LUISS

Department
of Business and Management

Course of Digital economy and innovation

Digitalization, smart manufacturing and it's application in the agricultural sector

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Academic Year 2021/2022

Summary

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1-INTRODUCTION

The Digital revolution in manufacturing, often referred to as the fourth industrial revolution or industry 4.0, has become a major topic of discussion for both entrepreneurs and policy makers, as it promises to bring to the table profound changes to the way we organize, manage and operate our production centers. Among the many manufacturing sectors, one can't forget the oldest among them: the agricultural sector. Due to an ever-growing demand for food and, at the same time, an increasing need to reduce our environmental impact upon the world, one can't help but wonder if innovations such as IOT or digital simulations could also be applied to the farm, and what advantages and challenges they could bring about. To this end, the following paper seeks to collect the relevant literature surrounding the application of "smart" technologies and processes in the agricultural sector, and assess the current situation on the field.

The paper is composed by two chapters; In the first one, a description of Kusiak's six pillars of smart manufacturing will be given, and they shall be used as a framework to see the current situation of the agricultural sector and the challenges they face in adopting the new technologies/processes. In particular, we will focus on precision agriculture, a farming managerial method which is powered by data, and the ways farmers can set up and use such method in order to reach a desired objective.

In the second chapter, we will take a look at the agricultural sector in Italy, and two farms will be analyzed in order to see how both of them improved their management of nitrogen fertilization through different applications of precision agriculture. By doing so, we can examine the possible ways precision agriculture could be applied to other farms, along with an observation of the context of both case studies in order to find potential factors which may have made adoption of digital technologies easier for them than they would be for others.

Finally, the research is concluded by a discussion on the findings, what they imply for the agricultural sector as a whole, and their eventual limitations.

2-LITERATURE REVIEW

The purpose of this paper is to study the insights gained in examining digitalization and smart manufacturing applied in the agricultural sector, and what advantages they could bring. In order to begin, we have to first address what are those insights, and which are relevant for our purpose. One way could be through a recontextualization of Kusiak' **six pillars of manufacturing,** used by Kusiak to briefly describe the "essence" of smart manufacturing**.**

Below is a brief description of each pillar (Kusiak, 2018):

1. **Manufacturing technology and processes:** of course, one of the core principles of smart manufacturing are the technologies and processes that we employ to produce goods. Thanks to them, new materials and, more importantly, new products can be discovered and integrated on the factory floor of smart enterprises. Kusiak uses 3D printing as an example of such technologies, as its introduction has introduced changes to the way we prototype products, and opened the way for other applications
2. **Materials:** Smart manufacturing is particularly flexible in the kind of materials that could be used in the production processes and, as such, it doesn't directly call for the specific development of new ones. One point of interest is the recycling of materials from products at the end of their life-cycle, which could greatly reduce the need to gather new resources, and the cost associated with it.
3. **Data:** The mass gathering and usage of data has become one of the strongest pillars of smart manufacturing. The data any smart manufacturing enterprise gathers can be used to power business-enhancing applications, and to preserve (or extract) past and future knowledge on manufacturing.
4. **Predictive engineering:** Traditionally, the manufacturing space is a reactive one, where the primary use for data comes in the form analysis, monitoring and control of past and/or current states of the manufacturing process and systems. With predictive engineering, smart enterprise can build digital representations that can be used to simulate phenomena of interest for the firm. These models, which can be either limited to a single aspect of the firm (such as a study on the supply management), or involve

multiple relevant systems, and can be integrated into the decision-making of a firm, together with the more traditional data analysis tools.

5. **Sustainability:** Sustainability in manufacturing is only going to become more crucial as interest in the environmental challenges grows, primarily because it permeates all sector of interest for manufacturing firms, from the production itself, to transportation, and finally consumption. The push for a more sustainable manufacturing has also provided strength to activities such as re-manufacturing, reconditioning and re-use, all three being manufacturing-adjacent activities that could become services provided by a smart enterprise.
6. **Resource sharing and networking:** The digital space is quickly becoming the primary environment in which decision making and creative activities happen. The main advantage comes from the fact that the physical environment of an enterprise, with its know-how and manufacturing assets, is protected from its digital one, thus allowing the sharing of information without damaging any potential competitive advantage the firm could have over its competitors. In general, sharing resources is seen as extremely advantageous for a smart enterprise, with concept such as "Open Innovation" being used to describe the sharing of knowledge between firms which may or may not be in the same industries. But resource sharing also comes in the form of transportation, both internal (as in, within the firm) and external (the firm's interaction with the supply chain). As transport is often seen as a not value-adding activity, we may see in the future shorter supply lines, which will not only cost less for a smart enterprise, but also have more beneficial effects on the environment.

Although Kusiak himself is the first to point out that this list is a tentative one, and that more research will show whenever the pillars are correct or lack in certain aspects, it should still prove a useful framework to study the ways digitalization is shaping the agricultural sector.

2.1 MANUFACTURING TECHNOLOGIES/PROCESSES

In recent years, the development of technology and processes in agriculture has been primarily in regards to the maximization of its outputs.

Of particular interest are the technologies that allow the use of Precision Agriculture (a farming managerial method which will be described in more details in the next chapters), due to the efficiency improvements and the reduced environmental impact it allows. Those technologies where outlined in a study by the Joint Research Centre (JRC) for the European Union, and they're presented below (2014):

1-Global Navigation Satellite Systems (GNSS) are perhaps the most important group of technologies that enable PA, as they are widely used both for geo-positioning solutions, and for solutions which require geo-referential information.

2-Sensors development has allowed the creation of many devices, that can be used either for data gathering and/or to provide relevant treatment information to farmers working on the field. In general, sensors are used to conduct various types of assessments, to name a few:

1. Status of the soil, either by studying its electrical conductivity, the radiation it emanates, or it's moisture.
2. Weather status, or data tangentially related to the weather itself (such as temperature, or humidity present in the air)
3. Plant status, using remote sensing principles and recording crops through images on various wavelengths (from visible to thermal) in order to create indexes which explain the condition of the crops' canopy (for example, by examining the level of chlorophyll present in each plant to ascertain its "stress level"), and how it changes as time goes on.

3-Sensors platforms have also improved in recent years, with the most significant development being the introduction of Unmanned Aerial Vehicles (UAV, more commonly known as drones) to the civilian market. Initially limited to military applications, drones have quickly become an indispensable tool for very precise remote sensing, being able to take images of high resolution (from 2, up to 10 cm), vastly outperforming the images taken through satellite cameras (usually between 0.5 to 10 m).

4-Geographic Information Systems (GIS) are indispensable for traducing the data collected by satellites, sensors and drones into maps that contain all essential data for PA

Among the most critical processes in a farm is water control; research has shown that 70% of all available freshwater in the world is used for irrigation, a huge burden on the already dwindling water sources. As such, a great deal of research has gone into developing more efficient systems that can provide the following benefits to a farm that makes use of them (ABB):

- **Safety:** The systems have to be developed in such a way that personnel isn't injured by a pipe suddenly bursting, or produce damaged by flooding due to damages to the pipes;
- **Energy efficiency:** In order to reduce the cost associated with pumps, new digitalized systems have to be employed in order to optimize and reduce their energy usage;
- **Productivity improvement:** Smart irrigation methods can allow a variable rate for all plants in a field, thus doing away with wasteful procedures such as using a uniform rate of water for all the crops;
- **Maintenance:** Using new sensors and software, farmers can easily check on the status of their irrigation pipes, and quickly notice when problems arise and where.

The white paper also outlined the major systems that are likely to become (or already are) the primary methods of irrigation in the foreseeable future:

1. Vertical farming
2. Greenhouses
3. Borehole pumping
4. Booster pumps
5. Centre pivot irrigation
6. Lateral Move irrigation
7. Solar Pumps

2.2 MATERIALS

Perhaps the most famous material innovation on the fields is the introduction of **Genetically Modified Crops (GMCs)**. Crop plants are usually engineered either in order to bolster a specific trait innately present within them, or to introduce a new one, foreign to them and impossible to transmit under normal circumstances (Kumar, et al., 2019). Despite the stigma surrounding them, GMC have become incredibly important tools to address challenges related to the environment; for example, introductions of the *cry* gene (a still-growing family of homologous genes) is able to induce an innate resistance to insects to various crops, thus drastically reducing the need for harmful pesticides, which can damage the soil and indiscriminately kill pests and pollinators (such as bees) alike.

The research for greener alternatives to coal and petrol, both harmful and limited resourced on Earth, has brought about the introduction of biomass, a renewable energy source which is derived from plant-based materials. It is also an extremely flexible energy source, being able to be converted into fuels (in which case we talk about biofuels), or burned to create energy (Department Of Energy). In light of this, new farm business models have been developed in order to accommodate for the creation of these two materials: a more limited one, in which only food and crop wastes created by the farm are used (thus severely limiting the production capability), or a model where crops are planted specifically with the purpose of being used to create biomass (it should be noted, however, that it is a controversial concept, as critics argue farm fields shouldn't be wasted on activities which don't directly feed the population).

2.3 DATA

Data collection in agriculture has already seen some practical uses since the early 80's, with the introduction of the first commercial use GPS in the early 1980s, which was used to power the first versions of "precision agriculture" (which will be explained in more detail in 2.4). With the introduction of commercial drones and, more importantly, of Internet of Things (henceforth simply referred as IOT), farmers have now the ability to collect far more precise data than ever before (Bonneau, Copigneaux, Probst, & Pedersen, 2017); Examples of data that they can collect include, but are not limited to:

1. **EV**
2. **Soil radiation emissions**
3. **Moisture**
4. **NDVI**
5. **Weather monitoring**

This data can then be fed to a Geographic Information System which, by associating it with a geo-referenced data, will use it to create better production models, such as yield maps.

IOT isn't limited to just the field, but can also be applied to the machinery and vehicles of the farm itself; By doing so, we can easily monitor their condition and, in case a loss in performance is noticed, pre-emptive measures can be taken before more serious damage is done to them.

2.4 PREDICTIVE ENGINEERING

Predictive engineering has been a use case in agriculture since the early 1980s, with the introduction of *Precision Agriculture*, a managerial method which makes use of a Decision Support System (DSS) in order to centralize productive decisions and more effectively control the use of resources in the productive process. Recent introductions, such as drones and IOT, have made data collection even easier for farms, and this data has been used to create models which improve overall crop yield and reduce their environmental impact.

Comparetti (2011) outlines the precision agriculture "cycle", composed by three phases:

1. A **data collection** phase, where a combination of sensors and GPS is used to, as the name implies, collect relevant data on the fields, with a special interest in the soil's spatial variability, ergo, the difference between the value of the soil in a particular lot and the average value of the entire field; The reason to do so is to avoid using a homogeneous treatment for an entire field, as doing so results in a significant waste of resources.
2. A **data interpretation** phase, where the data collected is integrated into the farm's systems and used to create models such as (model description here).
3. Finally, an **application** phase, where the models created in the previous phase are then used to apply the treatment on the fields, either through connected machinery (such as tractors or combines with GPS integration) or IOT.

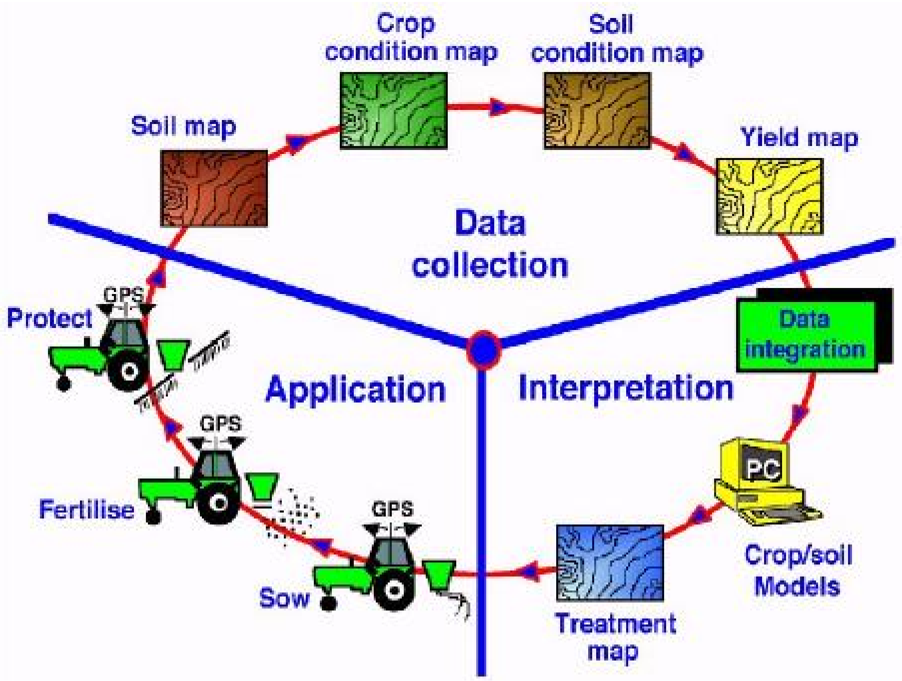

Figure 1: Precision agriculture cycle. By Antonio Comparetti

In the same paper, Comparetti outlines the various components needed in order for precision agriculture to work (2011):

- A **satellite positioning system,** such as GPS, in order to geolocate the position of the plot where treatment has to be made in order to "guide" machines in their treatment of said plot;
- **Sensors**, needed to make measurements of soil and crop statistics in a relevant field;
- **Devices**¸ which farmers have to use in order to interface with the applications that power precision agriculture;
- **Software**¸ that creates the maps needed to power precision agriculture by interpreting the data gathered from sensors on the fields;
- **Soil-crop simulation models**, that are used to identify the causes in soil's spatial variability and adjust the inputs accordingly for the next planting season.

It should be noted that models for predictive engineering aren't bound just to "production cases"; As noted in many recent reports and white papers, data could also be collected on the equipment of the farm, in order to recognize the first signs of a potential breakdown and act upon them before it actually happens (Bonneau, Copigneaux, Probst, & Pedersen, 2017; Soldi, et al.)

2.5 SUSTAINABILITY

Sustainability is a particularly sensitive topic for the agricultural sector. According to a report by the Intergovernmental Panel on Climate Change (IPCC), almost a quarter of the world's Greenhouse emissions come from agriculture and forestry (2014); Furthermore, by 2019, "2.1 billion people live without safe water" (Guterres, 2019). It is thus imperative that new technologies and processes have to be developed and employed to reduce the impact of agriculture on the planet.

Among the various ways to improve the sustainability of agriculture, the employment in scale of precision agriculture could prove to be a key instrument. As pointed out by Kenney et al. (2020), precision agriculture can deliver optimal quantities of fertilizer and water at precisely the right location in a field and, coupled with digital technologies that increase traceability, can significantly cut down waste and risk of damaging the soil.

In order to enable precision agriculture in smaller farms, which usually don't have the resources to create and set-up their own solutions, platforms to collect data in order to reduce environmental impact have started to appear, a recent case being the Italian DROLIVe, which uses data collected from sensors on the ground and on airborne drones to monitor and manage olive groves in Tuscany in a sustainable manner (DROLIVe), a particularly sensitive topic in Italy due to extensive damages done to olive groves in Apulia by the bacterium *Xylella fastidiosa*.

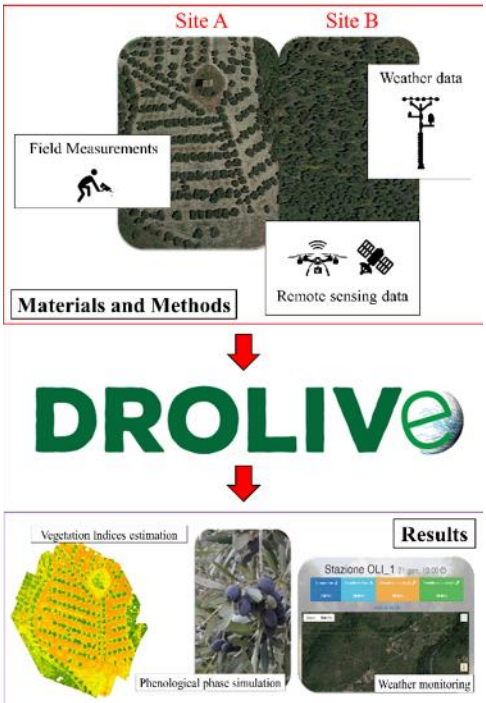

Figure 2: DROLIVe's workflow. Found at http://www.drolive.unifi.it/

2.6 RESOURCE SHARING AND NETWORKING

The following pillar encompasses many aspects of a farm's business, but the focus is primarily placed on the three most significant ones: data and know-how sharing, e-commerce and transportation.

In accordance with the principles of Open Innovation, first outlined by Henry Chesbrough (2003), networking and resource sharing between farms is only going to become more widespread going forward. Indeed, data which was used by one farm to improve productivity or crop yield can be shared with another farm so that it, too, can gain those same benefits.

An interesting development in recent years is the creation of E-commerce services tailored specifically for rural communities and industries, first brought to attention in a recent study by the FAO on its application in rural China (FAO and ZJU, 2021). Its application on a larger scale has great implications on the development of the rural zones, as well as good transportations in said zones.

Rural e-commerce essentially implies using the Internet to buy products or services from rural areas, and/or to sell goods or services to customers residing there. E-commerce can be a stimulus for the involvement of rural populations on both the production and consumption side, opening up scenarios for potentially huge developments. The marketing of agricultural products is particularly challenging, as there are numerous difficulties to be faced due to various factors such as:

- agricultural products are easily perishable;
- they are difficult to standardize in terms of both size and ripeness;
- they are cultivated on a small scale, and almost always without the possibility of minimum planning;
- consumers are particularly demanding in their choice of foodstuffs, with freshness, appearance, ripeness, size, being the key factors that guide the purchasing process.

To be able to make long-term decisions about what to grow and in what quantities, rural communities need many orders (much larger markets than those available today), a clear and transparent relationship with consumers, and timely estimates of demand to avoid waste and unsold goods. E-commerce certainly has the advantage of overcoming geographical and informational limitations. Of course, in order for e-commerce to express its full potential, it will have to rely on the upgrading of grid infrastructures, the widespread branching of broadband Internet, the improvement of transport networks and logistics services, and digital means of payment that are as popular and secure as possible.

All of these transformations will have the power to radically transform the consumer landscapes of rural areas, where people direct their energies either to weekly street markets or to large cities for shopping. By lowering the market entry threshold (especially for high-value goods), rural e-commerce will foster the emergence of new entrepreneurial activities in rural centers, which may act as a flywheel and an attraction to the crowded and increasingly less livable metropolises of the world for migrant workers and university students eager to return to their place of origin to rediscover their affections. This process will nurture an ecosystem that will lead by improving conditions in rural areas to diminishing differences between rural and urban youth.

Transportation of goods, and in particular how to improve its sustainability, is also another important topic in agriculture. In fact, even before the advent of “agriculture 4.0”, concepts such as the English "Food Mile" and its Italian equivalent "*chilometro zero*" where already becoming mainstream. The underlying idea behind both concepts is simple: reduce the emission by agriculture by promoting a more "local" production, which consequently reduces the distance needed to transport said goods, and the emissions which come from this transportation. However, it should be noted that there have been some pushbacks against both concepts, with a research by Weber and Matthews pointing out that, by strictly buying local, an average American household could only reduce their carbon footprint by about 4% (2008).

The role of platforms and apps for resource sharing and networking is readily apparent; as such, it's not surprising to find that many firms and organizations are developing their own in order to accomplish a particular objective. For example, Italian company Barilla spa. partnered with the Centro Ricerca Nazionale (National Centre for Research) to create Agrosat, a free application which uses satellite images to examine the optimal spots for fertilization from a tablet or smartphone, thus lowering the barriers of entry for many farmers who couldn't make use of precision agriculture solution before (Agrosat: l'agricoltura di precisione con lo smartphone, 2018).

2.7 CHALLENGES

The road to a connected, digitalized agriculture is one full of challenges, ones which have to be addressed in order to fully gain benefit from it. Below one can find some of the more difficult challenges, as outlines by recent literature (Bonneau, Copigneaux, Probst, & Pedersen, 2017; Kenney, Serhan, & Trystram, 2020):

Lack of standardization: Bonneau et al. mentions the lack of standardization as a primary liability and obstacle to a more connected farm (2017). The lack of standardization can either be **internal** in nature, or **external.** In the former case, we usually refer to the incompatibility between the newer IOT sensors and the older farming equipment. This can become problematic, as said equipment is replaced far less often than most communication technologies, primarily due to the high cost to do so and the fact that farming technology is far more "mature". As for external lack of standardization, it mainly concerns in the diversity of solutions employed by various farms, which result in difficulties when two or more interact between one another for the purpose of exchanging data that could benefit them. The lack of standardization, both internal and external, can be addressed through the creation of a dominant platform, whose purpose is the integration of modern systems with legacy ones, and that allows farmers to rapidly share information between one another, but such platform could also create problems, as explained in more details below.

Ability for farmers to modernize: The research of Bonneau et al. also pointed at the difficulties farmers have in modernizing their equipment and their production processes. This can happen due to a variety of factors, but the most relevant ones are the lack of funds and the relatively old workforce, which usually results in further funds having to be devoted to their training, funds which could have gone in better investments in infrastructure and connected machinery if the farmers where already well versed in the technology (Bonneau, Copigneaux, Probst, & Pedersen, 2017).

Many countries have since taken steps to address this possible problem, one (relatively) recent example being the SPARKLE project; Formed by a partnership of universities and farms found in Italy, Greece, Spain and Portugal, SPARKLE (an acronym for *Sustainable Precision Agriculture: Research and Knowledge for Learning how to be an agri-Entrepreneur*) was a "knowledge alliance" project which ran for two year, from 2018 to 2020, that resulted in the creation of a platforms for e-learning centered on training both new and old farmers on the various aspects of precision farming, creating what the project dubbed "agripreneur 4.0" (SPARKLE, 2020).

Lacking infrastructures: The agricultural sector is one where the vast majority of the productive process are done in a rural environment, as opposed to the more urban one of most other productive sectors. This brings out particular challenges for the heavily connective, data intensive applications that are needed in order for IOT and, more generally, digitalization as a whole. Thus, the sensor and applications farms are going to require either a heavy investment into new networks (such as 5G) or the capability to work intermittently. Furthermore, they also have to be resistant to excessive exposure to the elements or to animal attacks, both very likely scenarios in a rural setting.

Danger of monopolization or oligopolize of the market: As of the time of writing of this paper, there still isn't an IOT or general platform which can be considered more influential than the others. It certainly isn't for a lack of effort, as many actors in the market (American giants John Deere and Monsanto, to name a few) are attempting to establish themselves through their own platforms, be they merely technological or specifically data oriented.

While a more dominant platform may help in the important task of standardization, there is the risk (if not an outright certainty) of farmers becoming even more dependent on said industrial actors. Furthermore, if the servicization model of the products and platforms that these actors push is too aggressive, there might be some pushback against them, a recent case being the 2020 "farmer revolt" against John Deere and their policy on software modification and right-to-repair which, as one article puts it, "*create corporate monopolies—and destroy the agrarian ethos of resiliency and self-reliance*" (Waldman & Mulvany, 2020) . In their research, Kenney et al. pointed at **cooperatives** and to **specially formed entities** as possible organizational models which could compromise between the benefits platforms give and the farmers' needs (2020).

A cooperative is an association formed (and owned) by farmers who have aligning interests, and share resources between each other. While farmers cooperatives have existed much earlier than today's "Industry 4.0" revolution, they can "modernize" and become a primary method to push digitalization of its members, by becoming a trusted platform through which farmers can share the data they collect while still maintaining a stake in it (as opposed to platforms created by industrial actors). In fact, whereas a single farmer doesn't have much presence and thus is forced to make concessions on its data when he or she sends it to third parties, a cooperative can use its bargaining power to better control the way the data it agrees to hand over to other actors (be they of the agricultural industry or of another sector) is used by them. All in all, a cooperative offers the following benefits to its members:

- A share of the profits for the data they agree to hand over;
- More control on the data itself, including to whom it should be sold;
- Significantly less risk that the platform breaches the farmer's trust (for example, by recommending unnecessary repairs just to increase its revenue from the maintenance);

- Finally, due to the nature of cooperatives, it's members still have full control on how data is transferred to third parties.

Specially formed entities are born out of a necessity of its members of creating a model capable of bringing about the benefits of traditional platforms without losing control of data to a singular, central owner. Many such entities have emerged in Europe, with Kenney et al. making a few examples which will be talked about below (2020, pp. 27-30):

- The platform "Smart Dairy", formed by a consortium of universities, dairy cooperatives and dairy farms, was created with the purpose of providing farmers with a software platform which gave them the possibility of sharing and checking data through a singular dashboard, including an analytical component which gave recommendations for the treatment of cows. Since 2019, the original software was turned over to another platform called JoinData, which integrated Smart Dairy systems and became a "clearinghouse platform", ergo, a place where data could be transferred between two or more entities without the platform itself owning or storing said data.
- French platforms NumAgri and Num-Alim are examples of specially formed entities whose business goal isn't profit, but rather helping improving sustainability and transparency through the whole agriculture value chain, by either providing a database in which farmers can share and receive data from trusted sources (NumAgri), or improve transparency by declaring the origin of the product consumers buy (Num-Ali).

3- THE EXAMINED CASE

3.1 A BRIEF REPORT OF AGRICULTURE AND IT'S DIGITALIZATION IN ITALY

In the Common Agricultural Policy (CAP, the Eurozone unified agricultural planning), digitization and innovation are certainly seen as fundamental for the development of the entire sector. Recent studies unequivocally demonstrate the positive impact that new technologies have on agriculture. This is also why in the PNRR, in line with the next generation EU programme, funds have been earmarked for innovation in cultivation techniques, irrigation, fertilization of fields as well as milking and animal care.

Within a recently published study, ISTAT has examined the Italian agricultural sector to establish the degree of digitalization of Italian companies, focusing on both the scope of company applications (crop management, animal husbandry, etc.) and the use of the internet (marketing) (2022).

Innovation implies the presence of investments for the modernization of techniques and production management. The applications involve multiple aspects of the agricultural sector, from irrigation and fertilization to the milking of animals.

ISTAT data show the strong increase that the sector has had in ten years, rising from 3.8% ten years ago to 15.8% today. Unfortunately, the data also showed, as usual, the strong backwardness of southern companies and the difference between large, structured companies and small family businesses (2022).

According to the ISTAT census, the most digitized companies are:

- Those that carry out related remunerative activities such as agritourism, educational farms
- Companies run by men, particularly those run by men younger than 45 years
- Those that have an educated and specialized manager, especially if they have qualifications in the agricultural sector
- Often associated companies or part of producer associations.

As already mentioned, the size of the company, both in terms of the workforce and the agricultural area used, has a huge influence on the computerization of processes. For large farms, 78.2 % have achieved some forms of digitalization, while in smaller ones the percentage is only 8.8 %. For medium-sized companies, the gap is smaller, but the majority still do not make use of digital technologies (Gnesi, 2022).

In digitalized companies, most investments go into mechanization and the rest into plant and seeding. Residual investments in the workforce and new organizational structures.

Territorially, the most digitalized companies are found in the north, with peaks of excellence in the provinces of Bolzano and Trento followed by Piedmont and Emilia-Romagna. In the south, Sardinia stands out with a percentage of 11%, much higher than the average.

An overview of Italian agriculture wouldn't be complete without a brief, but poignant discussion on the current crisis happening in Europe. At the time of writing of this paper, the war in Ukraine is still raging on, with the agricultural sector being significantly affected by it.

While the increase in the prices of raw materials has been going on since 2021, the war has only worsened the situation, as the nations currently embroiled in the war are both major exporters of grain, with Russia also being the largest exporter of fertilizer, as shown in Figure 3. This has caused prices for vegetal product to rise as much as 20%; The main drivers behind this increase have been the cost of fertilizers (which rose by 27,4%) and energy (+19%) (ISMEA, 2022)

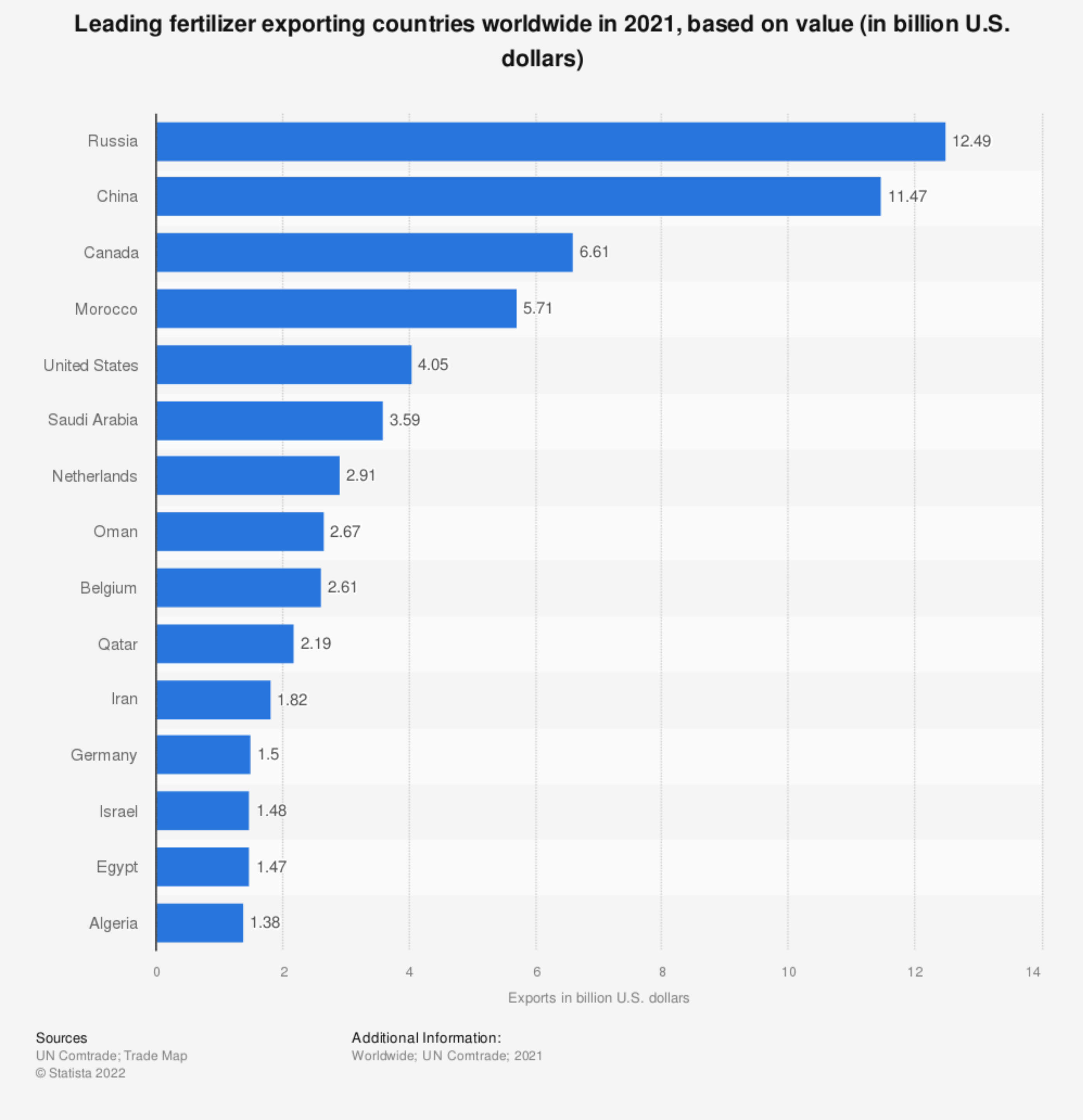

Figure 3: Trade Map. (August 1, 2022). Leading fertilizer exporting countries worldwide in 2021, based on value (in billion U.S. dollars) [Graph]. In Statista. Retrieved September 22, 2022, from https://www.statista.com/statistics/1278057/export-value-fertilizer

3.2 WHAT IS NITROGEN FERTILIZATION, AND THE NOVEL WAYS IT'S BEING IMPLEMENTED

Nitrogen fertilizers are among the most commonly used in agriculture. As the name implies, they are primarily composed of Nitrogen which, when sprayed on the soil, helps in maintaining or outright improving its fertility and plant nutrition (Da Silva, et al., 2020) However, it has been shown that an excessive use of such fertilizers not only results in decreasing returns to scale but, more importantly, severe damages to the soil itself, which can reduce yield of a field in the long run (Sainju, Ghimire, & Pradhan, 2020); Furthermore, as already mentioned in chapter 3.1, the cost of nitrogen fertilizers has been rapidly increasing, due to the fact that their largest exporters, Russia, is currently embroiled in a conflict with Ukraine, with punitive sanctions being applied to them due to their status as aggressors.

Due to these various factors, farmers have begun to look for methods to improve their usage for nitrogen fertilizers, and precision farming solutions might be the most promising among the rest. To that end, a series of studies were done in order to assess its utility on the fields, and in particular how it allows Variable Rate (VR) treatment over the more common (and more wasteful) uniform fertilizer treatment.

Two types of application of precision agriculture as a method to control nitrogen fertilization will be examined; The first one, set-up in the farm of Porto Felloni, is based on the creation of **prescription maps**, while the second, employed in the fields near Mantua, makes use of the **"on-the-go"** fertilization approach.

Before we begin, let us take a closer look at both methods, and understand how the two differ:

A precision agriculture solution based on prescription maps makes use of so-called **management zones**, defined as subsection of a field which have more or less homogeneous yields and soil characteristics, and can thus be managed uniformly (Cillis, Maestrini, Pezzuolo, Marinello, & Sartori, 2018). Literature indicates four ways to delimit a management zone:

1. Through a collection of soil data (such as organic matter and electrical conductivity) collected either through sensors/GPS, or through survey maps;
2. By using a crop production map as a basis, said map being created through empirical analysis made on the yield of each possible management zone;
3. Finally, by uniting the other two methods, in order to create a prescription map which gives a more complete observation of the field controlled.
4. The most recent method, consists in using crop data in order to understand how it would behave on different soils.

Regardless of how a prescription map is created, it can then be integrated into the farm' systems and vehicles' software, and used by farmers as a reference when treating their crops.

Meanwhile, the on-the-go fertilization approach primarily makes use of sensors installed on farm vehicles to guide farmers in applying their treatment while directly working on the field. This methodology is cheaper to implement than one based on prescription maps, due to the latter's needs for more specialized software and experts needed to fine-tune them (Schillaci, et al., 2020).

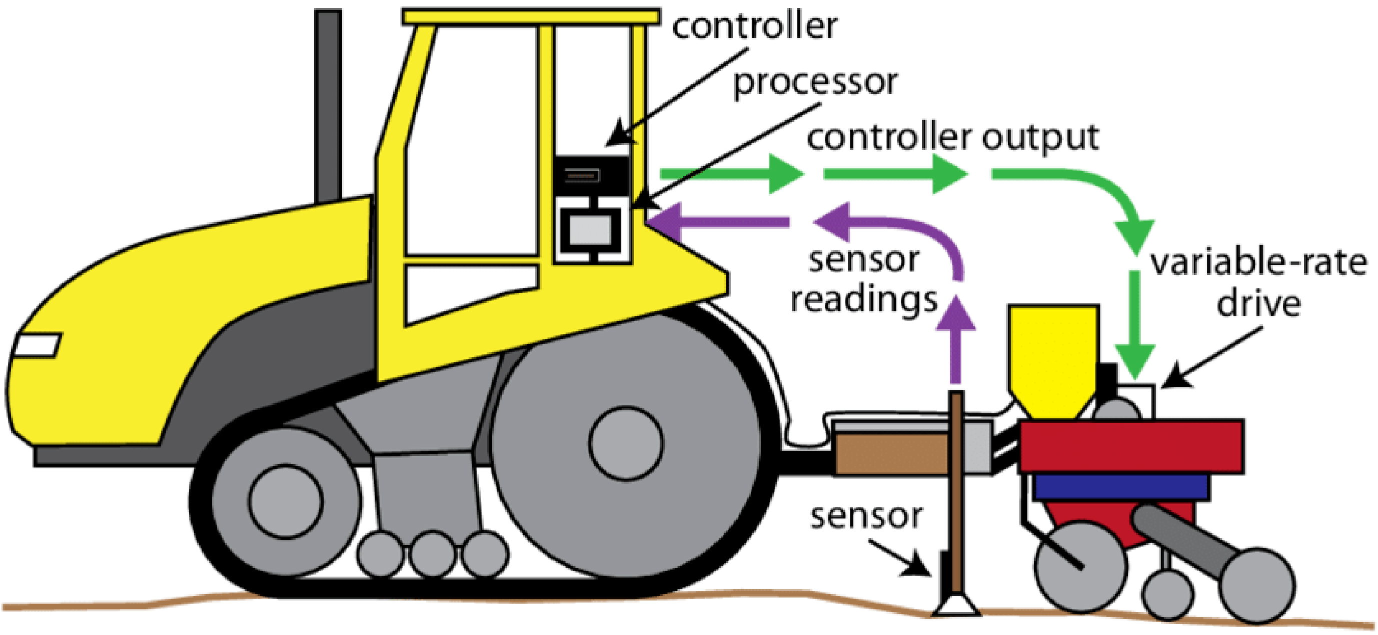

Figure 4: Visual representation of an on-the-go system. Reference: Precision farming tools: variable rate application – scientific figure on ResearchGate. Available on: https://www.researchgate.net/figure/On-the-go-sensor-texture-electrical-conductivity-EC-or-soil-organic-matter-SOM_fig10_309121121 [accessed 22 Sep, 2022]

3.3 THE CASE STUDIES ON SETTING UP PRECISION AGRICULTURE

The study was centered around two zones, one in Porto Felloni (a private farm in Lagosanto, in the province of Ferrara) and another in the fields of the Mantua district. While the former have been pioneers in the introduction of precision agriculture in Italy, the latter are positioned in a strategic location: the middle of the Po valley. Indeed, the fields surrounding Mantua are highly suitable for the plantation of maize, rice and soybeans, all highly valuable produces which make up the lion share of Italy's crop exports, as shown in Figure 3.

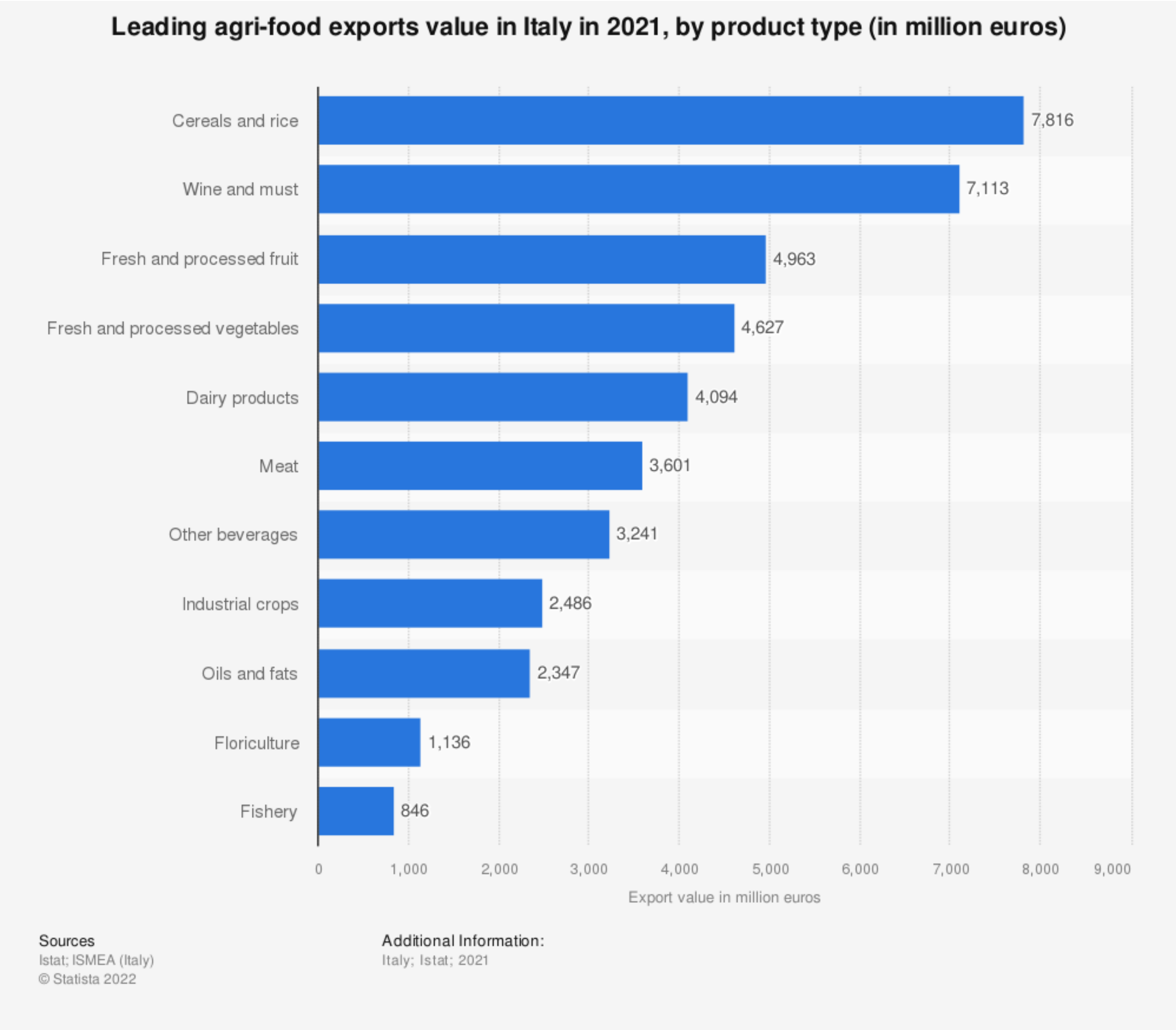

Figure 5:ISMEA (Italy). (March 25, 2022). Leading agri-food exports value in Italy in 2021, by product type (in million euros) [Graph]. In Statista. Retrieved September 16, 2022, from https://www.statista.com/statistics/543904/leading-agri-food-exports-in-italy

3.31 PORTO FELLONI AND PRESCRIPTION MAPS:

Let's start by the describing how an example of prescription maps was practically applied in Italy. The farm of Porto Felloni, located near the town of Lagosanto (FE), was the first, privately owned farm in Italy to make use of a precision agriculture solution, creating their first yield maps in 1999. The study was conducted on a 22-hectare field, irrigated through a center pivot system, and the yield maps where (at least initially) created by interpreting the data collected by the yield monitor present on their harvesters. During the duration of the study, which was carried out from 2008 to 2016, those yield maps where used in order to create prescription maps to assess whenever Variable Rate (VR) fertilization had any positive, long-run effects on the corn yield of the field.

The particularity of the study comes from the fact that, during the 8-year duration of the study, the farm enriched itself with more and more sophisticated PA technologies and processes, as outlined by the study itself through the following table:

Table 7.3.1

Technological evolution of the Porto Felloni farm.

Year	Technology	Effect on PA
1999	First yield paper maps	Recognition of variability
2001	First digital yield maps	Creation of a digital archive
2002	Soil sampling	Recognition of variation between fields
2005	Satellite guidance systems	Reduction of overlaps and monitoring
2007	DSS software	Field based recommendations
2007	Controlled rate fertilizer	VR fertilization
2011	ARP soil mapping	Recognition of within-field variability and precise definition of homogeneous MZs
2011	PA ready implements	VR seeding and spraying
2012	Higher resolution yield maps	Precise information on yield variability
2014	DSS software	Definition of MZ within fields and prescriptions
2015	Sentinel-2 and drone maps	Recognition of higher resolution variability

Figure 6: table outlining the technological evolution of Porto Felloni farm. Found in: Schillaci, C., Acutis, M., Kayad, A., Marinello, F., Fastellini, G., & Sartori, L. (2020). Italy - Nitrogen fertilization based on prescription maps and on-the-go variable rate

Indeed, the first prescription maps used by Porto Felloni where rudimentary, based just on limited data from previous years' yield maps and basic soil data collected by experts on the field. As more advanced technology began to appear, such as sensors that allowed to make

ARP analysis, management zones became more detailed, and the prescription maps from 2011 and forward started becoming of the third type, ergo created by including both yield data and soil data for any given management zone.

A further evolution was made possible with the employment of the ESA Sentinel-2 satellite' services; thanks to its sensor package, which allows it to run advanced remote analysis, Sentinel-2 is able to easily create maps based on the NDVI (Normalized Difference Vegetation Index) and NDRE (Normalized Difference Red Edge) indexes, both incredibly powerful tools through which farmers, using dedicated software, can quickly verify the health of their crops. To top it all off, the introduction of the Farmworks software made possible the integration of data which came from different sources into a single, centralized entity, allowing an even more precise division of the field into distinct management zones and subsequent distribution of nitrogen fertilizer in the soil.

The study measured the effectiveness of the treatment not just in terms of yield, but also in terms of the partial factor productivity for nitrogen (PFP-N, a unit which measures the effect 1 kg of nitrogen has on the total yield of corn). The end results where staggering: in 2017, the field produced 40% more corn than it did when the study first begin in 2008, and PFP-N went from 50 kg of grain per 1 kg of applied nitrogen, to 87 kg for the same quantity of nitrogen. Furthermore, spatial variability in the output of the field was greatly lowered, and homogenized; at the beginning of the study, almost all of the field (99%, to be precise) yielded less than 13 ton/ha, with a further 44% producing even below the 10 ton/ha; by comparison, the yield harvest of 2016 showed that more than 80% of the field produced more than 13 ton/ha of corn. Overall, average yield rose from 9.76 ton/ha in 2008 to 13 ton/ha in 2016, and the yield variety within each management zone shrunk every year by 0.6% (on average).

Ultimately, the application of PA in Porto Felloni through prescription maps can be considered a resounding success, with the study pointing out the strong correlation between the introduction of more sophisticated technologies on the field with an increase in the yield of the field, and showing *"how the farmer can profitably improve its management strategy year after year"* (Schillaci, et al., 2020)

3.32 THE FIELDS OF MANTUA AND "ON-THE-GO" FERTILIZATION:

The second method to control nitrogen fertilization was tested during a two-year study in the fields surrounding Mantua, a province in Lombardy. Situated near the Po valley, the rich soils of Mantua are used to plant corn, rice and soybeans, although for the study a field of corn was ultimately chosen. The reason is simple: in recent years, farmers of the region who planted corn have faced great competition from imports from outside the EU, and they sell at a far lower price (170 € per ton for Mantua farmers, as opposed to the 194 € per ton of outside the EU exporters) due to a lower quality and yield than their competitors.

In order to improve their standing against the competition, a study was conducted in order to test the capabilities of proximal active sensors (such as Topcon's CropSpec) in applying nitrogen fertilizer "on-the-go", and applying it through VR application rather than uniformly, like many farmers of the district do. It should also be noted that, through the study, the objective of the farmer was the optimization of nitrogen fertilization in order to achieve higher and more uniform yields through the field, as opposed to the more "ecological" objective of minimizing the use of fertilizer on the field.

Figure 7: The Topcon CropSec, a proximal active sensor which was used during the study at Mantua. Found at: https://topconcare.com/en/agriculture/crop-monitoring-technology/crop-canopy-sensors/

The vegetation index readings were taken using the Topcon CropSpec proximity sensor (variable and uniform fertilisation rate) The sensor works with a Topcon guidance system consisting of at least an X-Console, which allows sensors and spreaders to be operated via an ISOBUS connection, and a GNSS antenna. In order to use the system in real time or, as Topcon says, on the move, a variable rate console-controlled implement is required; in this strategy the sensor analyses the crop and sends the right amount of input in real time according to a distribution plan defined at the start of the job. The CropSpec sensor has the ability to measure high-frequency canopy reflectance data, associated with high-precision positions, in two active multispectral reflectance channels (RedEdge and NIR bands) that create a synthetic index (5-index) in real time, It can simply record the status of the canopy or it can guide the distribution with the appropriate rate of fertilizer in real time, after a quick set-up. At the time of fertilisation. The sensor is installed on the head of the tractor. The reading of vigor with the CropSpec was taken in conjunction with the reading of the Normalized Vigor Difference Vegetation Index (NDVI) using Sentinel-2 remotely sensed images.

The CropSpec sensors are mounted on the tractor cab 2.44 m above field level on the tractor. The connectivity of the technology used is ISOBUS modular for the variable rate spreader. The fertilizer spreader used was the Keeneland geo-spreader which is capable of spreading from +3 to 24 in a swath in a single pass. The fertilizer used was granular and urea-based. The tractor used was equipped with a Topcon automatic steering system; the console also controlled the spreader via the ISOBUS protocol and the harvesting machine was equipped with a Topcon YieldTrakk system. The latter offers a new level of high-precision yield/moisture monitoring and mapping, providing the farmer with optimal data in terms of yield quality and moisture content of the wet and dry crop.

. The sensors installed on the tractors, whose default statistics where set to a frequency of 10 Hz, and consequently allowed the generation of the desired target fertilization rates in real time. ISO 11783 (commonly called 'ISO Bus' or 'ISOBUS'), a communication protocol based on SAE J1939, ensured the correct positioning of both sensors and fertilizer spreaders, which where also controlled by a satellite guidance (in the case of the study, differential corrections where made using real time network kinematics (NRTK)) (Schillaci, et al., 2020).

The amount of nitrogen distributed in the test field at a constant rate was decided by the farmer's fertilization plan. The minimum and maximum variable fertilization rates ranged between 69% and 100% of the quantity applied in the first year in the fixed-rate field, while in the second year the variable-rate doses ranged between 85% and 100% (Schillaci, et al., 2020).

In this experiment, the farmer naturally aimed to achieve high production, but above all to improve the homogeneity of the field, using the same amount of nitrogen fertilizer which was used in the previous years. The results of the first year were surprising, thanks to the perfect calibration obtained in the field by determining the minimum and maximum fertilizer rate. An inversely proportional correlation was recorded between the value of the 5 index and the fertilizer rate, so the fertilizer level was increased where low canopy cover was evident.

During the first year, in the variable rate test plots of this experiment, it was observed that the yield in the maximum nitrogen dose areas was lower than in the lower dose areas, which showed the aptitude of the variable rate to find the less productive areas and try to improve their yields by giving the maximum dose allowed by the calibration. We can therefore assume that by giving the maximum dose, the sensor-guided distribution tried to close the nutrient gap and also allowed for a homogeneous yield for the year 2017.

The experiment made it possible to correctly determine the optimal nitrogen dose and distribution setting to improve crop productivity. Other useful agronomic considerations involved verifying the applicability of EU legislation in terms of maximum nitrogen distribution per hectare on farms with organic fertilizer availability. In fact, organic fertilization made it possible to reduce mineral nitrogen fertilization. Thus, this resulted in an overall reduction of costs, while at the same time maintaining good yields and a reduction of the impact on the environment.

The farmer's objective was not to save on fertilizer quantity, but only to achieve homogeneity of production: however, with the use of CropSpec, a net saving of 10% in terms of urea fertilizer and improved homogeneity of yield within the field was estimated for the entire test farm. CropSpec proximity sensors can also help the farmer to diagnose the state of the field and crops, because they may reveal a critical area in the middle of the field, most likely due to a lack of nitrogen, and may reveal other limiting factors (such as water stagnation due to heavy soils or the occurrence of infections or pathogens).

Variable Rate applications to manage yield differences within the field based on real-time sensing and application proved to be very successful, with overall improvements in terms of increased yield and reduced environmental impact.

3.4 CONCLUSIONS OF THE CASE STUDY

The studies done at Porto Felloni and Mantua showed the viability of precision agriculture in the Italian context, as well as the positive effects it has on both yields and maximization of the fertilizer used.

Furthermore, while the two studies where conducted before the current period of instability Europe is currently facing, they both demonstrated that precision agriculture succeeded in improving efficiency while at the same time reducing the input of nitrogen fertilizer, even when the latter wasn't the main objective (as was the case in the fields of Mantua). This opens the door for the possibility of fine-tuning PA practices for other purposes other than merely crop yields (reduction of expenditures come to mind, as well as attempts to become more sustainable).

However, the limitation of the following research should be noted; in particular, the size of the two farms which where used as case studies seemingly confirm the study done by ISTAT, since in both cases we're looking at large, structured firms from the north-center regions of Italy. As such, further research should be done on farms which present different sizes or geographical positions from those observed, in order to have a less biased outlook on the subject as a whole.

4-CONCLUSIONS

This paper has shown the current developments of the so-called “agriculture 4.0”, what it has achieved so far and where it is currently heading. It is clear to see just how important technologies, such as IOT and remote sensing, and processes similar to precision farming have been for agriculture as a whole, and as enablers of agriculture 4.0.

The recontextualization of Kusiak’s six pillars proved to be an effective framework in summarizing the major advances in the agricultural sector, giving us a perspective on how digitalization and other related technologies that have emerged in the last few years have changed its “landscape”. In particular, we have seen just how significant the development and subsequent improvements made to the precision agriculture managerial method have been, both as a way to improve the overall productivity of a farm, but also as a way to curb emissions, and help reach sustainability goals. Finally, the knowledge we gained from studying these developments was used in examining the two case studies, which showed us the advantages farmers could have by investing in these new technologies (for example, helping in reducing needed for costly inputs like nitrogen fertilizer, while at the same time maximizing the crops’ yields), and why governments should be keen in creating polices which help with their adoptions.

Due to the more generalist nature of this paper, further research may be needed on the topic: In particular, a closer inspection to the consequences of a more digitalized agricultural sector may be needed, such as the increased need for more white-collar jobs. While such phenomenon has already happened previously (the increased mechanization of agriculture after WWII comes to mind), it is still important to investigate what it entails for the future of the sector, to perhaps gain insights that could be used when similar situations arise in other manufacturing branches. Another topic which could be of interest is the role and shapes of platforms in this new agricultural paradigm. As explained in the paper, there are many doubts about the platforms created by industrial interests, primarily centered about who will own the data. For this reason, there should be a concerted effort in studying fairer alternatives, capable of satisfying the interests of farmers and platform-holders alike.

In the end, the field still has much to be explored, but hopefully this research has been useful in outlining the major changes that have happened in the sector, and has shown a clear path as to which aspects should be given priority for a more in-depth investigation.

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