for optimal usage of resources such as fertilizers and machinery. GPS and GIS facilitate in variable-rate fertilization, (section and row) controlled planting, and precision spraying for precise application of resources resulting in low-cost operations. Driven by the rising adoption rates in developed nations and growing awareness in the major agricultural economies, the PA market is estimated to grow at a rate of 12.9% through 2020. The guidance system dominates the precision agriculture market with a share of approximately 26%.

The advantages of PA include both ecological and economic benefits. In terms of economic benefits, PA increases farmers' profits and crop yields due to lower investment for agrochemicals and higher resource use efficiency and productivity. In terms of ecological benefits, PA reduces the negative and harmful impacts of farming activities on soil, water, biodiversity, and food quality that originate from overdoses of agrochemicals (Bongiovanni and Lowenberg-Deboer (2004), NASA). The potentially applicable technologies include machines equipped with smart sensors, easy-to-use data management tools, and simple decision support systems that can be used and promoted on different levels of development and farm sizes. Many cases farmers are lost in the increasing number of technologies and solutions for smart farming. Contradictory marketing materials are making decisions even more difficult, thus resulting in hesitancy. In this paper, some available technologies and solutions are described with benefits for farmers and the environment along with the recommended farm size to apply the technology. Farm size indications must be handled with care due to different profitability of the different crops in different regions (e.g. a small very intensive vegetable farm might be more suitable for certain technologies than mid-size regular crop farms due to their higher profitability). It is also important to note that a PA practice does not require to use all the discussed tools, but a selection of the most suitable and beneficial ones. The discussed technologies, methods and solutions are grouped and discussed separately:

Technological solutions:

This section contains all the solutions that are connected or related to farm machinery. Many of the following are now standard in new machines. One of the main concerns for many farmers is the cost of new machinery to practice PA. We show here that many of these technologies are also available for implementation in older machines (Table 1.).

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Guidance systems, Auto steering, GPS navigation, and Real-time kinematic (RTK) positioning, In-cab displays are the technologies making precision machinery work easier (Figure 2.). The price of the technology mostly increases while the accuracy of the equipment is improving from meter to centimeter range.

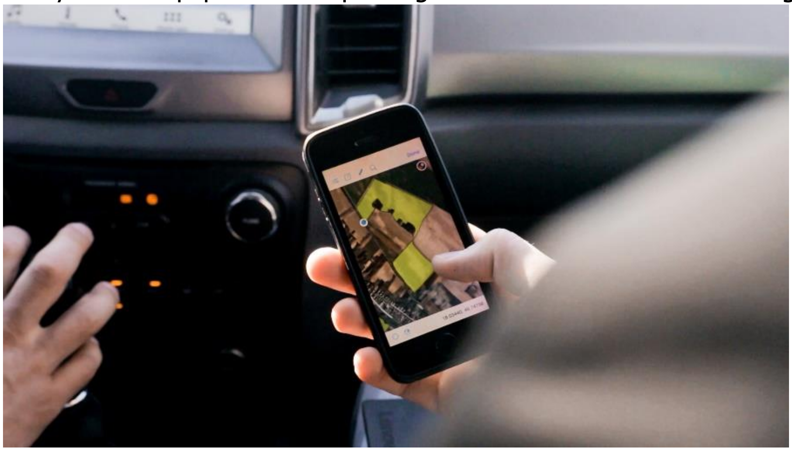

Figure 2. Easy to use GPS based applications, and equipment help farmers better monitor farm operations and to optimize input material usage (source: Discovery Center Kft)

One of the biggest advantages of these applications is that many manufacturers provide solutions for older machines, thus offers a cheaper option for low-budgeted farmers. Besides the higher accuracy of the machines, less experienced drivers can also achieve high-quality work due to the help of technology. In an industry lacking not only experienced manpower but manpower at all, and for an industry that has difficulties engaging younger generations the technology can provide support to tackle these problems.

The ISOBUS standard, section control, variable rate applications, and smart weeding technologies are mostly linked to the application of certain materials. The ISOBUS standard allows farmers to stay brand-independent, choose the most suitable machinery, and link that with ease to tractors of different brands. Section control allows farmers to apply desired amounts on the field while avoiding the areas where input material have been already applied. This is especially important on headlands where multiple applications occur, bearing a high risk of leaching to water bodies. Variable-rate applications as a higher-level technology allow farmers to handle fields in smaller units and apply different rates within fields, thus minimizing leaching through avoiding overdose or application at all.

The control of irrigation and sustainable application of irrigation is a key to success and profitability under the changing climate and unpredictable distribution of precipitation during the vegetation period. The smart irrigation technologies allow farmers to apply water only when needed and apply only where needed.

The prospect to apply PA systems in the future includes crop scouting (Figure 3.), yield monitoring, variable rate application, soil monitoring, field mapping, etc. Further fields of technological advancement will include also detailed analysis of various intervention systems used in different phases of crop production, namely guidance and sensing systems, and farm management systems.

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Table 1. Summarizing table for some technological solutions in PA

Type	**Benefits** ***(benefits for the environment with italic)***	**Suitability (farm size and type)**
Guidance system	More accurate guidance on the field, higher quality seeding, fertilizing, etc. *Less soil compaction, less overlap on application thus less load on the environment*	Any
Auto- steering	Accurate navigation on the field, higher quality of works. Decreases multiple applications on the same spot *Use of tramlines to concentrate soil compaction, less chemical load on the environment due to limited overlaps on applications*	Any, mostly from mid-size
RTK system	Very accurate navigation on the field, higher quality of works. Higher quality mechanical weed control possible Decreases multiple applications on the same spot *Less chemical load on the environment due to limited overlaps on applications and better weed mechanical weed control*	Any, mostly from mid-size
In cab displays	Better control over farm equipment, documentation, and data logging, in some cases data transfer with cloud services, etc. *No direct benefit*	Any, mostly from mid-size
ISOBUS standard	Farmers are not chained to one manufacturer. Machines can be combined to have the best products suitable for the farmer	Any, mostly from mid-size
Section control	Double application is negligible (seeding, fertilizing, chemical applications, etc.). A better environment for the plants. *Less chemical load on the environment due to limited overlaps on applications*	Any, mostly from mid-size
Variable-rate application	If based on a proper soil survey or plant measurements only the necessary chemical applications are applied *Chemical application according to needs, limited leaching to water bodies, etc.*	Any, mostly from mid-size
Sensored irrigation control	Sensor-based control enables effective irrigation based on actual moisture content *No excessive water usage, limited leaching of nutrients, chemicals*	Mostly large intensive farms
Irrigation section control	Irrigation is controlled in sections based on a soil parameters/plant health and/or sensors, thus water usage is fully optimized *Limited leaching of nutrients and chemical residues*	Mostly large intensive farms
Smart mechanical weeding	Cost-effective due to limited chemical usage *Weeding is fully done at high precision with no usage of post merging chemicals*	Mostly large farms

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Machinery is the bases of precision farming, thus PA must be based on accurate reliable data. Although different sources of data are available on farms with different spatial and temporal resolution and accuracy, these data sets are hardly compiled, harmonized, and used for decision support.

Figure 3. High precision RTK based crop monitoring enables farmers to realize site-specific input material applications (source: Discovery Center Kft)

Big data will aid farming in the future, but data collection and post-processing methods are still under development around the globe. Data collection methods are available for farmers, but due to a large number of options and information available on the market farmers are often undecided about how to make the first steps towards smart PA. Table 2 summarises some of the most common data collection and survey methods, which are used and tested on farms throughout the EU. The aim of these data collection and survey methods is to have a better understanding of the farming environment and to optimize farm operations and input material usage. This allows the farmer to apply only what is needed when it is needed and where it is needed. This not only enables to increase profit but also to minimize or avoid excessive chemical usage and contamination of the environment.

Farmer stories:

Gergely Toth, farmer: Member of an EIP AGRI OG in Hungary which focuses on an optimized soil sampling methodology for PA. Gergely has tested several soil survey technologies on his farm to map the area top optimize his framing practices and was surprised by the very inconsistent and sometimes contradictory results provided by the different tools and consultants. He asked for help to understand the diverse database and, joined the OG to test as many tools as possible and help the research team develop a more accurate survey methodology.

Table 2. Summary for some data collection and survey methods in PA

Data collection/survey methods				
Type	**Pros**	**Cons**	**Benefits** ***(benefits for the environment with italic)***	**Suitability (farm size and type)**
Satellite mapping	Easy to cover large areas Cheap	Data need to be processed before use on the farm level Weather dependent collection frequency	Easy to collect data on historical changes Current satellite data collection frequency has a high potential for decision making and variable rate applications *Can be a base for several site-specific chemical applications, monitoring of field for optimal chemical usage*	All, with a limitation on field size
Drones	Detailed monitoring on certain fields Several automated easy post-processing possibilities Cheap	Takes time to fly through the fields Weather dependent Quality varies with sensor	Monitoring is possible to do when needed and a base for decision support and application maps *Cheap and detailed data collection method for optimized chemical usage*	All
Yield monitors	Can be applied to older harvesters	Many cases need extra tasks during harvest for high-quality data	Real-time harvest data Bases for profit analysis and decision support Indicator of within-field yield potentials and supporting data for site-specific chemical application decisions *Data for optimized chemical applications*	All, mainly from mid-size
N sensor	Can be applied to many different machines	High cost	Optimized N fertilizer usage *Limited leaching of N fertilizers due to plant-based applications*	Mostly large farms
Weather stations	Cheap technology Forecasting applications (weather, and disease models)	Location of stations is crucial	Better time management for chemical applications. Warnings based on disease models *Forecasting tools enable optimized application times for chemicals, to increase efficiency and decrease leaching*	All
Soil surveys	One of the most important base data for farming	Varying accuracies Many times neglected	Optimized fertilizer usage, more suitable soil works, bases for site-specific applications *Surveyed soil properties enable the proper application of nutrients and some cases other chemicals, thus limiting the excessive leaching*	All

Databases collected and compiled with the use of technologies from Table 2 are the bases of decision support tools and farm management software that are available for farmers. The number of datasets and technologies are increasing in the farming industry, it is thus possible to better optimize and train models. In general, tools are available for all sizes of farms. Decision support tools are not only using the available farm data but also extrapolating data from other farms and datasets. From an environment perspective data-driven farming supported with proper data collection and processing tools must be more sustainable and resource-saving compared to common and routine farming practices.

3. Conclusions and further research needs

Most of the precision farming technologies are evaluated against their potential to increase income for farmers and to minimize the load on the environment, thus enhance sustainability and decrease soil pollution from agriculture. With the assistance of PA technologies, selected input materials (pesticides, fertilizers, and other chemicals) are only applied when and where there is a need. Some technologies enable applications with machine and hardware-based solutions (such as section control to avoid multiple applications on the same spot), while some are supported by machine learning and artificial intelligence. But they share the same goal to optimize profitability and further to increase sustainability with better management of natural resources (Figure 4.).

Potential environmental impacts

Findings by researchers of environmental benefits for site-specific management of fields

- *Less N lost to the environment and greater nitrogen use efficiency*
- *Less N loss in zones vulnerable to leaching*
- *Reduced N rates*
- *More accurate prediction of P pollution potential*
- *Reduction of P movement into surface waters*

Bongiovanni and Lowenberg-Deboer (2004)

Figure 4. Researchers studying a degraded farming landscape. Proper, in-depth data collection and understanding of the farming environment is the key to optimized and sustainable farm management. (source: Discovery Center Kft)

Although many technologies and solutions are available, research has so far mainly focused on the level of precision and how to increase the profitability of farms. Large scale data synthesis on how chemical applications have changed on farms across Europe with the application of PA has not been done or unknown to the authors. Therefore, we suggest actions to synthesise a European dataset on the chemical application of precision

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agriculture on farm level to identify the potentials and challenges in the technology for sustainable agriculture management.

Besides, a roadmap of PA that describes all available technologies, with potential benefits for different sizes of farms could increase the number of farmers to apply these technologies. An independent comparative study would also increase the trust and transparency towards the different technologies, which can help farmers find suitable tools for their environmental and economic conditions.

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