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DIGITAL (R)EVOLUTION IN AGRO-FOOD AND FORESTRY

ABOUT US

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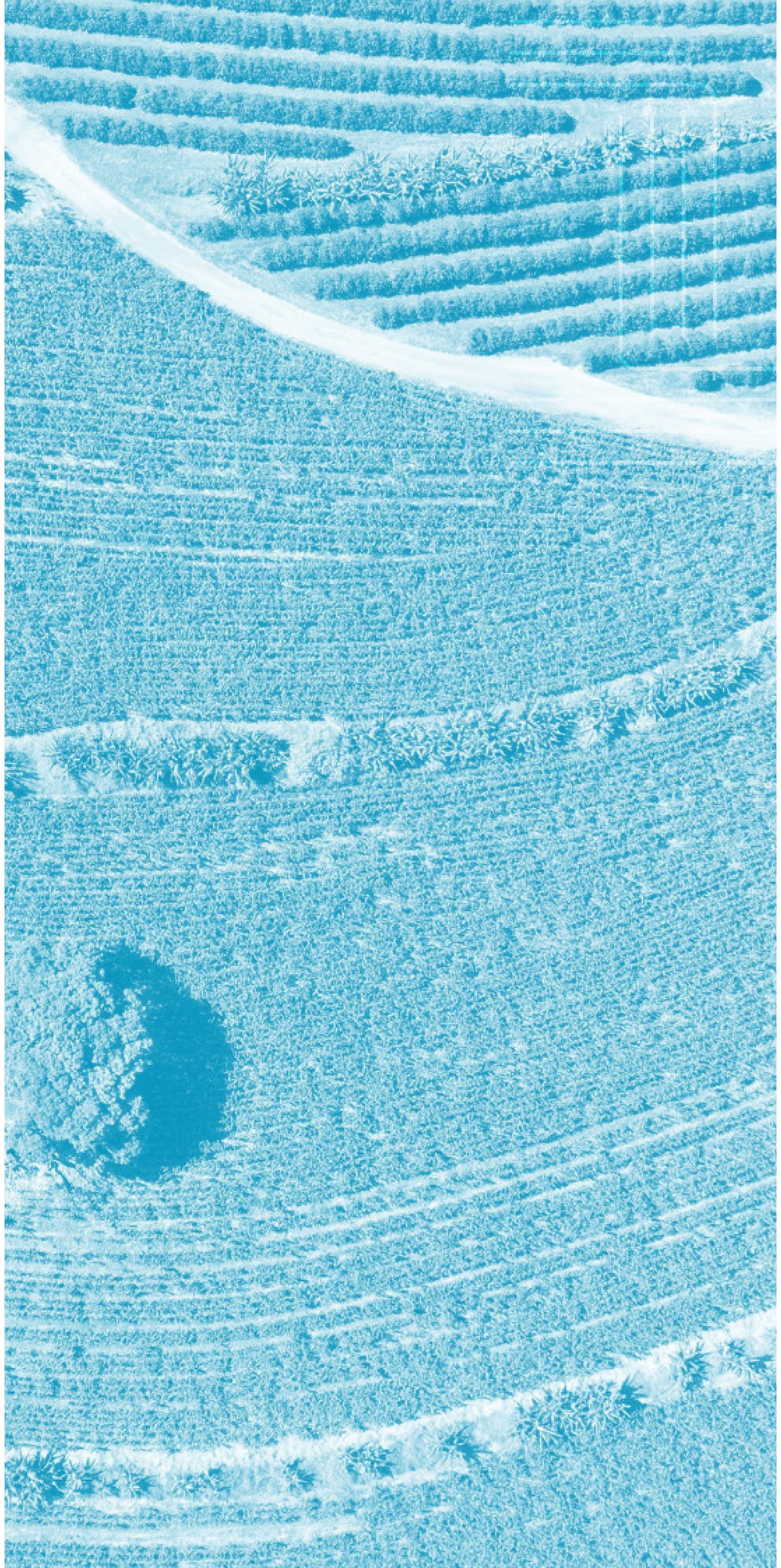

SCIENCE & SOCIETY

We present another issue of the magazine "INESC TEC Science & Society", created by INESC TEC with the objective of disseminating science to society in general and contributing to the debate of emerging issues, hoping that it may be of interest to managers, politicians and professionals of the systems involved in the activities of the sectors addressed in this issue.

The recognition of the first three issues was excellent, and we prepared this issue, dedicated to agriculture and forests, with the expectation of achieving it yet again. As in previous editions, the authors are INESCTEC researchers and external personalities that we invited to ensure a broader view of the topic.

Given the considerable number of articles received, other current articles are not included, as in previous issues. We hope to be able to contribute with a broad view of the subject and a characterisation of the impact of science and technology on the sector in Portugal.

The magazine is distributed online, in pdf, and on a platform, which we have been improving, enabling the access via HTML, more responsive to those who access it from their cell phones.

I'd like to thank all those who contributed to this edition, highlighting the work carried out by the Editorial Board and the Communication Service of INESC TEC, and, in particular, the team leading the Theme and all the authors.

We sincerely hope that the result will be to your liking.

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EDITORIAL

TEC4AGRO-FOOD ENWRAPPING SCIENCE AND SOCIETY

OVERVIEW

Moving from a Death Valley to a Cape of Good Hope, technology transfer is still a critical and complex step in the innovation process. Similarly, technology adoption is also a critical and challenging step.

Having this in mind, INESC TEC created in 2014 TEC4AGRO-FOOD, its Initiative for Agro-Food and Forestry. TEC4AGRO-FOOD is a new organisational approach aiming at structuring the market-pull innovation process, as opposed to the science-push that occurs naturally in INESC TEC's Research & Development Centres, supporting the establishment of the adequate balance between the two opposing motivations and the full knowledge-to-value chain. TEC4AGRO-FOOD's mission is co-shaping the digital (r) evolution in agro-food and forestry through research and technological development in digital technologies and robotics for the creation of long-term value for INESC TEC from customers, markets, and relationships.

Figure 1 TEC4AGRO-FOOD, INESC TEC's Initiative for Agro-Food and Forestry.

Taking advantage of INESC TEC's competencies, namely in the main digital technologies involved in the digital (r)evolution currently ongoing in agro-food and forestry, i.e. Internet of Things (IoT), Big Data, Robotics and Artificial Intelligence, resources, where the Laboratory of Robotics and IoT for Smart Precision Agriculture and Forestry, a differentiating asset of INESC TEC - a robotics and IoT lab fully dedicated to agriculture and forestry, plays a crucial role, and experience, including the one acquired in successful interventions in other sectors such as footwear, TEC4AGRO-FOOD has as main application areas Smart (digitalisation) Precision ("right time, right amount, right place") Agriculture and Forestry, Food Security and Bioeconomy. TEC4AGRO-FOOD may act in all phases of the Smart Precision Agriculture/Forestry cycle, from variability measurement to action with variable rate technologies (VRT), encompassing data analysis and decision and prescription map:

Typically (there are exceptions), INESC TEC researches and develops technologies until Technology Readiness Level (TRL) 7 - System Prototype Demonstration in Operational Environment.

To foster the creation of the "Innovation Triangles", INESC TEC is present in the relevant Collaborative Laboratories (CoLABs), Competitiveness Clusters (Clusters), and National Competence Centres, and in the Smart Specialisation Regional Platform Food and Environmental Systems (Norte Portugal Regional Coordination and Development Commission (CCDR-N)), has established partnerships, namely with INIAV, Herculano and complementary partners, and especially in what concerns Europe, INESC has started or is strengthening the participation in relevant European programmes/initiatives, together with its proactive participation in the INESC BRUSSELS HUB's Work Group Agro-Food & Forestry (WG Agro).

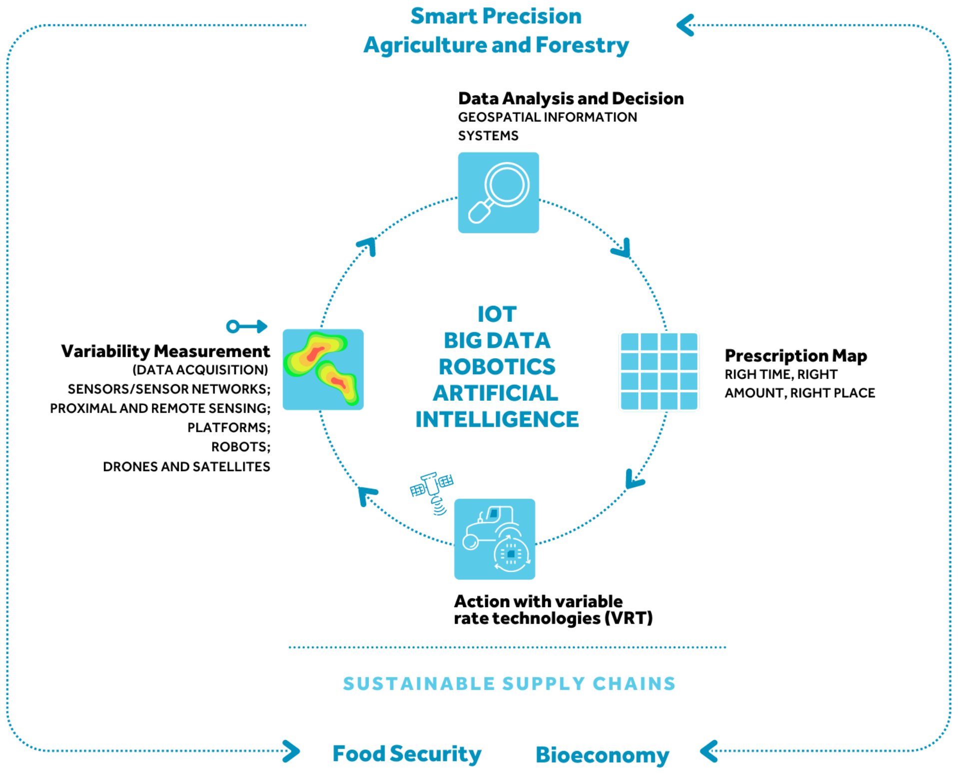

Figure 2 TEC4AGRO-FOOD's Application Areas.

For innovation to occur, the "Innovation Triangle" must be in place. End Users' (farmers, forestry producers and respective associations) needs (short term) and desires (medium-long term) must be captured by the non-business entities of the research and innovation (R&I) system, such as INESC TEC, and Technology Providers, so they can jointly develop innovative products and services, to be delivered to the End Users by the Technology Providers. INESC TEC may also provide advanced consulting directly to the End Users.

TEC4AGRO-FOOD approaches research and innovation always from a "why" (problem/opportunity), "how" (how to make things happen), "what" (solution) perspective, therefore having its research challenges aligned with the main R&I agendas relevant for agro-food and forestry, namely the Innovation Agenda - Terra Futura from the Portuguese Ministry of Agriculture, Research and Innovation Thematic Agenda for Agrofood, Forestry and Biodiversity from FCT (Portuguese Foundation for Science and Technology), Digitalisation Strategy from GPP (Office of Planning, Policy and General Administration of the Portuguese Ministry of Agriculture), and, at a European level, Horizon Europe and Digital Europe Programme (DIGITAL).

More information and statistics regarding TEC4AGRO-FOOD are included in this issue of the magazine, where it is clear the sustainable growth verified in the last years, both at national and European level.

The mechanisms of adoption and diffusion of digital technologies in agro-food and forestry must be understood on both end-users and system levels, where system refers to the identification and organisation of entities relevant for the adoption and diffusion as explained in the first two articles of this issue. The following three articles tackle technologies, management strategies for a sustainable future, organisations and public policies for smart precision in agriculture-livestock (articles 3 and 4) and forestry systems (article 5). The technology trends expected to drive the decision-making in line with smart precision agriculture and forestry are presented in article 6 (geospatial information systems), article 7 (automation and robots) and article 8 (artificial intelligence). Article 9 explains how multi-omic disciplines, fed by smart-spectroscopy sensors mounted in mobile robotic platforms coupled with artificial intelligence, can be explored to develop advanced smart precision agriculture systems. Article 10 characterises and exemplifies how digital twins can be used to acquire answers concerning questions that are difficult to answer without some context, such as irrigation and fertilisation in a specific environment, as well as climate and soil and their interactions. This set of articles ends with the vision of an end-user/association of end-users of the wine industry and smart precision technology providers in agro-food and forestry (articles 11 and 12).

TEC4AGRO-FOOD's vision is to become a relevant international player regarding research and technological development in digital technologies and robotics for agro-food and forestry.

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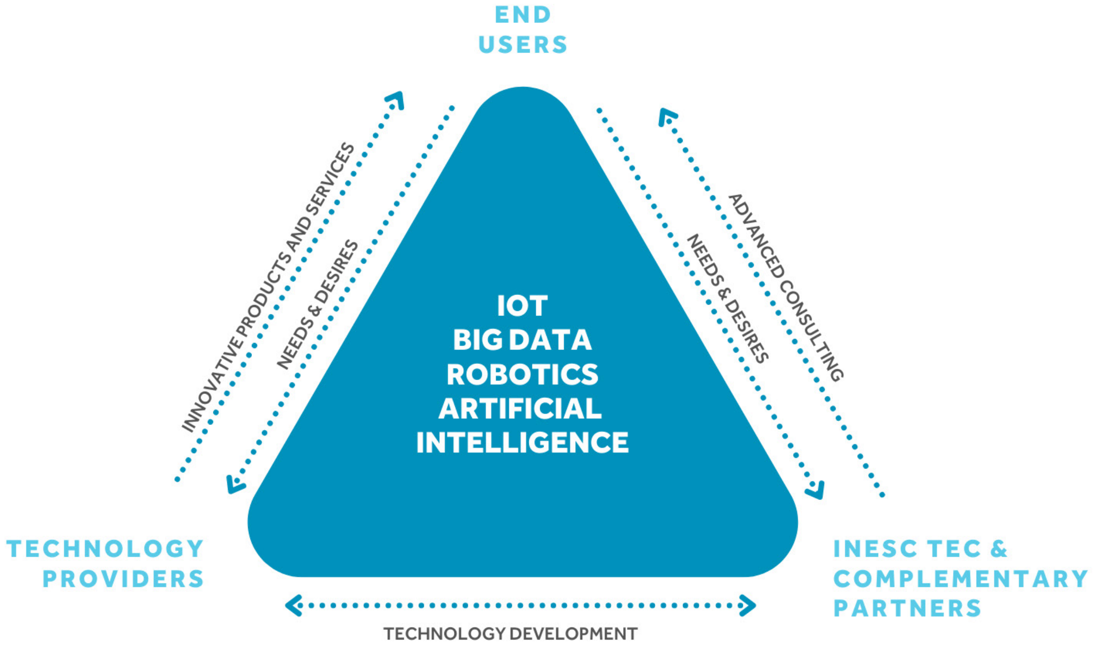

Figure 3 INESC TEC's Positioning - "Innovation Triangle".

INESC TEC ACTIVITY IN AGRO-FOOD

KNOWLEDGE AREAS

- IOT
- BIG DATA
- ROBOTICS
- ARTIFICIAL INTELLIGENCE

APPLICATION AREAS

- SMART PRECISION AGRICULTURE AND FORESTRY
- FOOD SECURITY AND BIOECONOMY

PARTNERS WITH COLLABORATION PROTOCOLS OR INESC TEC'S MEMBERSHIP

iniav Instituto Nacional de Investigação Agrária e Veterinária, I.P.

CITAB
Centro de Investigação e de Tecnologias Agro-Ambientais e Biológicas

INSTITUTO SUPERIOR DE AGRONOMIA
Universidade de Lisboa
Hinc Patriam Sustinet

GREENUPORTO
Sustainable Agrifood Production Research Centre

Herculano

SOGRAPE

ADVID COLAB
Cluster da Vinha e do Vinho
Vine and Wine Cluster

forestwise

FeedInov

SMART FARM COLAB
LABORATÓRIO COLABORATIVO PARA A INOVAÇÃO DIGITAL NA AGRICULTURA

InovTechAgro
Centro Nacional de Competências para a Inovação Tecnológica do Sector Agroflorestal

Centro Nacional de Competências para as Alterações Climáticas do Sector Agroflorestal

STATISTICS (2016-2020)

+30
RESEARCHERS

240
PUBLICATIONS WEB OF SCIENCE

12
SUBMITTED PATENTS

4
OPEN SOURCE TECHNOLOGIES LIBERATED

70
PROJECTS, PRIVATE AND PUBLIC FUNDING

4,4 M€
INCOME

INFRASTRUCTURES

13
INESC TEC RESEARCH CENTERS

CESE | CAP | CITE | CTM | CPES | CRIIS | CRAS | HUMANISE | CEGI | C-BER | LIAAD | CRACS | HASLAB

RESEARCH LABORATORIES

Robotics and IoT for Smart Precision Agriculture and Forestry
Optical and Electronic Technologies
Computer Graphics and Virtual Environments Optical Sensors
and Smart Grids and Electric Vehicles

AGRI-FOOD AND FORESTRY POLICIES AND TECHNOLOGY

THE NEED FOR AN INTEGRATED VISION

Developing an integrated vision for agricultural practices, food production and forestry management is more urgent than ever. In Portugal, we are developing a network of experimental stations (local field testing and living labs) to reinforce the national capacity for innovation in agriculture and food.

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Figure 1 INESC TEC robot in operational environment tests.

Developing an integrated vision for agricultural practices, food production and forestry management is more urgent than ever. Several national and international organisations have advocated this, translating it into different strategic approaches. However, it is clear to us that policy and technology development must be at the heart of the practical implementation of any strategic vision. Moreover, any of the policy, economic, environmental, or social goals we must ensure towards a liveable and sustainable future for generations to come, depend on our capacity to develop and deliver adequate technological solutions. There is no credible or feasible compromise between the world as we know it and adequate levels of investment in research and innovation. The mission is urgent and alignment of priorities at every level is crucial, from EU level policy and funding to regional or even institutional level management, as well as R&I agenda-setting.

Take, for example, the Food and Agriculture Organization (FAO) Strategic Framework 2022-2031, which aims to achieve better production, better nutrition, a better environment, and a better living conditions through the transition to more efficient, inclusive, resilient and sustainable, agri-food systems, with principles of social inclusiveness, and leaving no one behind. Or the Green Deal, developed as an integral part of the European Commission strategy to simultaneously address EU economic competitiveness, implement the United Nation's 2030 Agenda and the sustainable development goals. The Green Deal is the epitome of how complex and grand are today's challenges. It is perceived as a new growth strategy aiming at a future resource-efficient and competitive economy where there are no net emissions of greenhouse gases by 2050, and where economic growth is decoupled from resource use. A huge step and a dramatic change to our cultural, economic, and political bias, achievable only through technological solutions that are yet to be developed and made available to everyday citizens and industry. This is an effort that requires a multi-level approach and alignment of priorities, as well as an unprecedented collaborative capacity among the different stakeholders in regional and national R&I ecosystems and value-chains.

In our home country, Portugal, the new "Innovation Agenda for Agriculture", being implemented by the Portuguese Government with the support of stakeholders - is aligned with the Green Deal, the FAO Strategic Framework and the United Nation's

2030 sustainable development goals. Considering the specificities of southern Europe and the climate change effetcs in the Mediterranean area, this national agenda addresses the main challenges on the horizon, by granting a pivotal role to knowledge and technology, while focusing on regional specific conditions.

Let's take this opportunity to further explore this. First and foremost, the paramount digitalisation of food systems will be crucial to the competitiveness and sustainability of organisations, and to how countries prepare to address the main challenges in this field. Similarly to human systems, the ability to improve the health (sustainability) of the target land, water, agri and food (LWAF) systems depends on the ability to monitor, diagnose (assess), prescribe (manage) and implement treatment (restoration) protocols.

Considering that, over the next few years, we will need a dramatic increase in food production, while facing the significant impact of climate change and emergent and re-emergent diseases, together with the lack of work force in the fields, among others, the solutions available today are clearly insufficient.

Therefore, we must explore two main complementary areas: provide new solutions and reinforce the capacity-building of farmers, technical staff and organisations.

Regarding new solutions, we emphasise biotechnology, plant and animal breeding (development of molecular markers associated with physiological traits and new phenotyping tools) and the use of digital technologies to ensure:

a) Smart monitoring.

b) Intelligent planning and control.

c) Transparency, accountability, and security.

For example, real-time and remote diagnoses and sensorization, the development of high throughput phenotyping and the improvement of traceability and biosecurity are areas of core interest. Other important dimensions demanding a high level of computational competencies, translated into end-user friendly applications, are irrigation management (crop coefficients, water status indicators and quantification of water stress intensity); diagnosis of plant nutritional status and early detection of diseases; and use of digital technologies in livestock farming to improve performance and blockchain-based solutions – all of them key areas of research.

The capacity-building of farmers, technical staff and organisations is a critical success factor to the adoption of new solutions. Processes of upskilling and reskilling must be implemented on a larger scale and focus on specific needs of the agriculture and food sectors.

Experimental facilities and pilots for the development, test, and demonstration of different solutions will be crucial for achieving a large-scale adoption of innovative products and practices.

In Portugal, we are developing a network of experimental stations (local field testing and living labs) to reinforce the national capacity for innovation in agriculture and food. Simultaneously, we are strengthening the connection between research and innovation, experimentation and development of innovative applications focused on solving concrete needs. This is done through innovative organisational approaches towards increased proximity and interaction between the research performing organisations, private companies and other stakeholders. Competence Centres (i.e. National Center for Technological Innovation Skills in the Agroforestry Sector - InovTechAgro) and Collaborative Laboratories (i.e. Smart Farm Collaborative Laboratory), where both INIAV and INESC TEC collaborate, are good examples of this effort.

In sum, if we are to effectively address both the challenges that are common to us all, i.e., already identified in the Green Deal and all its "sub-strategies" and policies, and those that are region specific, we must ensure 1) a multi-level political and institutional alignment and complementarity of policy objectives; 2) clear synergies of funding instruments; 3) understand that the complexity of the challenges demands a much higher investment in R&I, at both public and private levels, but most of all, a co-created, integrated vision of the future policy priorities and R&I efforts that holds life and the planet itself as the main priority.

SMARTAGRIHUBS

A NETWORK OF DIGITAL INNOVATION HUBS TO ACCELERATE THE DIGITAL TRANSFORMATION OF THE EUROPEAN AGRI-FOOD SECTOR

The digital transformation of agri-food has entered a situation where innovations have proven to be promising, but must be upscaled to a higher level of adoption and broader integration. The nature of digitalisation is evolving and has become part of a more complex ecosystem.

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Figure 1 SmartAgriHubs brings together different expertise for a digital transformation of the European Agri-Food sector.

DIGITAL TECHNOLOGIES AND BUSINESS MODELS ARE PROMISING BUT CURRENT FRAGMENTATIONS AND MISALIGNMENT ARE HAMPERING BREAKTHROUGHS

Digital Agriculture is generally considered as a key technology to address the grand challenges for agriculture, such as ensuring a safe and sustainable provision of quality food, fostering resource efficiency, combating climate change and to develop the circular economy. Digital technologies, such as Internet of Things, Big Data, Robotics and Artificial Intelligence, enable a transformation into data-driven, intelligent, agile, and autonomous farm operations that can be remotely controlled and are seamlessly integrated in the food chain up to the consumer.

Despite the overwhelming interest of tech companies, investors, and policymakers, the adoption rate of Digital Agriculture is still limited. In most EU member states, there is a consistent but small group of farmers that are frontrunners in this field, which are often seen as role models for other farmers. In fact, the majority of farmers does not yet adopt digital technologies or only invests in proven and tangible technologies such as auto-steering tractors or milking robots.

The current impact of digitalisation in agriculture is thus way below its true potential. Main reasons for this are the current fragmentation of knowledge and technology expertise in the proximity of farms, and the lack of promising business cases for farmers and business models for the technology providers. At the same time, it should be acknowledged that – unlike other industries – farming is more subject to sector- and region-specific conditions. Another barrier is the fragmentation and misalignment between the various types of public and private funding. Especially, where public funding ends in promising concepts or prototypes, private investors are hesitating to invest because the market potential is still unclear and it is difficult to assess the risks. Instead, they tend to invest a lot in promising start-ups, that have already a market-ready solution. However, this has led to a plethora of apps, while farmers need more integrated solutions.

SMARTAGRIHUBS IS CONNECTING THE DOTS FOR DIGITAL TRANSFORMATION IN AGRI-FOOD

To overcome these challenges, the EU-funded project SmartAgriHubs is building a pan-European network of Digital Innovation Hubs (DIHs), fostering a broad digital transformation in the agri-food domain. SmartAgriHubs leverages, strengthens and connects localDIHs, connected with Competence Centres (CCs). This 'ecosystem of ecosystems' combines the various expertise that is needed to unleash the potential of digital solutions and realise the digital transformation of the agricultural sector in Europe (Figure 1).

SmartAgriHubs builds a strong, multi-layered network of agricultural Digital Innovation Hubs and Competence Centres, to exchange knowledge and create a pan-European market for digital solutions for farming and food production. The project combines five basic concepts that are based on validated methodologies and models (Figure 2):

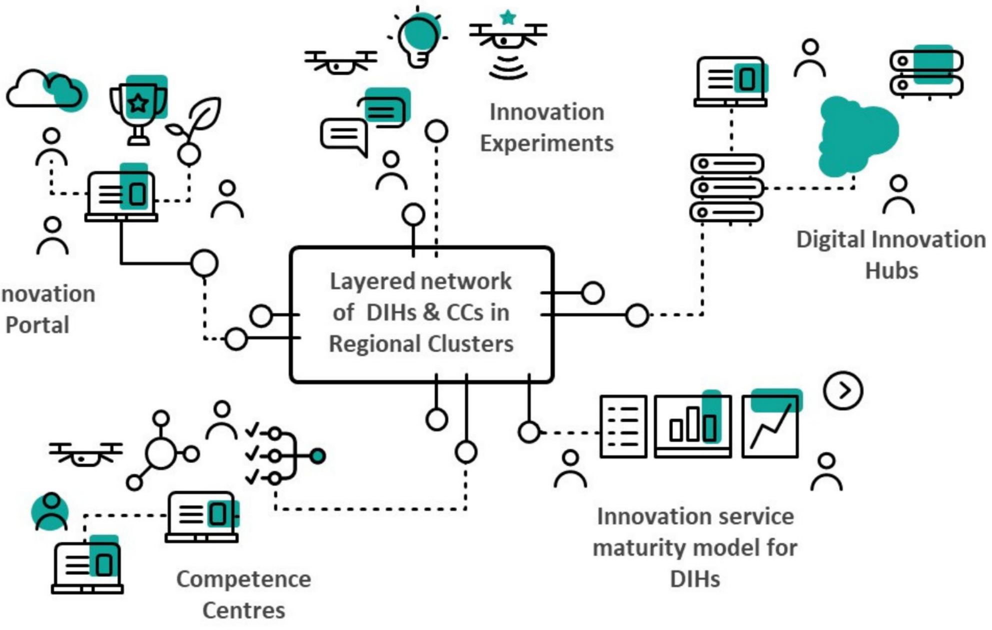

Figure 2 The 5 basic concepts to build up a multi-layered, pan-European network of DIHs.

A DIH refers to an ecosystem through which any business can get access to the latest knowledge, expertise and technology to test and experiment with digital technology relevant to its products, processes, or business models. It also provides the connections with investors, facilitates access to finance and helps to connect users and suppliers of digital solutions across the value chain (Figure 3).

Innovation Experiments (IEs) are developing and testing digital solutions in a real-life environment, conducted through DIHs, enabling access to the latest knowledge, expertise and technology (by CCs). IEs play a crucial role in the network expansion of SmartAgriHubs, strengthening the network of DIHs and CCs in numbers and quality of services.

SmartAgriHubs' Innovation Portal is a web-based interactive platform and a key instrument to support the ecosystem building at DIH, regional and pan-European level. It plays a crucial, central role in building the network of DIHs and the ecosystems around them.

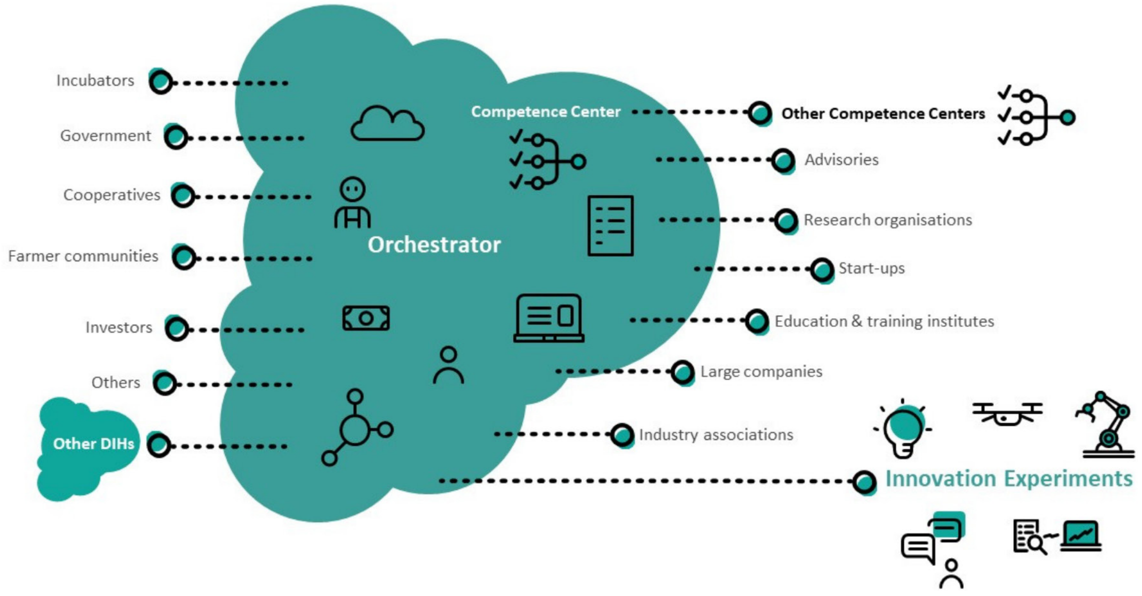

Figure 3 The Digital Innovation Hub as an orchestrator to connect various stakeholders to setup new Innovation Experiments.

SmartAgriHubs has expanded the number of DIHs to more than 300 and built a network of 160+ CCs that are findable and searchable through the so-called Agricultural Technology Navigator. Over 100 trainings of all kinds to improve the DIH innovation services are available and many more useful knowledge and information is available in the Innovation Portal. Through open calls many hackathons and challenges were organised leading to approximately 60 new IEs or related innovation activities. The 6 M€ public funding from the SmartAgriHubs project itself mobilized approx. 15 M€ of additional public and private funding. In this way, a vibrant ecosystem - with the network of agricultural DIHs as a kernel – was established, that will be sustained after the project.

MATCHING PUBLIC AND PRIVATE EFFORTS IN A RESPONSIBLE RESEARCH AND INNOVATION APPROACH

In conclusion, the digital transformation of agri-food has entered a situation where innovations have proven to be promising, but must be upscaled to a higher level of adoption and broader integration. The nature of digitalisation is evolving and has become part of a more complex ecosystem. The IT integration level is shifting from stand-alone applications that target single process operators to systems of systems that target complex business ecosystems in which many different stakeholders are involved. From a funding perspective, the challenge is to bring together the private and public sector to reap the benefits of both and make optimal use of the totally available innovation capital: the public sector benefitting from technological advancements in the private sector and the private sector benefitting from the research expertise often found within publicly funded projects.

A paradigm shift is needed involving multiple aspects such as collaboration, trust, inclusion around topics such as data sharing and new business models. A Responsible Research and Innovation approach, implemented in practice, can help to design better and more accepted digital solutions and improve uptake and should be based on:

- Innovation Experiments: experimental real-life environments in which all relevant stakeholders are collaborating on developing digital solutions, continuously interacting on technical as well as organizational aspects.
- Agile, iterative design - in which fit-for-purpose and user acceptance are leading and that can early detect risks and unintended consequences
- Multidisciplinary support and interaction - that concurrently deals with business modelling, data science and AI, governance at multiple scales, and ethics co-creating values and norms
- Ecosystem development - to upscale digital solutions stimulating cross-domain applications

This approach is embedded in SmartAgriHubs, leading to sustainable innovation ecosystems that will be better enabled to navigate towards sustainable food systems.

SMART PRECISION AGRICULTURE AND SUSTAINABILITY

Precision Agriculture requires innovative technologies and systems for its full realisation, many of which were not specifically developed for agriculture. Moreover, the industry's capacity to put technological solutions on the market is much higher than the capacity of producers to learn them and assimilate them into their cropping system, or of researchers to develop practical and agronomically useful solutions.

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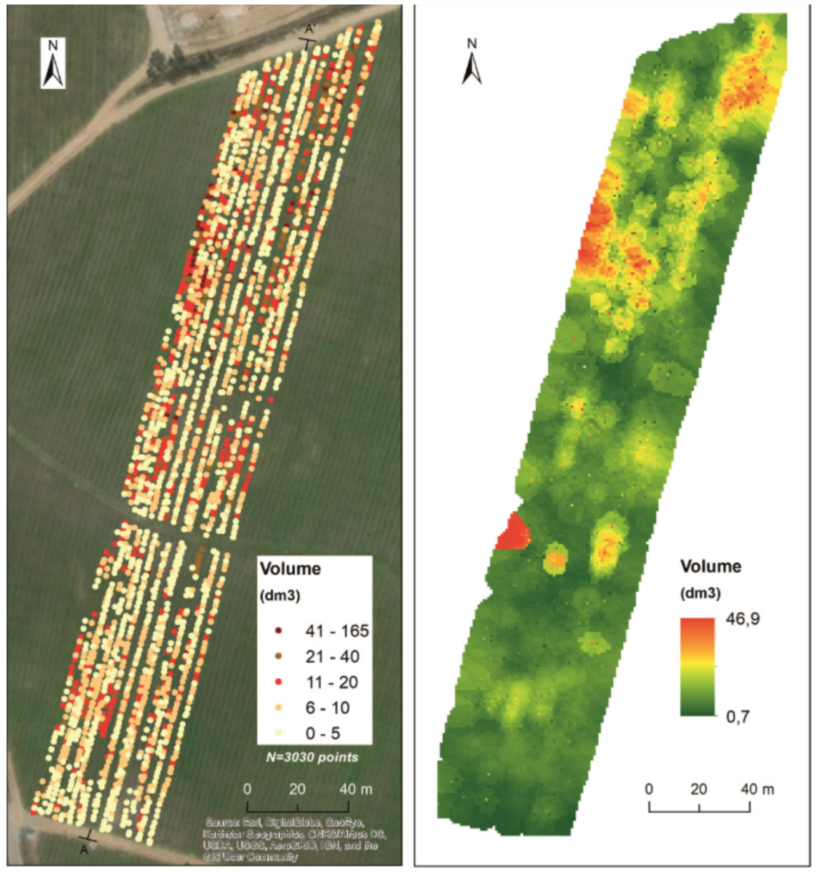

Figure 1 Technologies for detecting and mapping crop biophysical parameters to support precision agriculture.

What is the potential of Precision Agriculture (PA) for a sustainable future? How are PA´s objectives aligned with organisations and public policies? What is needed to leverage PA? These are some of the questions that this article aimes to address.

According to the International Society of Precision Agriculture (ISPA), PA "is a management strategy that gathers, processes and analyses temporal, individual and spatial data and combines it with other information to support management decisions according to estimated variability to improve efficiency in the use of resources, productivity, quality, profitability and sustainability of agricultural production".

This definition focuses on the essentials of the processes of using data to improve decision making. But obviously, the implementation of the concept encompasses the use of technology, more or less advanced, in its different phases: observation and recording; analysis; differentiated decision; and finally, the materialisation of the decision on the ground. Some examples of technology are multi-spectral images of crops (obtained by drone, satellite or terrestrial platforms), soil electrical conductivity sensors, or soil water sensors, productivity monitoring, the Internet of Things (IoT), geographic information systems (GIS), satellite positioning systems (e.g., GPS), variable rate technology, Artificial Intelligence (AI) and Machine Learning (ML) applications, among others.

The ultimate objective of improving decision making is the application of inputs in the correct amount, in the correct place and at the correct time (3 R's – Right Time, Right Place, Right Amount) depending on the production objective, and also considering the economic constraint inherent to any business. If this objective is achieved, that is, the optimisation of the use of inputs, then the convening between the needs of the crops and the availability of the different inputs, whether water or nutrients, will be ideal in each condition. As a result, not only obvious agronomic gains are achieved, but also cost reduction (once a certain production scale is achieved). Environmental gains are also fundamental, as it avoids inappropriate applications of inputs with greater polluting potential, such as nitrogen or phytopharmaceutical products.

This new production paradigm meets the challenges of the agricultural sector listed on the Innovation Agenda for Agriculture 2020-2030 (Terra Futura) to produce better (in quantity and quality) with fewer resources, in line with the sustainable use of natural resources and the adaptation to climate change scenarios. These challenges and their context are reflected in the Common Agricultural Policy (CAP) guidelines for the period 2020-2030 (Agenda 2030) and in the UN Sustainable Development Goals (SDG's).

Specifically, the "European Ecological Pact" refers to PA as a mechanism for implementing its "Farm to Fork" strategy, which must be guaranteed in the national strategic plans for agriculture. PA has a proactive role in supporting the strategic implementation of the SDG's. By promoting more efficient agronomic decisions and practices, PA is in line with SDG2, SDG12, SDG13 and SDG15 objectives, namely by contributing to ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, help to maintain ecosystems, strengthen the capacity to adapt to climate change, extreme weather conditions (e.g., droughts) and progressively improve the quality of the land and soil. PA promotes inclusive and sustainable economic growth, full and productive employment, especially for young people, and decent work for all, as referred to in SDG8. The implementation of PA to be efficient requires an "innovation ecosystem" (according to the editorial) that promotes scientific research and technological development, making PA also aligned with SDG9.

However, PA requires innovative technologies and systems for its full realisation, many of which were not specifically developed for agriculture. Moreover, the industry's capacity to put technological solutions on the market is much higher than the capacity of producers to learn them and assimilate them into their cropping system, or of researchers to develop practical and agronomically useful solutions. In this context, PA is still a marginal reality in Portuguese agriculture, as only 0.3% (5% in terms of arable land) of agricultural companies have adopted some type of technology. These figures contrast with the agriculture of North and South American countries or Australia, where PA technologies are present in more than 30% of agricultural companies.

This gap between the adoption of the PA by Portuguese companies concerning some foreign counterparts can only be mitigated by an effective liaison between the actors of the "innovation ecosystem" necessary for the implementation of PA: "end users", "technological companies" and " scientific system" (in addition to crop input companies, production organisations, among others). Currently, PA in Portugal has a great opportunity to boost the establishment of this "innovation ecosystem" through, for example, the national strategy for smart specialisation (ENEI) and collaborative laboratories (CoLAB) with recognition of the mutual benefits of work in efficient partnerships of PA's "multi-actors", the co-design of technological development, service creation and training.

The full adoption of the AP will tend to value the core competencies of primary production engineering through the integration of differentiating agronomic knowledge valued in technological markets into dense value chains, which will require trained human resources to operate in the different vertices of the triangle of "innovation ecosystem" of PA, with predictable social value, within the framework of the challenges of sustainable development.

The challenges facing the agricultural sector over the next 30 years are significant. We believe that PA will make a decisive contribution to the development of solutions that are necessarily sustainable in all their dimensions.

SMART PRECISION FOR SUSTAINABLE LIVESTOCK

Precision Livestock Farming technologies have many potential areas of application: feeding strategies, welfare, health and reproduction management. Genetic selection also has much to gain from this high throughput information, with genotyping being much less limiting today than large-scale phenotyping of traits of husbandry interest. However, most technologies focus on intensive farming systems and are still relatively rare in extensive farming.

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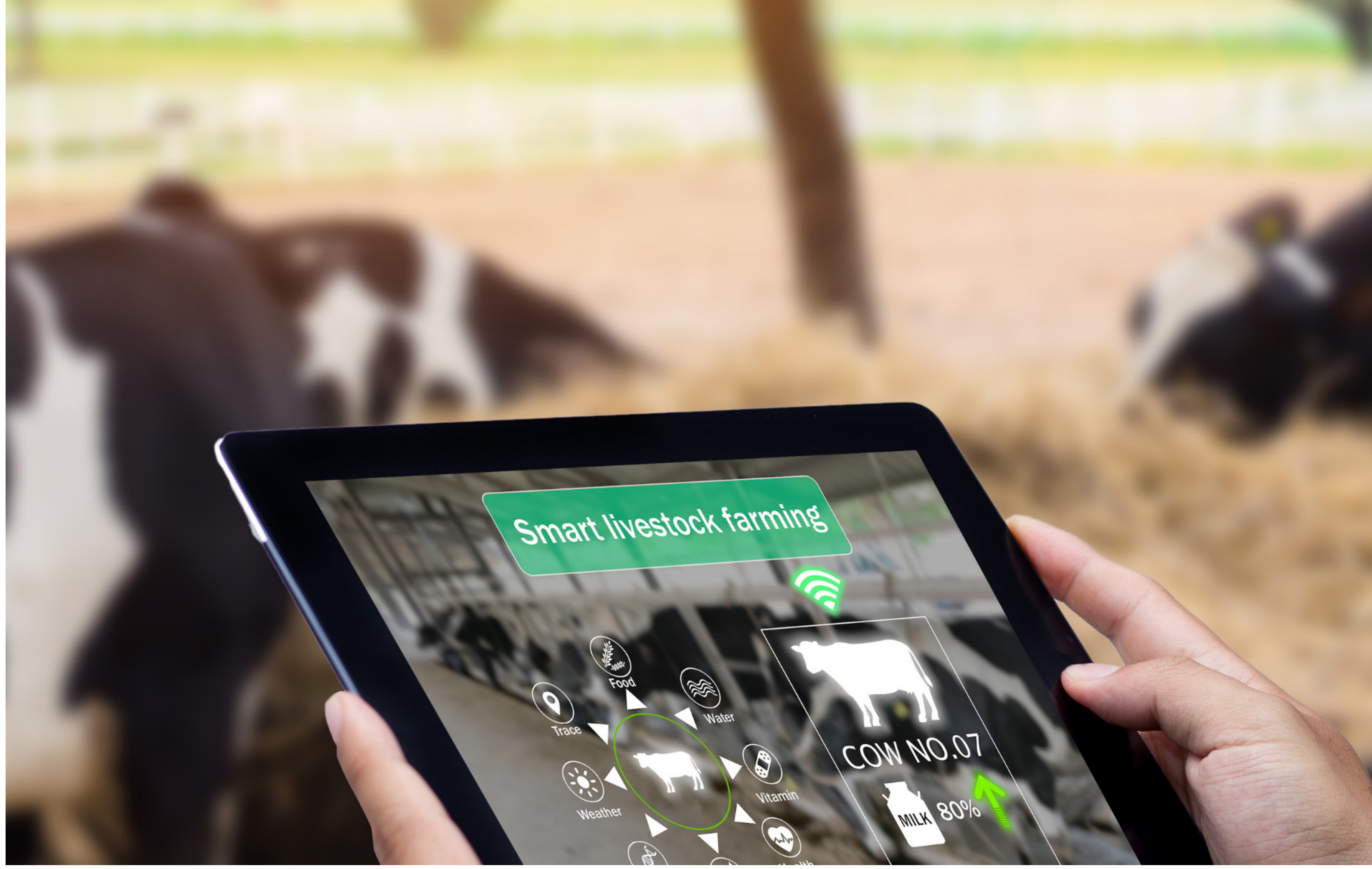


Figure 1 Smart livestock farming.

The ability to feed a growing population, which is expected to reach around 9.7 billion people by 2050, while minimising environmental impact, preserving human health, and addressing society's rising concern over animal welfare, is currently a huge challenge. Precision Livestock Farming (PLF) is potentially one of the most powerful developments amongst several interesting new and upcoming technologies with the potential to revolutionise livestock farming systems.

The primary goal of PLF is to make livestock farming more economically, socially, and environmentally sustainable, through the observation, interpretation of behaviours and, if possible, individual control of animals. Adopting PLF to support management strategies, may lead to the reduction of the environmental impact of farms (Schillings et al., 2021). PLF technologies are designed to support farmers in livestock management by monitoring and controlling animal productivity, environmental impact, as well as health and welfare parameters, in a continuous real-time and automated manner (Berckmans, 2014). PLF can be defined as: "the application of process engineering principles and techniques to livestock farming to automatically monitor, model and manage animal production".

The aim of PLF is to manage individual animals by continuous real-time monitoring of health, welfare, production/reproduction, and environmental impact. This means that PLF technology has the potential to measure and analyse every second, on a 24/ 7 basis, encompassing the full chain: from feeding to the consumption of animal-related products. Farmers can get a warning when something goes wrong, with the PLF system alerting to the animal(s) that require care at a given moment. The monitoring can be done via different types of sensors, including cameras and microphones, as well as sensors around or on the animal. The value and potential of the information is most evident when acquired data is processed in real-time. This is already a reality in top poultry pavilions, where animals are continuously monitored and housing conditions are monitored at the smallest details (ventilation, temperature, humidity, feeding and water lines, etc...).

Literature shows the potential of the application of PLF in farms, leading to a reduction of greenhouse gasses (GHG) and ammonia (NH3) emission, nitrates and antibiotics pollution in water bodies, phosphorus, antibiotics and heavy metals in the soil. If we consider precision feeding, for example, this will allow an increased digestive efficiency and, consequently, a decrease of nutrient loss (being methane in the case of ruminants, of N and P excretion in the case of pigs). Practical applications of precision feeding, particularly in terms of individual feeding, can have a major impact on the sustainability of production systems. It provides almost immediate and tangible benefits in swine production, for instance. Recent studies show that feeding individual animals with individualised diets reduces lysine intake by more than 25%, feeding costs by about 8%, nitrogen and phosphorus excretion by almost 40%, and greenhouse gas emissions by around 6% (Remus et al., 2019).

PLF technologies have many potential areas of application: feeding strategies, welfare, health and reproduction management. Genetic selection also has much to gain from this high throughput information, with genotyping being much less limiting today than large-scale phenotyping of traits of husbandry interest. However, most technologies focus on intensive farming systems and are still relatively rare in extensive farming.

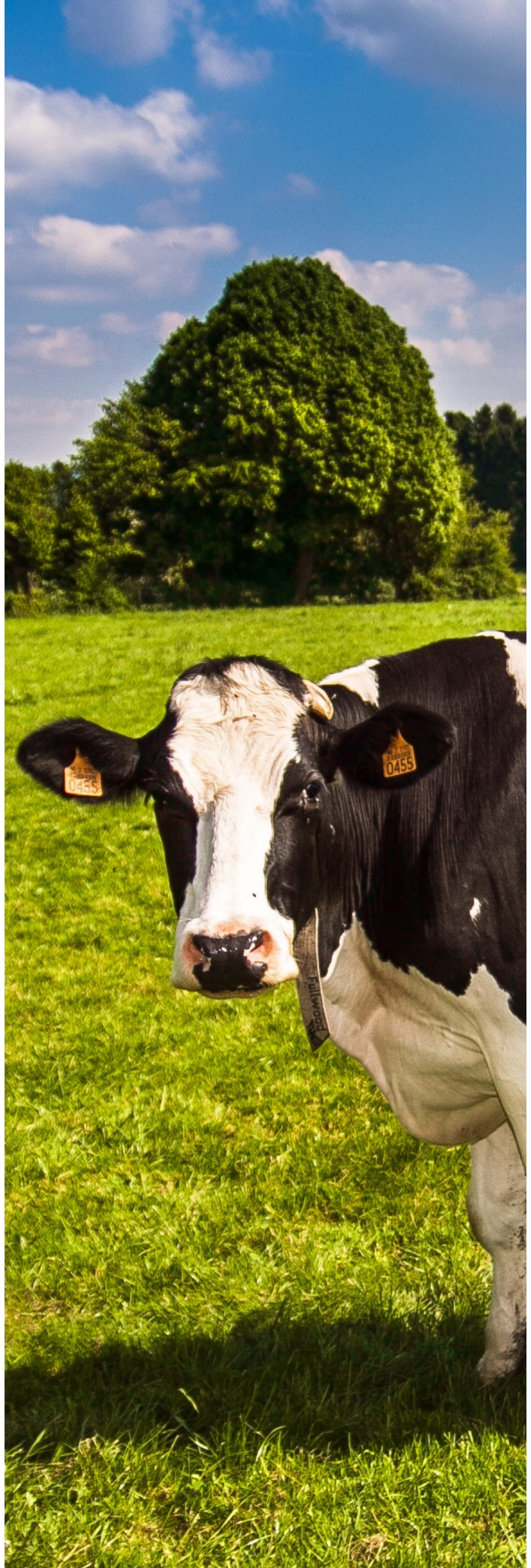
The usefulness of continuous monitoring of the many possible associated variables entails the automated processing of significant amounts of acquired standardised data and opens new possibilities with regard to production methods. Strategic harnessing of data processing, artificial intelligence and computer learning technologies will be critical to fully exploit the potential of PLF (ATF, 2020).

If properly implemented, PLF can (1) improve, or at least objectively document animal welfare on farms; (2) reduce greenhouse gas (GHG) emission and improve environmental performance of farms; (3) facilitate product segmentation and better marketing of livestock products; (4) reduce illegal trading of livestock products; and (5) improve the economic stability of rural areas. However, there are still only a few examples of successful commercialisation of PLF technologies (Berckman, 2017). The integration of PLF into the industry requires: (1) establishing a new service industry; (2) verifying, demonstrating and disseminating the benefits of PLF; (3) coordinating the efforts of different industry and academic organisations interested in the development and implementation of PLF technologies on farms; and (4) encouraging the commercial sectors to support through professionally managed product development (Banhazi et al., 2021).

The current technological reality provides exciting opportunities for the monitoring and management of environments, such as IoT technologies, low-cost and high-capability sensor devices, computer vision and artificial intelligence, especially machine learning. In the context of PLF, these can provide tools to help farmers remain competitive while meeting environmental and societal requirements and challenges. However, technology cannot be seen as a farmer replacement and applied blindly. Instead, they should provide the maximum information supporting farmers as decision-makers. The involved biological processes are far too complex to replace farmers by technology, but these offer more possibilities to save money, change farmers' lives by spending fewer working hours, and get a monitoring and management system to better approach the genetic potential of today's livestock species.

The penetration of technologies for the implementation of PLF needs to overcome farmer's technology illiteracy and be financially accessible to the sector. Hence, the development of suitable systems needs a close collaboration between people from different sectors, scientific disciplines, and technical fields. This appears to be difficult because each actor is often focused on pursuing their own individual goals with the underlying concern of assuring their financial survival.

To bring PLF technology further into field application, increased development and testing of PLF technologies is required in real farms to implement reliable solutions. This proximity will not only enable validation of technologies, but also promote dialogue and bring sectors together. Interface structures such as INESC TEC and FeedInov CoLAB are perfect partners and actors to boost the promotion and R&D regarding PLF in Portuguese territory. By themselves, these entities represent the two main scientific areas, but their role in society also supports the proximity of farmers and technologic companies.



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SMART PRECISION FORESTRY

"Digitalisation in the forest", as this phrase itself suggests the sustainable implementation of cutting-edge technologies for forestry, improving forest monitoring through data acquisition and analysis, and computerised decision support aids to electronic control, machine vision, supply chain planning and post-harvest management.

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Figure 1 The new ARG forestry machine is based on partial mobilisation for land preparation, promoting plant growth, increasing organic matter conservation, and improving water retention, which contributes to increase soil carbon sequestration. With new Forest 4.0 digital tools, this machine contributes to forest sustainability, as it promotes efficiency and safety of forestry operations with consumption and costs savings and a greater environmental gain. Photo: The Navigator Company and Fravizel (Project rePLANt)

Forests provide crucial ecosystem services to human societies and host the largest share of terrestrial biodiversity. Wood and other renewable raw materials from forests have numerous applications – furniture, paper, construction industry - and biofuel for bioenergy generation. European Forest-based industries employ about 3.5 million people and represent about 7% of EU manufacturing GDP . .[1] In many rural areas, the forestry sector is the largest employer. Furthermore, forests play a crucial role in the goals of carbon neutrality and mitigating climate change effects, as one of the most important natural carbon sinks and the source of biomaterials and biofuels, capable of replacing emission-intensive materials and fossil fuels.

A sustainable adaptation of forest ecosystems, modulated by more resilient and adaptative management strategies to meet the needs of current and future generations (in contrast to an uncoordinated adaptation), is required to face the challenges of this sector. Forest-based value chains should engage technological capabilities for preventing, containing, and mitigating climate change effects and increase resilience towards risks - such as forest fires. To achieve a more resilient supply chain, we need to increase the use of forest residues and the efficiency of woody biomass processing and transport, fostering the link between the bioeconomy and the circular economy. Public policies point to an increase in the contribution of the Portuguese forestry sector (biomass included), whose current contribution to the bioeconomy is estimated at 38.6 billion euros in 2014, according to the report by the European Forest Institute . [2]

"Digitalisation in the forest", as this phrase itself suggests the sustainable implementation of cutting-edge technologies for forestry, improving forest monitoring through data acquisition and analysis, and computerised decision support aids to electronic control, machine vision, supply chain planning and post-harvest management. Technologies that can be used effectively to achieve these objectives include the Internet of Things, Wireless Sensor Networks, Internet of

Trees, Deep Learning, LiDAR Technology, drones, geospatial data, and mobile apps. [3]

Portugal has witnessed an increasing mechanisation of forestry operations, particularly in forestry exploration and use of forest biomass, upstream operations related to the installation and maintenance of stands (see fig. 1), and fuel management to reduce fire risk. Recent forestry machinery is generally equipped to collect and report data for remote monitoring of material flows (quantities produced), equipment productivity and utilization rate (e.g., OEE), and operations status. However, this information is not collected or processed systematically. The solutions adopted for collecting and sharing data between landowners, service providers, and industry should allow remote monitoring of field operations, ensure transparency, and allow replanning/redeployment of resources to avoid efficiency losses in the use of the equipment and teams' performance. These problems tend to worsen with the growing workforce shortage in the sector.

Forestry and wood supply chains are developing the idea of Forest 4.0 by combining solutions available on the market for several years, such as LiDAR (see fig. 2) and RFID, but not widely used in the industrial forestry context, with the implementation and adoption of new technologies. This transformational and organisational change process shows challenges of a technical and socio-economic nature. Most of them are similar to other industrial sectors. The introduction of data standards between all equipment and operations is one of said challenges. The security of IT systems and data protection is another challenge, as ownership of data should be discussed with all stakeholders. Other forestry-specific challenges are the robustness and reliability of the equipment (sensor usage in an outside environment, the wireless transmission of data, and the complexity of the forest operations). The transformational aspects of the forestry digitalisation result in socio-economic challenges. The main challenge for the forestry sector is the willingness to cooperate across organisational borders and the trust in other organisations within the supply chain, which handles its high stakeholder fragmentation. [4]

The greater participation of all players in the forest supply chain is key to overcome these issues. These initiatives involve dissemination actions, workshops, webinars, and projects that mobilise forest owners, forest organisations, service providers (biomass, forestry, wood and non-wood products), suppliers (fertilisers, plants, and machines), paper, furniture, and energy companies, end customers, and technology providers (who will promote and commercialise the solutions developed by universities and research centres, and tested in pilot demonstrators).

The integration of these various levels of knowledge, innovation and technology is essential for the environmental, social, and economic sustainability of European forests and rural areas.

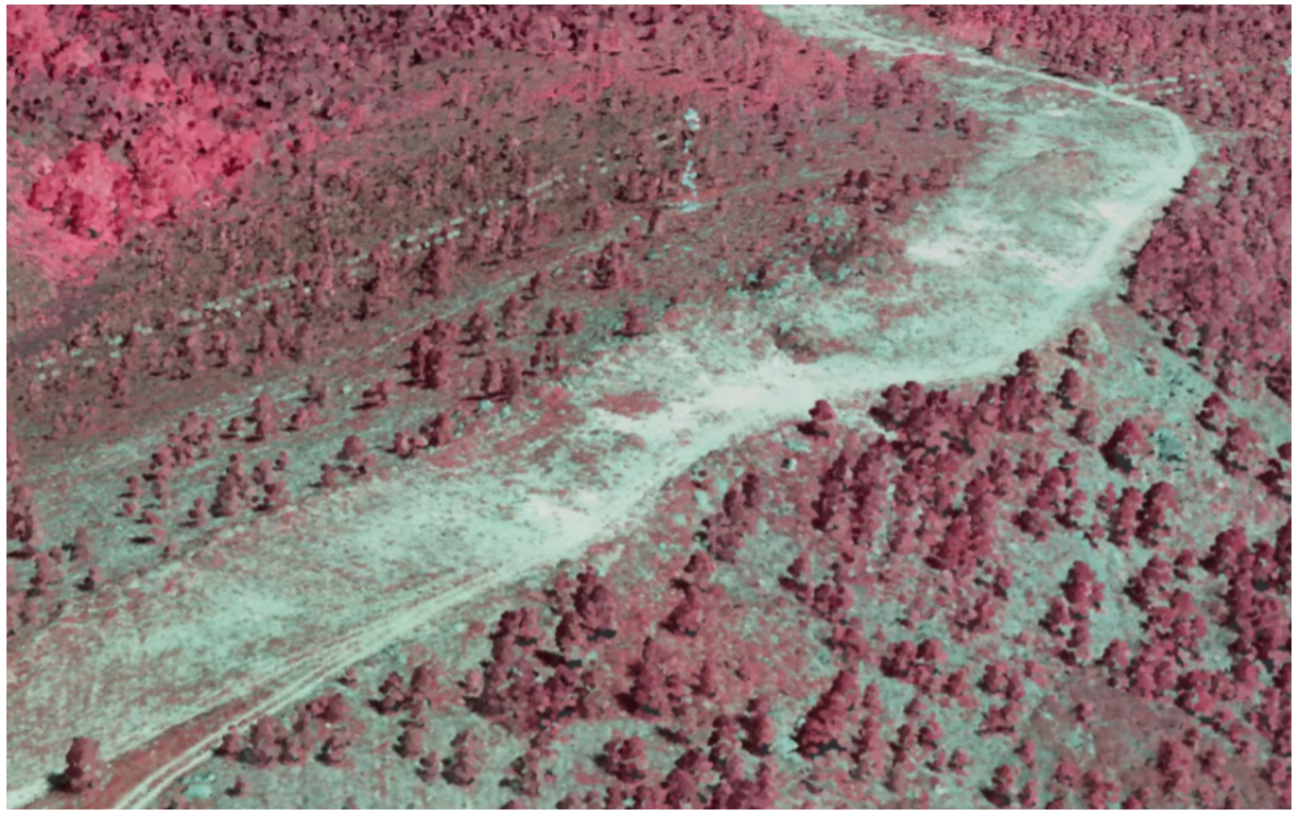

Figure 2 Data about forest structure and biomass fuels accumulation are increasingly important and demanded, as they are critical to forest planning and management and to prevent big rural fires. LiDAR (Light Detection and Ranging) technology provides detailed forest knowledge, including risk exposure and intervention priority areas. These data are an essential support to decision-making processes. Photo from project áGIL/ForestWISE/ICNF.

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GEOSPATIAL INFORMATION SYSTEMS IN AGRICULTURE AS THE KEY FOR DECISION MAKING

The ongoing farm management is currently supported by information on crops, growing conditions, seasonal progress, as well as on the impact of climate change, among others. The quality and timeliness of the information available is a critical factor that determines the quality of the decisions taken and, therefore, the quality of the results - of the crops produced and, ultimately, of the economic profitability.

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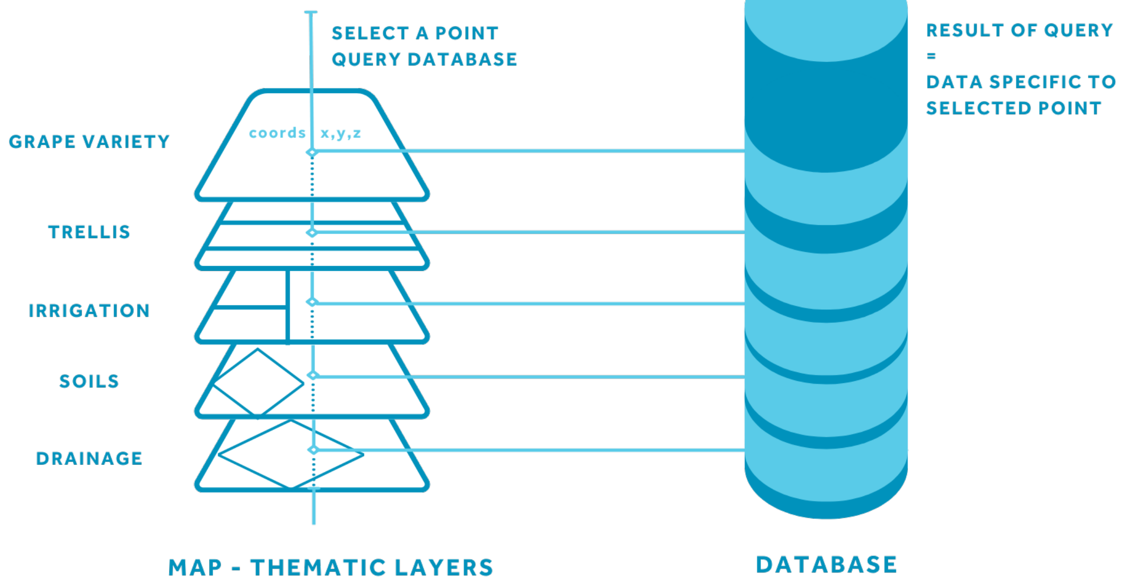


Figure 1 Aggregated maps in a spatial database (Map Query, of space and related data other query options would be – select an area, or zones of proximity)

The "decision support" concept refers to "organised efforts to produce, disseminate and facilitate the use of data and information" to improve decision making. It includes processes, decision support tools and services. Some examples include methods to assess trade-offs between options, future scenarios used to explore the impact of alternative decisions, vulnerability and impact assessments, as well as tools that help people find, organise, and display data in new ways. The results of effective "decision support" processes include building relationships and trust that can support long-term problem-solving capacity between knowledge producers and consumers.

"Decision support" activities that facilitate well-structured decision processes can result from a consensus on the definition of the problems to be addressed, objectives and options to be considered, criteria for evaluation, opportunities, potential consequences and options.

In the specific case of agriculture, the ongoing farm management is currently supported by information on crops, growing conditions, seasonal progress, as well as on the impact of climate change, among others. The quality and timeliness of the information available is a critical factor that determines the quality of the decisions taken and, therefore, the quality of the results - of the crops produced and, ultimately, of the economic profitability. As most of the information is linked to site location, spatial (geographical) relevance is a key feature of the data that can be made available. The relevance and applicability of spatially related and analysed information is one of the main motivations for its use in a decision support system, as many variables that affect crop quality are, inherently, of spatial nature.

Additionally, there are still insuficient technological tools based on spatial data infrastructures in the market, which, in an integrated and standardised way, provide a collection of maps with different information layers (e.g., land drainage, soil, irrigation) comprising a spatial database (Figure 1).

A system of this type allows the exploration of spatial correlations, associating attributes and functionalities that support the analysis of patterns and processes in a given farm. Another capability that stems from the use of a spatial data infrastructure applied to agriculture is the analysis of spatial extents with common characteristics, phenomena or similarities (or specific differences). This includes proximity to other plant species, agricultural zoning, fauna, or other integrated sets of information. A thematic Spatial Data Infrastructure in agriculture promotes and develops automated data analysis with the production of aggregated digital maps (Figure 2), or images, presenting specific reports to the farmer or producer for appropriate decisions and actions.

As an illustration, identifying potential agricultural plots of superior quality based on spatial patterns identified from certain areas that have orographic, soil, or other specificities, allows understanding and confirming the contributing factors to enhance quality.

The consolidation of all this information, presented graphically, intuitively and in real-time, will always be very relevant to decision support in mitigating problems.

One of the most critical problems today is the impact of climate change on agriculture. Climate projections should be based on a set of anthropogenic greenhouse gas emission scenarios. These scenarios allow the incorporation of uncertainties related to the different pathways of global socio-economic development in the upcoming decades. Moreover, these scenarios must also be based on different simulations, generated by different climate models (multi-model ensembles), thus allowing the assessment of the uncertainty regarding physical modelling, model initialisations and parameterisations. The accurate assessment and integration of uncertainties are essential for effective decision support. Furthermore, the spatial resolution of the global models (about 100 km) is insufficient to the useful application in agriculture. Therefore, the development of downscaling methodologies is key. These methodologies can be dynamic, by coupling regional climate models (spatial scale of about 10 km) into global models, in both cases physical-mathematical models. Subsequently, this information can be complemented with geostatistical methodologies that allow the reduction of the spatial scale to values of the order of 1 km. When networks of sensors are installed on farms, it is even possible to further reduce the information to lower scales (meters), allowing to addressthe microclimatic patterns of a given plot. In these cases, hourly data or even lower timescales can still be solved.

The use of diverse and extensive geographic information existing at the territory level, supported by the collection of agronomic information -namely on the phenological evolution, levels of water stress that the cultures are subject, degree of maturation and productivity - allow, on the one hand, the adoption of practices that mitigate the effects of climate change in the short term (e.g., application of deficit irrigation), and on the other hand the adoption of long-term mitigation measures (e.g., selecting more climate-resilient crops). Nonetheless, the collection of this type of agronomic and climatic information, at the level of each agricultural plot, located in different microclimatic and edaphic conditions, is not feasible to be carried out by each farmer. Besides, since this information can be extrapolated to a regional level (e.g., for a certain region), being most appropriately used by a certain sector, it can and should be complemented with climate information adapted/modelled to the territory (e.g., incorporating the impact of orography, solar exposure or geological information). The need for more and better information, namely in real-time, using networks of sensors in the field, collecting spatial-temporal data in a wide and integrated way, becomes essential to support effective decision making.

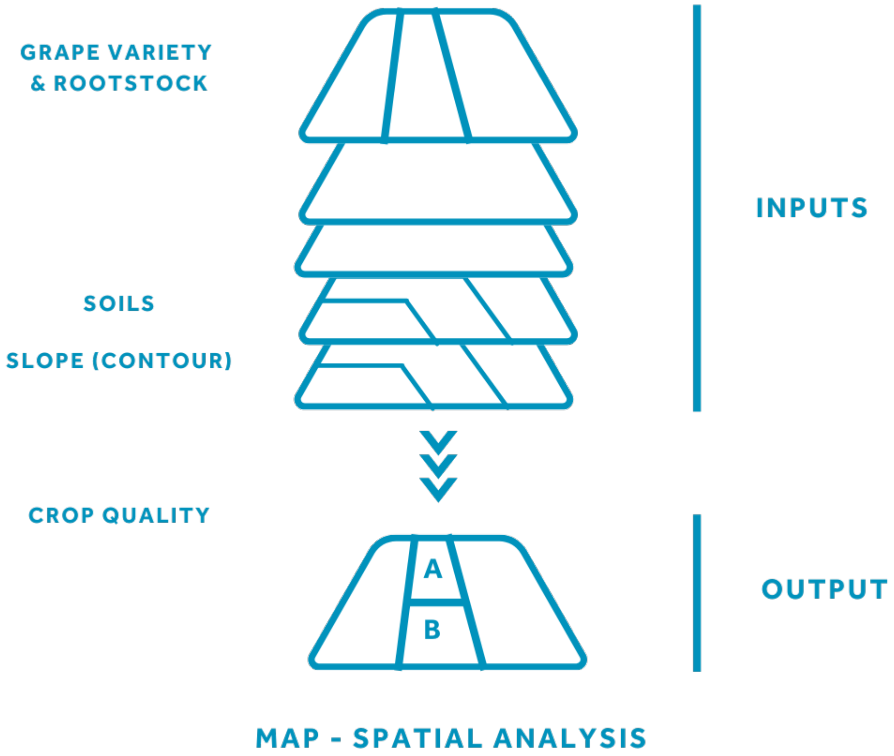
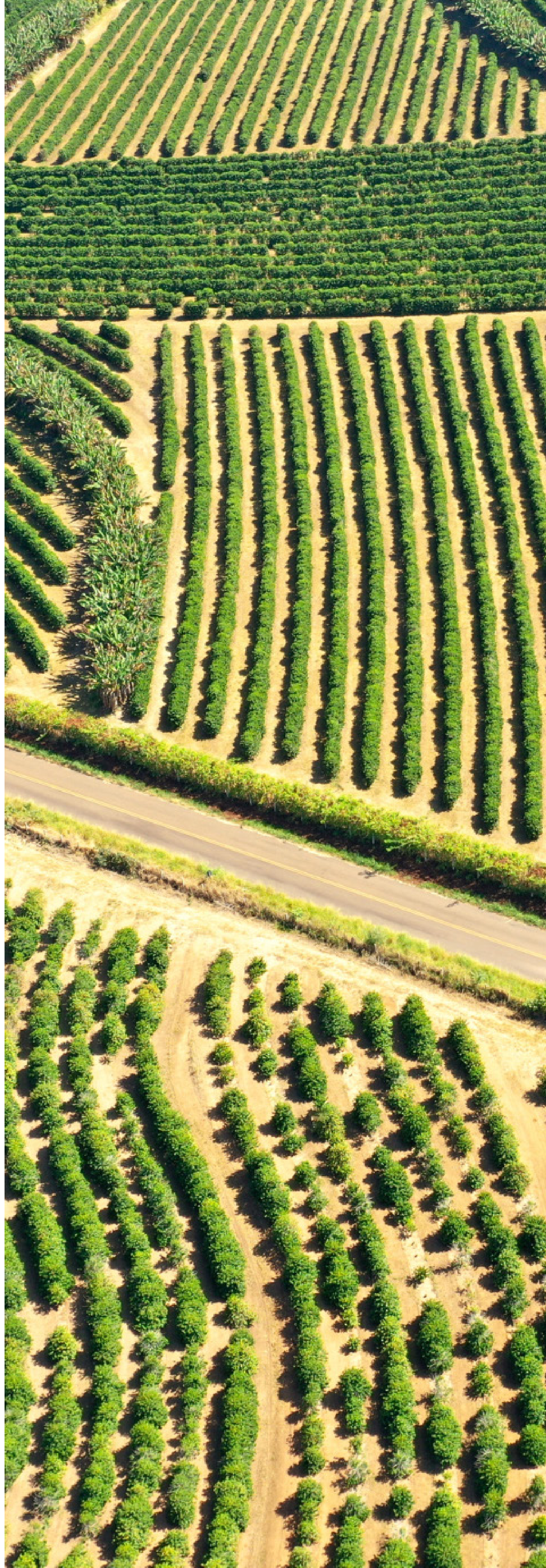


Figure 2 Aggregated maps in a spatial database (Map Query, of space and related data other query options would be – select an area, or zones of proximity)



AUTOMATION AND ROBOTS FOR A NEW AGE OF AGRICULTURE AND FORESTRY

How can robotic and automation technology support the reduction of overdosage of agricultural inputs (nutrients, water and farm chemicals)? How can robotic and automation technology support a better and more positive interaction between the production of the desired plant and remaining ecosystems? How can robotic and automation technology support a better quality of life for farmers?

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Figure 1 INESC TEC robot in tests in the forest.

AGRICULTURAL AND FOREST NEEDS CONTEXTUALISATION

Agriculture and forests are fundamental to sustain the world population. Both are fundamental to provide us with food, oxygen, wood, and raw materials for clothes or even furniture. Since they generate fundamental inputs to our survival, as a society, we have explored intensively agriculture and forest without considering the limited resources available on earth, and the need for a balance between plants, soil, water, animals, insects (sustainability). This overexploitation of agriculture and forests has given a fundamental contribution to increase our living quality, during the last century. However, it has also contributed to climate change, to the waste and overuse of nutrients, water, farm chemicals products, and soil. From this point of view, and according to a technology outlook, we can rise the next questions:

Question 1: How can robotic and automation technology support the reduction of overdosage of agricultural inputs (nutrients, water and farm chemicals)?

To extract the maximum production/yield from the fields, we have looked, as a society, to agriculture as a factory system, where we tried to simplify the production system, for example using just one crop (and plant variety) to simplify the production systems, and artificially fully organising and eliminating any kind of interference from ecosystems/nature by the means of overuse farm chemicals products. Besides, when we compare innovation on agricultural/forestry practices against industry practices, we notice that agricultural and forestry practices had witnessed less innovations, most of the time adopting the same approaches. These approaches are always trying to simplify the processes and trying to eliminate any unwanted interference from ecosystems/nature, as we work in closed factories where we can control all the processes. Plants originate in nature, with an enormous quantity of interactions with other ecosystems. Hence, another question emerges:

Question 2: How can robotic and automation technology support a better and more positive interaction between the production of the desired plant and remaining ecosystems?

Agriculture and forest, like other sectors, need humans to carry all operations and tasks needed to create the product of interest. Most of these tasks are labour-intensive, time consuming, far way from urban centres, and often performed in specific time windows (e.g., cannot be postponed to the weekends). However, since we increased the quality of life of our society, each person wants better and qualified jobs. Since agriculture and forestry-related tasks aren't always well remunerated or as appealing as other jobs, these sectors face a significant labour shortage problem, thus leading to another question:

Question 3: How can robotic and automation technology support a better quality of life for farmers?

ROBOTICS AND AUTOMATION AS AN ANSWER TO AGRICULTURAL AND FOREST NEEDS

To answer the previous questions, we need to explore the Precision Agriculture (PA) concept. PA is the most acceptable approach to reach more efficient agriculture and forestry sectors. In PA, we find the concept of applying "the right product, in the right time, in the right spot and in the right quantity", which requires the use of Variable Rate Technologies (VRT). VRT considers the use of prescription maps, supplied by Decision Support Systems (DSS), and Global Navigation Satellite Systems (GNSS) to enable the PA concept.

With this contextualisation in mind, we can address the main questions presented; regarding the first(How can robotic and automation technology support the reduction of overdosage of agricultural inputs (Nutrients, water and farm chemicals products)?), the overdosage/application of macro-nutrients (such as nitrogen (N), phosphorus (P) and potassium (K)) is a main issue, since NPK is quite problematic in terms of agricultural costs and negative impact on soil and groundwater quality. Here, the use of VRT can play an important role. The use of machinery tractors with VRT is already a reality, mostly in extensive crops, but not yet fully disseminated in small farms and permanent woody crops, due the inexistence of cost-effective technology and adapted machinery/robots to each crop needs/requirements. In the future, robots will play a fundamental role in performing NPK soil and plant monitoring tasks that will feed the DSS with more accurate data, thus enabling highly detailed prescription maps for NPK. In contrast, the overdosage or losses (to air or soil) on the application of farm chemical products is still a reality in agriculture. Robotic and automation technology could address this question. The use of farm chemical products has a well-defined target application time-window; failure to comply with it leads to higher doses and a negative impact. Robots can carry out near optimal treatments and fertilisation, because they can transport advanced sensors and actuators for precision monitoring and treatment/fertilisation process; more importantly, they can operate 24/7, enabling them to reach the optimal time and right moment. Besides, robotics technologies enable faster operation with higher levels of precision and accuracy.

Concerning the second question (How can robotic and automation technology support a better and more positive interaction between the production of the desired plant and remaining ecosystems?), if we ignore concepts like greenhouses (probably the most sustainable approach to produce food, but also the most expensive) fully isolated from the remain ecosystems, we need to keep in mind that agriculture and forestry in open fields should not be perceived as isolated systems; in this sense, the adoption of poli-crops, poli-variety and biological concepts could bring significant positive effects (for food quality, safety, yield). However, these concepts are hard to accept/consider because they are very labour-intensive - even with most advanced machinery -, unless we can consider the use of robots. As seen before, robots can help to reduce the overdosage of fertilisers and nutrients, relevant to increase agriculture and forestry sustainability, enabling a balance between plants, soil, water, animals, insects. But more importantly, robots can support the application of biodegradable and bio-friendly treatment products in a preventive way, while ensuring the continuous monitoring of diseases to avoid the application of more harmful products. In the same line, robots can be considered for precision pollination (for example, micro drones), vegetation control (mowing robots), seeding and weeding control, fertilisation and spraying, and all operations relevant to increase open field farms sustainability.

How can robotic and automation technology support a better quality of life for farmers? Without automation, agriculture becomes highly labour-intensive and physically demanding. Automation (namely weeding, fertilisation, harvesting) has increased the quality of life of farmers, yield and profits. However, automated solutions are not accessible to all farmers, due their cost and lack of adaptation to the specific needs of each farm and crop. Robots are becoming commercial and accessible, but just like automation, these technologies will not become widely accessible to all farmers (smaller and bigger) and all crops (extensive and woody crops). These robots can help to increase the quality of life of farmers, profits, and yields, while promoting rural development. However, there are several barriers to the adoption of robotic technology, which should be addressed, namely:

- Provide agricultural and forestry robots as a service, to reduce the risks and increase the return of investment for farmer.
- Increase the number of robotics manufacturers (make small and medium machinery manufacturers able to produce robots) to boost the number of solution providers, reduce prices and expand the number of solutions to satisfy the needs of small farmers and crops specificity.
- Create more adequate legislation for drones and ground robots, to reduce operation costs and enable real farm automation; and,
- Further develop robotic safety certification, liability, and insurance models to reduce risks and costs for farmers.

Figure 2 INESC TEC smart traps.

ARTIFICIAL INTELLIGENCE IN AGRICULTURE

CHALLENGES, BENEFITS, AND USE CASES

In order to present an idea of the benefits of using artificial intelligence (AI) in agriculture, we explore three use cases: water management, production estimation and human resources management.

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Figura 1 INESC TEC robot in tests in a vineyard.

Water management: If we think that: (1) the agriculture sector is, according to the United Nations, an activity that requires around 70% of all the water we consume worldwide; (2) some areas of the globe are feeling the impact of the global warming, namely having less availability of water for agriculture [1]; (3) and the optimised use of the water influences the quality of the production. All these notions show us the importance of optimising the use of water in agriculture. Within the scope of the Smart Farming project, INESC TEC has developed an irrigation system for a vineyard that allows to manage the irrigation according to the intended hydric stress that is expected to generate in the plants. The amount of hydric stress in the plant conditions the alcohol content of wine that is produced with these grapes. In order to produce the irrigation management system, it was necessary to have sensors at different depth in the soil. We also considered the predawn leaf water potential (PLWP), measured using the Scholander Pressure Chamber. However, due to the cost of obtaining PLWP measures, a regressor to estimate the PLWP was developed [4]. These estimations are used in the optimisation method to define the amount of water for irrigation over the next seven days. Genetic algorithms were used as optimisation method.

Production estimation: agricultural production is strongly sensitive to climate. Current climate change can disrupt the environment and change pest and plagues behavior, causing large inter-annual variations in crop production that do not match the constant growth in demand. Moreover, crop production is affected by farmer decisions such as irrigation, fertilization, and selection of crop seeds. Unpredictable inter-annual variations in crop production are a major threat to farmers, industry, and society. Therefore, there is a strong demand for predictive models that can improve the production efficiency, optimise the production plan/operations and support commercial strategies [1,2]. There is still a great lack of operational methods, particularly to predict the weather and production at farm level. Crop simulation models and data–driven models are the basis of the most popular approaches for crop yield prediction. The crop simulation models are very complex and expensive in terms of time and biophysical data requirements, thus hindering its operation. Data-driven predictive models of yield predictions are built empirically, and do not require a deep knowledge on biophysical mechanisms that produced the data; they are inexpensive and already proved to be extremely efficient methods [1, 2, 3]. Therefore, during the last few years, several

Machine Learning techniques such as regression trees, random forest, support vector machines and deep learning have been successfully applied to forecast crop yield. Most of these predictive methods explore climate data (e.g., NWP) and crop related information (e.g., phenostages) to make predictions. Moreover, these predictions can then be used as input to a mathematical optimisation model that can find the optimum production plan [2,3].

Human resources management: in order to hire experienced workers, producers are starting to offer higher salaries and benefits to their staff, like health insurance. This issue raises a concern that was not previously in mind of producers: are my workers doing the job properly? Is the effort proportional to the salary and benefits? Such concerns require productivity indicators of each worker, which paves the way to a new area in agriculture and fruticulture, related with the need to implement technologies for workers' monitoring. INESC TEC researchers believe that workers' monitoring might be of high benefit for the employee and the workers themselves, if we consider that not only productivity indexes can be estimated, but also health related indicators, important to ensure well-being and good working conditions, and support more informed decision-making. INESC TEC is already tackling this issue with a national project named AgWearCare, which aims to apply this monitoring concept to retrieve specific indicators in this area, together with WiseCrop solution. A system like this could have a wide range of advantages, such as understanding the distance made by each worker in a vine harvest, identifying the worker posture or even detecting exposure to extreme working conditions or high levels of human effort (combining wearable devices with advanced data processing and artificial intelligence methodologies). Like all amazing technologies, there are always disadvantages – to what extent would workers allow being monitored by their employee, and to provide them access to their performance during working hours? This is a huge issue that not only has an ethical and data protection concerns, but also labor laws and policies that should be taken in consideration. It might be a huge burden to the workers to expose that much to their employee, in a way that the latter would be aware of their movements, activities and ways of working in agriculture and fruticulture scenarios. It is vital to find a balance between these two approaches, in order to be able to collect enough productivity indicators to support decision-making without compromising the worker privacy – and, more than that, without losing workers' trust.

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SUSTAINABLE AGRICULTURE IN THE ERA OF FIELD-OMICS

LET'S IMPROVE AGRONOMICS

Omics tools like systems biology and bioinformatics are currently available and allow the development of very thorough computer simulations of this omics cascade (fluxomics) and the respective production of in-silico models to connect the information between the genotype and the phenotype.

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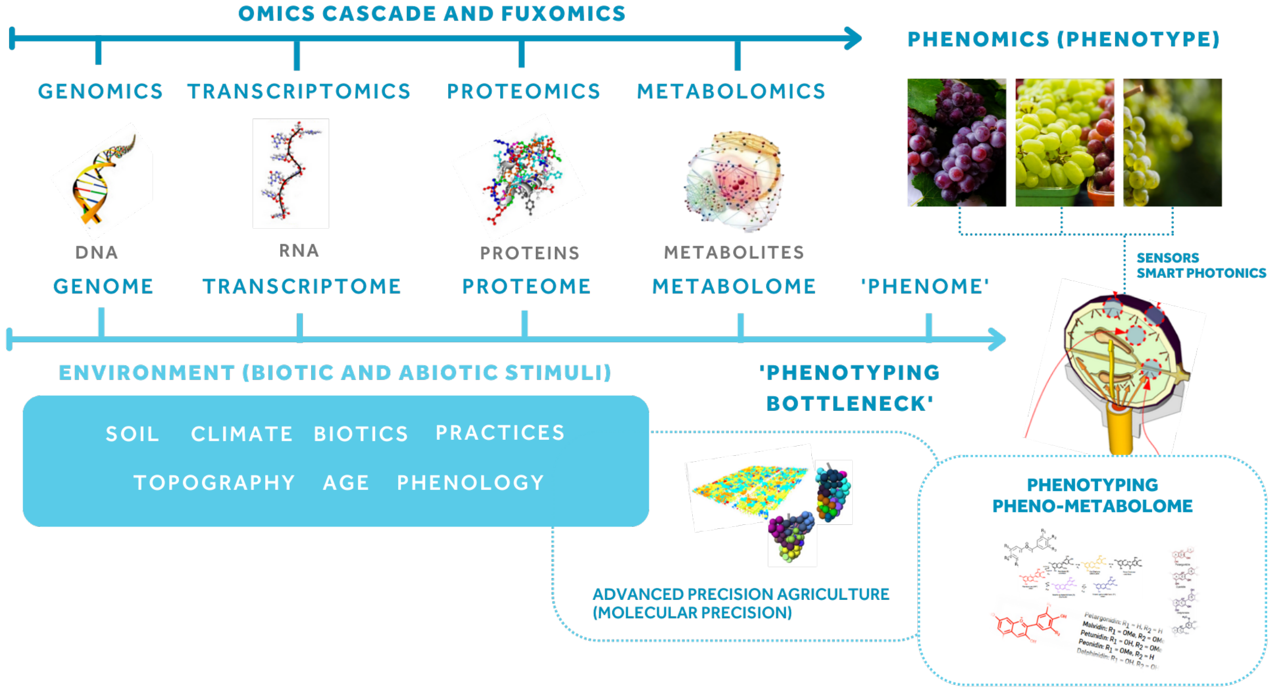

Figure 1 Model of advanced precision agriculture (molecular precision) based on omic disciplines and smart-photonic sensors

Agriculture faces the global challenge of producing more (in quantity and quality) with fewer resources, which must be aligned with the sustainable use of natural resources and the mitigation of climate scenarios. The significant gains in agricultural productivity resulting from the "green revolution" established after the Second World War were based on a model of intensive agriculture that is currently insufficient to develop sustainable food systems. This agricultural model was supported by several technological innovations, such as highly productive varieties, phytopharmaceuticals, fertilisers and mechanised systems that are no longer adjusted to the dramatic loss of soil fertility (e.g., erosion, salinisation), the need to preserve biodiversity and the escalating energy costs. Moreover, this model of agriculture was developed in a context of relative climate stability that is not suitable for climate scenarios in the 21st century.

In this model of productivist agriculture, agronomic decisions are based on simplified and standardised diagnoses that do not consider either the plant's physiology or its causality with the environmental context, that is, this agronomic process is not focused on the plant's performance (genotype) or its interaction with the environment (phenotype). This agronomic approach is, therefore, dissociated from the structured knowledge produced in technological laboratories (biotechnology and instrumentation) and is limited in assimilating the scientific and technological developments that have taken place in recent years within the scope of omics disciplines - genomics, transcriptomics, metabolomics and phenomics (Fig. 1).

Omics tools like systems biology and bioinformatics are currently available and allow the development of very thorough computer simulations of this omics cascade (fluxomics) and the respective production of in-silico models to connect the information between the genotype and the phenotype. These omic tools, combined with high-dimensional, high-throughput sensors, support the transfer of information to measure the plant's response at the cellular and metabolic level in the field, in a non-invasive way, thus enhancing the transition to a molecular precision agronomic model.

In this context, phenotyping has been developing the concept of genotype-phenotype mapping associated with genotype-environment-agronomic practices (GEP) interactions, which are an opportunity to promote advanced agronomic models based on omics disciplines.

Phenotyping consists of analysing a set of quantitative or qualitative characteristics of the phenotype of plants (e.g., dimensions, colour, and composition) and relating them to the performance of a genotype in certain environments (e.g., climate, soils) - which, in the agronomic case, includes cultural practices. Traditionally, phenotyping techniques focused on easily measurable plant characteristics, which farmers used to improve their production system since ancient times. Recently, plant sensing allowed to quickly and accurately obtain data related to the phenotypic characteristics of plants, including the most complex ones, such as molecules related to plant metabolism and physiology – pheno-metabolome (Fig. 1). These sensors can be mounted on different platforms and carry out "large-scale" mapping of the phenotypic characteristics of plants in their environmental context.

However, it is consensual that despite the clear advances in precision, speed and costs of the techniques applied to plant genomics in recent years, namely in DNA sequencing by "Next-Generation Sequencing -NGS", phenotyping techniques have not been developed at the same pace, currently being a "phenotyping bottleneck" so that agriculture, like medicine or the pharmaceutical industry, can also benefit from the major advances in omics disciplines (Fig. 1).

In the last decade, the convergence between omics disciplines has benefited from initiatives - developed in various areas of the globe - of plant phenotyping structures with advanced technology, excellent human resources, great international interaction, and comfortable financial endowments. The "European Plant Phenotyping Network – EPPN" stands out the effective liaison with similar plant phenotyping structures mapped in various parts of the globe. In this context, in 2016, the European Union, through the "European Strategy Forum for Research Infrastructures (ESFRI), identified plant phenotyping as a priority area of research and, in 2018, outlined in its roadmap the strategic role of the plant phenotyping infrastructures in Europe for the next 20 years. In this roadmap, the European Infrastructure for Plant Phenotyping – EMPHASIS stands out, which Portugal recently joined with INESC TEC as a partner.

However, the worldwide panorama of plant phenotyping is still heterogeneous. It presents limitations for farm implementation, namely the multidirectional translation of model species for crops and the integration of these data at different scales, with low-cost field applications that also consider perennial woody crops.

INESC TEC has been developing robots with omics capabilities, performing high-throughput, high-dimensional digital phenotyping, integrating the various omics disciplines in the agronomic process of different crops (including arboreal shrubs). The robot "Metbots" is an example that uses smart-photonics based on low-cost, point-of-measurement devices to measure, process and map critical parameters of plant metabolism related to its physiology, in a non-destructive manner. Also under development, the "Omicbots" robot is another example capable of combining metabolic monitoring with bioinformatics and systems biology tools for precision physiological crop diagnosis (Fig. 1).

These robots are equipped with sensors based on photonics and artificial intelligence to determine a myriad of molecules of cellular metabolism or phenometabolome (e.g., chlorophylls, pheophytins, anthocyanins, carotenoids, phytohormones) produced by plants in response to biotic or abiotic stresses. These are the basis of the plant's physiological diagnosis operationalised in agronomic decisions (e.g., fertilisation, irrigation of diseases, selection of varieties adapted to micro-zoning). These smart sensors allow for the metabolic screening of each plant in different environmental conditions (soil, climate), and using systems biology techniques, bioinformatics and in-silico models incorporated in the "OmicBots". This system will allow to understand which enzymes are active and which genes are being activated or silenced in each situation and understand the plant mechanism, allowing a very precise actuation in the agronomic process.

The integration of these omics, photonics and agronomic technologies is operationalised through virtual biological digital-twin models for real-time and in situ transfer of information between the laboratories and the agronomic process.

This molecular precision agriculture approach promoted by INESC TEC opens a new frontier to study and implement adaptation mechanisms, treatments and advanced agronomic interventions: i) more precise management of resources and production factors, namely water and nutrients, allowing to produce more with fewer resources, ii) early detection of diseases, even in the asymptomatic phase, allowing localised treatment before dissemination occurs and, even, support in the development of phytopharmaceuticals with greater agronomic and environmental efficiency and less impact on non-target species, iii) act thoroughly in the frequent situations of combined stresses (e.g., water stress associated with heat stress, light stress), since the plant metabolism changes accordingly, even if the phenotype is not and iv) to know the phenotypic plasticity of the plant when exposed to a set of environmental conditions (cultural practices included) as a tool for mitigating climate change. Genetic improvement is a time-consuming process, so we can take advantage of the phenotypic plasticity of plants (as long as it is known) to mitigate the unpredictable effects of climate scenarios.

The omics disciplines and tools envisage the development of a new Era of precise and causal agronomic action to support sustainable food systems. This requires advances in biotechnology and instrumentation flowing bidirectionally between the laboratory and the field. Basic science and technology are available, but the knowledge has yet to be applied. The technologies and scientific advances in this INESC TEC's research line received several prizes and awards and have recently been considered high-impact research for developing advanced models of precision agriculture.

DIGITAL TWINS IN AGRO-FOOD AND FOREST

Digital twin technology has been applied in healthcare, automotive, aeronautics and aerospace, but can also help solving many challenges in other scopes. For example, in agriculture, it helps managing problems such as resource management, food security, weather concerns and monitoring of soil and land.

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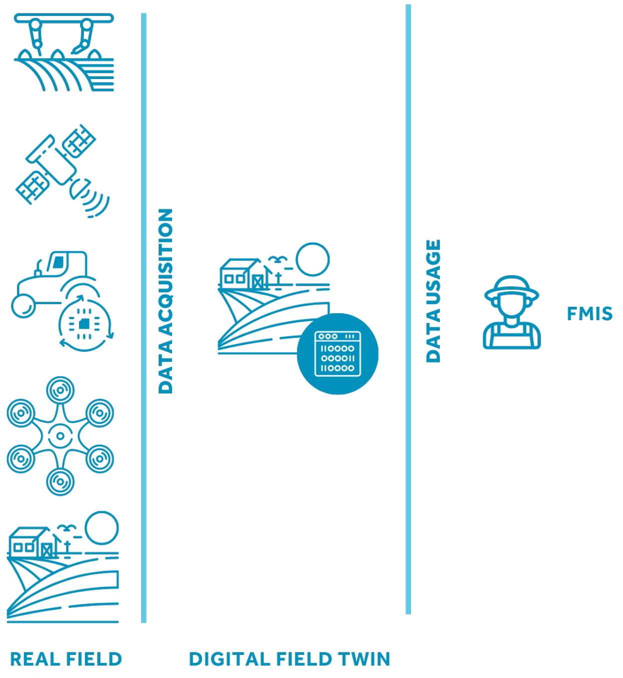

Figure 1 Digital Twin dataflow

A digital twin consists of a digital representation of a real-world object or infrastructure. Allied to real-time data, a digital twin can be used for remote monitoring and to simulate or predict a set of actions. This concept is characterised by three components: a physical entity, a virtual entity and the data that connects these two parts. This technology allows the visualisation and extraction of information in real time about an entity, eliminating the need for physical contact, and can be applied to an organisation, supporting its management and monitoring.

Digital twin technology has been applied in healthcare, automotive, aeronautics and aerospace, but can also help solving many challenges in other scopes. For example, in agriculture, it helps managing problems such as resource management, food security, weather concerns and monitoring of soil and land. More recently, there have also been efforts in creating digital twins of forest areas, as they could help in tasks such as forest management planning, inventory and harvesting plans, assess carbon calculations, understanding and monitoring the effects of drought and disease on trees.

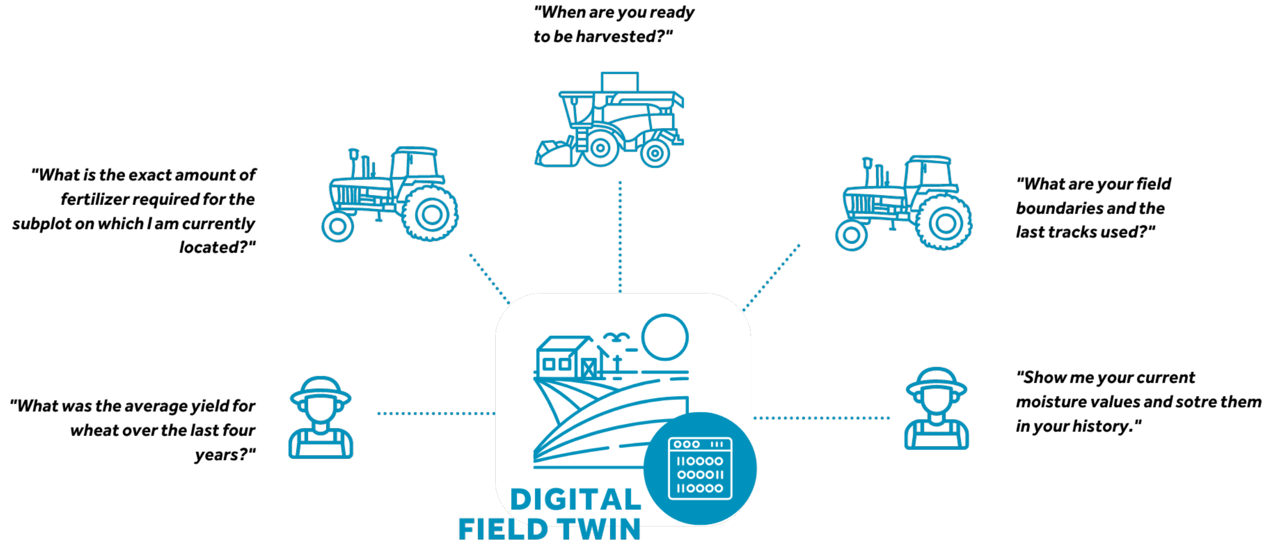

Figure 2 Possible farming digital twins' functions

When it comes to farming, digital twins can aid farmers by monitoring and controlling operations remotely, based on real-time digital information, thereby reducing the time and effort spent on manual tasks on-site. Farmers can be automatically informed if there is a problem and can simulate and evaluate corrective and preventive actions on the digital representation. This technology also helps farmers to minimise risks from factors such as weather, as well as to increase profitability.

There are many operations involved in a farming digital twin. Some of its possible uses are to acquire answers concerning questions that are often not easy to answer without some context, such as the amounts of fertiliser needed to a certain region of the land, land preparation times, meteorological values, historical values, among others.

The physical world requires measurement technologies and sensors to collect and receive data from the physical object. These measurements may be acquired through various technologies such as weather stations to monitor the environment, overall air quality and predict the weather status. Light sensors can be used to measure sunlight exposure on growing plants. When it comes to monitoring the soil, optical and electro-chemical sensors can be used to determine fertility and measure organic matter and moisture contents of the soil, along with mechanical sensors to measure compaction, deformation, and resistance. These measurements help to identify where and how the resources are stressed, whether by invasive plants and animals, soil quality, pollution, or other factors.

The use of drones can provide substantial support in monitoring activities and other tasks. They can be mounted with various sensors and actuators to perform agricultural tasks, from gathering data to sweeping terrains and sectors with fertilisers and seeds. In farming, drones also aid in gathering data for precision agriculture by producing map projections based on multispectral imaging. These can help to determine land boundaries that can grow crops. In forest management, drones can help to monitor large sections for environmental and ecological changes. They also acquire observation data such as the topography of the terrain, how and where trees are placed, thus providing support to build a virtual model.

The current advancements in technology, and the rise of methods such LiDAR, made it possible to create full 3D scenes from observations and measurements, more easily and manageably,easier and affordable, which enable building virtual worlds that represent reality accurately a much more feasible process [2].

Autonomous farm equipment can provide a fundamental support in saving costs and time involved in harvesting and yielding compared to manual farming machinery [3]. They can provide several advantages such as precise, fast, and repetitive operations, regardless of weather conditions. Due to these advantages, extensive use of unmanned vehicles such as tractors, as well as combine harvesters, has been increasingon the rise in usage [4].

A Digital Twin can also be used to measure and understand the content and capacity of the soil that a crop grows in, allowing a farmer to take full advantage of the land and increase the quality of a harvest. The land can also be visualised by creating accurate landscape models using digital elevation models, topography multispectral imagery and orthophoto maps capable of being integrated in a Geographic Information System (GIS).

Nowadays, there are already several real-world examples of tools that use Digital Twin technology as their basis of operation, due to the already enumerated advantages of its use:

For example, Intelligent Growth Solutions (IGS) has developed a solution focused on indoor controlled farming [5], which is able to tweak parameters such as light, water, nutrients, humidity, and temperature, and see its how they effect on aaffect plants. This solution scans the crops using cameras that capture two-dimensional and three-dimensional images, and it also uses sensors to measure water and nitrates.

Connecterra has created an intelligent cow-monitoring system based on artificial intelligence (AI) that allows the monitoring of health and well-being of a herd [6]. By attaching a sensor to a cow's collar, as well as other data sources, this system can generate alerts regarding an animal's health, heat, and operational changes, helping a farmer locate an injured cow.

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WHY WE NEED TECHNOLOGY IN THE WINE INDUSTRY

The constant search for optimisation of technology by small and large producers (regardless of their dimension), towards improving social, environmental and economic sustainability and, consequently, competitiveness and resilience comes as no surprise. This is the way to ensure the sustainability of the growth sought by the economic and social cluster of the wine industry.

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Figure 1 Remote sensing with drone in a vineyard.

WHY

It's broadly known and acknowledged that vineyards and wine are ancient realities, a result of the high resilience of an activity with a strong regional and national identity, which has characterised, until today, the territories and cultures where it thrives; a good is example is the recognition of the Douro region as a World Heritage Site, similarly to other world wine landscapes.

However, the "novelty" in terms of speed and intensity of current events, particularly regarding climate change, demographic and consumer behavioural issues, as well as market developments, put an unprecedented added pressure on the sector's economic agents. The technology tools stemming from scientific progress, also characterised by unprecedented "speed" and intensity, are one of the most effective and appealing training solutions for this purpose.

Nowadays, global threats like climate change, geopolitical instability, fierce competition between countries and regions, or local threats like low population density and consequent lack of workforce or poorly developed socio-economic fabric with insufficient capacities force this economy sector to evolve and transform to improve the retention and attraction of workforce and maximise productivity. In this sense, the use of current and developing technology solutions is the most logical approach - even if it's not the most immediate.

Hence, the constant search for optimisation of technology by small and large producers (regardless of their dimension), towards improving social, environmental and economic sustainability and, consequently, competitiveness and resilience comes as no surprise. This is the way to ensure the sustainability of the growth sought by the economic and social cluster of the wine industry.

WHAT

The notion and acknowledgement of the existence of a Vine and Wine Cluster in this economic sector - even if partially in a less structured form - allows to promote multi-actor approaches with the involvement of the State, R&D entities, associations, companies, cooperatives, and individuals, all playing an active role in the process.

The CoLAB Vines & Wines, as an interface entity, is one of the preferred means for the development of interactive processes that start by signalling needs and directing technological development to address them; this is followed by cycles of consultation with companies in terms of demonstrated or developed solutions, generation of "critical mass" to leverage the development of solutions by tech providers, and their democratisation - through cost reduction and the application of technology and technical knowledge, thus ensuring the fast assimilation among all economic agents, and narrowing the gap between companies and the research, innovation and development ecosystem.

HOW

Technologies represent both direct and indirect/cross-cutting solutions to most problems since they promote the retention and valorisation of skilled professionals and the creation of specific training capacities. One the one hand, this is crucial to advance the short-term implementation of technologies, thus fully benefiting from them. On the other hand, it allows retaining young and specialised professionals, leading to a valorisation in terms of wages, in line with the increase in productivity.

This "environment" that we designate as Smart Agriculture - and specify as Precision Viticulture concerning vines - will stem from three factors combined, explained below:

i) Improvement in operations management, carried out in a mechanised /automated or manual manner, using decision support systems (DSS): weather stations; NDVI (Normalized Difference Vegetation Index) or RVI (Ratio Vegetation Index) pictures in GIS (Geographic Information System) environments, obtained by drones/UAVs; sensors that transform holdings into smart systems that can register and communicate climatic and environmental practices and risks, as well as operational procedures (e.g., data on soil and environmental humidity, nutrient content, biomass indices, soil electrical conductivity, pests and diseases) in an IoT environment;

ii) Tools associated with smart platforms for the direct application of technologies, specifically through Variable Rate Technologies (VRT) solutions complemented with optical, ultrasonic or LIDAR (Light Detection and Ranging) sensors;

iii) Finally, improved training for professionals, exploring technological approaches and promoting the retention of young and qualified workforce.

In fact, the solution lies in how to make it happen, exploring and boosting the multi-actor approach through interface structures such as the CoLab Vines & Wine. This will allow maximising its benefits - which should (rather, must) be leveraged by the decision-making power by actively supporting this approach, assuming the scientific knowledge with another "speed" and applying it to the legislation. This way, there will be fewer barriers to the introduction of new solutions while acknowledging the importance of the involvement of all economic agents, including the companies' drive and leadership role in this process.

SMART AND PRECISION TECHNOLOGY PROVIDERS FOR ACTION WITH VARIABLE RATE TECHNOLOGIES

Among the factors that influence the adoption of precision agriculture, the following can be listed: agricultural entrepreneurs, technology and others, such as the existence of service providers.

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Figure 1 INESC TEC robot from PRYSM project in tests in a vineyard.

The main challenge to the sector is closely associated with the latest data released by the UN, which estimates that by 2050, the world population will increase between two and three billion (from seven to 10 billion). According to FAO , this demographic factor - alongside the increase in the economic power of underdeveloped countries - will double the demand for food and, consequently, agricultural productivity, due to the decline in terms of availability of arable land. The need to produce more with less resources will inevitably lead to the intensification of agricultural production systems, which may entail greater risks in terms of pests and diseases, reduced soil fertility and environmental issues, e.g., contamination, salinisation and soil erosion. The only way to mitigate these issues is the use of innovative technologies that focus on processes with high levels of performance, from a perspective of precision agriculture, which will have a positive impact on resource efficiency. In this sense, precision agriculture is a top priority in the future, with machines based on automation technology for precision processes able to apply the right amount of products, in specific places and at the right time, while evaluating and reporting the crops and soil's status, according to principles of agriculture 4.0.

In fact, the use of adequate systems allows to generate and analyse a significant volume of data to favour a more conscious and suitable decision-making process. The use of cutting-edge technology, like software, systems, equipment, and data science, helps to control, monitor, and support decision-making. Currently, the use of technologies encompasses soil analysis, pest and weed control, planting, and harvesting, and can also be found in management processes, i.e., resources distribution and management of administrative processes. By using these systems, it is possible to find ways to increase productivity and reduce production costs. One of the great advantages of agriculture 4.0 is the provision of essential and accurate information to the agricultural managers, enabling a positive and assured decision-making process.

Among the factors that influence the adoption of precision agriculture, the following can be listed:

- Agricultural entrepreneurs: level of education/ training, age, investment capacity, computer knowledge, human resources, risk aversion, dimension, and insight.

- Technology: gains perceptibility, ease of operationalisation, initial investment cost, difficulty of interpreting collected data.

- Others: existence of service providers, adequate and effective support by manufacturers/ sellers, strength of the "innovation system"/ communication.

Hence, we believe in the importance of introducing a set of actions to demystify and encourage the use of these technologies, such as:

- Change the paradigm of farmers and support the implementation of a more professional culture that focus on return on investment. Therefore, and concerning all technology, the premise is the same: how much will it impact costs and what's the return on investment. It's crucial to provide relevant and tangible services, that ensure return on investment. In this sense, it's important to invest in studies that compare the current and future situations, as well as in demonstration initiatives.

- It's also crucial to promote training actions for users/farmers, sharing knowledge and empowering them for this new era of agriculture. However, these initiatives should be carried out by the Ministry of Agriculture, in a structured way, by adopting incentive policies and creating networks and ecosystems to share competencies and skills among all stakeholders.

- Establish a national association of agricultural machinery manufacturers, which truly addresses the interests, needs and real difficulties of the sector and engages with the political authorities. A clear example is Ansemat (Spain), a reference in terms of representing the goals of manufacturers, with a strong mobilising power among political entities, also dedicated to informative and formative initiatives targeting the Spanish agricultural sector.

- Creation of direct funding instruments for farmers, namely for the acquisition of precision agriculture equipment; if companies and tech institutes are investing in technology, it's important to promote a nationwide engagement. It's hard to develop new products (agriculture 4.0) that don't find their place in the Portuguese market; in general, we're still in the mechanisation era, and it's crucial to overcome barriers, namely by renovating the equipment fleet.

- Address safety issues (e.g., replace potentially hazardous tasks with robotics solutions). Portugal is the third country in the EU with the most accidents involving agricultural machinery. More than 350 fatalities in five years are associated with tractor accidents (data available for the period between 2013 and 2017).

At Herculano, the digital revolution is a path we started three years ago, with an analysis of our strategy and market (current and future) as the first step. Soon, we realised that we lacked a piece to complete our puzzle, and that was when INESC TEC came in - in the first phase, within the scope of an isolated DPA project, a debit solution proportional to the advance in terms of cisterns and spreaders. This phase was important to establish a relationship before we decided to establish of a partnership protocol between Herculano and the Institute, signed at Agroglobal 2018, with the presence of the Minister of Agriculture. Then, we decided to promote a new project named "Smart Fertilizers", focusing on the R&D of smart cisterns and spreaders, at a competitive, efficient, and versatile cost, within the scope of agriculture 4.0. It was a clear contribution to increase the efficiency of the fertilisation operations, considering environmental, agronomic, and economic aspects.

Nowadays, fertilisation and organic soil correction - using manure spreaders and slurry cisterns - are agronomic operations carried out with very low environmental and economic efficiency. There are even European regulations, expected to become harsher, which require greater control in fertilisation processes to reduce the amount of nitrogen applied.

Currently, the shortage of raw materials has a significant impact on the availability of artificial fertilisers. Due to high costs, mainly caused by rising energy prices, fertiliser manufacturers are limiting their production. This threatens the availability of chemical fertilisers for the next season. There is a great need for a sustainable alternative, e.g., organic fertilisers, to ensure optimal growth.

Pulverizadores Rocha, SA, through its R&D department and together with some external entities, namely INESC TEC, has been working to develop technological solutions within the framework of the digital revolution in agriculture, and to increase the profitability of agricultural holdings while simplifying processes. In fact, agriculture cannot live under the notion of doing things because others do them, or because that's how things are usually done. It is important to innovate and address the current needs, like producing in smaller spaces, promote sustainability, tackle climate change, work out the lack of qualified workforces, among others.

A good example is the robot for mountain vineyards, stemming from the Prysm project, with Rocha and INESC TEC as partners in the development of equipment framed within agriculture 4.0. Considering the need for more precise agriculture with low levels of environmental impact, this project focused on developing a robotics solution with the capacity to perform low-rate treatments (100 litres/ hectare); the robot can obtain prescription maps and adjust the application according to said instructions, the robot's speed, and the actual volume of the foliar mass. It's important to mention that this robot can estimate the safest routes, analysing the slope of the terrain and its own centre of mass of the robot, while moving autonomously even in the absence of GNSS (GPS) signals.

Herculano and Pulverizadores Rocha, SA aim to create innovative and automated digital solutions for the sector, while disseminating the use of digital agriculture to all agents, thus facilitating, and democratising the access to technology.

Figure 2 GreenPrecision Tank, made by Herculano, powered by INESC TEC.

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