AGRITECH DAY BY AXEMA

AXEMA

2023 EDITION

AGRITECH DAY
6TH EDITION

The conference of innovations and solutions for efficient and sustainable agriculture

AGRITECH DAY - 6th Edition

The International Conference of Technologies and Solutions
for Efficient and Sustainable Agriculture
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FOREWORD

AXEMA, the reference association at the service of agricultural equipment.

Building the future

AXEMA is the French Association for agricultural equipment manufacturers and agricultural environment providers. Its 260 members include both French and foreign manufacturers of agricultural equipment for the various sectors of crop and livestock agricultural production and producers of equipment for the upkeep of green spaces.

A diverse sector

The agricultural equipment sector includes businesses that produce market equipment, fixed and rolling, intended for various users : arable crop farmers, livestock farmers, wine growers, horticultural producers, vegetable farmer, parks and gardens maintenance service providers and home gardeners. Moreover, this sector is increasingly focussing on solutions taking into account the environmental aspects of agriculture, livestock-rearing, parks and gardens, and more generally our territories, thus making it a true Agricultural Environment sector. Agricultural equipment covers a wide range of machines, uses and technical know-how. This diversity is also reflected in the economic organisation of the French agricultural equipment industry. The sector is composed of SMEs, French international industrial groups, and importing subsidiaries of foreign groups.

Governance & Operational team

AXEMA is administered by a Board of Directors composed of 16 representatives of active members. The Board of Directors elects a Bureau composed of a Chairman, two Deputy Chairmen and a treasurer who are also appointed for a term of three years. The association's daily activities are carried out by a 15-person team organised by unit and responds to members' requests :

- Technical and Regulation
- Economic and International
- Public Affairs and Communication
- Training and Employment
- Administrative and Accounting

Collective activities of AXEMA are generally conducted through Product Market Group (PMG) meetings, which include active or associate members involved in the same product family or market, and Commissions working on cross-cutting topics.

Trade fair activity

Trade fair activity AXEMA, in partnership with the COMEXPOSIUM group, organizes 2 world class biennial events : the SIMA (international exhibition of solutions and technologies for Efficient and Sustainable agriculture) and SITEVI (international exhibition of equipment and know-how for vinewine, olive and fruit & vegetable production) through the joint venture, EXPOSIMA. The Association is involved in defining strategies and policies and proposes developments to promote trade fairs considering changes in the agricultural world, render them more attractive and increase business volumes. These trade fairs are recognized as an international showcase for the French Farm machinery Industry.

AXEMA's objective is to show that the sector is innovative, attractive to young talents and offers growth prospects in the context of efficient and sustainable agriculture.

AXEMA is building the future for agricultural equipment & agricultural environment to ensure sustainable agriculture & responsible territorial development.

SCIENTIFIC COMMITTEE

The 6TH edition of the AGRITECH DAY gathered all the agroequipment research & innovation actors on October 12, 2023, on the Roazhon Park - Rennes, France.

Agricultural equipment supports the transformation of agriculture and takes part in developing new agricultural models more respectful of ecosystems. AXEMA created AGRITECH DAY to promote direct exchanges with agricultural equipment research & innovation actors and inform on ongoing developments. The strong mobilisation for this sixth edition is a testimony to the sector's vitality and expectations. Agriculture issues challenge many scientific and technological experts.

This event spotlighted thirty presentations under the form of plenary sessions and poster workshops, selected by a scientific and technical committee to whom we extend our warmest gratitude. It is thanks to the quality and expertise of the industrial, academic and research speakers that AGRITECH DAY has become the privileged event in France for innovation and research around the agricultural equipment sector.

Composition of the scientific committee :

- **Christian ADLER**, KUHN GROUP - Head of the Electronic department ;
- **Lionel LÉVEILLÉ**, BUREL GROUP - BUREL Innovation Director ;
- **David R WHITE**, HARPER ADAMS - UNIVERSITY (UK) - Senior lecturer in engineering ;
- **Julieta CONTRERAS**, ACTA - Digital Agriculture Engineer Head of the DIGIFERMES® network ;
- **Jean-Christophe ROUSSEAU**, FRANCE PULVÉ - Product Manager ;
- **Jean-Paul DOUZALS,** INRAE - Engineer Spray R&D ;
- **Dieumet DENIS,** SHERPA ENGINEERING - Head of advanced autonomous systems ;
- **Marco MEDICI,** POLYTECHNIC INSTITUTE UNILASALLE - Associate Professor ;
- **Emmanuel PIRON,** INRAE - Head of the Montoldre Technological Research Platform ;
- **Marie-Flore DOUTRELEAU,** FRCUMA OCCITANIE - Agroequipment and agroecology project manager ;
- **Marilys PRADEL,** INRAE - Research engineer in environmental assessment ;
- **Eric COURTEILLE,** INSA RENNES - Teacher / Researcher in mechanics and robotics ;
- **Pascal BOUQUET,** IN SITU VENSYS GROUP - Technical and R&D Director ;
- **Arnaud JAOUEN,** PICHON / SAMSON AGRO - Technical Director ;
- **Cédric SEGUINEAU,** NAÏO TECHNOLOGIES - Director of Quality, Autonomy and Impact ;
- **Andrii YATSKUL,** POLYTECHNIC INSTITUTE UNILASALLE - Teacher / Researcher in Agricultural Equipment Engineering ;
- **Philippe-Samuel HERITIER,** INRAE - Project Manager - Robotics and Systems for Agriculture ;
- **Xavier REBOUD,** INRAE - Director of the division Plant Health and Environment.

8.30	**CONFERENCE OPENING** - *ROOM A* *Laurent DE BUYER – General Director AXEMA*	
8.50	**POSTERS PRESENTATION** - *ROOM A*	
	R&D PROCESS AND EFFICIENCY - *Room A*	**AGRICULTURAL ROBOTS SAFETY** - *Room B*
9.30	« Automatic test bench » Yannick GUYOMARCH – KEREVAL / Tom LARATTE – BUREL GROUP	« Safe VRS corrections for autonomous robots » Paul CHAMBON – RESEAU TERIA
10.00	« Soil diphasic conveyance » Ilyes MNASSRI – CETIM	« Autonomous weeding in vineyards : How TED robotic solution operate safely without a local operator » Cédric SEGUINEAU – NAIO TECHNOLOGIES
10.30	« Intellectual Property practices in French agroequipment Small and Medium Entreprises industry » Lionel LEVEILLE – BUREL GROUP	« Sensitive Device for Probing and Recognition of Obstacles in a Natural Environment » Lama AL BASSIT – INRAE
11.00	**POSTER BREAK** - *CENTRAL ROOM*	
	AGRO-ECOLOGICAL TRANSITION - *Room A*	**DECARBONISING OF AGRICULTURE** - *Room B*
11.30	« Dynamic agrivoltaics: a solution for preserving quality of grapes and protecting grapevine from climate change » Damien FUMEY – SUN'AGRI	« Electric retrofit for decarbonization of off-road vehicles » François BROCHARD – IN SITU
12.00	« Preparing the Agri-Equipment Industry Ready to Make Conservation Agriculture the Future of Farming in France » Damien CALAIS – INSTITUT AGRO DIJON	«Does full autonomy improve the environmental impacts of agricultural robots? The case of vineyard weeding robots » Marilys PRADEL – INRAE
12.30	**LUNCH BREAK** - *CENTRAL ROOM*	
	DATA & IA - *Room A*	**CROP PROTECTION** - *Room B*
1.15	« 360° Monitoring for Agriculture » Xavier L'HOSTIS & Théophile Loïc EYANGO – ADVENTIEL	« Mandatory Inspection Database Results for Sprayer Calibration » Nesrine BOUCHEKOUM – INRAE
1.45	« Smartbox Traceability System and Data Valorization » Albane THOUERY – AGDATAHUB / Eric FONTES – ZEKAT	« Flashes of UV-C light, a physical plant resistance inducer and biostimulant that can be effectively used in cropping conditions » François SEMENT – UV BOOSTING
2.15	« Keeping an ear on your farm: The benefits of sound monitoring » Victoria POTDEVIN – ADVENTIEL	« ADDI Spray Drift: A spray drift model for vine sprayers » Jean-Paul DOUZALS – INRAE
2.45	**POSTER BREAK** - *CENTRAL ROOM*	
	INNOVATIVE AGRICULTURAL EQUIPMENT - *Room A*	**CROP PROTECTION** - *Room B*
3.15	« 4PTH and Weeder Pilot design, inspired by User Centered Design method » Pierre HAVARD – CORMIERS	« Evaluation of the guidance accuracy of non-chemical weeding robots in crop production » Véronique LECLERCQ – CRA WALLONIE
3.45	« TIM, rear top linkage and spreader developments » Fulvio ZERBINO – KUBOTA	« Spray drift measurements with herbicide application trains : Methodological issues and results » Jean-Paul DOUZALS – INRAE
4.15	**THINKING ON THE TECHNOLOGIE'S SUPPORT TO THE TRANSITION OF AGRICULTURE TOWARDS SUSTAINABLE SYSTEMS** - *Xavier REBOUD - INRAE / ROOM A*	
4.45	**CONFERENCE CONCLUSION** - *ROOM A* *Philippe COLACICCO – KUBOTA'S EUROPE R&D DIRECTOR / AXEMA Technical Committee Chairman*	

POSTER PROGRAM

« How do we ensure trusted ai for digital agriculture? » Anne-Laure WOZNIAK – KEREVAL
« Exploitation of simulation for the development of off-road robotic applications in the agricultural field » Pierre DELMAS – 4D VIRTUALIZ
« Ultrasonic wind sensor for precision agriculture » Christophe MICHEL – LCJ CAPTEURS
« Trial offers from the agrotechnopôle platform » Adriana SANCHEZ HALLEUX – INRAE
« Gea next generation farming : how our technologies improve farm performance and reduce farm greenhouse gaz impact ? » Frédéric FAVROT – GEA FARM TECHNOLOGIES
« Frugality the sustainable future of intelligent digital solutions in agriculture » Victoria POTDEVIN – ADVENTIEL
« An overview of agrobofood: achievements and future outlook » Farzam RANJBARAN – CEA-LIST
« I-smart: innovative and sustainable methods for agricultural robotics and off-road mobility » Dieumet DENIS – SHERPA ENGINEERING / Philippe HERITIER – INRAE
« Accelerating innovation and industrial transformation for off-road mobility players » Sébastien PERSONNIC – ID4 MOBILITY

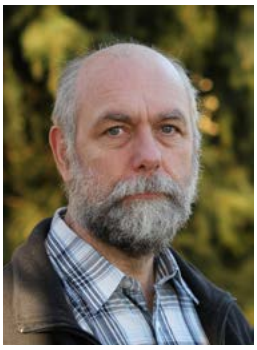
SPEAKERS BIOGRAPHIES

Plenary sessions

Philippe COLACICCO

KUBOTA'S Europe R&D Director / AXEMA Technical Committee Chairman

Philippe Colacicco holds generalist engineer degree and PhD of mechanics, he has first held various positions in Research and Development, Validation and Project Management in the automotive sector. Philippe then joined CLAAS Tractor in 2008, firstly in charge of developing the range of specialized tractors, before heading the Research and Development department for 6 years. In 2016, he joined the Kubota Corporation Group to create the European R&D Tractors Center that he leads. Since 2018 Philippe Colacicco is the President of AXEMA's Technical Committee.



Xavier REBOUD

Director of Research - INRAE

Xavier Reboud is Director of Research at INRAE's Agroecology Unit in Dijon. A specialist in weed management issues, his career has led him to take an interest in the evolution of agricultural models. He coordinated the report on alternatives to glyphosate in France in 2017 and took part in assessing the technico-economic implications of their mobilization. More recently, he has applied a similar approach to two other herbicides: S-metolachlor and Prosulfocarb. He has chaired the Scientific Research and Innovation Orientation Committee of the Ecophyto plant until 2023. He is also vice-president of the Robagri association. Xavier is currently in charge of the Scientific Department of INRAE, where he is working on the link between digital technology and agricultural equipment in agro-ecology and more sustainable agriculture in general.

R&D process and efficiency

Yannick GUYOMARCH

Project Engineer - KEREVAL

Yannick Guyomarch, is the manager of the activity « bus of communication» and the ISOBUS laboratory in KEREVAL since 2012. He have an experience of more than 30 years in the development and test of embedded product including CAN or ISOBUS bus. After to working, for several automotives subcontractors, like Delphi, Arvin Meritor, Yannick Guyomarch joined KEREVAL for implement the ISOBUS activity and permit the accreditation of KEREVAL by The AEF as one of the 5 certifications laboratories in the world. A second part of his activity is as trainer for ISOBUS for 10 years.

Tom LARATTE

Electronic Designer - BUREL Production

Tom LARATTE, 25, studied in Rennes in a professional degree specialized in embedded systems for transport and automotive. During this degree, in 2018, Tom completed a 6-month internship with the SULKY-BUREL company to set up software tests for Isobus machines from the SULKY and SKY Agriculture brands via Testlink. The internship culminated in a position with the company. During his 5 years with BUREL Production (formerly SULKY-BUREL), Tom became an electronics designer. Specializing in seed drills, where he develops software and hardware, he also works on the development of trailed fertilizer distributors and on certain production equipment such as test benches. Tom has also become Isobus activities manager within the BUREL Production development department, working on Isobus compatibility between tool and console.

Lionel LEVEILLE

Research and Innovation Director – BUREL GROUP

Lionel is the son of a Breton farmer and has a passion for machine design. He studied mechanical engineering at the University of Rennes, and recently completed a Master 2 in Intellectual Property Strategy and Innovation at the University of Strasbourg (IEEPI). His encounter with the BUREL Group dates back to 2001, since when he has held several positions within the BUREL Group's R&D teams. Since 2022, he has been the Director of Burel Innovation, which encompasses the BUREL group's product marketing, Research Innovation and Intellectual Property work (product Sky agriculture). Since November 2017, he has been vice-chairman of the AXEMA technical commission, and since 2021 a member of the Agrotechnopôle board.

Ilyes MNASSRI

CFD Engineer / Technical Business Manager - CETIM

Ilyes MNASSRI is a Thermofluidic CFD Flow Engineer who earned his PhD from Ecole Centrale de Nantes. Prior to his role as a CFD engineer in the industry, he was assistant professor at Bordeaux University and ENSAM. In 2021, he joined CETIM, where he has been actively involved in various industrial and R&D projects including multiphase sprays, hydrogen flow in reactors, aerodynamics, hydrodynamics of risers, among others. He has also developed a range of CFD tools aimed at optimizing hydraulic performance in areas such as pumps, gas dispersion, and particle-laden flows. His expertise lies in thermofluidic flow, turbulence, and numerical simulation.

Agricultural robots safety

Lama AL BASSIT

Research engineer – INRAE

Lama Al-Bassit is a research engineer at INRAE- French National Research Institute for Agriculture, Food and the Environment. She works on machine safety and the design of mechatronic systems for mobile and reconfigurable robotics. She studied mechanics at the ENS Paris-Saclay (ENS de Cachan). Between 1994 and 2000, she worked as a lecturer at Hiast - Higher Institute for Applied Sciences and Technology of Damascus. She received her M. Sc. degree in Robotics and Intelligent Systems from the Arts et Métiers Engineering School in Paris in 2001 and her Ph.D. in Mechanics for Medical Robotics from the University of Orléans in 2005. Dr Al-Bassit's research interests include robotic system design, modelling and optimisation of robot kinematics, design for safety, medical robotics, mobile reconfigurable robotics and soft robotics.

Paul CHAMBON

General Manager - Réseau TERIA

Paul CHAMBON, an ESTP engineer, joined EXAGONE-TERIA in 2008, creating and managing the Technical Department. With the help of his team, he finalized the development of the GNSS ground station network, set up the server side and developed the associated processing tools. To meet the challenges of the digital age, the Technical Department expands to include a team responsible for maintaining the TERIA service in operational condition. In 2018, the company took a new step forward and became a satellite data broadcaster via its own frequency. The aim was to provide a service enabling users to become independent of terrestrial telecoms infrastructures, particularly in response to 4G/5G coverage limits and needs following intense weather events. In 2020, EXAGONE-TERIA will develop its own RTK GNSS receiver, manufactured in France. From June 2023, Paul CHAMBON's role will evolve to take on the role of Managing Director in addition to his position as Technical Director.

Cédric SEGUINEAU

Cédric Seguineau, PhD, is the Director of Impact, Quality and Autonomy Programm at Naïo Techno-logies, a SME designing and producing Agricultural Autonomous Machines. He leads the Autonomy and Safety Naïo's roadmap. He is the current chairman of the PT4 working group, about Safety of Autonomous Functions, in the frame of the European Agricultural Machinery Association (CEMA), and is engaged in RobAgri, the French association representing Agricultural Robotics, where he also leads a working group on Safety of autonomous equipment. He is also in charge of Naïo's ESG and the environmental impact of robotics in agriculture assessment.

Agro-ecological transition

Damien CALAIS

Agricultural equipment teacher - Institut Agro Dijon

Damien Calais is a Doctor of Geography from Université Paris Cité and studies the spread of innovations in agriculture. He is particularly interested in the agricultural development of desert areas as well as conservation agriculture. He furthered his training at the UniLaSalle Polytechnic Institute in Beauvais. As an agronomy engineering student, he completed internships at Agro-Transfert Ressources et Territoires and AXEMA. Since September 2023, he has been teaching at the Institut Agro Dijon as part of the Agroéquipements team.

Damien FUMEY

R&D Department Manager – SUN'AGRI

Dr. Damien Fumey is an agronomist and plant modeling scientist. He leads the Research & Development team in Sun'Agri. Sun'Agri works on agronomic solutions based on digital tools and models to protect the crops from the effects of climate change and has developed the concept of dynamic agrivoltaics. Since 2009, through an ambitious research program (7 PhD's thesis, more than 20 researchers involved, 7 experimental sites…) Sun'Agri has demonstrated the benefits of climate protection of dynamic agrivoltaics on different crops (grapevine, fruit trees, horticultural crops, cereals…) by controlling the shade. Today, this win-win solution engineered as a farm tool and financed by producing green energy is deployed at more than 15 sites in France, with many more under development.

Decarbonising of agriculture

François BROCHARD

Electrification engineering leader for offroad applications - In Situ Experts Hydrauliciens et Décarbonation, Vensys Group

François Brochard graduated from "Université de Technologie de Compiègne" (UTC, France) as mechanical engineer and from Cranfield University (UK) as automotive engineer. With a strong experience in engine management system by Valeo and Bosch achieved in the scope of Euro5 gasoline projects as an application engineer, he moves to electric system for automotive as Bosch application engineer and coordinator for PSA diesel hybrid HY4 project. Moving from automotive to off-highway mobile applications, he joined Manitou BF as transmission design and application engineer. First involved in innovative hydrostatics developments, he took then the role of electrification expert for new electric powertrain within the corporate R&D department.Since 2022, François Brochard is leading the electrification engineering and training by "In Situ, Experts hydrauliciens et décarbonation" within Vensys Group. With a 10-engineer team, In Situ supports electrification project of OEM and develops electric retrofit kits for new and used machines.

Marilys PRADEL

Research engineer environmental assessment / LCA – INRAE

Marilys Pradel graduated from Purpan Engineer School in 1997. After several professional experiences, she started to work at INRAE, the French National Research Institute of Science and Technology for environment and Agriculture, as a research engineer in 2007. She graduated from a PhD thesis in 2017 on the definition of an allocation methodology by coupling product and process parameters for Life Cycle Assessment of waste-based products with an application to sludge-based phosphate fertilizers. She conducts her research in the field of environmental assessment using the Life Cycle Assessment method and develops methodological approaches to assess the environmental sustainability related to fertilization practices using waste-sourced fertilizers with a focus on the phosphorus resource and agricultural and robotic technologies as a lever for the agroecological transition.

Data & IA

Théophile Loïc EYANGO

Data scientist - ADVENTIEL

As a data scientist at Adventiel, Loïc Theophile EYANGO works on topics requiring the application of artificial intelligence methods. In parallel to his work, he is pursuing an interdisciplinary PhD, exploring areas such as deep learning and mathematical modeling to develop an innovative methodology for coupling different artificial intelligence techniques. His main goal is to develop an advanced predictive model aimed at anticipating respiratory diseases in young cattle, thus contributing to improved animal health and overall production efficiency.

Eric FONTES

R&D and Product Project Manager - Ercogener / ZEKAT Group

Eric FONTES trained as an optronics engineer at ENSSAT (Lannion). He worked for 1 year as a research engineer in Toulouse (ONERA / CNES) and wrote an international publication on Doppler lidar. Eric has 10 years' experience in embedded software development for color printing and smart card personalization systems, and 18 years' experience in mechatronics project management: industrial color printers, low-cost electronic board for electric radiators, biometric passport scanner, digital video recorder, EDF single-phase meter, motorization systems with embedded HMI, IIOT, 4G/WiFi/ETH industrial gateways. Eric has filed 3 patents (EP1155867, EP3376823, FR3078458). An expert in embedded software quality, Eric has been working at Ercogener, part of the ZEKAT GROUP, since 2009.

Xavier L'HOSTIS

Service Manager / Innovation - ADVENTIEL

Xavier L'HOSTIS has worked for almost 25 years in the digital sector serving the agricultural and food industries, with assignments involving the management, urbanization and architecture of information systems. For the past 5 years, he has been in charge of Adventiel's innovation strategy, which helps detect, test and implement innovations to meet the challenges of the industry. He supports companies from ideation to realization of innovation projects in areas such as data feedback automation (Iot, Remote Sensing), data storage, data enhancement using artificial intelligence, as well as the creation of innovative user interfaces (voice, conversational, etc.). Xavier is passionate about pragmatic innovation applied to the agricultural sector in a collective, collaborative approach.

Victoria POTDEVIN

Data Science Manager - ADVENTIEL

Victoria POTDEVIN is an agricultural engineer specializing in the application of artificial intelligence to agriculture, agri-food and veterinary medicine. As Head of Data Science at Adventiel, she works with her team to develop digital solutions aimed at diagnosing, predicting and anticipating the challenges specific to these sectors. Her expertise lies in her ability to mobilize the artificial intelligence technologies needed to bring these projects to fruition.

Albane THOUERY

Sales Director - AGDATAHUB

Graduated from a High School, Albane has worked in ESN and major groups in business development. She assisted startups in their market launch, then structured the data and software strategy for a player in the agri-supply sector before joining Agdatahub. In parallel, she was responsible for the Services Management course on a Master Grande Ecole program. In her role, she deals with a wide variety of subjects linked to the circulation of data within the agricultural and agri-food sectors, in order to deploy the evolution of uses that respond to the environmental, societal and technical issues of the players involved. Albane supports all these organizations, from Agtech startups to major industrial groups, cooperatives and agricultural technical institutes, in the development of standards and new information flows to develop markets for carbon, traceability, logistics optimization, better use of inputs and monitoring of agricultural equipment.

Crop protection

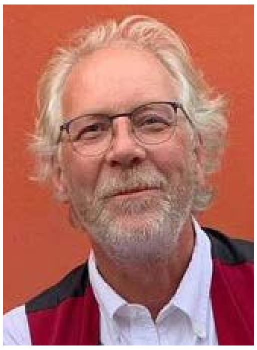
Nesrine BOUCHEKOUM

Research engineer - INRAE

Nesrine Bouchekoum is a research engineer with a double degree in Machinery Engineering and Agroequipment from the Higher National School of Agronomic Science (ENSA) in Algiers. She also holds a master's degree in Agroeconomics from the CIHEAM-IAMM (International Centre for Advanced Mediterranean Agronomic Studies, Mediterranean Agronomic Institute of Montpellier). With valuable apprenticeship experience, Nesrine has worked on developing an Intelligent Precision Spraying Prototype for weed control and conducting evaluations of agroequipment for relay cropping at the Unilasalle Institute in Northern France. She recently joined National Institute for Agricultural Research, Food, and the Environment the INRAE Montpellier team as the Neopulvé project manager, where she is dedicated to working on the sprayer calibration training program, based on the DataPulvé results.

Jean-Paul DOUZALS

Head of a research unit on spray application unit - INRAE Montpellier



Dr Jean- Paul DOUZALS is the head of a research unit on spray application unit at INRAE Montpellier, France since 2009. He first graduated as an agronomist with a specialization in Agricultural Engineering and started his professional career as a lecturer and assistant professor in a college of agricul-ture and higher education. During this period, he successively investigated several research topics linked to agricultural engineering and precision agriculture (i.e. weed detection) but also studied food processing at high pressure during his PhD. Since 2009, he is mostly involved in research, development and standardization in the domain of spray application techniques and at INRAE Montpellier. Investigations concern all phases of plant protection product application from the atomization, the transfer of droplets in the atmosphere and, finally, the deposition on target and off-target.

Véronique LECLERCQ

Project Manager - Walloon Agricultural Research Center

Veronique LECLERCQ is a bioengineer in Environmental Sciences and Technologies from Gembloux Agro-Bio Tech – Liège University (2015). She worked for two years in an environmental design office, soil pollution (2016-2017). This was followed by a year-long trip in New Zealand of discoveries and work on several farms. Since 2019, she has been a project manager at the Walloon Agricultural Research Center in the Sustainability, systems and prospectives Department. She has been working for four years on projects for sustainable vegetable farms, including the evaluation of robotic solutions for mechanical weeding.

François SEMENT

Head of Biology R&D - UV BOOSTING

After obtaining his PhD in «Cellular and Molecular Aspects of Biology» at the Institut de Biologie Moléculaire des Plantes in Strasbourg, François Sement began his research career at CNRS and Boston University. In 2019, he joined the UV Boosting team, where he focuses on understanding the biological mechanisms involved in UV flash stimulation. As head of the Biology Research and Development team, he is working on the development of this process aimed at boosting the natural defenses of plants, particularly vines and other plant species of agronomic interest.

Innovative agricultural equipment

Pierre HAVARD

Co-founder – CORMIERS

Pierre Havard is in charge of sales and after-sales and is involved in defining and developing products for CORMIERS. Passionate about agricultural equipment and having devoted his entire career to this discipline, Pierre Havard has built his experience on multiple cultural foundations: Technological - agronomic - technical-economic - human. His professional career has taken him into a wide range of activities: design office, initial training and training with a major manufacturer, agri-equipment consultancy (Cuma network), management of an agri-equipment experimental station. In this context, he has led or contributed to a number of studies on the spreading of organic fertilisers, alternative weeding techniques, fuel consumption and the adoption of new technologies by users. Along with Frédéric Gauthier, he is co-founder of Cormiers. Cormiers is a company in the Vensys group.

Fulvio ZERBINO

Chief Engineer of Precision Farming - Kubota R&D Europe center

Fulvio Zerbino was born in Avellino (Italy) on 18th of April 1983. He obtained B.D. and M.D. in Electronic Engineering at the University of Pisa in 2012. In 2013, he was hired by Re-Lab (Reggio Emilia, Italy) as firmware engineer getting deep knowledge of ISOBUS and off road electronic platforms. In the early 2014, he moved to Same Deutz-Fahr R&D (Treviglio, Italy) to work as software and system engineer representing also the manufacturer in the AEF TIM project. Since July 2018, he joined the Kubota R&D Europe center KRDE (Crepy-en-Valois, France) as system engineer and TIM project responsible representing also the manufacturer in the AEF TIM project. Then he extended his role to Precision Farming topics management for tractor and implements and he is currently the Precision Farming Chief Engineer for KRDE.

Posters

Pierre DELMAS

Chairman - 4D VIRTUALIZ

Pierre DELMAS holds a degree in electrical engineering, specializing in automation and control, as well as a PhD in electronics and systems. He first held various positions as a Research Engineer at the INRAE (TSCF Research Unit) and Institut Pascal laboratories in the development of simulation solutions with the aim of supporting various research activities related to autonomous navigation in urban and/or natural environments. In 2014, he co-created the company 4D-Virtualiz, which he has since headed as President. An expert in simulation and land mobile robotics, he contributes his technical knowledge and experience in modeling robotic systems, sensors and environments in connection with off-road industrial projects, notably in the defense and agri-equipment sectors.

Dieumet DENIS

Advanced Autonomous Systems Project Manager - SHERPA Engineering

Dieumet DENIS received, in 2015, the PhD degree in Control of Mobile Robots from Institut Pascal, Université Blaise Pascal in Clermont-Ferrand, France. During his PhD, he largely studied the thematic of vehicles dynamics stability leading to a patent deposit for designing an active safety and driving assistance device dedicated to off-road vehicles. Since 2016, after a post-doctoral position at CNRS and INRAE, Dr DENIS joined SHERPA Engineering company as Project Manager and Research Engineer in Autonomous Vehicles field. He is currently Director of SHERPA's Clermont-Ferrand Division. He is also part of AgroTechnoPôle board and runs the I-SMART joint laboratory between SHERPA and INRAE aiming to develop innovative and sustainable methods for agricultural robotics and off-road mobility in the perspective of the agroecological transition.

Frédéric FAVROT

Senior Division Representative - Gea Farm Technologies

Frédéric Favrot has held for 30 years the positions of business manager in the field of agri-supply industries in France and Europe. For 10 years, he has been working on the BioSolutions market for productive, profitable, rewarding and valued agriculture.
He joined GEA in 2023 as Senior Division Representative in charge of the WEMEA Region.

Christophe MICHEL

CEO - LCJ Capteurs

After a solid training in analog electronics, Mr. MICHEL worked for 18 years in maritime radio positioning, hyperbolic TORAN, RANA, LORAN-C, GPS and differential GPS systems. He worked on the development of radio reception cards and HF and SHF antennas. He helped found LCJ Capteurs in 1999. The company's objective was to create a compact, marinized, energy-efficient, lightweight and robust wind sensor. Ultrasonic technology was chosen. Drawing on the company's experience in radio positioning, the choice was made to measure acoustic propagation time using phase measurements, unlike the wind vane-anemometers on the market at the time. LCJ Capteurs subsequently registered 2 patents and became a forerunner in miniature wind sensors. Following its success in the marine market, LCJ Capteurs opened up land-based markets, including precision agriculture.

Sébastien PERSONNIC

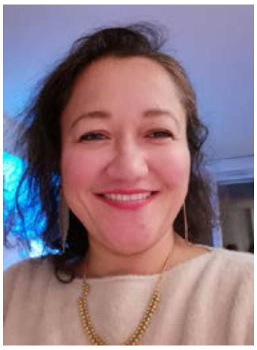
Development Director - ID4MOBILITY

Development Director of the ID4MOBILITY competitiveness cluster, Sébastien Personnic has been responsible since 2016 for the growth of a mobility innovation ecosystem of over 400 members based in the greater west of France. Our role: to support project leaders in designing, developing, experimenting & industrializing impact solutions for the future of land-based mobility. His training as an engineer and doctor gave him a solid technical base, which he rounded out with ten years' experience in innovation management and financing. In addition to his role as developer, he facilitates access to a business and technology network of excellence, defines the network's animation strategy, pilots thematic working groups and forges partnerships for the benefit of its members. It also contributes to the detection and emergence of innovation and industrial projects. As a key player in the machinery and off-road sectors, it has established strong links within the industry, encouraging project structuring and collaboration.

Farzam RANJBARAN

Senior Research Engineer and Project Manager - Institut CEA LIST

Since October 2020, Farzam RANJBARAN has been with CEA, LIST Institute working as senior Research Engineer and Project Manager in the department of ambient intelligence and Interactive Systems working mainly on European Collaborative Research projects.
He received his PhD in Mechanical Engineering from McGill University in Canada in 1996. Before joining CEA, he worked as staff engineer for Bombardier Aerospace, and Pratt & Whitney in Canada and the USA respectively. During 1999-2005, he was with the Canadian Space Agency, as senior mechanical engineer and programme manager. From 2005 to 2012, he worked for the European Science Foundation in Strasbourg, France with several responsibilities including head of the corporate Science operations unit. Following a period of three years as a consultant, he joined the University of Limoges, International Relations department and then worked at the European Commission's Research Executive Agency Unit A5 that managed the FET-Open programmes, now under European Innovation Council.



Adriana SANCHEZ HALLEUX

Business and Project Manager - AgroTechnoPôle Platform

Adriana SANCHEZ -HALLEUX is Business and Project Manager at the l'AgroTechnoPôle Platform, an open innovation platform led by INRAE' Research Unit TSCF (Technologies and Information Systems for Agricultural systems). She recently worked at the competitiveness cluster VEGEPOLYS VALLEY, as New Technologies and Practices for Production Systems Innovation Manager. Ms. SANCHEZ-HALLEUX holds a Master in Agricultural Engineering and Agricultural Engineer from the National University of Colombia. She has more than ten years of experience in defining Science, Technology and Innovation (ST&I) policies, and ST&I Management. She worked with several entities in Colombia, including the National University, the Ministries of Agriculture and Information and Communication Technologies (MinTIC), among others organizations.

Anne-Laure WOZNIAK

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Currently a research engineer at Kereval, Anne-Laure is finalizing her thesis on the software tes-ting of systems using artificial intelligence. Her area of expertise is the robustness of AI models, i.e. their ability to produce reliable results in all circumstances. In 2022, she took part in the Confiance.ai national program to develop a black-box robustness testing tool for computer vision systems.

Automatic test bench

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Abstract

REGRESSION testing, which should be carried out with each new software release, requires time, material and human resources. To ensure good repeatability, regardless of who performs the tests, it is necessary to detail the different steps of the tests. This requires a lot of upstream work.

In addition, manual testing can have a discouraging effect on the «push-button» tester, when campaigns are frequent and take several days, or even weeks, to complete.

The advantage of automation is that it reduces this resource requirement, while increasing test repeatability. The difficulty of automating tests may come from the type of product (Isobus in this case) you want to test, and the different sensors or actuators you want to simulate. But having automatic tests means that test campaigns can be carried out more thoroughly and more frequently than with manual testing.

The use of a test manager enables you to check the coverage of the requirements by the tests, to track changes in test assets, to keep a complete record of test campaigns carried out on different products, and to manage test phases using the indicators provided.

Keywords : Isobus, test, Automation, repeatability, quality.

1. Introduction

In the software development cycle, there are several levels of testing :

- Unit or component testing
- Integration testing
- System testing
- Acceptance testing

Unit and integration tests are the responsibility of the developer and require access to the source code. It is possible to automate these levels of testing, but with tools other than those described in this article.

System tests and acceptance tests correspond to the test levels where an automatic test bench can be set up.

When we upgrade software, we first test that the upgrades work correctly, then check that what worked before still works: this second part corresponds to what we call regression testing. The characteristic of regression testing is that you always carry out the same tests, which is why it's a good idea to automate them, as they are carried out many times.

To optimize the workload, when we run a manual regression test campaign, we select the tests to be run according to the risks and the probability of functions being impacted by the modification. If these tests are automated, we will be able to run all of them, the execution time of tests will be reduced and they can be run outside of traditional working hours.

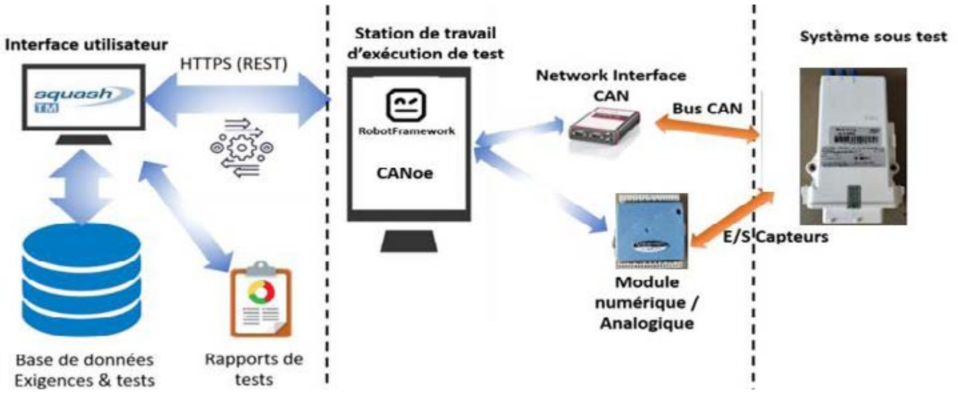
These automated tests can include functional tests (to verify product functionality), non-functional tests such as performance tests (to measure response times, for example) or tests to verify standards such as ISO 11783 (Isobus).

The difficulty for most agricultural machinery manufacturers is that software development is often outsourced. In this case, system tests are carried out by the subcontractor, and the manufacturer performs the acceptance tests. Unfortunately, it is often the case that the subcontractor mainly tests software evolutions and minimizes regression testing. If the manufacturer wants to guarantee the correct functioning of his product, he must take responsibility for regression testing. Therefore, it's a good idea to carry out these tests automatically, especially if there are many changes in the software.

2. Materials and Methods

In this type of test bench, there is a management part, including the test manager, a scheduling part and an execution part. The first two parts are often centralized, to provide access to the company's various departments. The execution part is specific to the product being tested and installed on a dedicated PC.

The architecture of a test bench is as follows :



The bench can be divided into three parts :

Management part :

- Squash TM

Scheduling part :

- Jenkins / Squash autom

Execution part :

- Robot-framework
- Canoe
- Input / Output card

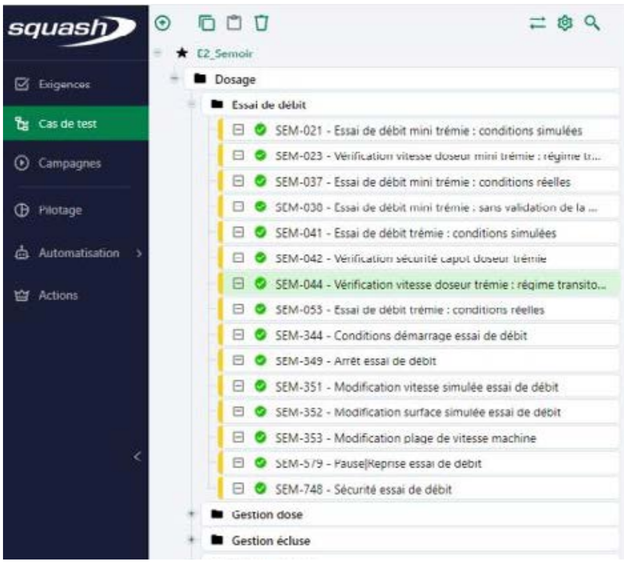
2.1. Management part

Squash TM :

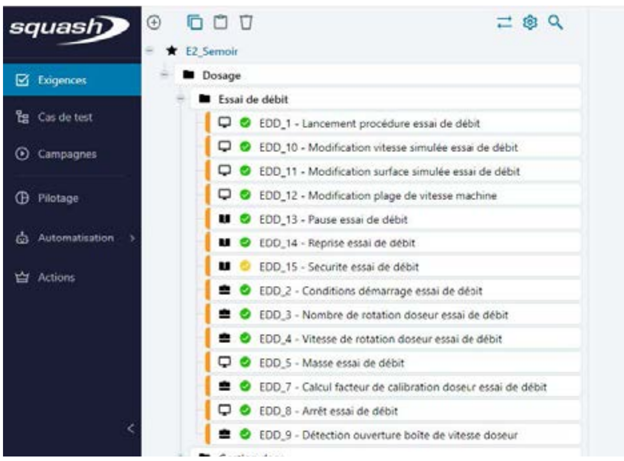
This is a test manager which includes requirement, test case and test campaign sections, with the ability to generate reports on the various test campaigns.

The advantage of integrating a test manager into the test bench is that it can be used to store the requirements repository and its evolutions, to store manual and automatic test cases and their evolutions, and to have bidirectional traceability with the requirements. It also enables test campaigns to be managed, and indicators to be supplied.

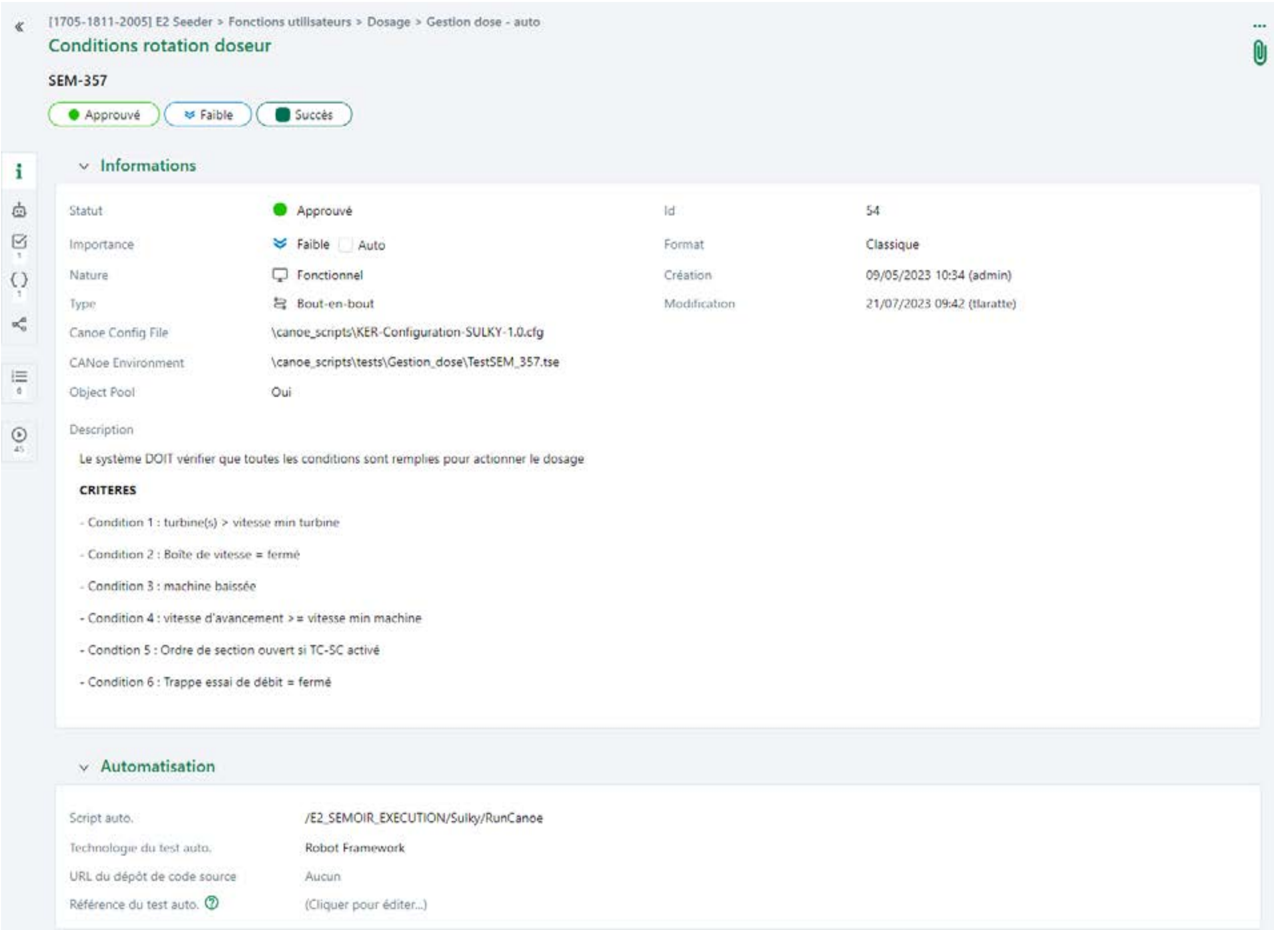
Espace Exigence



Espace cas de test



Test cases are defined as shown below, and linked to requirements.



2.2. Scheduling part

Jenkins / squash autom :

The role of the scheduler is to receive execution orders (lists of tests to be run) from the test manager and to tell the execution stations to run the tests. Its role is to keep the list of tests in memory and to ask the execution workstation to run them one by one.

Its second function is to transfer execution results to the test manager. Jenkins and squash autom are two types of scheduler to be chosen according to the technical choices of the architecture.

2.3. Execution part:

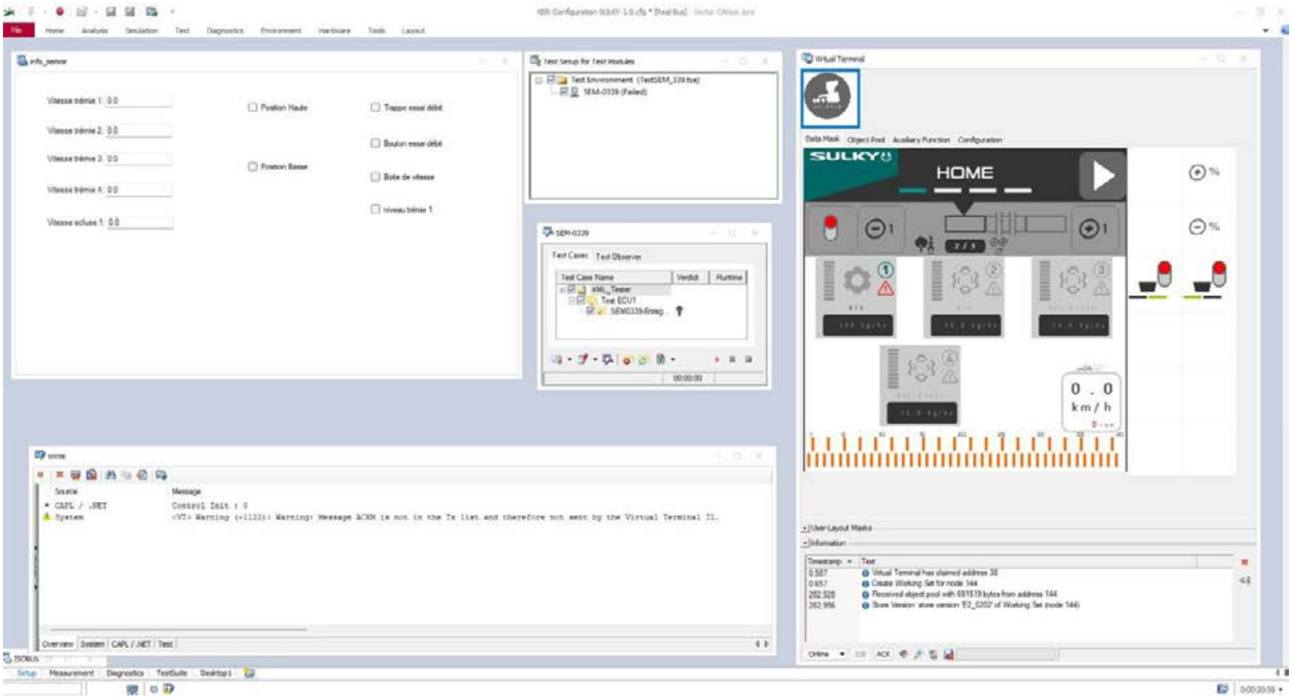
Robot framework :

Robot Framework is a test automation framework that enables test steps to be described in natural language using keyword libraries.

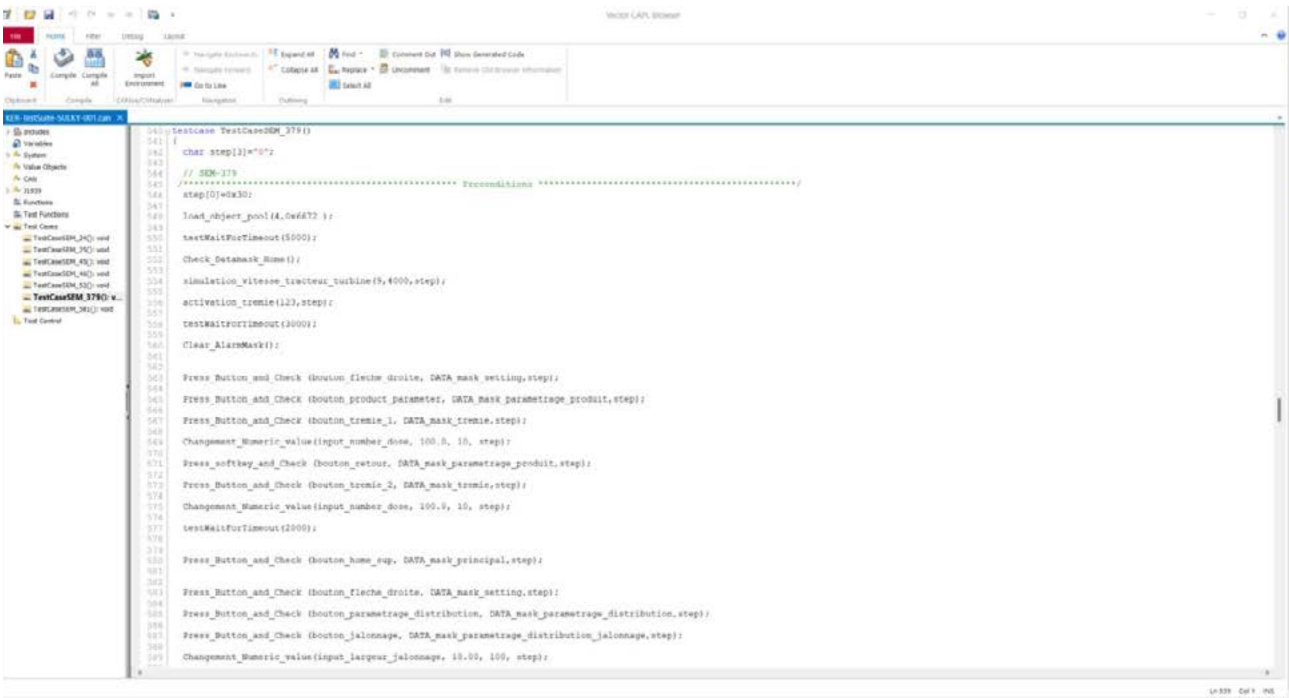
Robot Framework is based on the Python language and can be interfaced with various execution tools to carry out tests on both traditional information systems and embedded systems.

CANoe :

CAN analysis tool, with the ISOBUS option, which uses the «ISOBUS interactive layer» to simulate a UT (Universal Terminal). This interactive layer makes it possible to put itself in the place of a UT, to simulate all the actions performed on it and to analyse the SUT (System under test) responses. The use of CANoe minimized the development of the ISOBUS functions required for testing.



Test cases are programmed in CAPL (Communication Application Programming Language), a C-like language used to script tests in Vector's CANoe tool.



<u>Input/output board :</u>

Used to simulate sensors or actuators, controlled by robot framework or another runtime system.

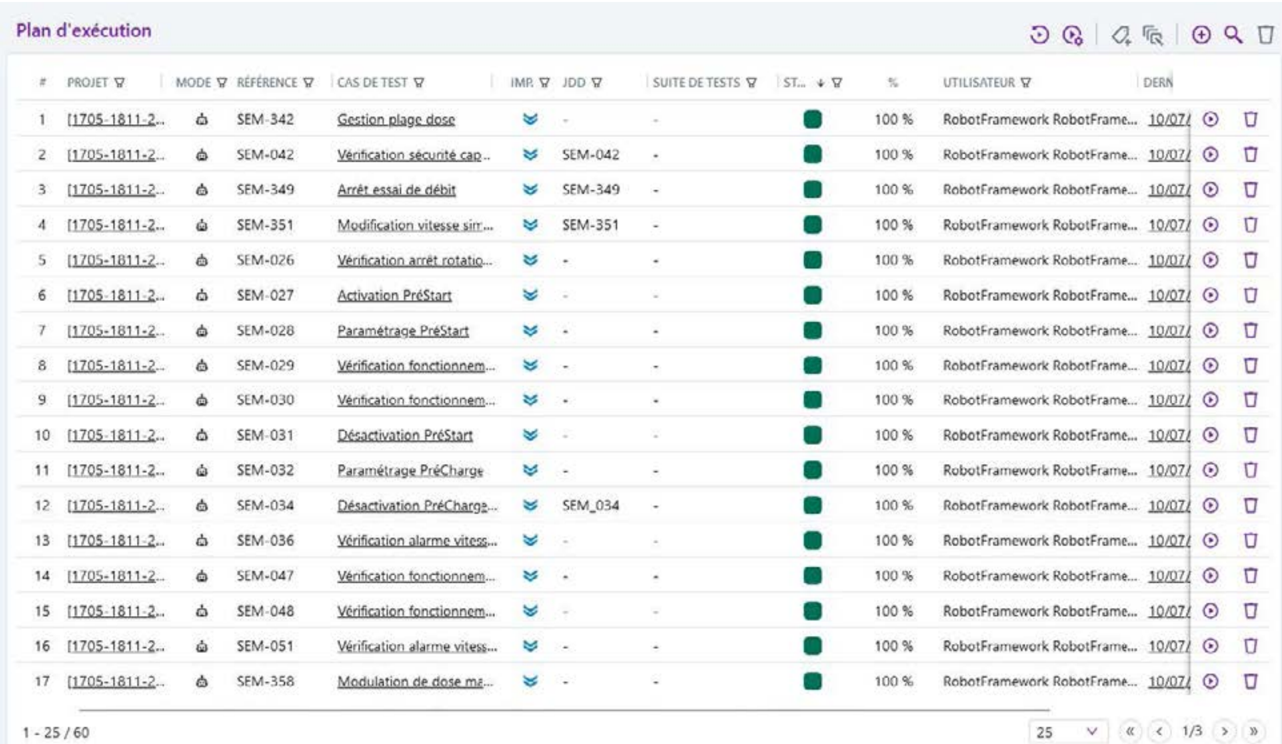
3. Results and Discussion

For this project, 71 tests were initially run manually. It took 4 days to run this campaign manually.

69 tests were then automated, and the entire test campaign took 2 hours to run. The remaining two tests were not automated, as they required the complete seeder.

The fact that we now have an automatic test bench has enabled us to integrate tests relating to the ISOBUS standard, such as checking the display Object pool, according to language and UT version. In this case, 6 languages and 3 UT versions were tested, resulting in 18 tests that detected the use of fonts not compatible with the UT version.

The results of the campaign are as follows :

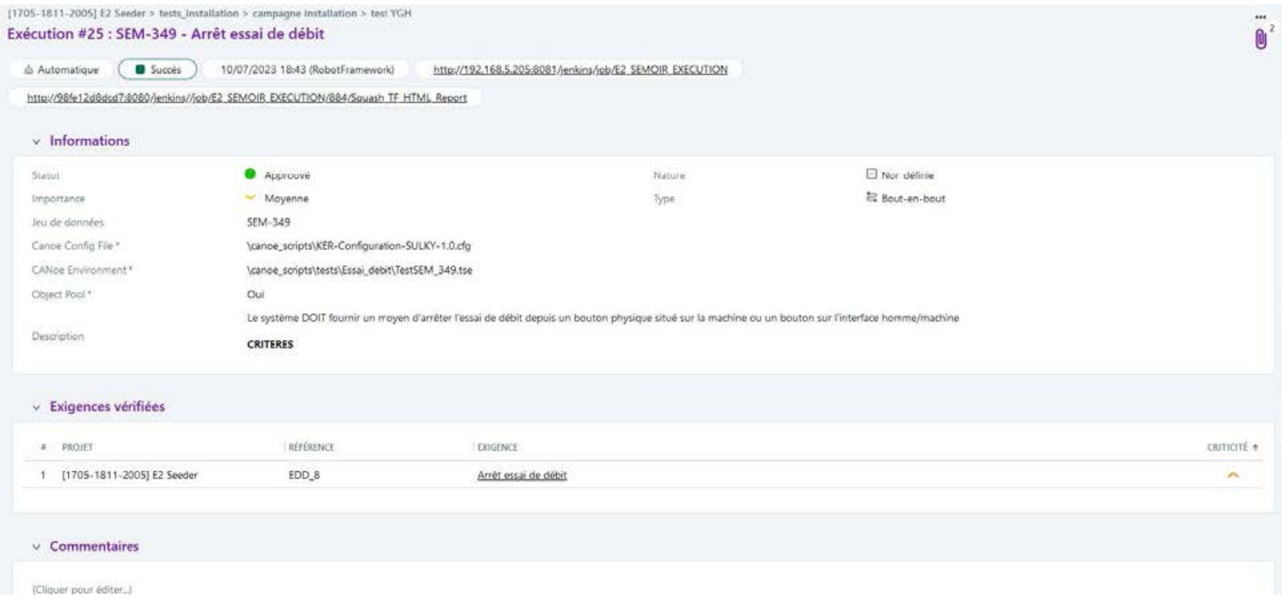


Plan d'exécution

#	PROJET	MODE	RÉFÉRENCE	CAS DE TEST	IMP.	JDD	SUITE DE TESTS	ST...	%	UTILISATEUR	DERN
1	[1705-1811-2...		SEM-342	Gestion plage dose		-	-		100 %	RobotFramework RobotFrame...	10/07/
2	[1705-1811-2...		SEM-042	Vérification sécurité cap...		SEM-042	-		100 %	RobotFramework RobotFrame...	10/07/
3	[1705-1811-2...		SEM-349	Arrêt essai de débit		SEM-349	-		100 %	RobotFramework RobotFrame...	10/07/
4	[1705-1811-2...		SEM-351	Modification vitesse sim...		SEM-351	-		100 %	RobotFramework RobotFrame...	10/07/
5	[1705-1811-2...		SEM-026	Vérification arrêt rotatio...		-	-		100 %	RobotFramework RobotFrame...	10/07/
6	[1705-1811-2...		SEM-027	Activation PréStart		-	-		100 %	RobotFramework RobotFrame...	10/07/
7	[1705-1811-2...		SEM-028	Paramétrage PréStart		-	-		100 %	RobotFramework RobotFrame...	10/07/
8	[1705-1811-2...		SEM-029	Vérification fonctionnem...		-	-		100 %	RobotFramework RobotFrame...	10/07/
9	[1705-1811-2...		SEM-030	Vérification fonctionnem...		-	-		100 %	RobotFramework RobotFrame...	10/07/
10	[1705-1811-2...		SEM-031	Désactivation PréStart		-	-		100 %	RobotFramework RobotFrame...	10/07/
11	[1705-1811-2...		SEM-032	Paramétrage PréCharge		-	-		100 %	RobotFramework RobotFrame...	10/07/
12	[1705-1811-2...		SEM-034	Désactivation PréCharge...		SEM_034	-		100 %	RobotFramework RobotFrame...	10/07/
13	[1705-1811-2...		SEM-036	Vérification alarme vitess...		-	-		100 %	RobotFramework RobotFrame...	10/07/
14	[1705-1811-2...		SEM-047	Vérification fonctionnem...		-	-		100 %	RobotFramework RobotFrame...	10/07/
15	[1705-1811-2...		SEM-048	Vérification fonctionnem...		-	-		100 %	RobotFramework RobotFrame...	10/07/
16	[1705-1811-2...		SEM-051	Vérification alarme vitess...		-	-		100 %	RobotFramework RobotFrame...	10/07/
17	[1705-1811-2...		SEM-358	Modulation de dose ma...		-	-		100 %	RobotFramework RobotFrame...	10/07/

1 - 25 / 60 25 1/3

A test result takes the following form:



[1705-1811-2005] E2 Seeder > tests_installation > campagne installation > test YGH

Exécution #25 : SEM-349 - Arrêt essai de débit

Automatique | Succès | 10/07/2023 18:43 (RobotFramework) | http://192.168.5.205:8081/jenkins/job/E2_SEMOIR_EXECUTION

http://98fe12d8dcd7:8080/jenkins//job/E2_SEMOIR_EXECUTION/884/Squash_TF_HTML_Report

Informations

Statut: Approuvé
Nature: Non définie
Importance: Moyenne
Type: Bout-en-bout
Jeu de données: SEM-349
Canoe Config File *: \canoe_scripts\KER-Configuration-SULKY-1.0.cfg
CANoe Environment *: \canoe_scripts\tests\Essai_debit\TestSEM_349.tse
Object Pool *: Oui
Description: Le système DOIT fournir un moyen d'arrêter l'essai de débit depuis un bouton physique situé sur la machine ou un bouton sur l'interface homme/machine
CRITERES

Exigences vérifiées

#	PROJET	RÉFÉRENCE	EXIGENCE	CRITICITÉ
1	[1705-1811-2005] E2 Seeder	EDD_8	Arrêt essai de débit	

Commentaires

(Cliquer pour éditer...)

To enable analysis of the test results, the test execution log file and a report from CANoe are uploaded to squash TM.

[-] **1 Test Group: Test ECU1**

[-] **1.1 SEM-45: Vérification fonction arrêt trémie: Passed**

Test case begin: 2023-06-14 14:00:02 (logging timestamp 0.125872)
Test case end: 2023-06-14 14:00:45 (logging timestamp 43.075872)

Main Part of Test Case

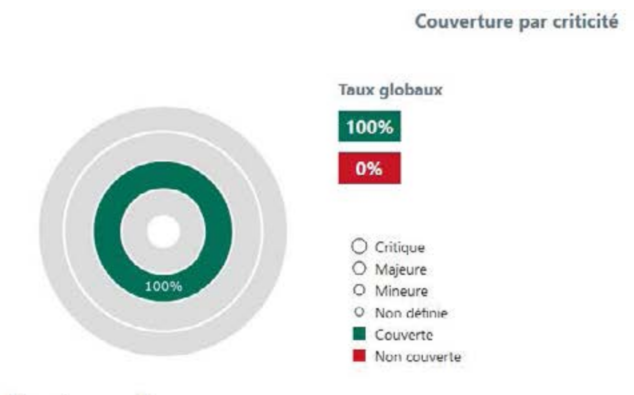
Timestamp	Test Step	Description	Result
16.375872	0	le numero de mask est le : 1000	pass
17.075872	0	le numero de mask est le : 1000	pass
17.775872	0	le numero de mask est le : 1000	pass
18.475872	0	le numero de mask est le : 1000	pass
19.175872	0	le numero de mask est le : 1001	pass
19.875872	0	le numero de mask est le : 1001	pass

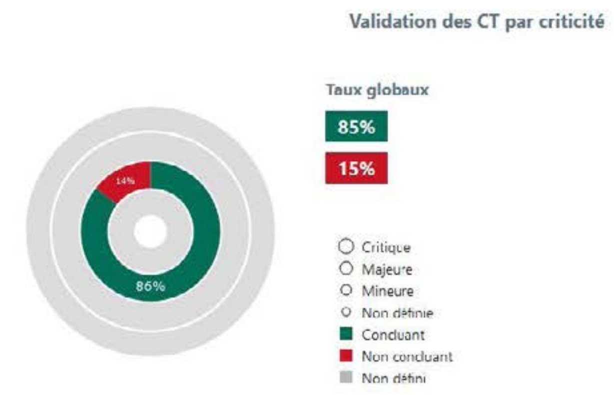
The result of the campaign is presented in two ways :

As a list of executed test cases :

	Synthèse			Avancement de l'exécution										Jamais exécuté			
Suite de tests	Total	À faire	Fait	À exécuter	En cours	Succès	Échec	Bloqué	Non testable	% Avanc.	% Succès	% Échec	Réel vs prév.				
Sans suite	7	0	7	0	0	6	1	0	0	100 %	85.71 %	14.29 %	100 %	0	0	0	0
Total	7	0	7	0	0	6	1	0	0	100 %	85 %	14 %	100 %	0	0	0	0

Or in the form of requirements coverage by the tests performed :





In test campaigns, we indicate the version of the software being tested, enabling us to track requirements, tests, and software versions.

4. Conclusions

Automated testing has made it possible to :

- Significantly reduce test execution time
- Reduce human resources, which can be assigned to other, more interesting tasks
- Carry out complete regression testing for each new software release
- Increase the scope of testing by integrating ISOBUS tests
- Provide traceability of requirements, tests, and software versions.

Soil diphasic conveyance

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Abstract

Predicting the behavior of earthmoving and agricultural machinery is a challenging and crucial engineering task. The interactions between agricultural equipment and soil pose an ongoing challenge for manufacturers, designers, and researchers. This challenge stems from the spatial variability of soil properties, the nonlinear and dynamic behavior of soil, and the complex contact between soil and agricultural machinery. In this paper, we introduce a numerical model utilizing the Discrete Element Method (DEM) to simulate the interaction between a rotary harrow-type tillage machine and soil. This equipment consists of two vertical-axis tillage blades followed by a toothed roller, which serves to consolidate the soil and control the working depth. Rotary harrows are typically used for breaking up soil clods, preparing seedbeds, mixing soil with organic matter to facilitate germination, among other tasks. We employ SIMCENTER STAR-CCM+, a Multiphysics numerical tool, to compute DEM interactions, contact forces, and erosion rates on the tillage tool. Understanding the contact forces exerted by the soil on the tillage tool is crucial for assessing its real-world behavior. Our model enables the calculation of local forces exerted by individual particles, which sum up to provide the total force on the tool. The component of this force in the direction of the tool's movement represents the drag force, while the vertical component corresponds to the soil's penetration force on the tool. Concurrently, we develop a Finite Element Model (FEM) alongside the DEM model, incorporating mechanical stress to account for the stresses arising from the forces acting on the rotating and translating blades. Furthermore, tillage tools are susceptible to erosion caused by soil particles. We combine the DEM model in STAR-CCM+ with an erosion model to predict material wear rates based on solid particle impact characteristics. This approach allows us to forecast both abrasive and impact wear. As part of this study, we compare characteristic quantities with experimental measurements found in scientific and technical literature. This model enables the estimation and prediction of several key factors :

- Soil void content before, during, and after the tillage tool's passage.
- Forces, especially drag and penetration, exerted by the blades in the soil.
- Stress resulting from the contact of the tillage tool with soil.
- Erosion rates attributed to the interaction between the tillage tool and soil.

Keywords : earthmoving, erosion rates soil void, numerical simulation, DEM.

1. Introduction

In the literature, various strategies have been employed in the past to mechanically size agricultural tools. Kushwaha and Zhang [(Kushwaha, 1998)] presented a finite element approach (FEM) to model the interaction between tools and soil by defining an a priori assumption about the soil-tool interface. Upadhyaya et al. [(Upadhaya, 2002)] conducted an in-depth review of the use of finite element models (FEM) for tool-soil interactions and concluded that the finite element model is suitable when soil is modeled as an elasto-plastic medium. However, soil deformation, especially during soil tillage, involves separation and mixing of soil layers, crack formation, and particle flow, which cannot be properly modeled by the finite element method. DEM models are particularly suited for modeling granular materials and studying the relationship between «micro» and «macro» mechanical behavior of agricultural fluids, especially soil. Thus, soil parameters need to be calibrated to account for this difference in particle size and shape.

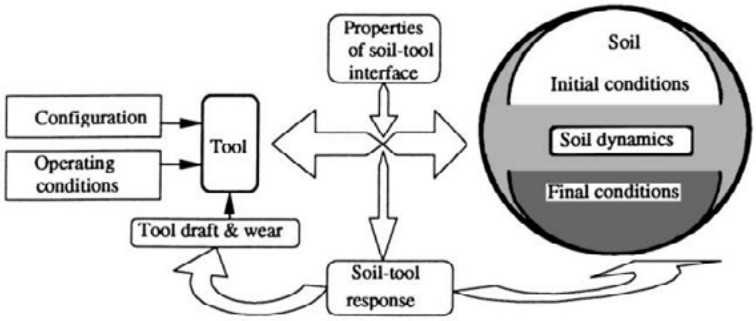

Figure 1 . Soil tool interaction scheme **[(Kushwaha, 1998)]**.

Soils, as natural deposits, cover a wide range of particle sizes and shapes. Predictive methods for minimum soil void ratio (also called maximum packing density) with different particle sizes are mainly based on empirical data. Cubrinovski and Ishihara [(Cubrinovski, 2002)] examined a large amount of data from tests on silty sand and presented a set of empirical equations to demonstrate the influence of silt content on the minimum void ratio. There are very few analytical models for predicting the minimum void ratio.

Vallejo [(Vallejo, 2001)], Chang et al. [(Chang, 2015)] proposed an analytical method to predict the minimum void ratio for sand-silt mixtures. Their analytical models focused on sand-silt mixtures, considered as composites of particles of two different sizes. These models cannot be applied to soils with a wide range of particle sizes. In addition to these studies, numerical simulation analyses using the Discrete Element Method (DEM) have also been implemented to study void ratios of particle mixtures [(Fuggle, 2014)]. The trend of numerical simulation results resembles that obtained from experimental tests.

In DEM codes, particle shape is approximated using spheres, bonded spheres (agglomerates), and non-spherical particles (e.g., polyhedra, ellipsoids). The spherical representation of DEM particles has advantages in terms of relatively simpler contact detection algorithms, simpler overlap-based force displacement calculations, and reduced computational effort. The choice between spherical and non-spherical shape approximation depends on the user's expertise in the engineering problem, measured dimensional properties, material behaviors, and affordable computational effort.

Sadek et al. [(Sadek, 2017)], worked on a DEM numerical model of soil to simulate soil penetration interaction and calibrated the model's micro-properties using laboratory measurements for two soil moisture conditions. They mention that the Cone Index (CI) is a crucial parameter in agricultural activity. Various articles and reviews have shown that soil properties affect the Cone Index (CI). Dryer soils have a higher CI than wetter soils, and soils with higher bulk density have higher soil CI values. The CI of the soil also varies within the soil depth profile. Lower soil CI values are associated with a plowed layer near the soil surface, while higher CI values are associated with a compacted soil layer beneath the plowed layer. Sadek et al. [(Sadek, 2017)] conducted soil compaction tests using silty sand with two different moisture percentages. The soil was collected from the Iowa State University-Agricultural Engineering Farm in Boone, Iowa. A predetermined soil mass for each soil moisture condition, «wet» 12.4%, and « relatively dry » 9.2%, was used. Bulk density calibration tests for different soil layers were reproduced using DEM simulation with a 10% relative error **(Table 1)**.

Layer	Target Bulk density (kg m^{-3})	Measured Bulk density (kg m^{-3})	Relative Error (%)
Top	1250	1250	0.00
Middle	1550	1495	3.54
Bottom	1400	1362	2.71

Table 1 . Relative errors between the measured and simulated CI.

Zeng et al. [(Zeng, 2016)] worked on the experimentation and simulation of soil-micro penetrometer interaction using the DEM method. The Penetrometer is a tool used to measure soil resistance.

The micro penetrometer consisted of a frame, a sensor to measure soil resistance, a drive system, and a data acquisition system. For model calibration, laboratory measurements were conducted on fine sandy loam soil. The soil was taken from the upper layer (60 mm) of a field in Manitoba, Canada. The results of the experiments show that the measured bulk density in the field was 1,060 kg/m³ for soft soil and 1,490 kg/m³ for hard soil. The results show that the simulated average CI is 0.554 MPa at the minimum bulk density of 733 kg/m³ and increases to 1.752 MPa at the maximum bulk density of 1558 kg/m³. They concluded that the calibrated particle stiffness is 10,300 N/m for fine sandy loam soil, and the measured CI values matched well with the model with low relative errors (15%) for two soil conditions (soft and hard). Chen et al. [(Chen, 2013)] worked on a DEM model of soil cutting in three different soils. Their goal is inverse calibration of model parameters using experimental data on soil cutting forces and validation of DEM model results using experimental soil disturbance data.

Ucgul et al. [(Ucgul, 2014)] study highlights the importance of considering the plastic deformability of the soil using the HSCM (Hysteresis Spring Contact Model) contact model to provide more realistic predictions of soil force and movement in DEM simulations, rather than assuming a simpler elastic contact model like the HMCM (Hertz-Mindlin Contact Model). Therefore, HSCM should be used for soil tillage interaction simulations rather than HMCM. Additionally, larger particle sizes yield suitable results, enabling faster 3D simulations of soil tillage using DEM. Later, Ucgul et al. [(Ucgul, 2015)] extended previous work on a 3D DEM model of a soil tillage tool by adding soil cohesion and adhesion using the HSCM contact model. The results show that to model a direct shear test using silty sandy soil, good predictions can be obtained using DEM parameters for beach sand, measured bulk density, and cohesive energy density equal to measured cohesive force. Furthermore, numerical results explain that including both cohesive and adhesive contact forces in the HSCM improved the prediction of traction and vertical forces. Thus, HSCM with the addition of cohesive and adhesive contact forces, along with using real soil parameters like wet bulk density, is a valid method for predicting both soil tillage traction and vertical forces in silty sandy soil. The bibliography presented in this report demonstrates a multitude of studies aimed at defining numerical parameters for soil behavior. The dynamic interaction that occurs in the soil-tool interaction process involves a high rate of plastic deformation and soil particle disruption, characterized by soil particle flow.

The Discrete Element Method (DEM) appears to be a promising approach to build a high-fidelity model to describe soil tillage interaction. However, there is no robust method to determine soil property parameters. This is the main obstacle to the widespread use of a DEM model, with a lack of reliable techniques to determine a wide range of physical properties needed to develop 3D DEM models for processes like soil aggregation and disruption. Another major challenge is to obtain a robust method for calculating model parameters to control soil void ratio and particle shape. It is also important to improve computation time and link DEM with other numerical methods to leverage each of them, such as FEM-DEM models and explicit CFD-DEM models.

2. Materials and Methods

In this part, we will define the various types of contacts and their corresponding physical models, along with the simulation parameters used for DEM simulation. The contact types In DEM simulations aimed at modeling soil as a collection of particles so it's important to define the types of contacts between particles to consider. There are three types of contacts: Frictional Contact which characterizes the movement of particles when they encounter each other or with boundaries (e.g., walls). Parameters such as the coefficient of rolling resistance, static friction coefficient, and coefficients of restitution determine how particles will roll, slide, or bounce off each other or boundaries, which represent the plowing tool in this study. The Cohesive Contact represents the molecular force that allows similar particles to unite. The cohesion work parameter defines how easily this union can occur and be broken. In this study, cohesive contact becomes more important when soil moisture content is high, as it enhances particle aggregation. The Adhesive Contact represents the attractive force between different materials, tending to bind them together. Typically, this contact type applies to interactions between soil particles and the plowing tool, defining the particles' ability to adhere to the tool. Several contact models exist with their specificities and limitations. In this study, two models are considered: the Hertz-Mindlin Model is a simple elastic contact model without plastic deformation. Particles interact based on various model parameters (friction, rolling, etc.) but do not deform. Cohesion effects between particles can be simulated by enabling the Johnson-Kendall-Roberts (JKR) model. However, it cannot model adhesive effects with boundaries. The Walton Braun Model called the hysteresis-type model accounts for both elastic and plastic contact, considering soil deformation when stresses on particles exceed a threshold. It is preferred for our work as it provides more realistic vertical and longitudinal forces exerted by soil on plowing tools compared to the simple elastic Hertz-Mindlin model. Cohesion and adhesion effects can be simulated with this model using a spring-dashpot system. Note that when clumps are used, particle-to-particle contacts can only be modeled with the Hertz-Mindlin model; the Walton Braun model can only be defined for interactions between particles and walls. For the simulation parameters, the particle is modeled as spherical particle representation to reduce computational requirements and facilitates calculations. However, non-spherical representations like «clumps» offer a more realistic soil behavior, allowing for the breaking of particle connections upon contact with the plowing tool.

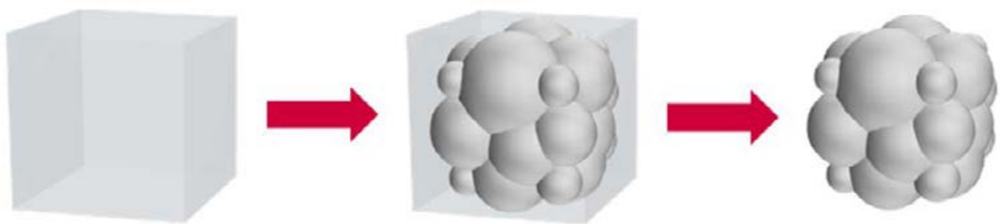

Figure 2 . Clump generation from a cube.

Clumps are injected **(Erreur ! Source du renvoi introuvable.)** into the system to ensure uniform and compact soil distribution. Lattice injectors with a Face-centered cubic method are employed for optimized filling. The total number of injected particles ranges from 150,000 to 500,000 depending on the desired soil depth, with the calculation time increasing as the number of particles increases.

Modeling soil with clumps enhances the behavior at the plowing tool-soil interface, enabling the breaking of soil aggregates. The parameters for tensile and shear strength is determined to simulate clump decomposition. According to references a value of 25 KPa was chosen. Properties of soil particles, such as density, Young's modulus, Poisson's ratio, and static friction coefficients, are determined based on soil composition. Values are chosen to match a particle diameter of 10 mm. The cohesive and adhesive contact parameters are defined based on available literature **(Table 2)**. Cohesion is modeled in StarCCM+ using the Johnson-Kendall-Roberts (JKR) model. Cohesion and adhesion force values are chosen based on available references. After some iteration, the cohesion work factor in JKR equation has been defined to be 5 J/m² for the cohesion between particles, and 100 J/m² for the adhesion of particles to the tillage tool. To observe mechanical stresses exerted by soil on agricultural tools, a Finite Element Method (FEM) model is used in parallel with the DEM model. Data mapping **(Figure 4)** is performed to transfer forces from DEM to FEM for stress calculations. STARCCM+ erosion model simulates two wear mechanisms: impact wear and abrasion wear. Impact wear predicts the erosion rate due to the direct impact of particles on the eroded surface and abrasion occurs when abrasive particles rub against a material's surface, slowly removing material over time. Mass loss due to abrasion is determined using Archard's formulation.

		Tekeste (2015)		Sadek (2017)	Wang (2020)	Chang (2017)	Ucgul (2014)	Wu (2022)	
		Base	ML				Sand	Clay	Sand
	Contact model	Hertz-Mindlin	Hertz-Mindlin		Hysteretic spring contact with cohesion effects	Hertz-Mindlin	Hysteretic spring contact with cohesion/adh	Johnson-Kendall-Roberts	Johnson-Kendall-Roberts
	Particles shape	Sphere	Sphere	Sphere	Sphere	Sphere	Sphere	Sphere	Sphere
	Particles size (mm)	10	10	5	10	2/3/5/15	10	1	1
	Particles total number	36432	36432		100000	1000 -> 300000			
	Soil volume l*w*d (mm)	790*265*408	790*265*408		1800*1000*400	155*152 (H*D)	2500*1500*300		
	Bulk density (kg/m3)	1700	1700	1250-1550			1269 -> 1880	670 -> 1450	1630 -> 1970
Particles (soil)	Material	Soil	Soil	Soil	Soil	Sand-silt	Sand	Clay	Sand
	Density (kg/m3)	2650	2650	2232	2500	2660	2600		
	Young's modulus (Pa)	2,6E+06	2,6E+06		2,6E+06	3,0E+10	1,1E+05	7,4E+04	1,1E+05
	Shear modulus (Pa)	1,0E+06	1,0E+06	1,0E+06	1,0E+06	1,2E+10	4,3E+04	2,85E+04	4,3E+04
	Poisson's ratio	0,3	0,3		0,3	0,3	0,3	0,3	0,3
Steel	Density (kg/m3)				7865		7865	1,3E+03	1,3E+03
	Young's modulus (Pa)				2,1E+11		2,1E+11	2,41E+03	2,41E+03
	Shear modulus (Pa)				7,9E+10		7,9E+10	2,41E+03	2,41E+03
	Poisson's ratio				0,3		0,3	0,383	0,383
Soil:Soil Interaction	Coefficient of static friction	0,36	0,6	0,9	0,078 -> 0,130	0,5	0,57		
	Coefficient of restitution	0,01	0,01		0,6		0,6	0,4	0,6
	Coefficient of rolling friction	0,4	0,6		0,313 -> 0,639		0,4		
Soil:Steel Interaction	Coefficient of static friction	0,33	0,3	0,4	0,5		0,6		
	Coefficient of restitution	0,01	0,01		0,6		0,6	0,4	0,6
	Coefficient of rolling friction	0,2	0,3		0,05		0,05		

Table 2 . DEM parameter simulation for some studies.

(Figure 3) presents additional parameters for the Walton Braun model include Stiffness Ratio and Yield Strength Fraction, which influence soil plasticity and contact forces with the plowing tool.

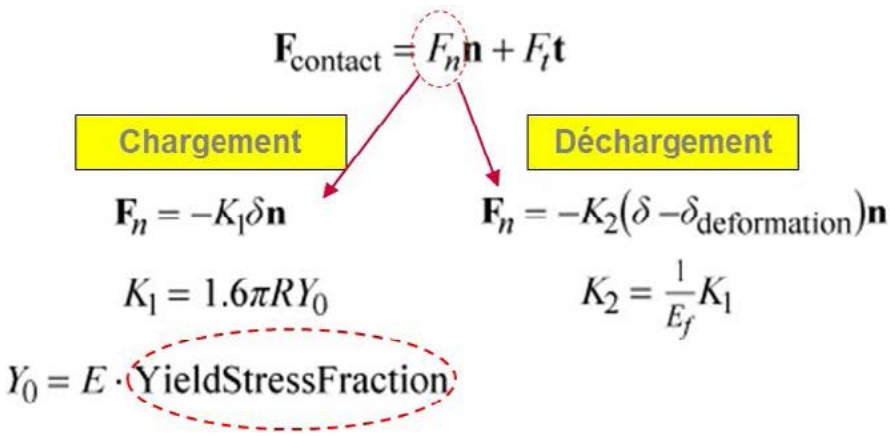

Figure 3 . Contact force formulation.

3. Results and Discussion

The value of contact forces exerted by the soil on the plowing tool is essential information for understanding its behavior under real usage conditions. Activating the DEM Boundary Forces model in STAR-CCM+ allows the calculation of forces that each particle locally exerts on the tool **(Figure 5)**. The sum of all these local forces provides the total force exerted on the tool. The component of this force in the direction of tool movement represents the traction force exerted by the soil on the tool, while the vertical component represents the vertical force exerted by the soil on the tool. To calculate the torque generated by all particles on the tool, we first need to compute the torque generated by the contact of a single particle with the tool. This torque is calculated based on the contact force, contact position, and the tool's axis of rotation. **(Figure 6)** show the torque generated by the soil on the tool is then the sum of all individual particle-tool contact torques. Monitoring the void ratio in the soil as the plowing tool passes through is crucial for assessing the tool's effectiveness in aerating the soil, a primary goal of plowing. Initially, a block is created at the center of the model, representing soil filling the block throughout the simulation. The void ratio is calculated on this block, equal to the total volume of particles divided by the block's volume. Since particles are arranged in clumps, the volume of overlap between particles is counted twice, so one volume must be subtracted to calculate the physically occupied volume of particles. This allows tracking the void ratio **(Figure 7)** within the defined block as the tool passes through.

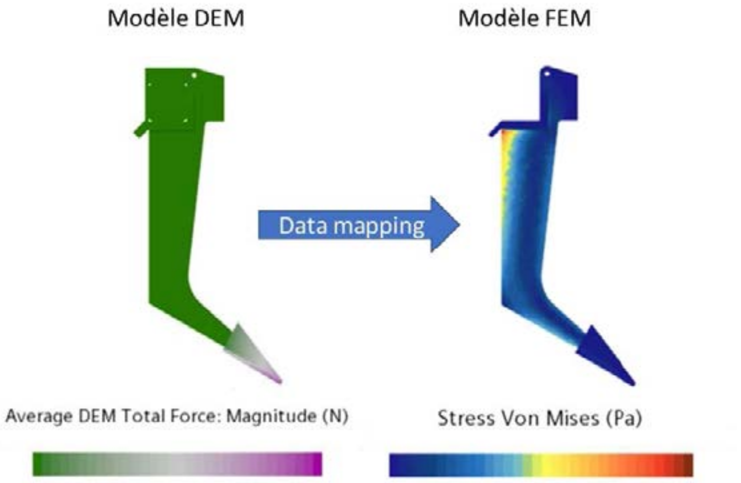

Figure 4 . Data mapping for mechanical stress modeling.

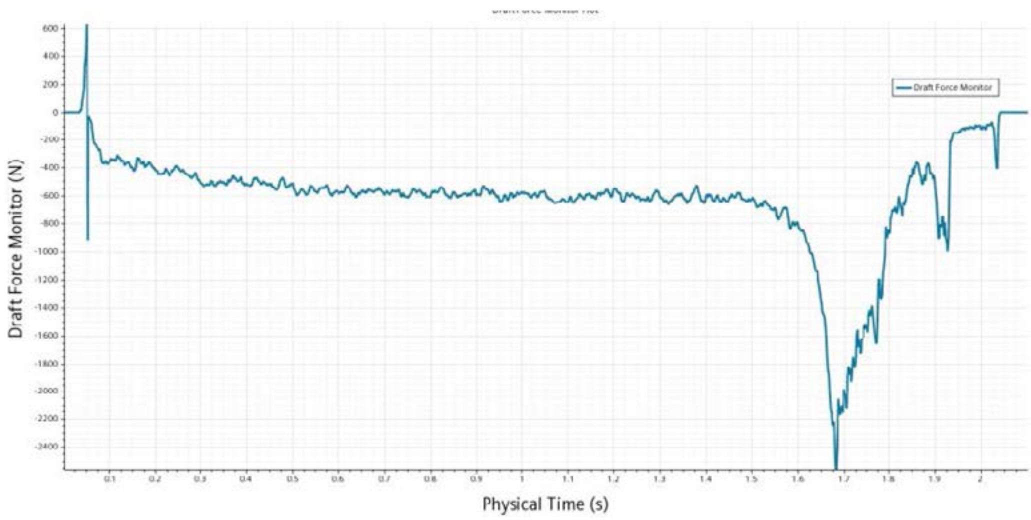

Figure 5 . Traction force

The SIMCENTER STAR-CCM+ tool enables mechanical stress calculations. To do this, a Finite Element Method (FEM) model is created in parallel with the DEM model, with mechanical stress.

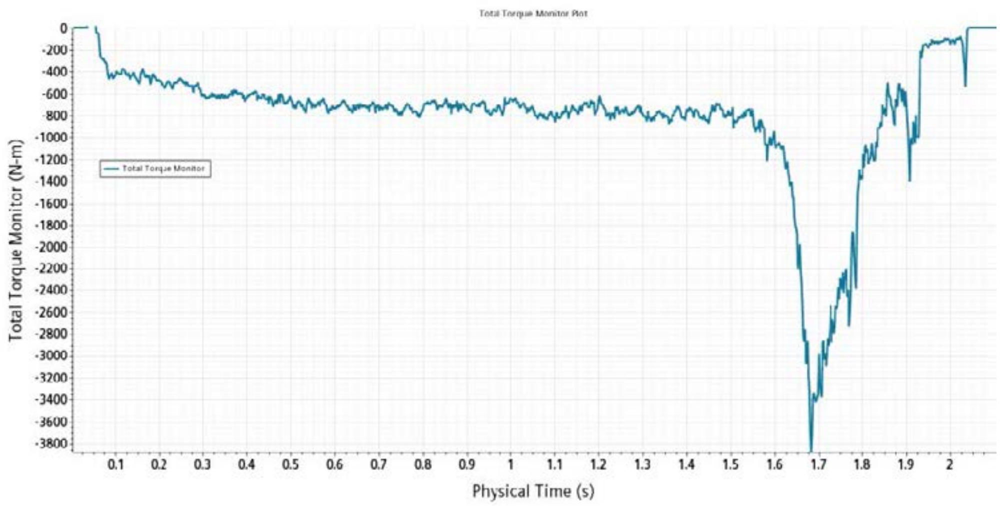

Figure 6. Torque exerted by the particles on the tool as a function of time.

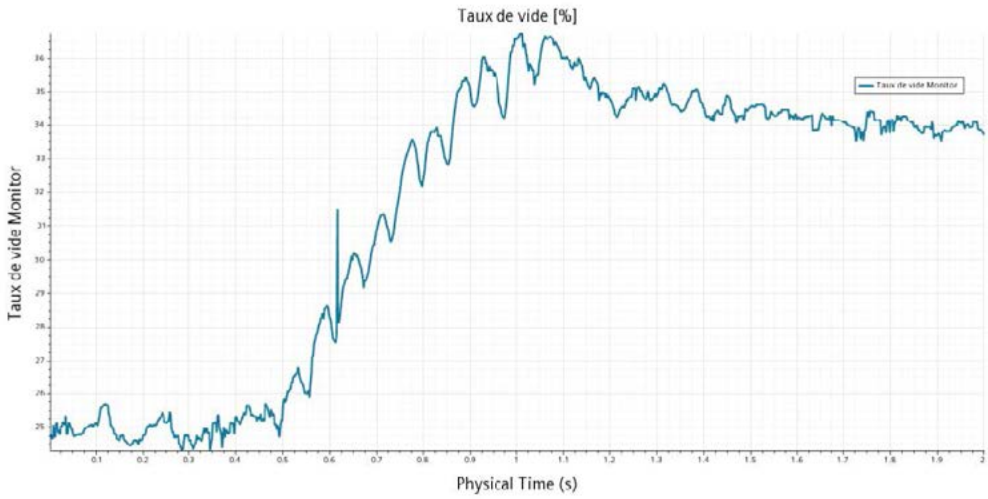

Figure 7. Evolution of the void content as the tillage tool passes.

The use of clumps allows the study of soil mixing. Initially, each clump consists of 25 particles, and the plowing tool breaks these clumps. The decrease in the average number of particles in the clumps **(Figure 8)** reflects the degree of soil mixing.

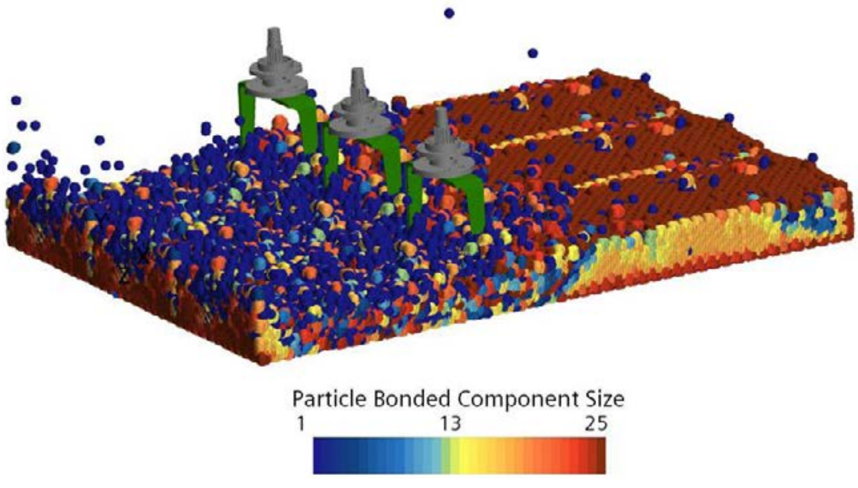

Figure 8. Number of particles per clump.

Data mapping **(Figure 9)** is used to transfer forces exerted by particles on the tool from DEM to FEM. This enables the calculation of mechanical stresses on the FEM model.

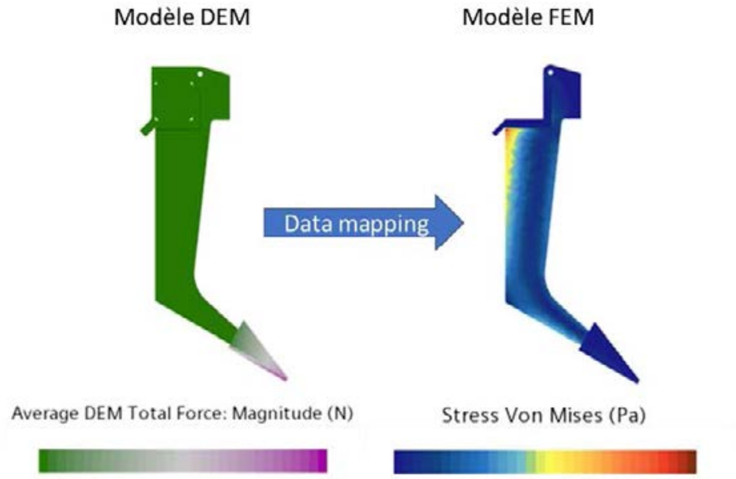

Figure 9. DEM/FEM coupling.

Using the erosion formulas mentioned previously, the rate of abrasion wear can be calculated as shown in **(Figure 10)**. This helps visualize the most impacted areas of the tool. It allows the calculation of mass losses in grams after the plowing tool passes through the soil.

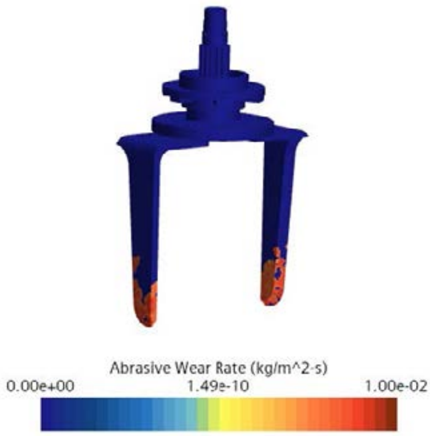

Figure 10. Abrasive wear rate

The Rotavator used in this study has specific characteristics listed below **(Table 3)**:

Rotation speed	500 rpm
Forward speed	1 m/s
Abrasion model	Archard formulation
Abrasion coefficient	0.01 kg/J

Table 3. Rotavator used in this study has specific characteristics.

In this section, a series of calculations are performed on the Rotavator-Soil system **(Table 4)**, varying clump sizes and the size of the surface mesh, and obtaining the initial void ratio, void ratio gain and mass losses. The void ratio is defined as: Void Ratio = (Total volume of particles - Volume of the block) / Volume of the block. The void ratio gain is the difference between the initial and final void ratios: Void Ratio Gain = Initial Void Ratio - Final Void Ratio.

Thes sensitivity to clump size analysis examines the impact of clump size on DEM simulation results. Different soil samples with clump sizes of 2 cm, 3 cm, and 4 cm are used. The distribution of spherical particle sizes forming each clump is shown in **(Figure 12)**.

The initial void ratio of each sample is calculated. Increasing clump size from 2 cm to 4 cm results in an increase in the initial void ratio, from 26.1% to 32.1%. After the tool's passage, the final void ratio is calculated to determine the resulting void ratio gain. Results show that increasing clump size influences the void ratio gain. Smaller clumps (2 cm) result in a higher void ratio gain, reaching 13.4%. This indicates that smaller clumps promote the creation of voids between particles, increasing the overall void ratio. Conversely, larger clumps (4 cm) result in a reduced gain of void ratio, at 6.15%. The sensitivity to surface mesh size study examines the effect of surface mesh size on mass losses in the system. The analysis shows that, for a fixed clump size, there are no significant variations in mass losses based on the surface mesh of the plowing tool. However, larger clumps result in higher mass losses. Additionally, smaller clumps tend to lead to longer calculation.

4. Conclusions

This work presents an in-depth study on numerical simulation using the Discrete Element Method (DEM) applied to the interaction between soil and agricultural tools, with a specific focus on the Rotavator plowing machine. The literature review provides a solid context, describing the origin of the research problem, identifying the needs to be addressed, and defining the problem statement. Furthermore, a detailed introduction highlights the significance of soil and its interaction with agricultural tools, with a specific emphasis on the Rotavator plowing machine, along with an illustrative DEM simulation example. The section section of the present work investigates the DEM numerical simulation. It explores various types of contacts and contact models employed, along with the essential simulation parameters required for particle modeling, particle and clump injection, clump decomposition, soil properties, Walton Braun interaction model parameters, cohesion, mechanical constraints, and abrasion. Post-processing of results is also discussed, focusing on aspects such as traction force, torque, void ratio, mechanical stresses, and mass losses. In conclusion, this report provides a comprehensive overview of applying DEM numerical simulation to the soil-agricultural tools interaction, with a specific emphasis on the Rotavator plowing machine. The various sections of the report, contribute to understanding soil dynamics and enhancing the performance of agricultural tools. This report serves as a valuable resource for researchers, engineers, and agricultural professionals seeking to improve the efficiency and sustainability of agricultural operations.

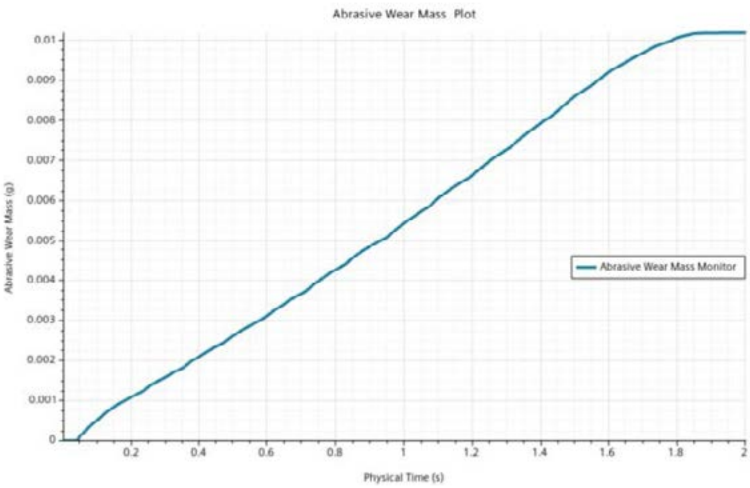

Figure 11. Abrasive wear mass

Soil clump size cm	Base size cm	Initial Void Ratio %	Particles number	Void Ratio Gain %	Mass losses mg
2	0,2	26,1	937534	13,4	10
2	1	26,1	937534	12,4	10
2	5	26,1	937534	13,2	10
3	0,2	27,3	295990	11,4	11,4
3	1	27,3	295990	10,2	10,2
3	5	27,3	295990	9,94	9,94
4	0,2	32,1	117156	16,5	16,5
4	1	32,1	117156	18,4	18,4
4	5	32,1	117156	18,1	18,1

Table 4. Passing Law

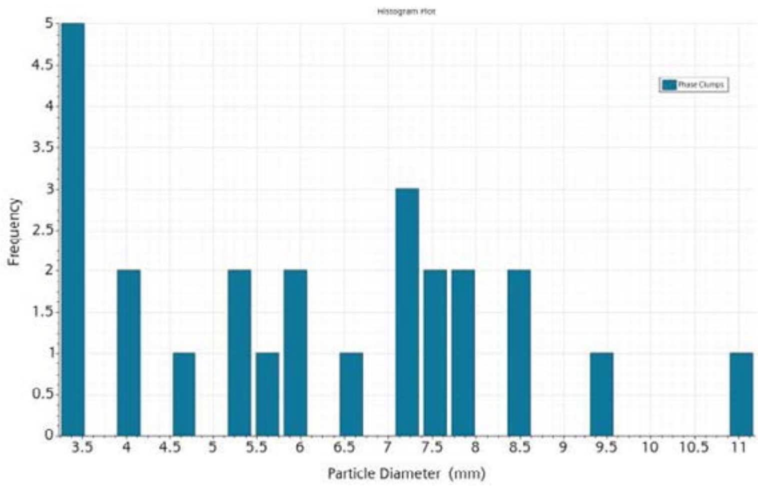

Figure 12. Particle diameter distribution for 2cm clump times due to the increased number of particles (Figure 13).

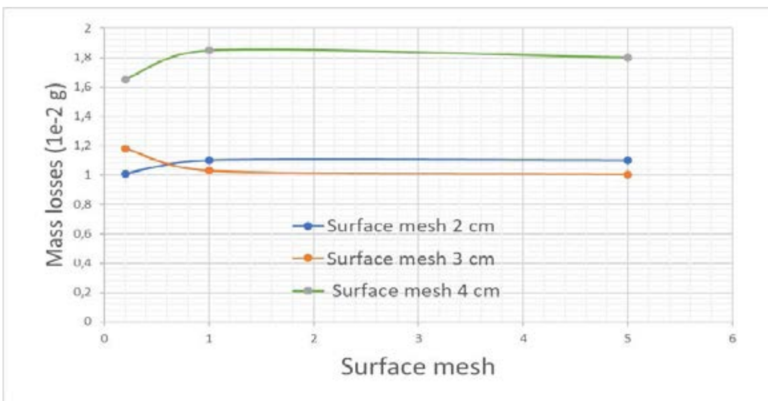

Figure 13. Sensitivity to Surface Mesh Size.

Acknowledgements

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Intellectual Property practices in French agroequipment Small and Medium Entreprises industry

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Abstract

INTELLECTUAL PROPERTY (IP) is a crucial issue in a globalising economy but studies show that business management models have a more or less mature use of IP management (Harrison & Sullivan, 2011). Some large groups give IP a very central and visible role in their corporate strategy in order to drive the company and its employees towards greater performance. This is less the case in Small and Medium Entreprise (SMEs) and mide-size companies.

The aim of this publication is to study the current situation of IP in SMEs and Mid-Size companies. The analysis will be based on a panel of French companies in the industrial off-road sector, mainly in the agricultural equipment sector. Companies have been selected by criterias of turn-over, number of employees and product with technologies integrated.

The study focus on different topics such as communication on IP, recognition of inventors, collective intelligence approach, IP indicators, technical IP tools, managing innovation through IP and finally, obstacles to the implementation of proactive management of IP.

The main conclusions to be drawn from the analysis of this survey are as follows :

- The number of patents filed by small and medium-sized companies in France is low, and management practices need to be adapted to this volume of IP, while seeking to boost this activity.
- There are relatively few practices in place that use IP as a motivational tool, so there is place for improvement in this area.
- Practical day-to-day IP tools are under-used.
- On several points, there is a gap between the practices of SMEs with less than 250 employees and those of companies with more than 500 employees, with the latter showing greater maturity.
- The lack of allocated resources remains a major concern on a daily basis.
- Identifying IP within the organization and looking at it as a whole are areas of work mentioned by respondents.

This work is a starting point for proposing a vision of motivating IP management in the service of innovation within SMEs and mide-size companies. It is particularly well suited to the world of agricultural equipment, which in many cases is changing in terms of company size and increasingly international competition.

Keywords : Intelectual Property, management, Innovation, Employee recognition, SMEs and Mid-size companies.

1. Introduction

IP is a crucial issue in a globalising economy where the pace of product development is accelerating. Intellectual Property Rights are powerful intangible assets that can secure a dominant position in a market for longer, boost a company's competitiveness and increase its intrinsic value. (EPO & EUIPO, 2019)

Studies show that certain business management models have a more or less mature use of IP management (Harrison & Sullivan, 2011) (Corbel & Chevreuil, 2009) (Ernst & Martin, 2014) (Hackl & Guillermin, 2020) (Lallement, 2009) (Potekhina & Blind, 2012) (Pénin, 2011) (Somaya, Williamson, & Zhang, 2007). Some large groups give IP a very central and visible role in their corporate strategy in order to drive the company and its employees towards greater performance. This is less the case in SMEs and mide-size companies.

The aim of this publication is to study the current situation in SMEs and Mid-Size companies in France. The study will be based on a survey using a questionnaire and interviews with members of French SMEs and with IP consultants working with SMEs. It will be particularly close to the Off-Road sector.

2. Materials and Methods

Method description
First we started by reviewing the state of the art of IP management practices in industry. In particular, I looked at work dealing with IP management in relation to the company's overall strategy on the one hand and staff motivation on the other.

Then, we decided to make a specific survey adapted to the specific domain of activity of French agroequipment Small and Medium Entreprises industry.

The analysis will be based on a statistical study using GoogleForms-type web questionnaires, created and distributed to a panel of companies. The questionnaire is sent to PI contacts within the SMEs/MideSize companies. The responses to this questionnaire are then cross-checked by several phone interviews to ensure that they are properly understood and to add verbatim informations that cannot be collected using a short questionnaire.

Particular attention was paid to the risk of rejection due to concerns about the confidentiality of the results. One of the challenges was to reassure people on this point, and to this end we adopted a treatment of the results as a whole or by groups / categories of companies, but never on an individual basis. In what follows, therefore, no analysis will be presented for a specific company.

Definition of the profile of interviewees.
The company selection criteria were as follows:

- Companies with more than 50 employees and sales of € 10 millions.
- Companies with less than 1,000 employees and sales of less than €250 millions.
- Companies in the industrial sector with technology integrated into their products (not service, retail or agri-food companies).
- Practical experience of intellectual property. The company regularly files IP applications, even if the volume is low (less than 2 applications per year). The company must hold a portfolio of IP rights (minimum of 5 patents).

A list of around fifty companies was compiled with the help of IP council and use of professional network and finally the list of members of the AXEMA (union of agricultural equipment manufacturers).

It should be noted that this survey does not claim to be statistically representative of all French SMIs and Mide-size companies. Because of my professional experience, my panel is focused on the west of France and on the off-road agricultural and construction machinery industry. This study is also deliberately based on French companies. For example, I wondered about questioning German SMEs, but due to technical and cultural specificities it seemed difficult to use the same questions for foreign companies. It should be noted that some of the companies surveyed do have staff abroad (in Europe).

The people questioned were identified as being responsible for IP within their organisation. The list of interviewees has been kept confidential at the request of several interviewees.

Description of the questionnaire
For the construction of the survey, we adapted it according to the state of the art. The aim was not to ask questions that had already been studied in the past, unless we were looking for more recent feedback or feedback that was more focused on companies in a particular sector of activity or on large SMEs. This questionnaire was intended to focus into areas where we have little data in previous studies, namely the broad and motivating use of IP in innovation management. The aim was also to question the practical implementation of certain good practices proposed by the researchers.

A survey conducted by the INPI on the remuneration of employee inventors was used to identify a list of levers of recognition for inventors (Doyen & Fortune, 2016).

The questionnaire contains 15 questions divided into 6 categories. A few open-ended questions were used to gather verbatim and additional suggestions. A rating based on a numerical scale, such as the Osgood or Likert scale, with 5 levels has been used

Group 1: Companies Intellectual Property communication, recognition of inventors.

The aim is to find out what motivational levers are used. What are the most important factors in motivating inventors, using reward/recognition and reputation/promotion as levers? Internal and external communication about IP is discussed. (Potekhina & Blind, 2012)

Group 2: Collective intelligence, economic intelligence approach

The aim is to find out what is being done in terms of business intelligence. We want to ask questions about the process of anticipating and analysing technological or market trends. We also want to see the impact of collective, structured questioning, which can have a positive influence on the company's strategy (Gloaguen, 2014)

Group 3: Intellectual Property indicators/key figures

The purpose of these questions is to see whether IP results (not just the number of patents) are measured and communicated as a performance indicator of companies' innovation activities.

Group 4 : The use of technical Intellectual Property tools

The objective is to assess the level of maturity in the use of specific IP tools within the innovation activity (De Kermadec & Sterwen, 2000). These are more technical questions that also allow us to assess a level of expertise through concrete examples.

Group 5 : Leading and managing innovation through IP

The aim is to assess the practices in place in terms of IP management. We want to question the means of coordination such as collective portfolio reviews, the setting up of referents and training.

A particular focus is placed on the interactions between R&D / Project and IP. The «Stage-Gate» methodology standard is used as a common reference (Hackl & Guillermin, 2020).

Group 6: Obstacles to the implementation of proactive management of Intellectual Property

The objective is to assess what, in the concrete reality of companies, can disrupt or prevent proactive management of intellectual property. By inverse deduction, we can understand how to create favourable conditions for the use of IP in innovation management within SMEs.


Pratiques de management de la Propriété Intellectuelle au sein des PME et ETI

Dans le cadre de mon Master 2 'Stratégie de la Propriété intellectuelle et Innovation' réalisé à l'Institut Européen de la Propriété Intellectuelle de Strasbourg, je mène une étude sur les pratiques courantes en terme de management de la Propriété intellectuelle (PI) dans le monde des PME et ETI présentant moins de 1000 salariés. C'est dans ce cadre que je vous sollicite pour répondre à une enquête.
Cette enquête menée vers des dirigeants ou employés de PME/ETI en lien avec la PI va m'aider à faire un état des lieux des pratiques.
Cette étude est centrée sur les PME du secteur secondaire (industries, PMI).
Le thème centrale de l'enquête est le management proactif de la PI dans les PME/ETI. Les aspects liés à la reconnaissance des inventeurs, la motivation et la communication sont spécifiquement abordés.
Seuls des éléments de synthèse (aucune réponse individuelle) seront restitués dans le cadre d'un mémoire d'étude.
Vos coordonnées ne seront en aucun cas communiquées ou réutilisées à d'autres fins.

*Obligatoire

1. Adresse e-mail *

Vous et votre entreprise

Les questions de cette rubrique serviront uniquement pour l'analyse. Vos réponses seront anonymisées dans la présentation des résultats de l'enquête.

2. Votre nom *

3. Nom de votre employeur PME ou ETI *
Uniquement pour l'analyse. Vos réponses seront anonymisées dans la présentation des résultats de l'enquête.

Figure 1. Extract of first page of the Googleforms survey.

3. Results and Discussion

Of the 50 companies approached, 39 responded to my requests and received the questionnaire, and 33 actually agreed to fully answer the questionnaire and authorised the results to be used in this report. This gives a return rate of 84%. As might be expected, some companies were concerned about the sensitivity of the information, but only 6 companies out of 39 refused to answer for internal reasons of confidentiality about their practices.

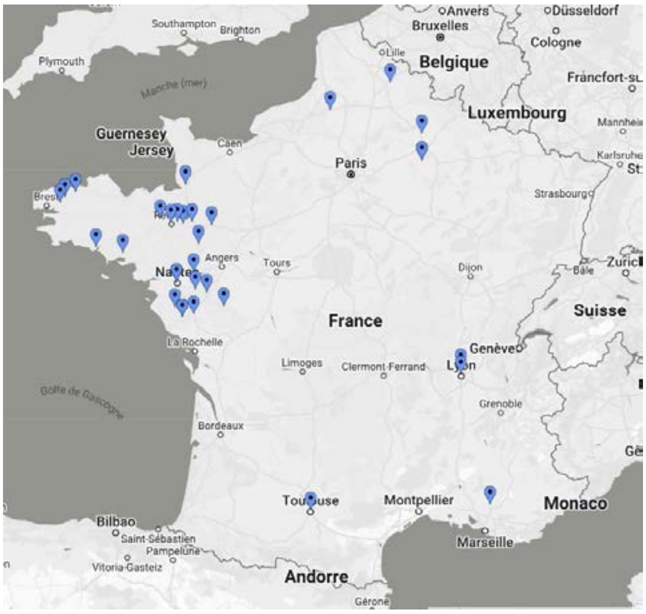

Figure 2. Location of 33 companies fully interviewed.

3.1. Company profile

The aim of the survey was to target relatively structured SMEs and mide-size companies that had not yet achieved the structure of large groups, with a typical target of 250 to 500 employees and a turnover of between €50m and €100m. The table below shows returns from companies of various sizes within the panel, both in terms of number of employees and declared turnover. The panel questioned therefore appears to be representative for the objective of questioning the transition from SME to mide-size.

Nombre d'employés	< 150	150 à 250	250 à 500	500 à 1000	> 1000
répartition en %	30,3	12,1	24,2	18,2	15,2

Chiffre affaire (M€)	< 20	20 à 50	50 à 100	100 à 250	> 250
répartition en %	21,2	24,2	24,2	6,2	24,2

Figure 3. 3 companies profiles.

It should be noted that the IP function in SMEs / Mide-size companies is generally link to the technical staff (70% of cases). In 15% of cases, an in-house IP manager handles matters on behalf of the company. It should be noted that this IP manager sometimes has both R&D and IP responsibilities (combined function). Lastly, in 15% of cases, this subject reports directly to general management or the legal department.

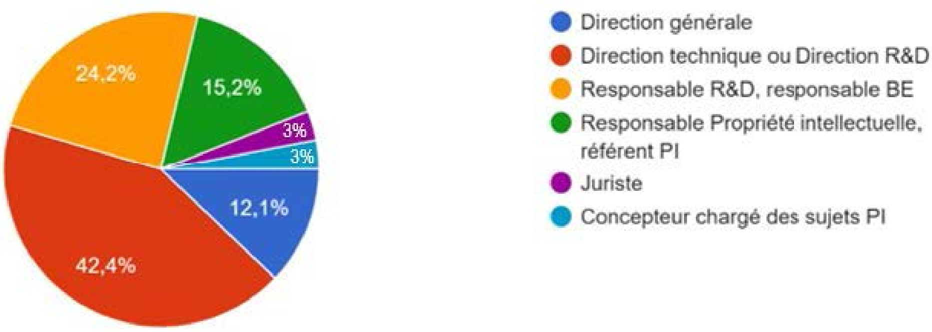

Figure 4. Locating IP responsibility within companies organisation.

3.2. Company intellectual property activity

As mentioned, there are previous studies quantifying the use made of patents according to the category of company (Lallement, 2009). The aim of this study was therefore to gain a better understanding of the actual patent practices of the companies in our particular panel. The annual volume of IP is relatively low (lower than the average of the industry according to INPI (Observatoire-des-PME & BPI, 2020)), and only 48.5% of the companies responding file at least 2 patents applications per year.

Répartition des entreprises suivant le nombre de brevets déposés par an (en % des répondants)	< 2 demandes	2 à 5 demandes	5 à 10 demandes	10 à 20 demandes	> 20 demandes
Toutes entreprises	51,5	24,2	15,2	9,1	0,0
PME < 250 personnes	78,6	7,1	14,3	0,0	0,0
ETI > 500 personnes	27,3	27,3	27,3	18,2	0,0

Figure 5. Companies by number of patents filed per year.

A closer look at the data reveals a very significant impact of company size. For companies with less than 250 employees, the rate of companies filing less than 2 applications per year rises from 51.5% to 79%. On the contrary, for companies with 500 or more employees, this rate falls from 51.5 to 27.3%. There is therefore a clear link between company size and regular use of IP in this business sector. This is a logical phenomenon, since the larger the company's economic activity is, the more R&D it carries out, and therefore the greater the volume of innovations it can potentially protect. It's interesting to take this into account for future recommendations, because we cannot imagine the same management methods and the same tools for an annual volume of 1 or 15 patent applications.

3.3. Companies Intellectual Property communication, recognition of inventors

It can be seen that communication about patented technologies is relatively widespread among end customers and sales teams. On the other hand, it is rarely used with internal company staff. A more detailed analysis does not reveal any particular differences between company sizes. SMEs may show an ability to communicate widely on IP, including internally to their staff. The interviews and verbatim reports show that this is generally linked to the IP sensitivity of the manager.

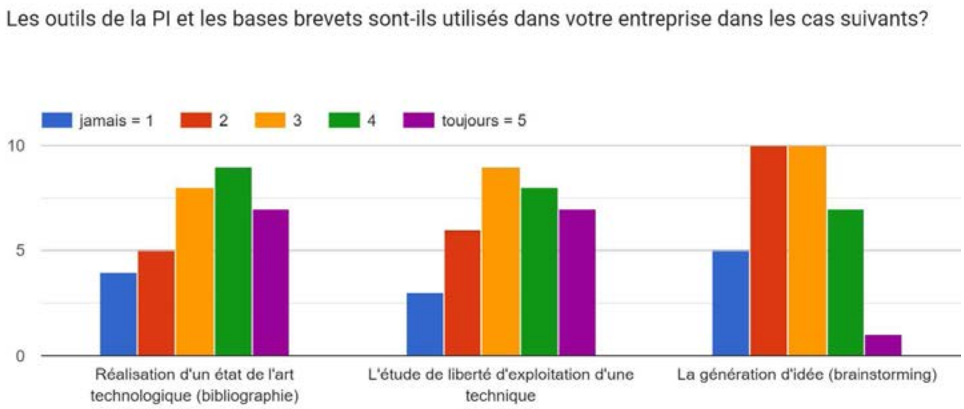

Figure 6. Are patented technologies promoted in the company's communications?

We then asked companies about their inventor recognition practices.

Are the following inventor recognition practices in place in your company?? (% of respondents)	1 = never	2	3	4	5 = always
challenge/price/innovation award	78,8	12,1	3,0	3,0	3,0
Internal communication article (newsletter, internal social media, poster…)	54,5	24,2	3,0	15,2	3,0
Additional remuneration for inventors	36,4	12,1	15,2	9,1	27,3
Congratulatory letter from the manager	69,7	9,1	9,1	6,1	6,1
Internal event around the innovation	36,4	30,3	21,2	12,1	0,0
Involvement of the inventor in the product launching	33,3	12,1	24,2	21,2	9,1
Inventive activity taken into account in career development	24,2	30,3	27,3	18,2	0,0

Figure 7. Recognition practices for employee inventors.

It should be noted that although this has been obligatory in France since 1990, 36% of companies have not introduced a system of additional remuneration for employee inventors. This figure is quite far from the rate of non-implementation communicated by the INPI in its latest survey, which stands at 8% (Doyen & Fortune, 2016). The explanation probably resides in the fact that this INPI survey, although carried out for all sizes of company, has a return rate that is very much focused on large groups with a high volume of annual filings and implementing the most virtuous practices.

Other mechanisms for recognising inventors are used very little, and this is an interesting area for development in terms of giving employees an IP Vision.

3.4. Collective intelligence and economic intelligence approaches

The study shows that a large majority (more than 63% of respondents) of companies have a patent monitoring tool in place, this tool is well structured and shared within the company (score ≥ 4 in our survey).

On the other hand, it appears that trademark monitoring is more difficult to implement. Only 33% of companies have a trademark monitoring tool that is structured and shared.

Finally, we note that competitor monitoring is very much in place in companies. An analysis of the verbatim comments, shows that there is room for improvement in the structuring and sharing of competitor monitoring.

Are collective monitoring tools in place in your company? (% of respondents)	1 = No, not at all	2	3	4	5 = Yes, structured and shared
Patents monitoring	3,0	21,2	12,1	30,3	33,3
trademark monitoring	27,3	18,2	21,2	27,3	6,1
Technology watch	3,0	9,1	39,4	21,2	27,3
Competitor monitoring	3,0	3,0	27,3	33,3	33,3

Figure 8. Companies' monitoring practices.

3.5. Key indicators and figures for Intellectual Property

The study shows that a high proportion of companies (42.4%) have no tool at all for monitoring their IP portfolio. Analysis of the verbatim report and the interviews suggests that when this type of tool is introduced, we are facing companies with a high level of maturity. The tool is therefore intended to be structured and shared, with the aim of being used for effective patent portfolio reviews.

The introduction of a tool for monitoring and steering IP titles is much more widespread in large organisations (54% with a score $\geq$ 4 in companies with more than 500 employees compared with 21.4% in SMEs < 250 employees), which can also be explained by the greater number of annual filings, which automatically generates an effective need for portfolio management.

Does your entreprise have a tool for managing IP titles? (% of respondents)	1 = No, not at all	2	3	4	5 = Yes, structured and shared
All companies	42,4	12,1	15,2	6,1	24,2
companies < 250 pepole	64,3	14,3	0,0	0,0	21,4
companies > 500 people	18,2	9,1	18,2	18,2	36,4

Figure 9. Diffusion of tool for managing IP titles.

Concerning the implementation of IP indicators, it should be noted that this practice is not very popular. Only 30% of companies use it for the number of patent fillings and 12% for trademark registrations. Other indicators are very rarely used, surprisingly, even though they could be an interesting solution. The number of Soleau envelopes filed would enable us to communicate on new ideas and the pool of innovation to be matured. The number of scientific publications encourages open innovation and collaborative work with public research. The indicator on licences granted shows the financial role that IP can play in a company's results.

Does your company use the following IP indicator (KPI)? (% of respondents)	1 = never	2	3	4	5 = always
The number of patents or design patents	60,6	6,1	3,0	3,0	27,3
The number of "enveloppe Soleau"	81,8	3,0	6,1	0,0	9,1
The number of trademark	69,7	18,2	0,0	0,0	12,1
Number of scientific/technical publication	97,0	0,0	3,0	0,0	0,0
The number of innovation awards	72,7	9,1	15,2	3,0	0,0
Licences agreements (in number or in €)	81,8	15,2	3,0	0,0	0,0

Figure 10. IP indicators practices

3.6. The use of technical Intellectual Property tools

The study shows that patent database tools are relatively well used by companies, particularly when it comes to carrying out a state of the art, a bibliographic study or when they want to verify freedom to operate. The proportion is lower when it is a matter of using them as a tool for generating ideas.

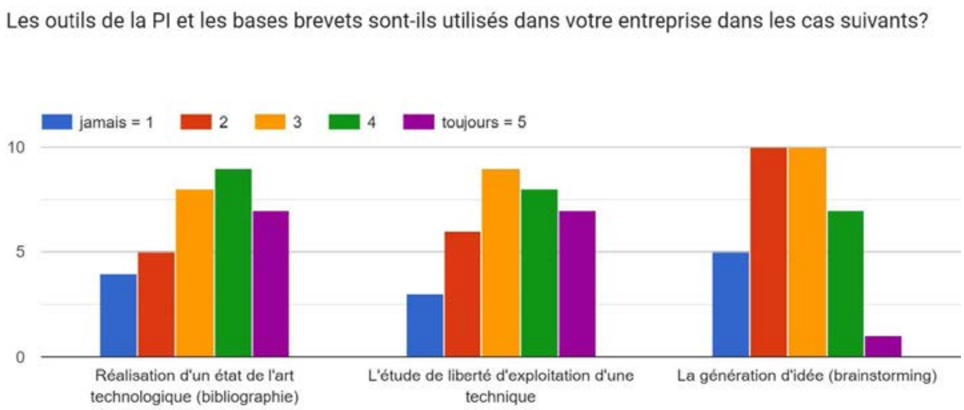

Figure 11. Use cases of IP tools and patents databases.

The companies do not make frequent use of certain IP tools. In particular, over 90% of respondents do not use tools designed to generate new solutions based on patent databases (TRIZ method or ASIT method). The verbatim report shows that they are considered too complicated to apply.

On the contrary, confidentiality agreements are used in over 80% of cases. This shows that companies first want to protect themselves in their dealings with third parties.

The Soleau envelope and the innovation memo, which are excellent tools for transforming an idea into an innovation, and which are also very easy to access and affordable, are not widely used. A more detailed analysis shows that this is slightly more pronounced in SMEs with less than 250 employees than in mide-size with more than 500 employees.

Does the following IP tools used in your company? (% of respondents)	1 = never	2	3	4	5 = always
Creativity method base on patents (Triz, ASIT)	78,8	12,1	9,1	0,0	0,0
Graphical patent tools like 'the tree model for patent'	78,8	18,2	3,0	0,0	0,0
Envelop Soleau model / Mémo Innovation	18,2	30,3	33,3	3,0	15,2
"cahier de laboratoire"	87,9	12,1	0,0	0,0	0,0
Invention declaration	57,6	6,1	15,2	6,1	15,2
NDA	0,0	9,1	9,1	27,3	54,5

Figure 12. IP indicators practices.

3.7. Leading and managing innovation through IP

In general, there are very limited practical solutions for managing IP within organisations. The most common practice is to have an IP officer within the organisation.

The introduction of a company IP policy is rarely used, whatever the size or type of company.

However, it is a powerful management tool, because it establishes that the company's top management considers IP to be a strategic area and gives the company a clear direction on the subject of IP in the specific context of the company's business.

Are the following systems in place in your company? (% of respondents)	1 = never	2	3	4	5 = always
IP company policy	51,5	24,2	15,2	3,0	6,1
Collective review of IP portfolio	45,5	24,2	6,1	9,1	15,2
IP training modules for employees	42,4	24,2	12,1	12,1	9,1
IP officer in the organization	27,3	24,2	12,1	9,1	27,3

Figure 13. Practices in term of IP management.

As far as IP portfolio reviews are concerned, there is a difference according to the size of the company. Almost 55% of companies with more than 500 employees regularly carry out collective IP portfolio reviews, only 14% for SMEs with less than 250 employees practice IP portfolio review,

This shows a good ability to open up IP, to look at it not just from the point of view of the internal specialist, and to discuss choices collectively, depending on the challenges.

Concerning interactions in the project life cycle between the project team members and the IP coordinator, there was a wide disparity in the responses. In almost 40% of cases, there was no more than one interaction in the life of the project. This seems to be too low to ensure that the IP strategies to be adopted during the development of the solutions are properly considered. On the other hand, 42% of respondents interact at least once a quarter, which seems to be a good per-formance for effective and collaborative IP work, and above all, for the benefit of the project.

Quantify the number of interactions between the IP coordinator and the product project teams (% of respondents)	Never, no interactions	Once during the project life	Once a year	Regulary, once a quarter	Once a month
All companies	12,1	27,3	18,2	21,2	21,2
Companies < 250 people	21,4	28,6	21,4	0,0	28,6
Companies > 500 people	0,0	9,1	18,2	45,5	27,3

Figure 14. Interaction between IP and project teams.

3.8. Obstacles to the implementation of proactive IP management

Below is a summary of the response concerning potential obstacles to a proactive IP management. Results are shown for all companies and by size of companies.

The main obstacle, whatever the size of company, is the lack of ressources dedicated to IP.

Next, come the fact that IP is not well identified inside the company organization so it can be seen as an additional task.

The cost of IP is seen as a major obstacle for companies < 250 employees.

Companies bigger than 500 employees regret that IP is not seen as a whole and lack of knowledge of manager concerning IP.

Parmi les potentiels freins suivants à la mise en place d'un management proactif de la PI dans les PME/ETI, lesquels sont impactants selon vous? (en % des répondants)	1 = impact faible	2	3	4	5 = impact fort	*Cumul impact notés 4 et 5*
Le manque de sensibilité PI du dirigeant						
Toutes entreprises	24,2	6,1	24,2	15,2	30,3	*45,5*
PME < 250 personnes	28,6	0,0	42,9	7,1	21,4	*28,6*
ETI > 500 personnes	36,4	9,1	18,2	18,2	18,2	*36,4*
Une mauvais formation PI des managers						
Toutes entreprises	9,1	18,2	30,3	24,2	18,2	*42,4*
PME < 250 personnes	21,4	14,3	42,9	14,3	7,1	*21,4*
ETI > 500 personnes	0,0	27,3	18,2	27,3	27,3	*54,5*
Formation inexistante en PI des collaborateurs						
Toutes entreprises	9,1	27,3	21,2	18,2	24,2	*42,4*
PME < 250 personnes	21,4	21,4	21,4	28,6	7,1	*35,7*
ETI > 500 personnes	0,0	36,4	18,2	18,2	27,3	*45,5*
Le manque de ressources dédiées à la PI						
Toutes entreprises	3,0	15,2	15,2	33,3	33,3	*66,7*
PME < 250 personnes	7,1	14,3	7,1	28,6	42,9	*71,4*
ETI > 500 personnes	0,0	18,2	18,2	36,4	27,3	*63,6*
La PI n'est pas identifiée dans l'organisation						
Toutes entreprises	3,0	9,1	30,3	30,3	27,3	*57,6*
PME < 250 personnes	7,1	0,0	50,0	14,3	28,6	*42,9*
ETI > 500 personnes	0,0	18,2	18,2	36,4	27,3	*63,6*
Le coût de la PI est trop important						
Toutes entreprises	9,1	18,2	33,3	30,3	9,1	*39,4*
PME < 250 personnes	7,1	7,1	28,6	42,9	14,3	*57,1*
ETI > 500 personnes	9,1	18,2	36,4	36,4	0,0	*36,4*
La PI n'est pas vue/utilisée dans son ensemble						
Toutes entreprises	3,0	6,1	39,4	39,4	12,1	*51,5*
PME < 250 personnes	0,0	7,1	57,1	28,6	7,1	*35,7*
ETI > 500 personnes	0,0	9,1	27,3	45,5	18,2	*63,6*

Figure 14. Potential obstacles to IP.

4. Conclusions

To summarize very quickly this study we can highlighted the followings :

- The number of patent filings by SME and mis-size companies in Agro equipment in France is low and management practices must be adapted to this IP volume, while seeking to boost this activity.
- There are relatively few practices in place using IP as a motivational tool and there is therefore room for improvement on this point.
- Practical everyday IP tools are underused.
- On several points, we note a gap between the practices of SMEs < 250 people and those of mide-size companies > 500 people, the latter showing greater maturity.

Main differences are the followings:

- Carrying out a collective review of the IP portfolio and use of the management dashboard
- Interactions between IP and R&D team
- Interactions between IP and project management
- Uses of practical IP tools

- The lack of allocated resources remains a major concern for all companies.
- Identifying IP in the organization and seeing IP as a whole are areas of work mentioned by respondents.

The conclusions of this study then made it possible to build an intellectual property management strategy adapted to growing SMEs. The lessons and the proposed strategy must be adapted to the size of the company, the volume of innovation and the strategic aspect of product differentiation through innovation. There cannot be a single strategy but an adaptive toolbox for proactive IP management is possible.

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Safe VRS corrections for autonomous robots

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Abstract

The purpose of this project was to develop and provide safe RTK corrections for autonomous system like robots in agriculture. The RTK technology is well known since years but there is a lack regarding the safety aspect of such source of corrections. The RTCM format standardize the exchange of data, but for the moment they are no specific message regarding the integrity aspect.

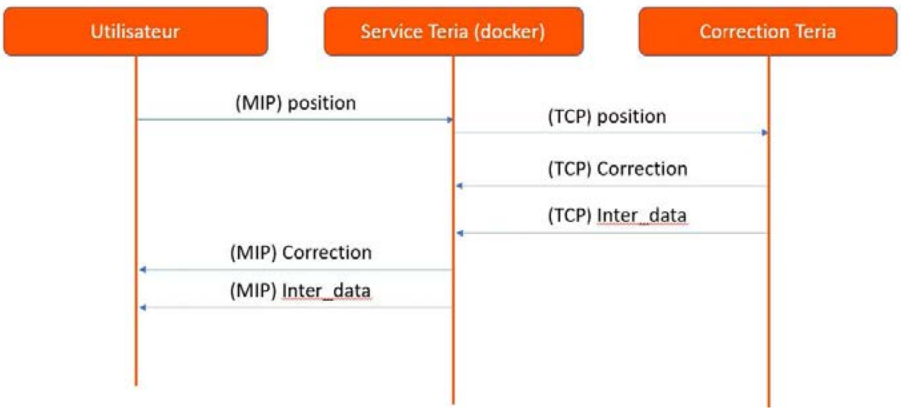
The project was based on a VRS network in France, TERIA, and different level of software were developed to propose in addition to the correction a safe message in the RTCM format. Also, the protocol to exchange the data between the end user equipment and the server have been redevelop to fit to this safety aspect. At the end a global chain was redevelop based on the RTCM format.

In the global project also a second step was involved, the use of this message at the rover side at the RTK algorithm itself. This part will not be presented in this document.

During the project we demonstrate that the safe corrections enable a robot to move safely and detect corrections issue link to a server or a local issue or just degraded performance.

1. Introduction

The objective of the project was to successfully implement a «Safe» and precise GNSS positioning engine using virtual reference station solution. Today positioning can be ensured thanks to an RTK algorithm requiring positioning frames of the mobile machine whose position is to be determined as well as positioning frames from a nearby fixed antenna. Technically, this now requires installing a fixed antenna at the edge of each plot but also constantly checking the integrity of the fixed antenna.
In the Space-tour project, we set up services around a library and a common communication protocol to interface the corrections provided by TERIA's EXAGONE network.



The system set up is designed to allow the robot to receive accurate position corrections in real time. The overall operation of the system is relatively simple. First, the robot sends its position using the MIP protocol developed by AgreenCulture during the project. Then we retrieve this position which is encapsulated in the MIP protocol. The recovered NMEA frame is sent to the server correction source. The correction source returns RTCM3 messages that contain the corrections needed for the precise position of the robot as well as information about the integrity of these corrections. The exagon2Mip service receives these RTCM frames and then encapsulates them in MIP format. In this MIP message, we also add security information, such as timestamp, signature or counter to ensure safe transmission and reception.

This metadata ensures that the information transmitted is reliable and that any transmission errors can be detected quickly. In this way, we can guarantee that the information received by the recipient is what was sent and that it is free from errors or alterations. This counting system is an asset to ensure the reliability and accuracy of the data transmitted. This process ensures that the robot receives accurate and reliable information about its position in real time, which is essential for many precision agriculture applications.

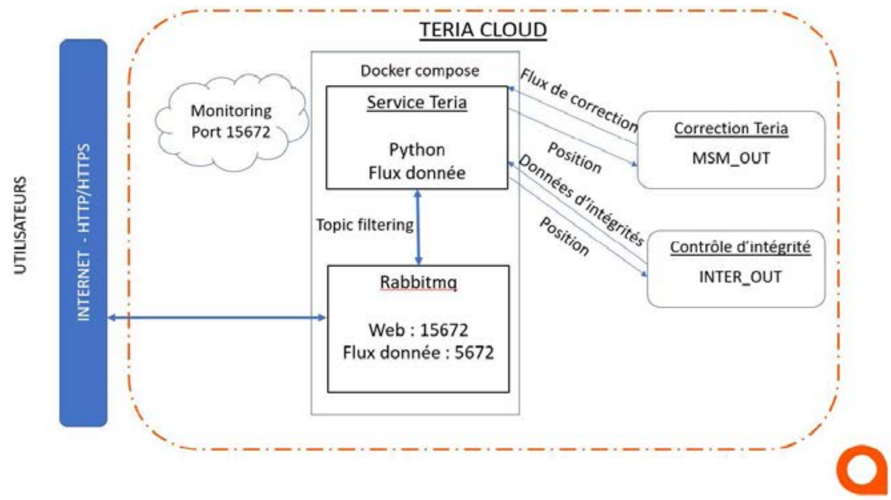
2. Materials and Methods

The diagram above makes it possible to understand how we ensure the connection between the MQTT server and the TERIA VRS service. When the Docker service is launched, we have an automatic connection to TERIA's internal process.

The TERIA server retrieves NMEA frames from the Docker, programming being carried out in Python on the TERIA side. To do this, we used a program that allows to interface the TERIA control center and the Docker service dedicated for integrity checking. This interface ensures smooth communication between the different components of the system, which ensures the reliability and accuracy of the data exchanged.

TERIA's Python program is based on two threads (or classes) that work independently but complementarily. Some variables are shared between these two classes.

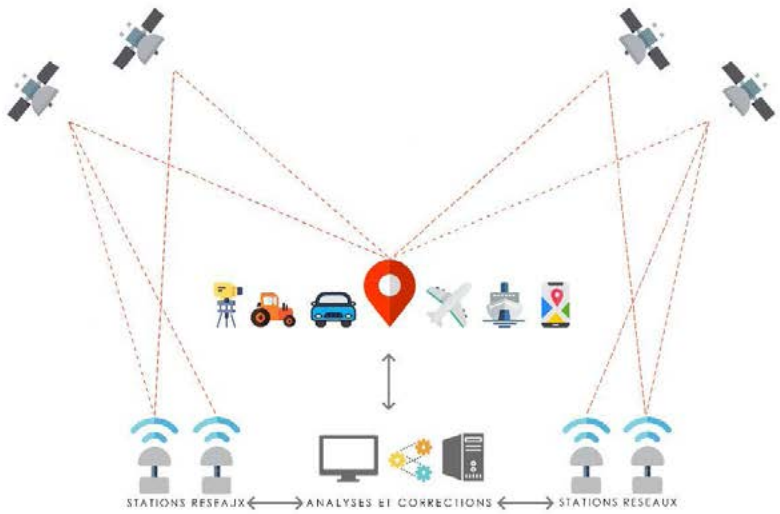
The first class deals directly with sending corrections, while the second focuses on managing the integrity of the data. This architecture optimizes the performance of the program by distributing tasks between the two classes and allowing effective communication between them. Shared variables make it possible to transmit the necessary data between the two classes, which facilitates their coordination. In this way, the TERIA program is designed to ensure accurate and reliable data transmission, while guaranteeing optimal performance. Also, the "Safe" class work independently from the VRS computation and decimation enabling a full control of the corrections.



The correction key includes a section where we establish a TCP/IP connection with the TERIA network via internal servers. The TERIA service has been adapted in response to AgreenCulture's specific requirements regarding the type of message to be sent. We have opted for the use of MSM7 messages in our implementation. We also use an array of antennas to send the VRS correction specifically for this project.

The VRS corrections calculated by the TERIA network are the result of multilayer processing. TERIA use the GNSMART software from GEO++, a German company specialized in this domain. The objective of a part of the integrity message is to allow control of each step.

The first part consists of retrieving data from the stations. The raw data is received on several servers, then synchronized and upgraded to the same level as the constructor biases.
Once this step is completed, the raw data is transmitted to servers for processing. The first treatment consists in fixing ambiguities between stations in the same geographical area. Then from the fixed signals to calculate models of tropospheric and ionospheric corrections. These errors are then quadratic individualized in FKP form.
The last step is the generation of the virtual station depending of the position of the rover.
For this based on the position of the user, we will associate the raw data of the nearest physical station and the associated FKP coefficients to generate virtual observations.
The data is then transmitted via TCP/IP.
This configuration allows us to ensure fast and accurate data transmission, while minimizing the risk of disturbance or signal loss. Thanks to this implementation, we are able to provide reliable and accurate position corrections to robots, which is essential for precision agriculture applications.



In order to guarantee optimal correction quality, we have set up a system that sends the NMEA frame to the server every 5 seconds. This sending frequency allows us to maintain constant communication between the docker and the server, which ensures accurate and reliable data transmission in real time.

In order to avoid any data transmission problems, we have set up an automatic reconnection system to the servers. This system ensures that data sent and received correctly, even in the event of a temporary loss of connection. In addition, through the use of integrity messages, it is possible to quickly detect any alteration or corruption of the transmitted data.

During the project, we had to deal with problems related to the size of the correction data. Initially, we opted for a size of 1024 bits for the correction frame. However, after reviewing the RTCM standard, we found that for each constellation, a minimum size of 1024 bits was required. In addition, every 30 seconds, an additional message must be sent. So, we had to increase the size of the correction frame to a size of 3084 bits.

The following image shows all the messages that are sent in the RTCM format. This image makes it possible to visualize the different types of messages used to ensure the transmission of correction data, as well as their organization and structure. We removed the RTCM frames corresponding to the GLONASS constellation because the RTK algorithm we use for positioning does not take these measurements into account, and they therefore overloaded the payload of each correction message unnecessarily.

Type:	Size	Count	Description
1006:	27	32726	ARP Coordinates (full)
1008:	26	32726	Antenna Type (full)
1013:	15	32726	System Parameters
1030:	56	32726	GPS Network Residuals
1031:	44	32726	GLONASS Network Residuals
1032:	26	32726	Physical Reference Station Position ARP
1033:	52	32726	Ant/Rcvr Type
1074:	235	326976	MSM Full GPS code and carrier phases plus CNO
1084:	161	326976	MSM Full GLONASS code and carrier phases plus CNO
1094:	225	326976	MSM Full GALILEO code and carrier phases plus CNO
1124:	148	326976	MSM Full BDS code and carrier phases plus CNO
1230:	18	32726	GLONASS Differential Code-Phase Bias

Centimeter positioning in GNSS is a technique that makes it possible to determine the position of a receiver with great precision. For this, it is necessary to use correction techniques that make it possible to correct systematic errors of the GNSS signal. One of these techniques is RTK (Real-Time Kinematic) positioning, which provides real-time centimeter accuracy.

Each station in the Teria network receives real-time signals from GNSS satellites. It then performs data processing to determine its position with centimeter accuracy. The raw GNSS data (pseudodistances, reception time, etc.) are then transmitted to a central server, which performs a positioning calculation by combining data from all stations. However, it is possible that some stations are out of service for various reasons: hardware failure, power outage, bad weather, etc. These failures can lead to a decrease in the accuracy of the positioning system or even render it inoperative in some areas. To minimize the impact of outages, the Teria network made a risk management system. From the beginning of the project, failure risk analyses were conducted to identify the different possible failure scenarios.

These scenarios have been listed in risk tables, which make it possible to set up appropriate maintenance and repair plans in the event of a plant failure.

Risk analysis		Health Message
1	Checking the position of the reference base in RTK	0 to 6 for accuracy in cm in 2D, if 7 beyond, if 8 steps of RTK. 9 unknown.
2	Control of the reception of GNSS raw data	Analyzes availability on the 3 nearest stations, 3 or 2 or 1 or 0. 9 unknowns.
3	NRTK output control of GNSS raw data	Availability of local NRTK correction: latency from 0 to 6, if 7 beyond, 8 no data. 9 unknown.
4	Control of the NRTK position of a monitoring station	0 to 6 for accuracy in cm in 2D, if 7 beyond, if 8 steps of RTK + distance in km to the monitoring station on 3 digits, 998 = 998 or plus. 9 and 999 unknown.

Below we present more in details each point mentioned in the table.

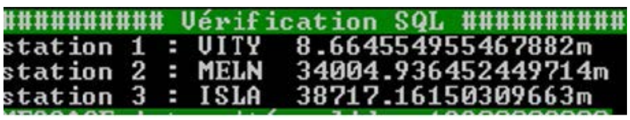
- Checking the position of the reference base in RTK

In RTK positioning, the position of the baseline plays a crucial role. Indeed, the reference base is a point whose position is known with precision, and which makes it possible to correct errors in measuring the GNSS signal. To know if the reference base station is able to provide RTK corrections, it is necessary to check its position. This control is done by receiving information about the stations used by users. This information is communicated internally, and makes it possible to know if the reference station is able to provide RTK corrections. Thus, by knowing the precise position of the reference stations, users can determine whether the data they receive is reliable or not.

- Control of the reception of GNSS raw data

To verify the reception of GNSS corrections, for this, we have a database that directly queries the stations to know if they are in working order. This database allows us to identify in real time the three stations closest to the user (in this case, a robot) and tell him if they are operational or not. The process consists of retrieving the user's position at the NMEA Frame and searching for the three nearest stations. Then, we directly query these stations to find out if they are able to transmit GNSS corrections. If all stations are operational, the user receives GNSS corrections in real time and can benefit from accurate positioning. However, if one of the stations is down or out of service, we immediately inform the user of this situation via health messages. Thus, the user is notified of the availability of GNSS raw data and can adjust its positioning accordingly.

Within our system, it is possible to consult the stations closest to the user from the central server. This function allows us to identify in real time the stations potentially available to transmit GNSS corrections to the user.



- <u>VRS output control of GNSS raw data</u>

To ensure optimal accuracy in GNSS positioning, it is essential to control the latency of real-time GNSS corrections (NRTK). To do this, we use software provided by Geo++ which allows us to measure the latency of GNSS corrections in output. Latency is the time elapsed between the transmission of GNSS corrections and their reception by the GNSS receiver. In general, lower latency is preferable because it allows for increased accuracy in GNSS positioning. This is because high latency can lead to positioning errors and lower accuracy of GNSS data. The software provided by Geo++ therefore allows us to monitor the latency of GNSS corrections in real time, so as to ensure optimal accuracy in GNSS positioning.

- <u>Control of the NRTK position of a monitoring station</u>

An NRTK (Network Real-Time Kinematic) monitoring station is a reference station that is part of a network of real-time GNSS monitoring stations. These stations are usually equipped with a high-quality and accurate GNSS receiver, as well as other equipment such as antennas and computers to collect, process and disseminate GNSS data.

It is important to distinguish between reference stations and monitoring stations. Reference stations are fixed stations that provide GNSS raw data for the creation of VRS corrections. These corrections are then transmitted to users to improve the accuracy of their GNSS positioning. However, unlike reference stations, monitoring stations also receive real-time GNSS corrections from VRS servers but are not part of the computation of them.

We have added four additional digits in case the project evolves or to be able to add values later.

Now that we have identified the data to send from our side on the Docker so that users have access to it. We mentioned earlier that we will use the same topic as the correction messages, namely the SPT topic. Correction, to send the health message.

- <u>Transmission of Health Messages</u>

As corrections are transmitted in RTCM3 format, it is also necessary that our messages of completeness are sent in the same format. RTCM3 is a data transmission protocol used to transmit real-time positioning correction information for satellite navigation systems such as GPS, GLONASS and Galileo. This format allows correction data, including transmission time errors, propagation errors, and clock biases, to be transmitted to improve the accuracy of positioning measurements. The RTCM3 format is widely used in real-time geolocation applications, including navigation systems for aircraft, ships and land vehicles.

Table 1: RTCM-3 Message Structure (RTCM Standard 10403.1, 2006)

Preamble	Reserved	Message Length	Data Message	Checksum
8 bits	6 bits	10 bits	n bits	24 bits
0xD3	Not defined	Message Length in bytes	Variable length in bytes	QualComm definition CRC-24Q

The screenshot above shows a type frame for integrity messages, which is added directly to the end of the correction data. The checksum of this frame is calculated in the correction part to avoid any problems with data transmission and processing. Thus, the integrity of the correction data is guaranteed during the transmission and subsequent use of this data.

To convert messages to bytes in Python, you can use the encode() method on a string. This will return a sequence of bytes, also known as bytes.

With the screenshot above, it is possible to monitor frame uploads to the MQTT server in real time.

```
29.4519151,E,1,7,0.70,199.3510,M,0.0000,M,,,*5E\r\n\x00$GNGGA,105748.0,4334.1011853,N,00129.4519151,E,1,
MESSAGE integrité valide: 13205830000
from serv_monitoring :  D3000e88813205830000   :  b'\xd3\x00\x0e\x88\x812\x05\x83\x00\x00' b'\x14\x1c#'
1098
MESSAGE integrité valide: 13205830000
from serv_monitoring :  D3000e88813205830000   :  b'\xd3\x00\x0e\x88\x812\x05\x83\x00\x00' b'\x14\x1c#'
1098
MESSAGE integrité valide: 13205830000
from serv_monitoring :  D3000e88813205830000   :  b'\xd3\x00\x0e\x88\x812\x05\x83\x00\x00' b'\x14\x1c#'
1098
MESSAGE integrité valide: 13205830000
from serv_monitoring :  D3000e88813205830000   :  b'\xd3\x00\x0e\x88\x812\x05\x83\x00\x00' b'\x14\x1c#'
1363
########## Vérification SQL ##########
station 1 : TLIA   1132.2821442934987m
station 2 : LACO   45773.35520703047m
station 3 : BMNT   53723.27085301928m
```

3. Results and Discussion

Once all the communication channels were in place, we were able to run the entire chain.

- <u>Convergence of RTK rather fast</u>

Tests were therefore carried out on one robot before testing on several. The first results observed still contained some inconsistencies in the communication between exagon2mip and the AGCbox. But after fixing these data model differences and a small VRS positioning problem, the RTK was able to converge properly.

```
235242.200 5 1 7 9.494 -12.589 -9.231 39.528 39.528 32.011 -0.00001343 0.002 0.000 1.205 0 330 1.200 -0.017 0.002 -0.083 -0.002 -0.001 -0.006
235242.300 5 1 7 9.497 -12.581 -9.194 39.467 39.467 31.953 -0.00001346 0.001 0.000 1.205 0 330 1.300 -0.013 0.009 -0.081 -0.001 -0.000 -0.007
235242.400 5 1 7 9.505 -12.565 -9.150 39.406 39.406 31.896 -0.00001347 0.003 0.000 1.205 0 330 1.400 -0.007 0.015 -0.053 -0.000 -0.003 -0.003
235242.500 5 1 7 9.513 -12.555 -9.109 39.344 39.344 31.839 -0.00001348 0.002 0.000 1.205 0 330 1.500 -0.011 0.017 -0.049 0.002 -0.000 -0.001
235242.600 5 1 7 9.520 -12.547 -9.064 39.282 39.282 31.782 -0.00001349 0.001 0.000 1.205 0 330 1.600 -0.012 0.017 -0.050 0.001 -0.001 -0.004
235242.700 5 1 7 9.519 -12.541 -9.018 39.220 39.220 31.725 -0.00001350 0.006 0.000 1.205 0 330 1.700 -0.013 0.013 -0.055 -0.006 -0.001 -0.010
235242.800 5 1 7 9.529 -12.537 -8.977 39.158 39.158 31.668 -0.00001352 0.003 0.000 1.205 0 330 1.800 -0.012 0.006 -0.065 -0.001 -0.003 -0.009
235242.900 5 1 7 9.532 -12.523 -8.931 39.095 39.095 31.612 -0.00001354 0.003 0.000 1.205 0 330 1.900 -0.013 0.003 -0.048 -0.003 0.000 -0.007
235243.000 5 1 7 9.545 -12.517 -8.889 39.032 39.032 31.555 -0.00001356 0.003 0.000 1.205 0 330 2.000 -0.029 -0.000 -0.090 -0.003 -0.001 -0.009
235243.100 5 1 7 9.552 -12.505 -8.843 38.969 38.969 31.499 -0.00001358 0.002 0.000 1.205 0 330 1.100 -0.024 0.002 -0.085 -0.002 0.000 -0.008
```

```
235305.800 5 1 7 9.165 -11.386 -5.930 10.585 10.585 9.784 -0.00001104 0.011 0.000 1.204 0 330 0.800 -0.004 0.011 -0.041 -0.009 0.006 0.008
235305.900 5 1 7 9.166 -11.390 -5.929 10.568 10.568 9.768 -0.00001104 0.008 0.000 1.204 0 330 0.900 -0.007 0.008 -0.039 -0.008 0.002 0.001
235306.000 5 1 7 9.168 -11.389 -5.926 10.551 10.551 9.753 -0.00001103 0.004 0.000 1.204 0 330 1.000 -0.008 0.007 -0.041 -0.003 0.003 0.005
235306.100 5 1 7 9.170 -11.393 -5.925 10.533 10.533 9.737 -0.00001103 0.001 0.000 1.204 0 330 1.100 -0.006 0.011 -0.039 0.000 0.001 0.000
235306.200 5 1 7 9.172 -11.397 -5.920 10.516 10.516 9.722 -0.00001103 0.000 0.000 1.204 0 330 1.200 -0.011 0.006 -0.061 0.000 -0.000 0.003
235306.300 5 1 7 9.176 -11.400 -5.916 10.499 10.499 9.707 -0.00001104 0.003 0.000 1.204 0 330 1.300 -0.011 0.006 -0.061 0.003 -0.001 0.005
235306.400 5 1 7 9.178 -11.403 -5.911 10.481 10.481 9.691 -0.00001104 0.004 0.000 1.204 0 330 1.400 -0.012 0.009 -0.059 0.004 -0.001 0.007
235306.500 5 1 7 9.181 -11.405 -5.907 10.464 10.464 9.676 -0.00001104 0.004 0.000 1.204 0 330 1.500 -0.012 0.012 -0.047 0.004 0.000 0.010
235306.600 5 1 7 9.182 -11.409 -5.904 10.447 10.447 9.661 -0.00001104 0.002 0.000 1.204 0 330 1.600 -0.017 0.014 -0.054 -0.001 0.001 0.008
235306.700 5 1 7 9.179 -11.412 -5.904 10.430 10.430 9.646 -0.00001104 0.011 0.000 1.204 0 330 0.700 -0.018 0.010 -0.058 -0.011 0.003 -0.005
235306.800 5 1 7 9.178 -11.417 -5.902 10.413 10.413 9.631 -0.00001104 0.010 0.000 1.204 0 330 0.800 -0.015 0.003 -0.063 -0.010 0.001 -0.010
235306.900 5 1 7 9.176 -11.423 -5.899 10.396 10.396 9.616 -0.00001104 0.007 0.000 1.204 0 330 0.900 -0.010 0.009 -0.057 -0.007 -0.001 -0.013
```

Figure 11. Extract from the logs of the service ensuring the positioning of the machine (boxes, the values of uncertainties as to the position of the machine that evolve. The RTK converged in minutes)

In the image above, we can see framed in red the estimates of uncertainties of the positioning (in meters), at 6 sigmas, on the 3 axes East / North / High. We can see on the two consecutive screens that we went from an uncertainty of 40 to 10 meters in 1 minute and 4 seconds (timestamps are the first values on the left, in seconds).

<u>Negligible latencies</u>

Due to the large number of information flow processing services, the corrections received by agc-space-tour arrive with a delay of a few tens to a few hundred thousand seconds late, but for Agreenculture's positioning algorithm, these latencies are not blocking. Optimization and improvement work have begun, but there is still room for improvement.

<u>Result obtained on the Teria side</u>

The work carried out has made it possible to obtain significant results to ensure optimal accuracy in GNSS positioning. Indeed, thanks to the various functions put in place we were able to control the latency of GNSS corrections in real time, the position of the reference base in RTK, the reception of GNSS raw data, the NRTK position through a monitoring station, which allows us to considerably improve the quality of the data.

This work will also be used to qualify the data for which an installation plan for 8 monitoring stations is planned. The monitoring stations, equipped with high-quality and precise GNSS receivers, will collect, process and disseminate GNSS data in real time. Thanks to these stations, it will be possible to provide real-time GNSS corrections to users, which will significantly improve the quality of their GNSS positioning.

4. Conclusions

Spatial data is used and needed in many applications of agricultural robotics. From surveying, geofencing, guiding autonomous machines performing mechanical weeding tasks...

The Space Tour 2021 project proposed by CNES, allowed the two French companies: Agreenculture and EXAGONE-TERIA to develop a common solution for users of autonomous agricultural machines. Both companies are now able to supply an autonomous agricultural machine with corrections enabling it to ensure an RTK Safe positioning.

Historically, Agreenculture uses a fixed station, called GRS (Ground Reference Station), to transmit secure corrections. It is the security of this communication as well as the securing of the navigation box of the engine that makes it possible to certify a virtual safety contour called Safencing© (allow users of autonomous agricultural machines to let their machine work without requiring the presence of an operator who monitors).

However, the precision necessary for the work of an agricultural machine, implies that the machine is less than 10km from the GRS, beyond it is not possible to guarantee quality work. It was therefore necessary to position GRS within 10km of all the worked prates, and also to ensure the exact positioning of the GRS at each use, (so that there is no risk of offset, related to bad weather for example). The positioning and integrity of this SRM therefore represent important technical concerns for autonomous and safe work.

TERIA have developed a correction flow system through virtual reference stations: VRS, which make it possible to mesh the entire territory in an ultra-precise way and thus improve network availability.

These two coupled solutions, a secure correction flow through VRS, make it possible to offer users of agricultural machinery a better availability of the network, having the guarantee of a secure environment.

Through the Space Tour project, CNES has developed an affordable, precise and secure solution to develop the agriculture of tomorrow, the objective is to feed more and more sustainably.

Acknowledgements

Thanks to the SpaceTour project financed by the CNES, Agreenculture and TERIA are able to offer a unique solution for secure positioning and guidance for end users.

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Autonomous weeding in Vineyards: How TED robotic solution operates safely without a local operator

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Abstract

Viticulture faces many challenges in the implementation of its ecological transition. Alternative solutions to the use of herbicides rely on mechanical weeding solutions which require more operations for the same results. When using traditional thermal-powered agricultural machines or tractors, these practices aiming to limit chemical inputs therefore produce more carbon emissions related to the use of the machine, and also require more labour. Electrically powered robotic solutions are an alternative that reconciles an itinerary without chemical inputs for grass management, a reasoned need for labour, and a solution with a very low impact on global warming. For several years, Naïo Technologies has been working to develop an electric-powered vineyard straddle carrier, TED. Until now, the safety of operations required the presence of an operator near the operations while the machine was automatically working the soil. Under these conditions, the interest of robotics was still limited insofar as an operator was always mobilized.

This year, a new version of TED was put on the market which now makes it possible to operate the soil in vineyards without the need for a local operator. This innovation is notably made possible thanks to the use of a patented device for detecting obstacles present in the vines.

This article will present in a first part the requirements associated with autonomy, and how TED is designed to be operated in an autonomous mode. The results are focused on the impact of the autonomous mode on the performances of the robot, whether in terms of work rate, or duration of mission. The discussion focuses on the issues associated with the security of autonomous operations and specifies the role of the operator during TED autonomous operations, and the shared responsibilities between the manufacturer and the users.

Keywords : autonomous machine, augmented autonomy, autonomous weeding, vineyards, robotics for agriculture

1. Introduction

Naïo Technologies is a French AgTech pupose-driven company founded in 2011, which aims to make sustainable agriculture a worldwide reality. Its activity results in four outcomes in agriculture. The robots aim farmers to shift toward a sustainable management of arable lands, to strike against climate change by avoiding generating carbon emissions and to improve their wellbeing and their health, while promoting a sustainable production model for robots manufacturing. TED has been designed following these objectives as a design guide. It provides a convenient and automotive machine to perform mechanical weed control in vineyards, and then to avoid the use of herbicides. It is lighter than a conventional tractor and its implement (less than two tons), which has a positive impact on soil compaction (Pradel et al, 2022). It is electrically powered. That choice has a great impact on equivalent carbon emissions. Using such a solution instead of a thermal engined tractor is an efficient way for farmers to reduce their carbon footprint. Agricultural machinery is known to be one of the most important causes of injuries and accidents for farmers (Jadhav et al, 2016). TED is designed to operate the vines autonomously, resulting in a strong decrease of exposure to mechanical risks and then having a positive impact on the health of farmers. Autonomy is also thought by Naïo as a solution to reduce the arduousness of operations, and reduce the psychological stress of users.

Nonetheless, introducing autonomous operations in farm management is challenging, both from a technical perspective and a legal point of view.

The development of TED has been an incremental process. The first rover was proposed a few years ago (Figure 1). That concept focused on the concept of autonomous weeding operations. The rover was equipped with technologies allowing automated movement adjustment to provide an efficient agronomic solution for weeding. These prototypes had to operate the vines under the strict supervision of an operator who had to keep an active eye on the robot to ensure the safety. The location of the tools in the rear of the robots especially was problematic for operator safety. That is why a redesign of TED was performed three years ago.

Figure 11. First prototype of TED robot (left) and view of the current product (right)

The rover offers a natural protection to the exposure of the operator to mechanical dangers associated with tools (Figure 1). However, a local operator still has to overwatch the operations to ensure nobody standing in front of the machine could enter in the area where the tools are working. Even if that situation already reduces the exposure to mechanical risks, it is not satisfactory, either from an economical point of view or from a mental load point of view.

That is why we focused our work these last years on the safety management, so as to be able to provide an enhanced autonomy where the machine can work alone, without the need for the operator to remain on the field.

This paper focuses on the challenges associated with this development, and the solutions put in place to be able to offer a safe and reliable product equipped with an effective autonomous mode. At first, it describes the regulation framework and the definitions associated with autonomy, the particular risks induced by perennial crops to be straddle like vines. In the second part, it describes the technical solutions which have been designed and developed, with a focus on the obstacle detection system ability to handle obstacle detection in the straddle area, with proven performances. The results will be presented, especially in terms of workrate or availability of the machine in the fields when it is equipped with its enhanced autonomy. The discussion will focus on the new supervisory functions, and what are the remaining open points about the integration of autonomous units in farms, especially what are the challenges for the user of autonomous units.

2. Materials and Methods

<u>Autonomy Concept</u>

First, "autonomous operation" has to be defined in the framework of agriculture applications. Quite often, autonomous vehicles refers to road applications where a classification in five levels of autonomy is commonly used (SAE Internationals, 2021). It cannot be used as is for off-road applications, as it refers to a main function which is to carry out people or goods from one point to the other. As long as humans are in the loop, the levels of autonomy describe in detail the fewer and fewer interactions between the autonomous vehicle and the driver.

If an agricultural machine is designed to go on the road, it is then the road regulation which applies to that machine when it takes the road, including any relevant regulation related to autonomous vehicles if the use of the road is done in an automated way. In that case, the classification in five levels of autonomy may apply to that specific use of the machine evolving on the road.

When the machine is designed for off-road application only, that framework is not relevant anymore. Indeed, the main difference is that an agricultural operation refers to a large variety of functions, which can be ensured by using several kinds of equipment, tools or mobile platforms. On the field, machines and tractors are involved in various combinations to perform one or several defined functions, like soil-working operations or spraying.

As a result, it is more convenient to describe agricultural systems as machines or tractors embedding more or less automated functions. These functions can then be operated in a manual mode, an autonomous mode or a semi-autonomous mode. That is to say an automated function can either performs operations :

- under direct command from an operator in manual mode,
- without any interactions with humans in autonomous mode,
- with limited interactions with humans on some specific actions in semi-autonomous mode.

Thus, an autonomous agricultural machinery refers to a machine equipped with automated processes smart enough for the machine being able to operate and do its job without any help from an operator once it has been launched in its autonomous mode. It includes the safety of the operations which is ensured by the machine itself, as long as the machine operates within the appropriate boundaries.

A common misunderstanding about autonomous robots is the confusion between semi autonomous and autonomous units. Indeed, a robot can be designed to perform automated operations, like soil-working functions. The automation can be high enough for the machine to decide by itself how to move and how to act on soil, in order to maximize target performances. In that case, no interactions with the operator are needed anymore for performance purposes. Besides, it is still a "semi autonomous unit" as long as the safety of the operations is ensured by an operator who has to stay close to the machine or on the field to overwatch and anticipate hazardous situations (mainly, a bystander coming close to the machine and exposing himself to danger from the machine movement, or the machine leaving the designated area where it is supposed to operate). It is a mandatory interaction with humans for the semi-autonomous machine to operate safely.

Based on the common definition of autonomous machines, the designation "autonomous machine" should only be used to describe machines equipped with automated functions where the safety of the operation in the autonomous mode is ensured by the machine itself, without the help of any operator interactions.

Safety for vineyards application

TED is a machine, dedicated to off-road applications only and operated in Europe. As a consequence, it shall comply with the European Machinery regulation, namely the Machinery Directive 2006/42/CE up to 2027. A new regulation (EU) 2023/1230 has been published recently and will come into force at that time. This regulation is the output of a revision process of the Machinery Directive triggered to encompass the "New Technologies" which are more and more integrated in solutions design. New technologies is a generic term which includes internet of things, artificial intelligence and robotics among other things. The word "autonomy" is never used in the Machinery Directive, and the use of autonomous units is not prohibited. There are hardly any requirements dealing with autonomy, which involves for manufacturers to take position and innovate in the safety management of autonomous units. Even if the regulation (EU) 2023/1230 is not applicable yet, it may be used to provide a guideline about how to deal with risks and associated requirements dealing with autonomy in fields. Agricultural robots which do not involve rotary circular saw nor sawing tools can be put on the market by using a self-certification process. That is to say the manufacturer takes the responsibility to ensure the product is compliant with all the essential health and safety requirements described in the Machine Directive. When available, the manufacturer can rely on harmonized standards to help him go faster in implementing solutions. Up to now, no type-C standards have been published dealing with autonomous operations for agriculture. The only standard available is a generic type-B standard, the EN ISO 18497:2018, entitled "Agricultural machinery and tractors — Safety of highly automated agricultural machines — Principles for design". This standard is currently under revision at ISO level. It provides guidelines for marking out safety functions associated with autonomous operations. Whatever the technical solution involved in the safety functions, manufacturers must prove the efficiency of the safety system. Especially, there is a need to collect evidence of the performances of critical safety functions or subfunctions like the detection of a human.

For the last year, several solutions have been developed and put on the market to help vehicle drivers to detect and deal with humans. These solutions are based on vision sensors, machine-learning algorithms to learn and detect people in various conditions (Kukkala et al, 2018). They are part of the Advanced driver-assistance system (ADAS). As the name explicitly indicates, it is primarily a driving assistance for the driver. The transposition of these technologies to autonomous off-road autonomous units requires a jump from the assistance to the proven performance of the system to ensure the safety by itself. In an agricultural environment, these performances must be proven under conditions which are far from the conditions for which the systems are developed at first. One of the characteristics of the agricultural environment is the high discrepancy of environmental conditions and the poor structured environment (Tian et al, 2020). Up to now, there is a lack of methods to be able to prove the performance of a machine-learning algorithm in accordance with the defined limit of use of the autonomous units on which these systems may be used in safety functions. (Hamon et Al, 2020). As a consequence, technical solutions for safety systems which rely on Artificial Intelligence software cannot be deployed by using a commonly accepted method to assess and prove the performance of the safety function.

The EN ISO 18497:2018 standard gives information on how to manage risks associated with automated movements or changes of direction, as well as the need to have a person detection device to avoid collisions. It defines a reference obstacle which shall be detected when placed on the machine path. In any case, the autonomous unit shall reach a safe state prior to the contact with the obstacle. Tests protocols have been designed and implemented since the standard's publication, like ARPA1 developed in the frame of a project led by INRAE (Debain et al, 2021). We've been able to pass the tests on Dino, a rover designed to develop autonomous solutions for market gardening. The functional requirement for an obstacle detection system may become difficult to ensure as soon as we are considering straddle units for perennial crops like vineyards or orchards. In that case, the obstacle shall be detected in front of the driving unit path, but also in front of the straddled area where the crop to be worked on is already present.

Obstacle detection systems should then be designed to deal with situations where people may be partially hidden by vegetation and may present themselves in various postures depending on the activities they are carrying out. A link may be established between these particular risks, and the lack of autonomous units available on the market to deal with vineyards. All the units available for now involve an operator to stay reasonably close to the operations, to ensure that nobody would be hurt by the machine during the automated operations. They are semi-autonomous units.

<u>Robotic solution description</u>

The straddle robot Ted is a product launched in 2020. It is capable of automated navigation through vineyard parcels, at a maximum speed of 4.5 km/h. It is designed to do several operations, especially mechanical weeding. It can run in vineyards with slopes up to 20% and counter slopes up to 5%. The maximum weight for Ted including its tools is 2500 kg. The mechanical platform is made up of 2 lateral beams, 1 upper platform and 4 wheel blocks which contain the steering and the driving actuators. Ted has 2 lifting cylinders, one on each side, which allows the use of conventional weeding tools due to its standard interface.

Ted is 100% electric, with a maximum electric capacity of 40 kWh. The battery technology is NMC which provides a high density of energy.

The electrical architecture is made of 2 different subsystems :

- the navigation system first, which includes an embedded computer. It handles the navigation of the robot by using a GNSS receiver, and controls all the actuators of the machine.
- The safety system acts like an external supervisor of the operations and can put the robot in a safe state at any time by removing the power of the actuators.

Initially, an operator was required to stay close to the machine, he was equipped with an emergency stop button, capable of performing a safe stop of the robot at any time. The whole risk analysis has been reconsidered for the implementation of the autonomous mode.

Independently of the autonomous mode, risk assessment according to the ISO 12100:2010 (ISO 12100:2010) with the mandatory presence of a local operator, in addition to the application of the Machine Directive 2006/42/CE and the EN

ISO 18497:2018, have lead to the basic safety features :

- Side control panel including emergency stop buttons
- Signs and machine marking, especially the light column and other alarms recommended by the EN ISO 18497:2018
- Delays with visual and audible warning prior to resuming movements in automated operations
- Safe stop of the machine, with 2 redundant safety relays which power off the actuators and activate the brakes (PLr = d for this safety function, according to the safety-related parts of control systems standard EN ISO 13849 (EN ISO 13849-1:2015)
- A key selector to choose between a supervised mode, and the autonomous one. An emergency mode is also available to perform limited movement with the bumper deactivated when they are pinched on a fixed obstacle.

According to the revision project of the EN ISO 18497:2018 standard, the light column is equipped with 4 colors which have the following meaning :

- white light: the electrical power is on ;
- flashing amber: the machine is moving and represent a danger for bystander ;
- green light: the machine is working autonomously. No human interaction is needed for TED to operate ;
- red light: a fault or a defect has been detected, the machine is waiting for a human intervention. Only trained people can intervene.

Twenty additional significant risks have been identified from the autonomous mode, and their criticality evaluated following the guidance ISO/TR 14121-2:2012.

The most critical risks to deal with are

- People standing in front of the wheels and being hurt by the rover;
- People standing in the tools area (in a vineyard row);
- TED leaving the autonomous work area and creating hazards.

The following safety functions has thus been identified (with their required performance level according to EN ISO 13849-1:2015 :

- Preventing collision with people in front of the wheels (PLr = d)
- Preventing collision with people in the tools area (PLr = c)
- Preventing TED to leave the work area (PLr =c)

An obstacle detection system is used to ensure the safe detection of people exposed to the machine motion. The detection of obstacles in front of the wheels consists of 4 safety bumpers, integral with the wheel. The components used are compliant to the ISO 13856-2:2013 and designed for a machine with the mechanical characteristics of TED.

The analogy with the standard ISO 3691-4:2020 concerning the driverless industrial trucks leads the maximum travel speed to be limited to 0.6 m/s (2.16 km/h) if the detection is only based on contact devices. This limitation forces the conditions of use to be changed for the autonomous mode, with a safety function to ensure the speed remains below 0.6m/s when working in autonomous mode. The height of detection is fixed to 20 cm above the ground, in accordance with the recommendations of ISO 13857:2019 standard. The distance between the safety bumpers and the wheels has been calculated then tested in the worst case scenario, regarding the stopping distance of the machine (descending slope of 20% and slippery soil).

The detection of obstacles inside the vineyard row is done by a patented device (FR3127668) based on a mechanical probing of vines. It measures the apparent diameter of the obstacles being straddled by the robot.

This device allows the creation of a security exclusion zone of 40cm, centered on the axis of TED. Every obstacle with an apparent diameter larger than 20cm, or partly or totally outside this area triggers a safe stop before the obstacle comes into contact with the tools. The vines row itself represents a natural obstacle that prevents a person from standing in this exclusion area. Consequently, TED is designed to operate in autonomous mode on vines only. The robot performs a safe stop if the obstacle crossed is over 20 cm diameter.

In order to ensure TED stays in the autonomous work area, a geofencing system has been designed and integrated in the safety system. It is based on the comparison of two different GNSS sources, and allows the machine operations inside a set of predefined plots. The definition of the contour is made manually by trained people. In most cases, the user is not allowed to manage the safety maps by himself. The possible inconsistency of the GNSS receiver and the stopping distance have to be taken into account when defining the plot in order to allow safe operations.

The integrity of the location data is validated at first by the operator programming the mission, and all along during the operations by the safety doors which ensure the TED remains centered physically on the vines row. The autonomous mode cannot be activated if the robot is located outside the authorized areas stored on the machine.

In accordance with the future Machine Regulation (EU) 2023/1230, a supervisory function is also defined (Figure 2). A cloud connection is needed at any time. The connection link is tested continuously and any significant loss of signal leads to a safe state of the machine. This function allows a supervisor to have an overview of the operation in real time, and consult machine data and mission status. There is no need for the supervisor to stay locally on the field, nor to have an active role in the mission safety. The supervisor can then be located elsewhere and he can be designated to supervise several machines at a time. Very specific commands are available at that supervisory station. At first, he can order the machine to stop its autonomous operations. The machine is then on-hold, the safety functions are still activated. The supervisor can authorize the machine to resume its autonomous operation, while the machine has not left the autonomous mode. The supervisor is also able to order a stop, leading to the termination of the autonomous operations. Once the autonomous mode has been deactivated, a local operator has to go on the machine itself to take commands manually. At least, he can tune the speed and the tool lifter height, as long as they remain in the safe boundaries of the operations.

Figure 2. Supervision station giving information about the autonomous mission, and providing restrictive commands like stopping the autonomous operation.

3. Results

TED has been successfully operated in several regions, in order to test the system in several conditions. Five units have been used to perform mechanical weeding in Languedoc Roussillon at first. There is no plant cover in the inter-row. Several fields were equipped with suspended irrigation systems. Tests were also successfully performed in Gaillac vines (IFV) with a plant cover implemented between and on the rows, and in Charente, with larger inter row spacing and higher vines. Moreover, tests were conducted on both young and old vines, with several planting methods (manual planting and GPS-assisted planting vines). An example of vines is given in Figure 3. The tests were performed from the first time in Spring up to the end of September, in order to evaluate performances with several grass conditions, and also several levels of leaf and grape formation.

Figure 3. TED's safety device in interaction with an old vine and suspended irrigation system.

Figure 4. Field of 1.3 ha (4,000 vines per ha) weeded by TED in 177 min, with only one interruption.

First, one has to notice that the autonomous mode, as defined on TED, limits the speed to 2.2km/h. As a consequence, some tools which are used on TED in supervised application are less effective at such a speed, such as Kresse fingers or discs. On the other hand, no impact on the efficiency of intervine blades were noticed. In nominal conditions, the actual work rate has been measured to 2.3 hr/ha in Languedoc-Roussillon (density of 4,000 vines per ha). That estimation includes the time to launch the mission, to deal with interruptions, and the autonomous navigation in a field of 1.3 ha. Only one interruption was registered during that mission.

Secondly, one of the main challenges of these tests was to evaluate at first if the safety doors device does not trigger false positive cases. Indeed, once the safety doors detect an obstacle supposed to be outside of the exclusion zone or larger than 20 cm, a safe state is reached. An operator is then needed to intervene on the machine, and launch again the autonomous operation after checking no danger would be generated by the machine. After 120 hours of weeding activities operated in autonomous mode, the analysis of the log helps to identify the interruptions associated with the safety functions dedicated to the autonomous mode. The impact on the interruption rate is lower than 20% in several cases: when the field is correctly prepared (dead vines removed from the interrow area for instance), TED manages to operate autonomously during the full day with no or one interruption only. No interactions with suspended irrigation were noticed during all the experiments. In several cases, interruptions have been monitored on old vines which are manually planted. In these cases, a safe state has been reached after some vines were detected out of the 40cm large exclusion area. In any case, the movement was stopped soon enough to avoid damaging the trees. The switch of the mode selector to the supervised mode allows it to pass the obstacle and then the operator has been able to resume the mission.

The third aspect was the duration of the mission, directly linked to the energy capacity of the batteries. Indeed, because of the electrical engine, a trade-off must be defined between the power capacity, and the weight of the machine. The autonomous mode has a strong impact on that parameter, insofar as the speed is limited.

As a result, one has noticed an increase of 50% of the duration of the missions. In Gaillac conditions especially (full cover plant), the batteries discharge analysis coupled with the time of the missions let suppose missions of 12 hours can be carried out without any charging operation of the machines. For a density of 4,000 vines per hectare, by taking the work rate estimated during the experiments, one can assume TED is able to weed a field of 5ha autonomously per day.

4. Discussion

The tests and associated performances obtained on TED equipped with an autonomous mode highlights the autonomy would have some impact on practices. At first, the main current limitation is due to the limited speed at 2.2km/h. If interblade are relevant at such a speed, the discs require the machine to go at higher speed. That operation can still be done, under the overwatch of a local operator. Several contactless sensors probing farther in front of the machines have been tested in order to work at a faster pace. Up to now, the impact on availability was too high to be implemented on the product. Sensors trigger false positive detection on vine leafs, leading to interruptions requiring an operator to come again on the field. The actual work rate, which includes the time required to deal with slow down and interruptions would be lower, even if the instantaneous speed would be increased. That point will be improved in the coming months, by implementing sensors able to operate at higher speed while preserving the availability and the efficiency of TED.

Safety has also been challenged during the experiments, especially the behavior of the new safety doors device. The width of the exclusion area has been adjusted to find the best compromise between detection of obstacles which may not be vines, and misaligned vines. The stops which have been triggered by the device on some out-of-the-rows old vines is a very positive result. Indeed, it helps to ensure the TED remains centered enough over the row to avoid damage on vines during the weeding operations. As soon as vines are scattered around the line, even if the map has been adjusted for TED to adjust its trajectory, lateral stub or too much shifted old vines are likely to be damaged during the autonomous operations. The current detection by the safety doors help the winegrower to locate the danger, and take appropriate actions to prevent damage. Nonetheless, this additional safety helps to consider using the machine on plots that would not have been considered eligible for mechanization. The second kind of sensor involved in the obstacle detection system is the bumper devices which remain active, whatever the mode of operation. As a result, the interruption rate can rise significantly if old trunks or branches have been thrown between the rows and will trigger the pressure sensitive sensors. Likewise, using a tractor on poorly dried soils can lead to the creation of ruts and clods of earth which will disturb the bumpers afterwards. The success of the implementation of a robotic solution for weeding relies on the preparation of the ground.

Another subject has been raised about liability concerns during autonomous operations. Indeed, insofar as TED is equipped with an autonomous mode, Naïo, as manufacturer, certifies the machine is safe enough to operate without any human interactions. Nonetheless, that autonomous mode is defined to work in specified conditions of use. For instance, the private roadway which may be used by the robots during the u-turn shall be closed to traffic during the operation. TED is equipped with safety devices which prevent the robot from hurting people standing or walking near the machine, but cannot anticipate high speed incoming vehicles. As a result, some requirements are needed about the integration of the robot in a field to ensure the autonomous mode can be safely activated. It is the responsibility of the operator to ensure the conditions of use are met (access closed, signs in place,...) prior to actually launching the autonomous mode. During the autonomous operations, the user still has to ensure the appropriate occupational measures remain in place. The choice made by Naïo to deal with that particular topic is then to ensure a supervisor is designed by the user for every mission to be launched in autonomous mode. It may be the operator himself. That person must log on its supervision station, and check he can have access to the command at any time. That supervisor shall ensure that the conditions of use of the autonomous mode are always in place during the mission. That is why that supervisor should be considered on duty during the operation, should remain at any time in a place where he can exchange information with the autonomous units, and can be joined by phone at any time.

His cellphone number shall be clearly visible around the autonomous working area. In this way, he is able to intervene if unforeseen events disrupt the site, or if he considers that the conditions are no longer met for the safe running of autonomous operations. Because autonomous units are a very emergent technology in the field, it appears farmers need to be adequately trained in the implementation of these units.

Especially, a good understanding of the definitions of conditions of use is needed, and guidance for occupational safety should be given by the provider of the autonomous unit, about access restrictions, appropriate signs and training of people to be in close interaction with the robots.

5. Conclusions

That paper highlights a new autonomous mode which has been deployed on TED, a straddle autonomous machine designed to operate in vineyards. The main challenge to ensure autonomous operations is the operations of the machine remain secured at any time. In vineyards, specific risks associated with the crops arise. These risks have been mitigated by using a patented device to ensure the detection of people standing close to the vine rows. TED is the first rover of more than one ton able to work in an advanced autonomy mode, that is to say without the help of any operator staying near the machine or on the field. That solution has been tested, and Naïo certifies that TED equipped with this autonomous mode is compliant with the European Machinery Directive 2006/42/CE. In particular, definitions which have been introduced in the upcoming Machinery Regulation (EU) 2023/1230 have been used to help and clarify operator responsibilities and safety requirements associated with autonomy. Tests have been performed all along the season, in different conditions of soil, leaf and grape development, irrigation system and on manual and RTK-planted rows. The results are quite promising, with no interruptions coming from additional safety systems. The safety doors happen to be a convenient way to ensure the safety of crops, especially when vines are scattered around the lines. In that case, the doors help to reach a stop before causing any damage to the vines, helping winegrowers to manage these specific cases. It helps to deploy autonomous mechanization on plots where it would not have been possible before.

In order to ensure the availability of the autonomous operations, and to prevent the operator from coming to the field only for managing interruption, we have chosen to use only pressure sensitive sensors to detect obstacles in front of the machine. As a consequence, the speed of the current version of TED remains limited to 2.2km/h. The tools which require higher speed can still be operated in the semi autonomous mode, with a local operator overwatching the operations. The duration of the missions realized in autonomous mode have then been extended, the power needed to operate at such a speed being lower. Missions up to 12 hr can be realized, with only one interruption during the day. Looking at the actual work rate which has been measured, it means TED is able to autonomously operate a field of 5 hectares per day without any intervention (4,000 crops per ha). It appears that the main causes of interruptions were found on specific plots, and are not linked to autonomy, but are associated with ground preparation. The use of robotics solutions requires the ground to be clear of vegetable waste and too high ruts.

At least, actual operations of autonomous units have also highlighted the need to support farmers in their adoption of autonomous units. Liability concerns are expressed, and the responsibility of autonomous units users should be clarified. Autonomous operations can only be done within specific boundaries, which have to be clearly defined in the instruction manual. While the manufacturer takes the responsibility of the safety of the operations, the operator is responsible for ensuring conditions are still in good accordance with the requirements for the autonomous operations. In particular, he has to ensure roadways which may be used by autonomous operations are closed to traffic, and that signs are clearly visible, for everybody to be able to contact the supervisor. We consider the latter should be on duty, in order to be able to have a quick reaction and put on-hold or stop the machine the time to remove doubts. Even if the results are quite promising, it is only a first step on the path of more autonomy in the farms. Beyond the technical issues associated with the use of new technologies like artificial intelligence, questions about the sharing of responsibilities and the level of training needed to operate these machines are still present. The actual deployment of autonomous units at large scale involves farms and their ecosystem to be ready for these new technologies. The work at sector level seems appropriate to pursue the development of autonomy in farms.

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Sensitive Device for Probing and Recognition of Obstacles in a Natural Environment

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Abstract

Perception technologies used by mobile robots, based on cameras, LiDAR or RADAR can detect obstacles in the robot's path during navigation. However, the challenge lies in accurately differentiating between traversable and non-traversable obstacles. LiDAR alone can detect soft vegetation, like tall grass, and identify it as a non-traversable obstacle even though it might not affect neither the vehicle's movement nor safety. This paper introduces a mechanical device called a « Sensitive Bumper Probing System » which can be integrated into mobile robots and interact with the environment to help differentiating physically traversable from non-traversable obstacles and ensure the system's safe operation. To achieve this goal, the sensitive bumper provides force measurements as it interacts with the environment. Combined with a 2D LiDAR, this measurement permits to decide whether the detected obstacles are traversable and collects data about objects to contribute to the environment recognition.

Keywords : Robot-Obstacle Interaction, Traversability, Obstacle Probing, Perception by Direct Interaction, Sensitive Bumper, LiDAR.

1. Introduction

An autonomous vehicle operating in natural environment needs to be equipped with sensors to detect obstacles along its path. This is essential to avoid harmful collisions. Other than preserving the integrity of the vehicle, this also protects humans, animals, and other objects of the environment. For mobile robots, terrain traversability analysis is a critical task that directly affects the robot's performance and safety (Papadakis, 2013).

Research on terrain traversability can be divided into two main categories. The first is research on robot geometry and kinematics design to give a robot the ability to overcome obstacles without relying on perception. It is the case of the robot proposed by (Chavdarov et al., 2020) which has a specific wheel-leg geometry allowing it to advance and overcome obstacles. Alternatively, robots with specialized wheels are designed for better obstacle climbing ability. (Lee et al., 2020) propose a climbing robot whose wheels have inclined spokes. In addition to the omnidirectional deformable six-wheeled robot of (Huang et al., 2022), the Quadruped of (Chen et al., 2014), and the TurboQuad robot of (Chen et al., 2017) are examples of robots designed to overcome obstacles.

The other category is research on perception and sensory data processing for measuring terrain traversability. (Papadakis, 2013) distinguishes between two types of sensory data processing employed in this domain upon the need for physical contact: exteroceptive sensory data processing and proprioceptive sensory data processing.

Exteroceptive sensing methods analyze vision sensory data such as camera or LiDAR. They are common approaches for detecting obstacles and inferring their properties. As examples, (Lucas et al., 2019) propose a method for detecting linear vegetation elements in agricultural landscapes based on classification and segmentation of high-resolution LiDAR point data. (Ahtiainen et al., 2017) propose traversability mapping in outdoor environments based on LiDAR data. Similarly, (Broome et al., 2020) attempt to predict terrain traversability by using point clouds collected from laser rangefinders. Researchers from Southampton (Tomsett and Leyland, 2021) use an UAV equipped with LiDAR and a multi-spectral camera to identify vegetation areas. (Takagaki et al., 2013) propose an image processing method to discriminate between traversable and non-traversable regions. (Kahn et al., 2021) develop a model that learns from a robot's experiences to navigate in outdoor environments, using RGB images and associated labels to identify tall grass as traversable.

(Howard and Seraji, 2001) employ a technique that utilizes visual perception and a neural network to characterize and estimate terrain traversability. (Cunningham et al., 2015) propose a method for predicting the looseness of terrain by estimating its thermal inertia from temperature observations over a day. (Jiang et al., 2022) describe a solution using faster R-CNN for thermal images to detect pear tree trunks, enabling navigation under various lighting conditions in orchards.

Proprioceptive sensing is employed during the traversal of terrain. It is based on data issued from physical interaction between the robot and the environment using different types of sensors. In legged robots, for example, different sensing modalities are used to probe the ground and determine the robot-ground contact information. These sensing modalities include electric capacitance (Wu et al. 2016, 2020), pressure (Tenzer et al., 2014), airflow (Navarro et al., 2019), and magnetic Hall effect (Tomo et al., 2016) to detect varying forces. In (Haddeler et al., 2022) vision and terrain probing with force sensor are combined to analyze traversability. On autonomous ground vehicles (AGV), flexible contact bumpers are often used to detect impacts (Norcross et al., 2015). In (Armbrust et al., 2011), a highly responsive bumper system is developed to enable the RAVON robot to distinguish between passable vegetation and rigid obstacles. Bio-inspired whisker sensors using various approaches such as piezoresistive materials, optical fibers, or MEMS are also proposed to enhance robots' ability to interact with their environment and perform tasks like object detection, localization, and navigation (Yu et al., 2022).

In this project, the implementation of mechanical sensing system at the front of a mobile robot coupled to a LiDAR is investigated to analyze the traversability of the robot path. This paper proposes a new system called "Sensitive Bumper Probing System" (SBPS). It is composed of a 2D LiDAR and a mechanical device able to probe objects on the robot's path. SBPS allows differentiating between traversable obstacles (such as tall grass, foliage, etc.) and non-traversable obstacles. The concept of the sensitive bumper probing system is introduced in the following section (section 2) where the proposed design of the mechanical device and the operation principle of the system are described. Section 3 details the tests carried out to validate the concept of the sensitive bumper and the obtained results. The limitation of the system are discussed.

2. Materials and Methods

Giving a mobile robot the ability to decide to continue or to stop its planned trajectory when an object is detected on its path is the aim of our project. When the detected object is traversable, like tall grass, foliage, small branches, etc. (Figure 1), the decision of the robot must be to overcome the object and pursue its planned trajectory. For non-traversable objects like human, animal, tree trunk, etc., the robot decision must be to stop or to adapt its trajectory in order to avoid the obstacle.

Our robot detects the presence of obstacle-object by LiDAR. It probes the detected object with the sensitive bumper and measures their resistance to the advancement of the robot. Depending on the value of the measured force, the robot decides to continue its trajectory or to stop immediately. The following subsections introduce the design of the SBPS probing device and its operation principle.

a)

b)

Figure 1 . Examples of traversable objects, a) branches, b) plant.

2.1. Sensitive Bumper concept

The proposed probing device is a sensitive bumper mounted on the front of the robot. It relies on the robot's progress to touch objects, probe them and measure their resistance to the advancement of the robot. To do so, before reaching the object, the robot's velocity slows down significantly (between 0.1 m/s to 0.2 m/s). Then, it continues its slow movement while the bumper is in contact with the object and until the measured effort passes a threshold. The proposed sensitive bumper is composed of a moving assembly connected to the robot body by two parallel translational joints that each contains a spring and force sensor (Figure 2a).

a)

b)

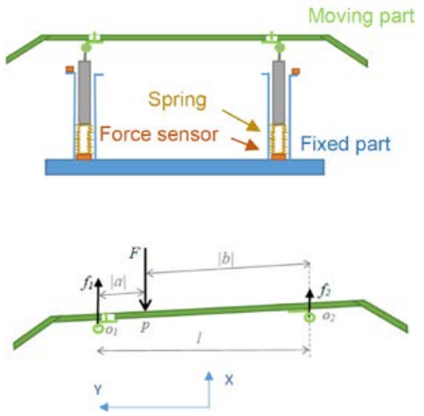


Figure 2 . (a) Sensitive bumper concept and (b) force applied on the moving part, F, and measured forces f1 and f2

The sensitive bumperÂ probing system is designed to measure the interaction force when in contact with an object. Wherever the contact point on the bumper is, the contact force, *F*, is obtained by adding the forces measured by the two force sensors, *f1* and *f2*: *F=f1+f2* (Figure 2b). The difference between the two force sensor measurements allows to determine the position of the contact point on the bumper.

A mathematical modelling of the bumper is established to study the influence of robot and bumper parameters on the forces applied on the probed objects. The case of probing rigid and fixed obstacle is considered. Before meeting the object, the robot moves at slow speed, *V*. When it meets the object, bumper springs, of stiffness *k*, are compressed and a force, *F*, is measured. When the value of the force reaches a threshold, F_1, the robot controlled speed drops to zero. During a response time, tr, the robot continues its movement, then it decelerates and stops. The final force, measured when the robot stops, is then bigger than the threshold. For a safe probing, this final force must be minimized.

The theoretical study showed that, on the robot side, robot velocity when probing, *V*, and its response time, t_r, are the most influencing parameters on the final force. Other parameters like deceleration value and force threshold also influence the obtained final force. Figure 3(a) compare the forces obtained with two different velocities of probing (0.1 m/s and 0.2 m/s) while all the other parameters are fixed (t_r=0.1 s, F_1= 49 N, deceleration= 1.5 m/s2, *k*=3.6 N/mm). The force increases when the velocity increases. Figure 3(b) compares between forces obtained by a robot having a response time of 0.1s and another having a response time of 0.2 s. For the same impact velocity (0.2 m/s) and the same deceleration (1.5 m/s2), force threshold (49 N) and springs stiffness (3.6 N:mm), the robot having the higher response delay measures the highest forces.

On the bumper side, the spring's stiffness has the most significant influence on the measured force. The mass of the mobile assembly of the bumper has a limited influence in our case. Figure 3(c) shows plots of forces obtained when the springs stiffness is 3.6 N/mm then when it is 1.5 N/mm with the same probing conditions (*V*=0.2 m/s, t_r=0.1 s, F_1= 49 N, deceleration= 1.5 m/s2). The maximum value of force is obtained for the stiffer spring.

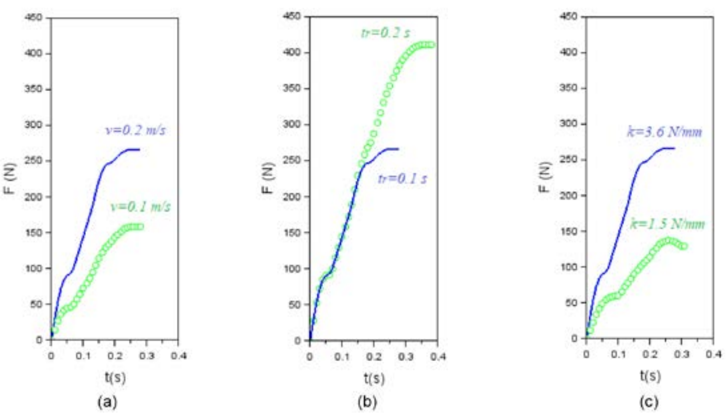


Figure 3. Force as function of time when probing a rigid and fixed object compared, a) for two different robot speeds (0.1 m/s and 0.2m/s), b) for two response times of the robot (0.1s and 0.2s) and c) for two bumper spring stiffness (3.6 N/mm and 1.5 N/mm)

The modeling of the sensitive bumper helps to adapt the new design on mobile robots. Two prototypes are built for tests, the first for a small robot with spring's stiffness of 3.6 N/mm and the other for a larger robot with spring stiffness of 1.5 N/mm. The corresponding propping speeds for these robots are respectively 0.1 m/s and 0.2 m/s. The approach to use the sensitive bumper is introduced in the next subsection.

2.2. System operation

The mobile robot, equipped with SBPS, detects the obstacle's presence in advance using the LiDAR. Then, if it is a known non-traversable obstacle, the robot will go around the obstacle and follow the trajectory. In the case of an unknown type of obstacle, the robot will reduce its speed and move towards it to measure the interaction force when contact happens. A measurement above a high threshold ensures a total stop of the robot.

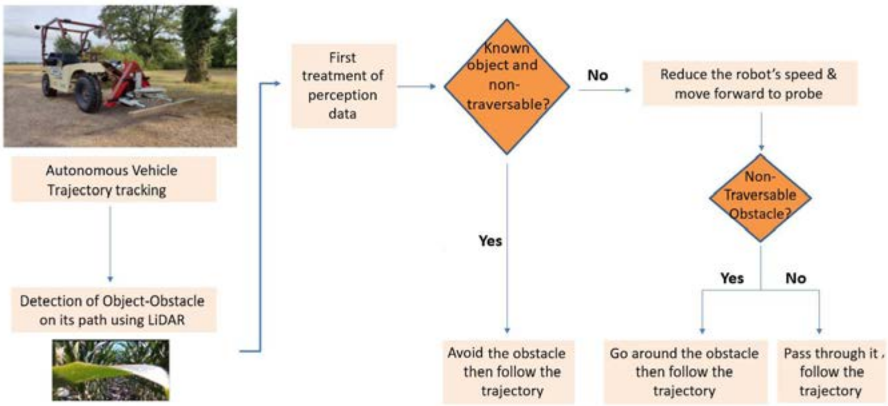


Figure 4. Flowchart of SBPS

System operation, as shown in Figure 4, needs to add the following functions to the robot:

- Deciding if an object is a known non-traversable object based on a first perception from LiDAR data treatment;
- Determining whether to traverse a probed object or to avoid it based on probing force data;
- Adapting the robot's velocity with the situation;
- Managing changes in the trajectory to go around a non-traversable object (not in the scope of this paper).

A first classification of obstacles detected remotely is executed using point clouds obtained from a 2D LiDAR. Initial observations showed that vegetation exhibits scattered points while some obstacles, especially walls, are characterized by aligned points. Scattered points can be grouped in clusters using RANSAC algorithm (Fischler and Bolles, 1981). For each cluster, its classification is done with respect to the regression line obtained through RANSAC. If the average distance of each point in the cluster to the regression line, or standard deviation (σ), is low, then the points are aligned on a straight line. In this case, the obstacle is considered to be a wall. A high standard deviation indicates scattered points, or vegetation (Figure 5).

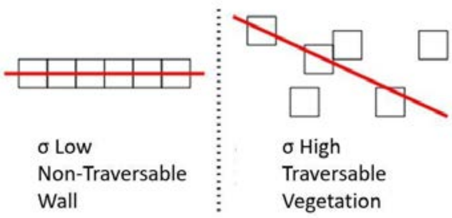


Figure 5. First approach of classification

The approach using LiDAR combined with the SBPS probing can enable distinguishing between traversable and non-traversable objects. Thus, the robot's velocity depends on the situation based on LiDAR and SBPS data. The velocity command can be summarized as shown in Table 1.

Robot speed		*LiDAR data*		
		No nearby points detected	potentially traversable points	potentially traversable points
Bumper data	F < low threshold	Unchanged	Reduced	Null
	low threshold <F <high threshold	Reduced	Reduced	Null
	F > High threshold	Null	Null	Null

Table 1. Summary of velocity control laws.

3. Results and Discussion

3.1. Probe concept validation tests

The new designed sensitive bumper probing system is mounted on "Effibote3 Robot", which weighs about 20 kg, with a Tim Sick LiDAR sensor (Figure 6). An Arduino microcontroller is used with a serial port to collect measurement data.

Figure 6. Sensitive bumper probing system mounted on « Effibote3 Robot »

Probing tests are carried out to validate the concept of the sensitive bumper and to assess the influence of different parameters on the forces measured by the bumper. A typical test goes through the following steps. (1) The robot follows a straight-line trajectory at 0.2 m/s faced to the object. (2) The robot slows to 0.1 m/s when under 2 m of distance to the tested object. (3) When the force sensors measure a contact force of 5 kg-force (49N), the robot speed drops to 0. The robot continues its progress at 0.1 m/s in case the contact force is still lower than 5 kg-force. The tests that were conducted are listed as follow:

- Probing a tree trunk (Figure 7a).
- Probing a rigid wall at speeds of 0.1 m/s and 0.2 m/s while on smooth ground.
- Probing an 8 kg drum (Figure 7b), which can be filled with water up to 14 kg total, on smooth ground. This drum can be covered with foam for an additional external flexibility. The drum respects the test object dimensions given in ISO 18497:2018 intended to represent a small human. The test with 14 kg has the objective of validating whether or not the robot stops when the bumper probes a child having this mass.
- Probing tall grass.
- Rolling on different types of ground (grass, tall grass, bare soil and bitumen) at 0.1m/s and at 1m/s to study the influence of vibrations on the SBPS (Figure 7c).

a)

b)

c)

Figure 7. Sample pictures of the SBPS validation tests, a) tree trunk, b) 8 kg drum and c) tall grass.

Probing tests, carried out with SBPS, study the forces measured when probing different objects of the environment. The measured force when probing rigid and fixed objects shows, as depicted in Figure 8, that when the measured force, on the blue curve, reaches 5 kg-force the commanded speed of the robot, on the orange curve, decreases to zero. However, the measured force continues to rise up (to approximately 25 kg-force in the case of a wall probed at 0.2 m/s). This increase is due to response and braking time as shown in the theoretical study. The other tests produced at a lower speed of collision shows that the maximum value of the measured force decreases when the speed decreases.

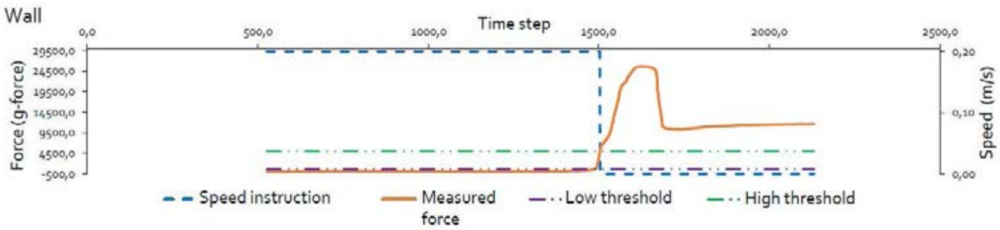


Figure 8. Measured forces and commanded speed while probing a rigid wall at 0.2 m/s with high threshold of 5 kg -force

Figure 9 represents the interaction between the robot and a drum on smooth ground (Figure 7b). This drum is filled with water to weigh 14 kg in total. The mass of the obstacle affects the maximum effort applied almost proportionally. Moreover, observations in these two cases (8 kg drum and 14 kg drum) reveal that the initial collision did not surpass the upper threshold of 5 kg-force, causing the robot to slow down rather than stop. The force peak in the middle of the plot reflects the robot pushing the drum short distances before stopping, in the case of the 14 kg obstacle. To prevent pushing the obstacle, the threshold was lowered to 3 kg-force.

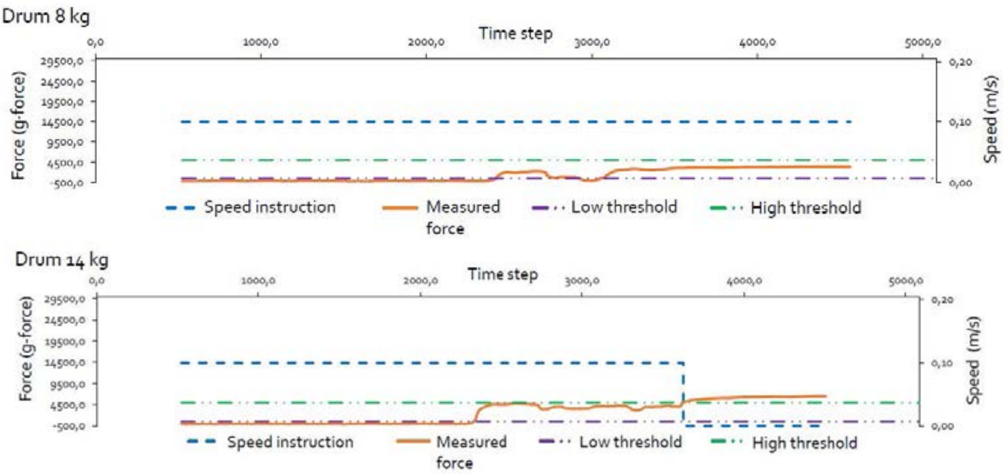


Figure 9. Measured forces and commanded speed while probing 8 kg object (top) and 14 kg object (down) with high threshold of 5 kg-force.

The curves shown in Figure 10 depicts the most relevant scenario for the robots equipped with the SBPS. Indeed, one of this project's objectives is to navigate through tall grass even when the LiDAR detects an obstacle. Here, the maximum force reached is only 228 g-force. This is much lower and easily distinguishable from the case where the robot collides with an obstacle. Navigating through tall grass poses no significant challenge as long as the robot maintains a minimum speed, ensuring its integrity and the safety of its environment in the event of an unexpected collision.

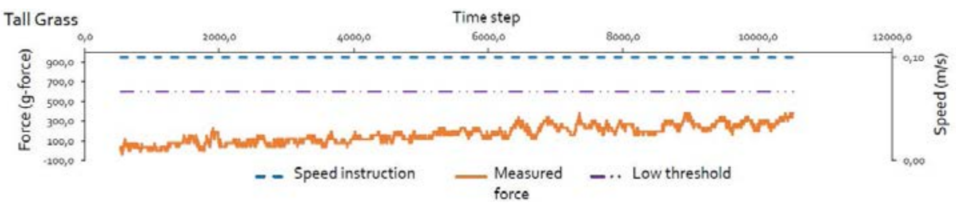


Figure 10. Measured forces and commanded speed while navigating through tall grass.

Sensitive bumper tests and their results show the possibility to rely on force data to distinguish between traversable objects and non-traversable obstacles. A first level of classification (considering that the speed at probing is always less than 0.2 m/s) can be summarized as follows:

- Non-traversable obstacle when the measured force is greater than 3 kg-force
- Grass or other traversable vegetation when the measured force is less than 0.5 kg-force
- Ambiguous obstacles (such as an empty cardboard box) when the measured force is between 0.5 and 3 kg-force.

3.2. System operation testing

A numerical model was developed to test the system operation algorithms implemented for the different scenarios of SBPS. Gazebo simulation software allows us to observe the robot's navigation within the simulation environment. To be able to simulate the bumper under Gazebo and ROS middleware, an equivalent open-loop model of the bumper is used. This model is composed of one translational joint and one rotational joint (Figure 11). A linear and torsion springs are added to the joints to obtain a stiffness equivalent to that of the bumper. Contact bar displacements are measured through two laser range finders positioned at the location of the two translational joints of the real SPBS. The displacements are used to obtain the contact forces.

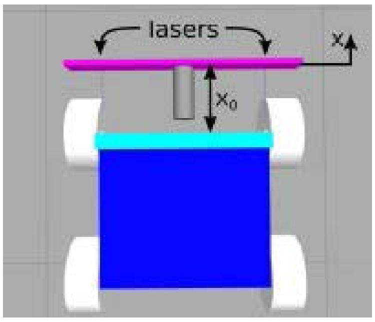
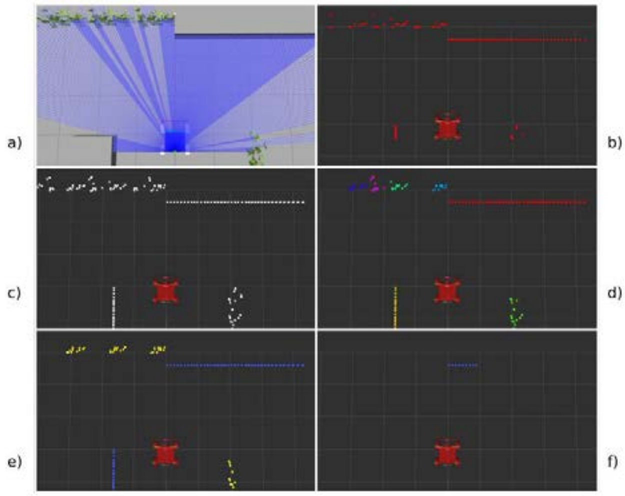
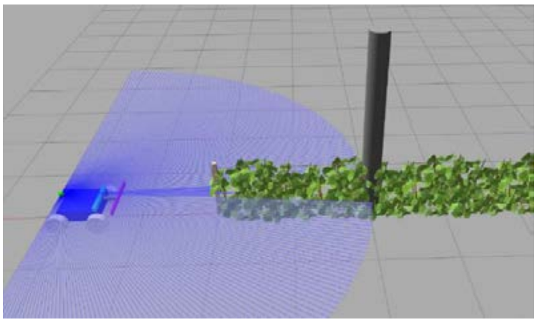


Figure 11. Numerical model of the sensitive bumper equipped to a mobile robot.

The implemented algorithms allow the robot equipped with SBPS to take decisions related to traversability of the probed objects. Probing is not necessary if the robot detects a non-traversable obstacle, such as a wall, in advance. All other object geometries are considered potentially traversable and need to be probed to confirm their traversability. The steps of this first LiDAR data treatment are illustrated in Figure 12(a), using point cloud data visualized in Gazebo and RVIZ: a) shows a small robot with LiDAR surrounded by obstacles, including walls and rows of vegetation, in Gazebo. b) shows LiDAR data in RVIZ. In c) PointCloud voxelization, showing fewer points than in b). In d) clustering is carried out, and random color scales differentiate the groups. In e) the clusters are classified, distinguishing vegetation from walls. In f) only the points situated at a certain distance in front of the robot are retained.



a)



b)

Figure 12. (a) Point cloud processing seen under Gazebo and RVIZ, (b) View of a simulated test.

Different tests (simulated and real tests) are performed to validate the ability of the robot to decide and adapt its speed with respect to the encountered situation. In the simulated situation of Figure 12(b), the small robot slowed down its speed before reaching the plants, then it rolled through them at low speed and stopped when touching the fixed post.

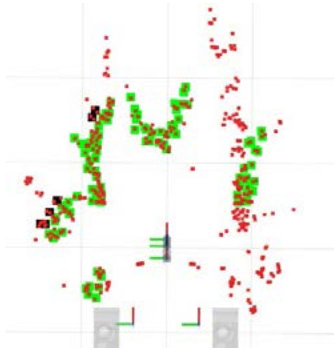
3.3. System limitations

The SBPS produces interesting data that, combined with other perception data, can help in object classification and recognition. Even though, the proposed system has some limitations. Implementing and operating the sensitive bumper on a mobile robot requires that the robot has the ability to navigate at a very low speed (less than 0.2 m/s of controlled speed) in order to probe obstacles safely and that it has a short reaction and braking time to avoid applying significant forces on the environment.

Sensitive bumper with softer springs and greater maximum deformation reduces the forces applied during braking time. However, the design proposed for the sensitive bumper introduces friction in translational joints and does not help to increase displacements much. Regarding the geometry of the probing system, it could be interesting to probe objects at different heights. The presented geometry leads to a single direction and height probing.

Classifying obstacles as traversable, vegetation, or non-traversable, walls, done using LiDAR was shown, in Figure 12, to work well in a controlled environment. In a natural environment (Figure 13), however, the method is not as reliable. Figure 13(b) shows LiDAR data in RVIZ, taken in a tall grass field (green=traversable obstacles, black= non-traversable obstacles and red=non-identified obstacles). Some clusters on the left, highlighted in black, are incorrectly identified as walls due to being aligned on a straight line. In this case, the classification algorithm could be improved by either adapting the employed parameters or by changing the method altogether.

a)



b)

Figure 13. (a) ALPO tractor robot equipped with SBPS and LMS Sick LiDAR, (b) Classification using LiDAR in tall grass field (green=traversable obstacles, black= non-traversable obstacles and red=non-identified obstacles)

Concerning the operation limitations, since the system is mainly used in agricultural environments with plenty of vegetation, such as tall grass or plants, the robot might always navigate with the minimum commanded speed, even if there is no necessity to probe objects.

4. Conclusions

The perception technologies used during the navigation of mobile robots, such as LiDAR, RADAR or camera, need complex algorithms or models to differentiate traversable from non-traversable obstacles. This paper discusses the design, implementation, and simulation of the "Sensitive Bumper Probing System." The conducted probing tests make it possible to differentiate physically traversable from non-traversable obstacles. On the other hand, they ensure the safe operation of the system, which stops the robot if an object weighing more than 14 kg is probed. This device offers data, combined with other perception data, improving environmental recognition.

To simplify the operation of the robot for probing and to gather more data about objects' characteristics, such as color, reflectance behavior, temperature, etc., an improved version of the mechanical sensing system called the "Proximity Sensitive-Whisker" is in prototyping phase.

Acknowledgements

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Dynamic agrivoltaics: a solution for preserving quality of grapes and protecting grapevine from climate change

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Abstract

Climate change is affecting grapevine production and the quality of the wine (too much alcohol, low aromatic potential and imbalance due to lack of acidity). Sun'Agri's dynamic agrivoltaic (DAV) system could be a solution against climatic hazards like heat wave and frost events. As part of the Sun'Agri 3 research program, a plot of Grenache N has been monitored under DAV systems in the southeast of France between 2019 and 2022 and compared with a control plot to observe microclimatic and agronomic responses to this technology. A large-scale DAV system of 4.5 ha in southwest of France complements the response of other grape varieties at a commercial level since 2021. DAV systems improve micrometeorological conditions which avoid undesirable effects on the canopy (more growth under DAV, less sunscald damage on leaves) and on fruits (less sun burn, shrivelling...) but also modifies the quality of the berries (less sugar under DAV : until 2,2 °Brix less and more acidity under DAV : until 0,5 g.l-1 H_2SO_4 more) and the occurrence of phenological stages (eg. a delay in veraison was observed for DAV plants). As a result, the quality of the wine is also modified with less alcohol degrees, more acidity and organoleptically different. The results confirm that DAV systems can be a good solution to protect grapevine from climate change and to enable the grapevine grower to produce the expected quality of grapes.

Keywords : agrivoltaics, crop protection, quality, adaptation.

1. Introduction

Climate change is challenging traditional agriculture with an increase in climatic hazards such as heat waves, drought episodes and extreme climatic events (Pörtner et al., 2021). The impact is major for crops who complete their productive cycle in warm and dry seasons (Hannah et al., 2013) and even more for perennial plants, where the effects of one year have repercussions on production in subsequent years, such as grapevines. By increasing the temperature, climate change is accelerating the phenological development of the vines, which shifts the ripening period to hotter and drier conditions in midsummer (Duchêne et al., 2010). Consequently, there is yield loss due to growth arrest or dehydration of berries, higher sugar concentration in berries and wines that are too high in alcohol and bland (Jones and Davis, 2000).

Sun'Agri's agrivoltaics solution, consisting of smart louvers controlled by artificial intelligence has made it possible to protect vines from the various climatic hazards (heat waves, frost, drought, hail...). This protection system based on dynamic agrivoltaics (DAV), consists of photovoltaic solar panels positioned above the crop. Panels can be tilted +/- 90° to adjust the level of shade in the vineyard according to the needs of the grapevine. As part of the Sun'Agri 3 research program, in partnership with INRAE, IFV, Chambre d'Agriculture du Vaucluse and Chambre d'Agriculture des Pyrénées-Orientales, a plot of Grenache N has been monitored over the last 4 years under DAV systems in Piolenc (44°10'30.95''N 4°47'52.74''E) between 2019 and 2022 and compared with a control plot. A large-scale DAV system of 4.5 ha in Tresserre (42°32'47.25''N 2°51'51.21''E) complements the response of other grape varieties (Grenache B, Chardonnay and Marselan) at a commercial level where the first wines have been produced since 2021. For this demonstrator too, grapevine under DAV were compared with a control plot, without shade. The objective of this study was to determine the effect of intermittent shading with dynamic agrivoltaic system on grapevines. Over four consecutive seasons (2019 to 2022), microclimate at the canopy level, crop reference evapotranspiration (ETo), amount of irrigation, predawn water potential, visual observation of the canopy, yield components were selected as indicators of grapevine performance of 'Grenache N' cultivated in an experimental DAV vineyard of 600 m2. Fruit quality measurements at harvest and a sensory analysis by a panel of experts were also carried out on the 3 vintages of Piolenc wines and a tasting by a panel of professionals was carried out on the 2 vintages of Tresserre wines. The results of this study will help to improve an existing algorithm by which the periods of shading are determined by artificial intelligence using environmental and plant indicators derived from sensors and crop models (Chopard et al., 2021). This algorithm is necessary to pilot commercial large-scale dynamic AV. A brief description of the algorithm and a large-scale DAV system of 4.5 ha is included in the study to illustrate an example of a commercial DAV park and how we expect to pilot the level of shading using artificial intelligence.

2. Materials and Methods

Plant material:

Two grapevine dynamic agrivoltaic systems (DAV) were constructed by Sun'Agri in the South of France. An experimental DAV system in Piolenc (44°10'30.95''N, 4°47'52.74''E) to perform fundamental research and a demonstration DAV system in Tresserre (42°32'47.25''N, 2°51'51.21''E) to serve as extension activities for growers (Sun'Agri, 2023) (Figure 1).

Figure 1. Photos of the experimental system at Piolenc (44°10'30.95''N, 4°47'52.74''E) (left) and the commercial system at Tresserre (42°32'47.25''N, 2°51'51.21''E) (right) in the south of France.

The experimental DAV system of Piolenc was constructed in beginning of 2019 over a mature 'Grenache N' vineyard planted in 2000 and trained in vertical shoot positioning pruned with Cordon training system. The whole vineyard was divided in two DAV replicates of 300 m2 each and a control plot of 340 m2 without solar panels. The maximum amount of electricity the system can produce under ideal conditions is 70 kW peak. The DAV site of Tresserre was put into operation in beginning of 2018. Three cultivars ('Grenache blanc', 'Chardonnay' and 'Marselan') were planted just after the completion of the structure and trained in vertical shoot positioning pruned with Cordon training system. The DAV vineyard consists of 4.5 ha for the DAV divided in three replicates for each cultivar and 3 ha for the control. The maximum amount of electricity the system can produce under ideal conditions is 2.1 MW peak. All experimental results have been measured in Piolenc, while the demonstration DAV system in Tresserre is mentioned in this study only for the perspectives of work. To determine if DAV can improve the grapevine growing conditions if they are shaded during periods with high evaporative demand, this study focuses on a treatment that was shaded in the afternoon from veraison until leaf senescence over four consecutive season (2019-2022). Both DAV and control treatments consist of five rows of 40 plants but only the middle one was used for physical measurements. Irrigation was managed separately for the DAV and control plants to maintain an optimal predawn water potential (pwp).

Weather & Plant measurements:

To evaluate the capacity of protection of the DAV system from heatwaves and drought, the following variables were determined during the whole season for each experimental year at Piolenc: air temperature from a weather station (HMP155, Vaisala, Germany) installed at the border of the vineyard, air temperature at the canopy level, irradiance reaching the plants, crop reference evapotranspiration (ETo), amount of rain and irrigation, predawn water potential. During summer, visual observation of the canopy and cluster were performed to assess the impact of heatwaves. Air temperature around the grapevines was measured continuously during the whole-season with thermo-hygrometers placed inside radiation shields for control and DAV vines. One sensor (CS215, Campbell scientific, USA) was placed close to the canopy of one grapevine at around 0.8 m height. Irradiance was measured using photosynthetically active radiation (PAR) sensors located just above the canopy in each treatment (PAR Quantum sensors, Skye, UK). The Penman-Monteith method was used to estimate ETo for DAV and control plants considering the incoming irradiance as the most relevant variable. The amount of irrigation was recorded with manual water meters for the DAV and control plot. Predawn water potential (pwp) was measured between five and twelve times during the season (one measurement every three weeks) using a pressure chamber (PMS 600, PMS instrument company, USA). Measurements were performed on 6 vines for control and 6 vines for DAV located in the central row following the recommendations of Turner and Long (1980).

Berry measurements and wine tasting:

At Piolenc, harvest was initiated according to the Brix level of each treatment (different dates for DAV and control treatments), whereas at Tresserre, harvesting was carried out on the same day for control & DAV for each variety. At harvest, various berry quality measurements were carried out in Piolenc and Tresserre: 200 berries were analysed for weight, °Brix, total acidity, pH, potassium, available nitrogen, malic acid, tartaric acid.

After a micro-vinification (in 100l stainless steel tanks) for the three last vintages in Piolenc for each treatment, a sensory analysis by a panel of trained experts (around 20 experts) were also carried out each year. A visual evaluation was carried out, followed by an olfactory and gustatory evaluation (with repeated scoring) using several descriptors and a linear scale with a 'low' to 'high' boundary. The analysis was carried out using an analysis of variance and a multi-dimensional analysis.

3. Results and Discussion

Climate description:

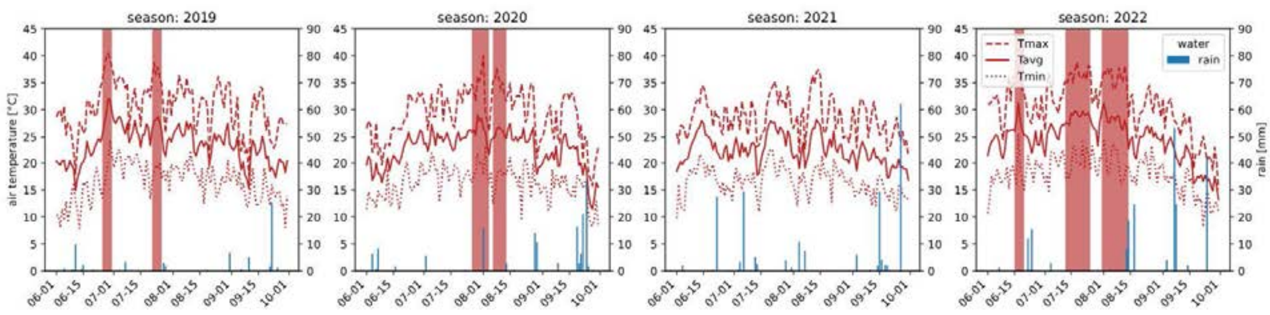

Figure 2: Air température [°C] with maximal, mean and minimal saily values and rain [mm] during the four growing seasons in Piolenc (44°10'30.95''N, 4°47'52.74''E). The red vertical stripes indicate periods of heat waves, as described by https://www.francebleu.fr/infos/environnement/chaleurs-records-france-ete-1661489777.

The four years studied have very different climates (Figure 2). In terms of rainfall, 2019 was a very dry season (66 mm of rain over the whole season), while the 2021 and 2022 seasons received more water (206 and 213 mm of rain over the whole season in 2021 and 2022 respectively). 2021 was also marked by a rainy summer. In terms of temperatures, the 2021 season had just 5 days when the temperature reached 35°C, compared with 31 days in the 2022 season with several heat waves. This diversity of climatic years makes it possible to observe contrasting results and supports the interest of a dynamic system, which makes it possible to adapt the shading to the needs of the plant in a given year.

Air temperature at the canopy level during heatwaves:

DAV systems alter the thermal environment (Barron-Gafford et al., 2019) and therefore the air temperature around crops. In Piolenc, during the periods of high evaporative demand (ca. all the afternoons from flowering until leaf senescence), grapevines shaded by a DAV system had near canopy an air temperature around 2°C lower than control when the panels are in solar tracking (maximal level of shade). These results are in line with the agrivoltaic literature (Barron-Gafford et al., 2019; Juillion et al., 2022), which confirms the potential of the DAV system to maintain crops in a less stressful environment. However, Ferrara et al. (2022) reported that the use of fixed shading to protect plants from dry environments may be associated with a decrease in yield. Dynamic shading according to specific air temperature thresholds can help to protect vines from heat waves only when necessary and allow full light to grapevines to maximize carbon production when the climate is favourable.

Irrigation and grapevine water status:

'Grenache N' under DAV system had more comfortable water relations than control grapevines (Eto between 518-579 mm for DAV grapevines compared to 790-900 mm for control) (Table 1), as describes in other agrivoltaic experiments in kiwi (Jiang et al., 2022), apple (Juillion et al., 2022), and grapevine (Ferrara et al., 2022). These results were associated with a reduction in the irrigation needs of DAV grapevines (Table 1), confirming that DAV vines, the amount of water in the soil, was still higher in comparison with control plants. It was difficult to keep the exact same soil water status with irrigation between control and DAV plants as reported in other field experiments (Jiang et al., 2022). Therefore, we think that the water saving of about 37 to 75% reported in this study is conservative and higher savings could be observed in different systems.

season	ETo CONTROL [mm]	ETo DAV [mm] ([% control])	irrig CONTROL [mm]	irrig DAV [mm] ([% control])
2019	869	569 (65%)	63	40 (64%)
2020	851	568 (67%)	64	26 (40%)
2021	790	518 (66%)	127	48 (37%)
2022	902	579 (64%)	136	81 (59%)

Table 1. Reference evapotranspiration and irrigation.

Computed ETo from micro-weather variables in each treatment. Amount of irrigation applied in each treatment as read on meters.

Visual observation of the canopy and cluster :

Figure 3. Visual aspect of canopies and clusters after strong heatwaves in 2022, (above) control (below) dynamic AV; left 2 photos during veraison (2022/07/29) & right during harvest (2022/09/06).

As described before, the summer of 2022 was characterized by hot and dry conditions in Piolenc. The berries were damaged by these extreme summer conditions on the control treatment, while the berries under the DAV system remained intact (Figure 3). This damage has not been quantified, but it can represent a significant loss of production: in another study on 'Cabernet Sauvignon', 25% of the berries were damaged by a 4-day heatwave event that occurred 21 days before harvest. In the future, it therefore seems important to quantify this damage and make the link between heat waves/yield and quality to quantify the cost of protection that agrivoltaic systems can provide.

Yield :

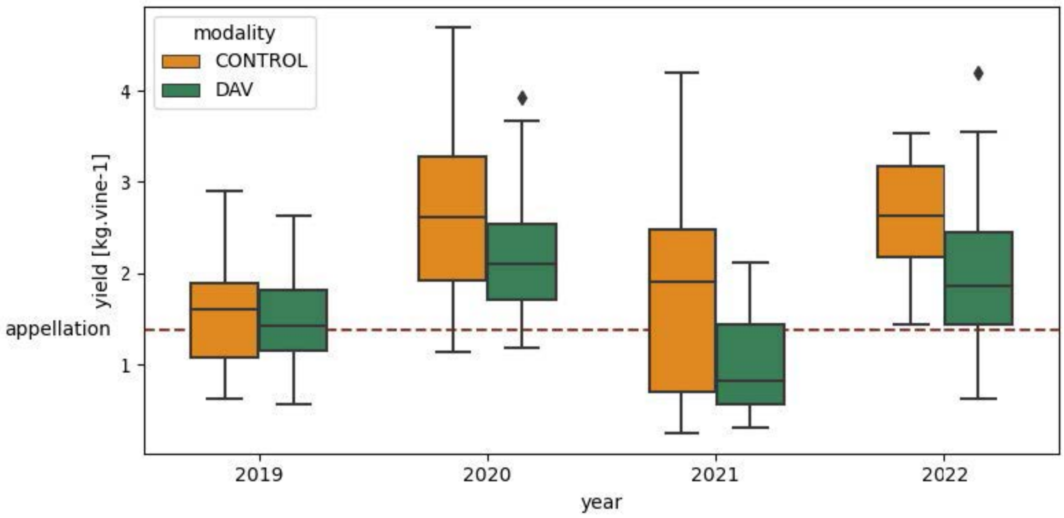

Figure 4. Yield [kg.vine-1] for DAV and CONTROL grapevines between 2019 and 2022 in Piolenc. Red dashed line indicate yield reference for the regional AOC (51 hl.ha-1 from https://www.legifrance.gouv.fr/loda/id/JORFTEXT000021162905).

Yield variation was observed in Piolenc experiment between years with higher yields in 2020 and 2022. An ANOVA test indicated that there was a significant effect of season and treatment on yield but that the difference between yields were more explained by a vintage effect than by the agrivoltaic system. While in 2019 and 2020 no significant difference was found between yields under the DAV and control systems, a significant decrease in yield was observed under the DAV system in 2021 and 2022. This decrease is explained by a lower number of bunches despite a significant bigger weight of bunches under DAV system. However, in 3 of the 4 years, yields under the agrivoltaic system were higher than the regional average of 51 $hl.ha^{-1}$.

Fruit quality and wine quality:

in both sites, the chemical analysis of the must (table 2) shows that in a case where the DAV treatment is harvested at the same time as the control (e.g., in Tresserre) the must have less alcohol which can be explained by the berry's slower sugar load. Total acidity remains higher in the large majority of cases, even when harvested at the same °Brix level as in Piolenc (which necessitated a 6 to 7 days harvest delay).

Location	Year	Treatment	Harvest Date	berry weight (g)	Degree Brix	Alcohol (%vol)	Total Acidity (g/l H2SO4)	pH
Piolenc	2019	Control	09/09/2019	1,23	24,5	14,51	2,86	3,44
		AVD	09/09/2019	1,48	24,1	14,21	3,12	3,37
	2020	Control	09/09/2020	1,66	24,5	14,51	2,9	3,49
		AVD	09/09/2020	1,49	22,3	12,97	3,45	3,33
	2021	Control	03/09/2021	2,28	22,8	13,32	3,98	3,24
		AVD	09/09/2021	2,33	21,2	12,22	3,95	3,25
	2022	Control	15/09/2022	1,25	20,9	12	3,23	3,31
		AVD	22/09/2022	1,44	20,6	11,82	3,51	3,39
Tresserre	2021	GB_Control	10/09/2021	1,98	23,5	12,98	3,62	3,34
		GB_AVD	10/09/2021	1,93	23,3	12,99	3,88	3,35
		CHA_Control	23/08/2021	1,21	24,5	13,62	3,64	3,46
		CHA_AVD	23/08/2021	1,11	22,6	12,54	3,75	3,39
		MARS_Control	30/08/2021	1,06	24,4	14,99	4,38	3,28
		MARS_AVD	30/08/2021	0,98	22,2	13,55	5,03	3,16
	2022	GB_Control	30/08/2022	1,66	23,9	13,58	2,63	3,27
		GB_AVD	30/08/2022	1,76	22,2	12,17	3,27	3,11
		CHA_Control	11/08/2022	1,21	23,7	13,9	2,81	3,44
		CHA_AVD	11/08/2022	1,49	23,9	13,8	3,04	3,46
		MARS_Control	23/08/2022	0,71	24,3	15,28	2,75	3,27
		MARS_AVD	23/08/2022	0,85	23,8	14,6	3,68	3,16

Table 2. Chemical analysis of must & berry weight.

With regards of wines of Piolenc, the 3 vintages (2020-2021-2022) were analyzed by an expert panel through a sensory analysis. Every year, both treatments (control or AVD) were statistically discriminated on taste and color criteria. The control treatment was characterized by more astringency and a darker color while the AVD treatment had more acid notes and, depending on the year, fruitier notes.

Artificial intelligence to steer panels:

All the results presented in the previous sections show the need to steer the panels differently throughout the season depending on the environmental conditions of the year and the plant needs. A conceptual algorithm is shown in Figure 6. The solar panels are oriented using information collected by the environmental and plant sensors. Variables that are difficult to assess continuously in the field, such as predawn water potential, can be estimated by crop models and used to make decisions (Chopard et al., 2021). This solution is currently being evaluated in the commercial field experiment located in Tresserre. Experimental research such as this study allows the algorithm to be refined with specific environmental and plant thresholds. The main objective of this research program is to be able to implement the best steering policies in large-scale commercial vineyards and to help winegrowers mitigate the effects of climate change on their crops.

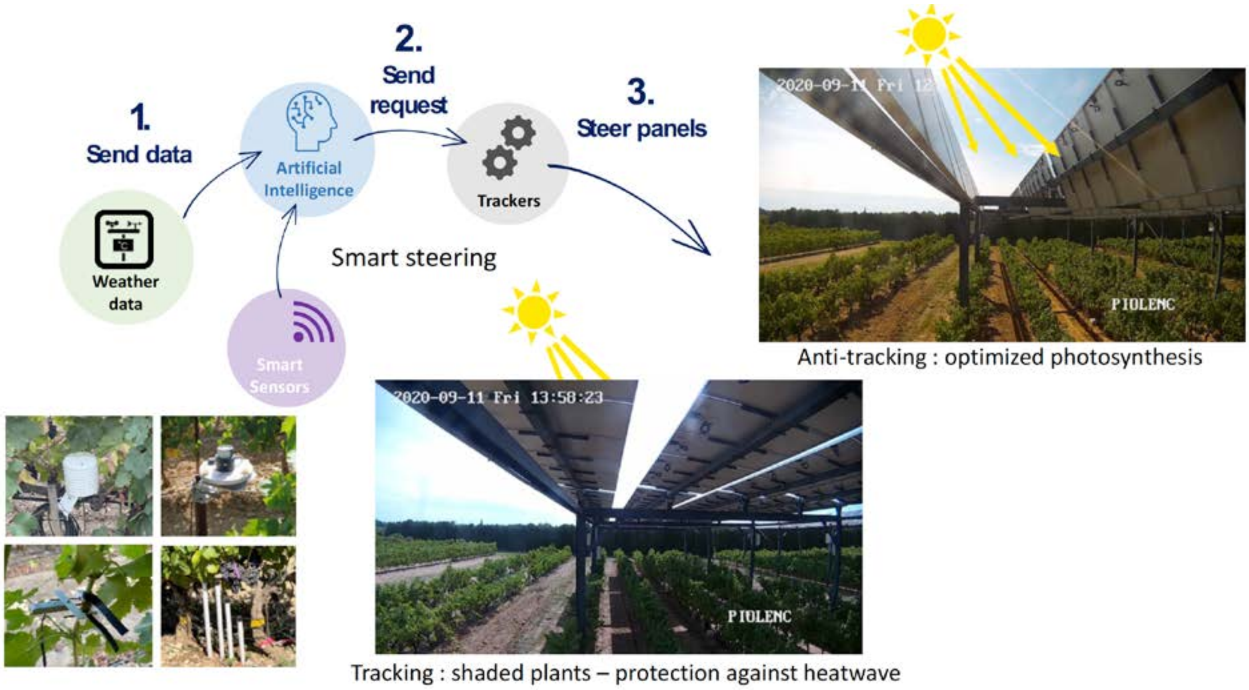

Figure 5. Schematic representation of the use of artificial intelligence to combine information from sensors and mechanistic models to steer panels.

4. Conclusions

Grenache N grapevines shaded thanks to dynamic agrivoltaic system over four seasons with a DAV system showed interesting results. By providing shade when grapevine is suffering from high temperatures and high irradiations, dynamic agrivoltaic systems improves micrometeorological conditions and therefore irrigation needs. The modification of irradiation during the season not only avoids undesirable effects on the canopy but also modifies the quality of the berries. As a result, the quality of the wine is also modified, less alcohol degrees, more acidity and organoleptically different. The results confirm that dynamic agrivoltaic systems can be a good solution to protect grapevine from climate change and to enable the grapevine grower to produce the expected quality of grapes. The management of the shading level throughout the season will become a new horticultural practice. This could be an extremely difficult task for vine growers. Shading interacts with multiple factors driving the physiological and agronomical responses of the plants. As demonstrated by the differences in yield observed in 2021 and 2022, the control of shading with steering policies seems to be a necessity. Therefore, as implemented in Tresserre, we propose to use an artificial intelligence to pilot the orientation of solar panels using environmental and plant indicators derived from both sensors and crop models.

Acknowledgements

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Preparing the Agri-Equipment Industry Ready to Make Conservation Agriculture the Future of Farming in France

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Abstract

THIS RESEARCH aims at outlining an action plan to make Conservation Agriculture (CA) widespread in field crops and mixed farming in France by about 2035. CA is recognized as enhancing and sustaining a large number of ecosystem services. It has mainly been established across the Americas and Australia, under semi-arid or subtropical climates, in areas where herbicide-tolerant GM crops are widely grown and the range of approved pesticides higher than in the European Union. The dissemination of CA in France therefore cannot take the form of a spread of standardized practices brought over from distant lands.

The study is based on the redesign and ex-ante evaluation of four farming systems. The results highlight the economic and environmental benefits of expanding CA in France, provided the focus is on reaching performance and progress on track with set targets, through strategies that fit local contexts. For the time being, the feasibility of scaling up CA is hampered by shortcomings in the technology of tillage, sowing, crop protection, and harvesting equipment, and a weak industrial capacity to manufacture tools for cover crops mechanical termination.

Equipment is only one ingredient for success. Training farmers and their employees is crucial. Above all, the shift from conventional agriculture to CA will only happen with a systemic change in the agricultural sector, in which food industrials and agricultural contractors will play a decisive part.

Keywords : agroecological transition, future studies, public policy, systemic shift, technology shortcomings.

1. Introduction

Conservation Agriculture (CA) is the design and application of cropping systems intended to improve soil fertility and avert depressive effects of farming on soil functions and ecosystem services. The aims and forms of CA have evolved along with its dissemination. CA emerged at the end of the 1930s with the initial aim of keeping farming alive in the Great Plains of the US, which had just been devastated by the Dust Bowl. CA first consisted of contour plowing and strip cropping. The herbicide revolution then enabled low-till or no-till farming. From the 1960s onwards, CA reached Australia, New Zealand, Canada and South America, with the drive to boost productivity by saving time and fuel, and by developing double cropping in some countries such as Argentina. Since the 2000s, CA has been part of the agroecological transition and has taken on new functions: closing of nutrient cycles, integrated pest and weed management, mitigation and adaptation to climate change (KASSAM et al., 2015; SCOPEL, 2022).

This has been where CA becomes theorized as the concurrent implementation of three compliance standards: no-tillage, a minimum of 30 percent soil cover all year round with either or both of crop residues and cover crops, sequences and associations involving at least three different crops (FAO, 2023; APAD, 2023). Since the late 2010s, food industrials have been embarking on regenerative agriculture to stave off soil fertility decline in their supply basins. Their initiatives draw on CA, organic farming and agroforestry. Such public and industrial concerns resonate with those of the French farmers, who declare soil conservation as their number one goal, ahead of enhancing production quality and increasing yields (IPSOS, 2023).

The hopes placed on CA appear in public policy documents, press releases from food industries and restaurant chains, dedicated websites, and reports from associations that promote CA. However, the goals of extending CA are rarely associated with performance indicators, as what can be expected from CA in environmental matters is still discussed. The extent of CA's dependency on glyphosate and the reality of CA's impact on carbon sequestration are especially controversial. The confusion is kept going with the coexistence of two visions of CA: one that considers it to be synonymous with absolute no-tillage and another that accepts low-intensity tillage as long as cover crops are planted during intercropping. Those issues are arising in a context of global uncertainty where the problem of food sovereignty is coming to the fore. The ability of CA to meet the calls of the agroecological transition and to do so better than conventional or organic farming can nevertheless be assessed by a review of the most recent scientific research.

According to available data (LANDERS et al., 2021), CA covers around 14 percent of arable land worldwide (200 million hectares) but less than 4 percent in France (700 thousand hectares). These figures factor in observance of no-tillage and soil cover, but exclude the criterion of species diversity. As a result, 70 percent of the estimated area under CA stand in five countries where single- or two-crop systems are usual (United States, Brazil, Argentina, Canada, Australia). By contrast, in France, 87 percent of arable farms have a main rotation of at least three crops (IPSOS, 2023).

Although the three conceptual principles of CA form a coherent whole to ensure soil structuring and pest control in the absence of tillage, such a perfect system is hard to find in the field. While species diversification may be difficult to achieve in a semi-arid climate, no-tillage is the stumbling block in temperate zones (LANDERS et al., 2021). French farmers tend to prefer shallow cultivation to a complete ban on tillage: they practice low-till on 4.6 million hectares, representing a third of the country's arable land (REBOUD et al., 2017; LEBAS, 2020). The French National Institute for Agricultural Research advises to dispense with plowing only where shrink-swell of clay-rich soils can create suitable porosity (INRA, 2013); the recommended clay content of over 15 percent is rarely reached in French field crops regions. Another obstacle is that glyphosate has become the sworn enemy of regular campaigns for banning chemical pesticides across France and Europe; yet most no-till farming systems would be deadlocked if this substance were prohibited (REBOUD et al., 2017). Although spot spraying looks to be the future of crop protection, it would be of no help for the many farmers who use glyphosate for desiccating cover crops. Resistances to glyphosate have emerged and may eventually jeopardize the viability of no-till systems.

The time has come for a change of mindset. The old-fashioned model of top-down agricultural advice based on prescribing ready-made solutions has been giving way to consultancy, that views farmers as heads of agricultural businesses and supports them in the pursuit of their objectives (CORNU et al., 2018). There is no reason why CA should escape this trend. CA should no longer be defined by pre-set principles to apply as objectives in themselves, but should be examined from the ecosystem services being sought: perennial supply of agricultural products, lower consumption of inputs, mitigation and adaptation to climate change, recharging of water tables, biodiversity – and the list is not exhaustive. The means of achieving these goals should suit the soil, climate and state of the agriculture industry in each given area (BOIZARD, 2023).

This study intends to answer the following questions: what are the readiness levels of the agri-equipment that would enable various soil conservation methods to be applied in French cropping systems?
What action plan would raise these readiness levels so that CA would possibly become a well-established agricultural model in France by 2035?

2. Materials and Methods

The scope of the study includes field crops and mixed crop-livestock farming, accounting for 42 percent of the farms in mainland France (DUBOSC, GENEIX, 2019). Permanent crops are not considered because they neither involve rotations nor intermediate crops, and their potential tillage operations are much less frequent than they are in arable fields. French administered territories outside Europe are not covered by the study because of the major differences between them and mainland France in terms of soil, climate and average farm size. The year 2035 has been chosen in order to envision the spread of cropping systems that substantially differ from the conventional farming of the early 2020s. The period from 2023 to 2035 gives a twelve-year horizon beyond which it seems difficult for agri-equipment manufacturers to picture themselves.

Semi directive interviews have been conducted with agri-equipment manufacturers (CEO, marketing departments, R&D units), agri-food industry professionals, service providers related to CA (insurance companies that insure the risk taken by farmers who change their cropping systems to move towards agroecology, companies that perform and interpret soil analyses, companies that certify carbon credits), farmers, scholars and research engineers. From the information gathered, the feasibility of disseminating CA in different types of farms under various pedoclimates is been explored, whether CA emerges as a third path alongside conventional agriculture and organic farming, replaces them, or combines with them in possible trade-offs.

The study is based on the redesign of cropping systems on four typical farms, with corresponding changes in equipment, to meet objectives that CA can reasonably achieve in the light of existing scientific knowledge. An ex-ante economic and environmental assessment of the redesigned systems is used to identify the conditions for their feasibility and to estimate their potential acceptance by farmers.

The limited time of this study led to restrict the sample to two field crop farms (with continuous maize in Alsace; beetroot, potatoes and industrial vegetables in Picardy) and two mixed farms (with a dairy herd in Normandy and a suckler herd in Limousin). The typical farms are selected in regions where field crops or mixed farming occupy a larger proportion of their farmland than the French average. The redesign of the cropping systems focuses on agronomic aspects and adaptation to local concerns. It is based on two principles. The first principle is to introduce techniques (well established or to be consolidated) favorable to soil conservation, including those outside the usual range of practices by which CA has been commonly defined. The second principle is to keep any other changes to the cropping system to a minimum.

The typical Alsatian system covers 70 hectares of irrigated field crops: three years of grain maize followed by a year of winter barley. Continuous maize cultivation leads to heavy pressure from weeds and high levels of run-off, causing erosion, nitrate leaching and water pollution from herbicide molecules. This system threatens small mammals which are unable to protect themselves from their predators due to insufficient soil cover (TOTOSON, WOHLFAHRT, 2019). The redesign of the cropping system attempts to remedy these problems by alternating maize and barley from one year to the next, adding a winter cover crop after the mandatory summer catch crop, sowing barley or even maize with no-till technology, and undersowing barley with soybean (SCOHIE, 2023).

The Picardy case study is a 210-hectare field crop farm on silty soils. The six-year crop rotation includes oilseed rape, winter wheat, irrigated potatoes for industrial processing, winter barley, sugar beet, and winter wheat again. Despite straw returning, erosion is a significant problem, with negative externalities for society. Along with the compaction that especially results from potato and beetroot harvests, erosion threatens soil fertility. To address these problems, the redesigned system involves strip-till, fall bedding in potato fields, wheat sowing into a living dwarf white clover intercropped with the preceding rapeseed, and multi-species cover crops.

The Normandy mixed dairy farm includes 108 hectares of crops intended for sale, 82 hectares of forage, and 97 dairy cows (Idele, Chambres d'agriculture France, 2019). The estimated gross operating surplus is between 700 and 1,000 € per hectare (after Agreste, 2023). The main six-year rotation consists of rapeseed, soft winter wheat, spring fava beans, soft winter wheat again, winter barley and fiber flax. Wheat and silage maize or wheat and oilseed rape follow each other on the other plots. Straw is exported and soil cover is limited to the greening requirement, leaving the soil bare for prolonged periods. In the redesigned system, the presence of intermediate crops is maximized so that they protect the soil from erosion in fall and winter and their residues cover the surface in spring. The cover crop species are chosen to limit the risks to the main crops (reduction of seedling emergence, disease, lodging) and to ensure that they can be destroyed as frosts are rare and not severe in the region. Clover is undersown into maize to improve the bearing capacity of soil at harvest time. Dwarf white clover is combined with rapeseed and can be perennial especially if the system is run without glyphosate. All crops go no-till, step by step (first winter cereals, then oilseed rape and finally spring-sown crops), or all at once if the dwarf white clover is perennial. Occasional plowing remains possible in critical situations, such as a very wet fall or high weed pressure.

The case study chosen for mixed suckler farming is a breeder and fattener system in the Limousin region, run by two partners with no employees. It covers 148 hectares of grass, 7 hectares of silage maize, 16 hectares of wheat intended for the livestock's feed and 9 hectares of rapeseed grown as a cash crop. There are 130 births of calves per year. Gross operating surplus is slightly over €100,000 (Idele, 2022). Concentrates and fertilizers account for more than half the operating costs of the herd and crop production respectively. Forage self-sufficiency is threatened by climate change despite the diversification of forage with harvested intermediate crops. In the redesigned system, zootechnical performance is maintained by reducing the proportion of wheat in the ration, increasing the proportion of maize and introducing winter fava beans into the rotation (according to DEROCHE, DOUHAY, 2022). This change frees up 4 hectares, on which a winter barley or a winter pea is introduced as a cash crop, that can nevertheless supplement the livestock ration in the event of weather damage. Temporary grassland is sown in the fall under a cover of meslin that is harvested for forage in the following spring (according to Chambres d'agriculture Centre-Val de Loire, 2020). Intermediate crops return nitrogen to the following main crop. Other changes include oilseed-legume intercropping, relay cropping soybean with barley, planting maize with an air seeder for water-use efficiency and weed restriction, sowing no-till winter crops.

The economic evaluation consists of calculating the changes in gross operating surplus and working time brought about by the redesign of the systems. Several dozen parameters are taken into account, including production costs (seeds, fertilizers, pesticides, machinery, labour), expected yields and payments to farmers (sales, subsidies, carbon credits). The default value for each parameter is a median of data observed between January 2021 and March 2023, sourced from chambers of agriculture and research or technical institutes. The treatment frequency and the number of tillage or cover crop management operations is estimated on the basis of reference scenarios designed by INRAE, the French National Institute for Agricultural Research (CARPENTIER et al., 2020).

The environmental assessment is carried out using the MEANS-InOut application created by INRAE and CIRAD, the French Agricultural Research Centre for International Development. The input data includes soil and climate characteristics, crop succession and the various cropping operations, each with its date, the equipment and the procedures for carrying them out. The output data includes the mass of soil eroded, the quantity of phytopharmaceutical products in the soil, the emissions into the air and water, and the energy consumption. The application works with the International Life Cycle Data (ILCD) System set of multi-criteria methods.

Among the parameters selected, tillage is transverse to the slope where it exists, the slope is 2 percent over a length of 30 meters, and the nearest surface water is less than 30 meters from the field.

3. Results and Discussion

Cover crops

The presence of intermediate crops above regulatory requirements, and cover crop mixtures instead of a single species sown at low density, entail expenses for seeds, sowing and termination (mechanization and labor). Depending on the case, this increase in costs can be partially or totally offset by yield gains (especially on wheat), lesser nitrogen and phosphorus fertilization, and reduced tillage if the cover effectively suppresses weeds. With the default values, the development of intermediate crops increases the gross operating surplus of a 210-hectare farm in Picardy by €6,193 (scenario without glyphosate) or €6,317 (scenario with glyphosate), mainly due to the sharp reduction in the beetroot fertilization (-60 kg N ha^{-1} and -150 kg K ha^{-1}). According to the assessment on the MEANS-InOut application, reducing fertilization by 90 kg N ha^{-1} crop rotation would lead to 265 g ammonia (NH_3) and 400 g nitrous oxide (N_2O) less direct emissions in the air per hectare and per year (the drop in nitrous oxide emissions would correspond to a reduction of 120 kg CO_2

eq ha^{-1} $year^{-1}$). NH_3 contributes to the formation of particulate matter and causes environment acidification, whereas N2O has nearly 300 times the warming power of CO2 and contributes to stratospheric ozone depletion.

It is noteworthy that both systems – with and without glyphosate – are economically viable in Picardy. The farm could give up glyphosate if its price continued to rise: abandoning glyphosate would cut the gross operating surplus per hectare by €13, but this would be almost entirely offset by the glyphosate phase-out tax credit established by the French Government (€2,500 per 210 ha). In the Normandy case, the cost of the redesigned system is far from being balanced out by the outcomes, regardless of whether glyphosate is used or not: once in routine operation, the gross operating surplus per hectare with the default values recedes by €103 in the former scenario and by €138 in the latter compared to the initial system. Even in this case, sticking to conventional methods may not be an option if soil erosion requires the introduction of conservation practices. Should glyphosate not be available, this would have no impact on the potential for expansion of CA in France if the industrial capacity were sufficient to manufacture mechanical tools for the termination of cover crops. However, a previous study showed that the industrial capacity of manufacturers is insufficient at the present time if chemical weed control were to be entirely replaced by mechanical methods (PANNETIER, 2022). The same can be imagined regarding cover crop termination.

The challenge of cover crop establishment during increasingly dry summers is creating interest in broadcast undersowing, a practice initially used to sow fallow fields. Innovative techniques such as seeding drones and multi-species seed balls are likely to become more widespread. Seed balls for cover crops have begun to be manufactured on an industrial scale by seed companies. Blockages in the seed tubes or spreader shutters are problems that still remain to be resolved for the seed ball technique to be mastered (interview with Bertrand Deloste, Agro-Transfert Ressources et Territoires, April 2023). Collaboration between seed companies and manufacturers of sowing implements should therefore be on the agenda.

Cover crop termination equipment has a promising future, especially as a ban on glyphosate before 2035 can be expected, and as each cover crop has its own peculiarities. The market should therefore be large enough for a wide range of manufacturers, including small companies that will meet niche markets. If fall bedding becomes more common in potato fields, it will drive demand for specific implements to terminate cover crops sown on raised beds. According to a trial in the Pas-de-Calais department in 2021 (interview with Bertrand Deloste, Agro-Transfert Ressources et Territoires, April 2023): between 11 May and 2 September, compared with conventional management, fall bedding halved runoff (334.7 liters of water instead of 697.5 liters collected on the trial plot) and divided erosion by eight (17.96 kg of suspended matter instead of 149.47 kg).

Crop diversification

For the two typical farms where a crop diversification strategy is applied, gross operating surplus increases. In the Limousin case, the redesigned system makes it possible on average to sell 1.7 hectare of wheat, 3.3 hectares of barley and 2.7 hectares of peas each year, in addition to the 9 ha of rapeseed which used to be the only cash crop in the initial system. This result is achieved while reducing nitrogen fertilization by an average of around 60 kg N ha^{-1} over the 32 hectares cultivated. According to the MEANS-InOut application, this reduction leads to 50 percent less nitrous oxide emissions (-485 kg CO2 eq ha^{-1} $year^{-1}$). In the Alsatian case, switching to a crop rotation of 50% maize and 50% barley instead of 75% maize and 25% barley increases gross operating surplus per hectare by about €165 thanks to the reduction in nitrogen and potassium fertilization and the lower need for irrigation. Compared with the initial system, which emitted 1,977 kg CO2 eq ha-1 year-1, simply alternating maize and barley from one year to the next reduces greenhouse gas emissions of the farm by 12.0 percent.

Out of the 452 totaled cultivated hectares of the case studies, legume production would increase by 45 hectares, representing one tenth of the area, including 40 hectares for human consumption. If a yield of 40 q ha^{-1} is assumed for peas on 2 hectares and 15 q ha^{-1} for underseeded soybean on 38 hectares, then production would be 80 q of peas and 570 q of soybean, providing more than 22 thousand kg of plant protein which can cover the requirements of 1,200 adults for a year.

Pulses have long been the poor relation in varietal research in France, but this could be about to change. As part of the Cap Protéines program, the research component of the Plant Protein Plan (itself a section of the Plan France Relance), a technical institute, a research center and three plant breeding companies have just signed a research agreement to broaden the genetic base and available varieties of lentil and chickpea (ESCOFFIER, 2023).

Rapeseed-legume combination

By sowing dwarf white clover at 3 kg ha^{-1} at the same time as oilseed rape, it can be expected to reduce the amount of fertilizer applied to the crop by 20 kg N ha^{-1} and avoid the need for two herbicide sprays. If followed by wheat, the yield potential of the latter can be increased by almost 3 percent while reducing fertilization by 10 kg N ha^{-1} (Terres Inovia, 2022). Over the two-year sequence of rapeseed and wheat, combining rapeseed with a companion plant increases gross operating surplus per hectare by €150 to €306 depending on the market assumptions used, and €225 with the default values.

Undersowing spring-sown crops in winter-sown cereals

In the Alsace and Limousin systems, undersowing barley with soybean results in additional costs: seed, wear and tear on the seeder, fuel and labor for sowing and harvesting the soybean. Using the default values, these costs represent a total of €509 per hectare cultivated under this method, plus a €70 irrigation episode in the Alsatian case. These expenses are more than offset by the €832 per hectare increase in sales, not to mention a likely reduction in the need for herbicides and a possible subsidy under the plant protein plan.

Establishing a maize crop without a maize planter

Maize sown with an air seeder is less affected by slugs, makes better use of water, is less susceptible to weed development and significantly reduces erosion compared with sowing in rows. This method makes economic sense as long as yields are maintained, which is possible at least under certain soil and climate conditions if the technique is mastered. From an environmental point of view, the soil erosion can be reduced if maize is sown this way (COUFOURIER et al., 2008).

The change in sowing method has a major impact on maize harvesting. One option is to use a picker with a tight spacing between the spouts, but this is profitable only if the maize cover several hundred hectares. This therefore only seems feasible if it is of interest to a large number of farmers: they could then call on the services of a contractor, or one farm could equip itself and provide the picker as a service to neighboring farms. The other possibility is to cut maize in the same way as wheat, but the productivity is then lower compared with a conventional maize harvest. The advantage is that the farm could sell its planter and make the most of one seed drill.

This practice may be difficult for the farmers to accept. Not so long ago, it was met with derisive comments on the online French discussion groups: in response to a request for advice on sowing grain maize with an air seeder, a farmer asked his colleague if he wouldn't also like to sow wheat with a sprayer (read on Agriavis, 2012).

Sowing equipment not ready at the present time for an expansion of CA in France

Diversification of main and intermediate crops, combined crops, undersowing, sowing maize with an air seeder instead of a dedicated planter: if these practices become widespread, farmers will need multi-purpose equipment capable of sowing seeds of very different weights at different depths with precision and regularity whatever the season.

Low-till and no-till seed drills as well as strip-tillers do not currently meet this need for versatility and modularity. A no-till drill can be used for low-till farming, but a low-till drill cannot be used for direct seeding unless the seeding units have been adapted and weight adding to them. A seed drill specifically designed for no-till is not likely to do a proper work after an occasional plowing, unless the soil is levelled afterwards by a cultivator (interview with Andrii Yatskul, lecturer and researcher at UniLaSalle Beauvais, April 2023). Success with strip-tilled crops depends on the not-so-common even spread of threshing debris during the preceding harvest, and on the cover crop species composition and management. As for sugar beet growing, progress has been made but yields and margins remain lower under strip-tillage than with conventional farming (Saint Louis Sucre, 2019, 2023). According to the soil texture, a strip-tiller may not be able to reduce soil structural defects (GUYOMARD, 2023).

The economic evaluations show that the surface areas of the typical farms studied are not sufficient to invest in a no-till drill. The already high species diversity of most crop rotations complicates the introduction of this type of equipment: the switch from conventional to direct seeding degrades the emergence and therefore the yields of crops that cannot compensate for this loss by tillering (LABREUCHE et al., 2014). From this standpoint, any crop other than those belonging to grass family may be an obstacle to the introduction of direct seeding; besides, tillering has become very uncommon in the modern day maize cultivars (NIRMAL RAJ et al., 2020).

This assessment is somewhat regrettable given the benefits no-tillage could bring. Experiments have shown that sowing under live cover crops can increase the yield of some spring-sown crops such as soybean (BORDEAU, 2019). No-tillage should be a option to face the shortage of workforce. In the Normandy case, it would decrease the time of traction per hectare and per year by 25 minutes if glyphosate is available, or 12 minutes if not. In the Alsatian case, the potential time saving with no-tillage would reach 3 hours per hectare and per year. From an environmental point of view, on the entire Alsatian typical farm, the MEANS-InOut application estimates that soil erosion is reduced by 63 percent if barley is grown with no-till and by 76 percent if maize is also grown this way. Switching maize and barley from conventional to direct seeding can reduce greenhouse gas emissions of the Alsatian farm by 4.6 percent (-91 kg CO_2 eq ha^{-1} $year^{-1}$) and nitrogen fertilization by 11.4 percent, or even 19.0 percent if barley is undersowing with soybean. To appreciate the significance of this reduction, it is worth remembering that the European Union has set a target of 20 percent less N fertilization by 2030.

The potential for no-tillage in France could be reviewed after some years if the agricultural contractors continue to develop and farm outsourcing becomes more widespread (NGUYEN, 2022). It could also be revised if research and development (R&D) makes it possible to develop no-till seed drills that are more affordable and much more versatile than they are at present.

4. Conclusions

For the time being, the feasibility of scaling up CA is hampered by shortcomings in the technology of tillage, sowing, crop protection, and harvesting equipment, and a weak industrial capacity to manufacture tools for the mechanical termination of cover crops. These shortcomings include: hardpans formed by tillage implements, insufficient versatility and modularity of sowing equipment, collaboration to be developed between manufacturers and seed companies, harvesting and crop protection equipment not adequate enough for combined crops, need for a better residue management, tuber harvesting equipment and operations to be reconsidered in order to prevent deep soil compaction, need to develop the industrial capacity to manufacture mechanical tools for the termination of cover crops and to optimize their use. The growing integration of digital technology could be an opportunity for CA, as it offers a flexibility that mechanical equipment does not have to adapt machines and farming operations to local specificities.

CA can only be successfully implemented if all the players of the agriculture industry are involved, both upstream and downstream of farms. To succeed in extending the area under CA, it is crucial to select a number of relevant objectives and define them precisely in order to draw up a clear roadmap to secure everyone's commitment. The development of CA requires skills and therefore a public relations strategy to attract talented people to the agriculture industry and to ensure that consumers understand the benefits of CA.

To train farmers, contractors and their employees in new practices, the first step is to raise awareness and persuade them of the benefits of changing their habits. The establishment of this collective belief shared by the agricultural sector will also have to extend to society: diversification of the species grown by farmers, in particular the production of plant proteins, will only happen if the agri-food industry is prepared to go along with it, which implies that consumers will also accept changes in their diet. The shift from conventional farming to CA will either be systemic or it won't be.

If glyphosate were to be banned, a definitive multi-year exit plan would have to be drawn up to enable manufacturers to acquire the industrial capacity to replace chemical destruction of cover crops with mechanical destruction. The current timeframe of regulations in the European Union is inappropriate and leaves too much uncertainty about the outcome of each application for renewing the approvals of active substances.

Nothing can convince a farmer to change his practices better than the example set by other farmers. To prepare for the transition of French agriculture to CA and to design a model of CA that does not leave out root and tuber crops, a first step could be to generalize CA in an area that would act as an experimental laboratory. This area could be in the Hauts-de-France region, which includes the departments of the former Picardy region as well as Nord and Pas-de-Calais. The impetus has already been given in this area by multinational agri-food companies that process potatoes and sugar beet and are committed to regenerative agriculture programs with ambitious targets.

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Electric retrofit for decarbonization of off-road vehicles

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Abstract

In the context of accelerating the energy transition, the massive decarbonization of off-road mobile machines involves the incorporation of battery-electric powertrains. Two business approaches are generally considered by economical players: either offering brand new electric machine based on conventional diesel machine platform, partially modified for better meeting the market demand; or retrofitting the powertrain to battery-electric system with limited changes of the original machine.

This paper focuses on the retrofit case, pointing out benefits and engineering similarities and differences with the usual OEM new machine development which must deal with process standardization concerns.

The regulation trend with the future machinery regulation in 2027 is that aftermarket players will support the product responsibility if substantially modifications like electrification are made to the original equipment. This involves strong design and validation engineering skills for retrofit players, like OEM (Original Equipment Manufacturer) : duty cycle assessment, requirement management, safety, mechanical, electrical, software and regulation knowhow. This paper described step by step how retrofit makers can apply this process, including some observation and numerical simulation methodologies for strengthening their knowledge of the original mobile machine before conversion into EV.

However, the assembly process for retrofit making remains much simpler than within an OEM environment, because assembly productivity and process standardization are less demanding, since the overall machine cost mainly comes from the electric component supplies. Therefore, the retrofit process offers shorter time-to-market delay compared to a conventional new machine development project.

From both performance and energy range point of views, comparing brand new electric machines to electric retrofit of similar machines from the market shows similar results. Indeed, standardization constraints for OEM with conventional diesel machines is nowadays limiting the potential of efficiency optimization, making new electric machine and electric retrofit machines quite similar.

In addition, the paper discusses the supply cost by enhancing the limited impact of low volume orders of the battery, Emotors or converters which are mostly made of standard submodules: cells and modules in batteries, laminations and magnets in Emotors, power modules in converters.

Finally, this paper concludes how electric retrofit must be considered as a serious and complementary offer to the OEM new electric equipements. This statement is even more meaningful for the offroad mobile market, which is made of a wide range of specific products meeting various professional needs.

1. Introduction

Climate is changing faster than us. Agriculture is considered as a high greenhouse gas emitter; the sector represents 19% of the equivalent direct CO_2 emissions in France in 2019 with 85 Mt CO_2, mostly due to methane CH_4 (44%) and Nitrogen protoxide N20 (42%) emissions issued by livestock manure and mineral nitrogen fertilizers respectively. Focusing on the agricultural machinery, lowering CO_2 emissions from the internal combustion engines is the main concern although it represents a low part of the overall greenhouse gas emissions from the sector. Agricultural machines and attachments are however expected to be part of the global energy transition, where electrification and sobriety are the main driver.

Every option must be implemented to lower emission levels and energy consumption. Both hydrogen and full battery electric systems combined with low carbon energy supply, are considered as the best solutions for stopping vehicle emissions. Even more emissions and energy can be saved by re-using existing machines with the electric retrofit; considering an electric car used in France, the manufacturing process represents half of the over greenhouse emissions therefore the electric retrofit is doubling greenhouse emission benefits compared to manufacturing a new electric machine used in France. Retrofitting also makes sense economically, since the residual value of used offroad machines is generally significant and mostly dependent on the combustion engine ageing.

It can already be observed the very limited offer from offroad machine makers considering construction, handling and agriculture markets. On the contrary to the automotive, bus and truck markets, the offroad sector consists in a wide diversity of machines covering various professional needs. Re-engineering all the machines from scratch, investing and designing dedicated manufacturing process is a huge task for OEM that can hardly be successfully achieved within the climate change timeline.

In such a context of speeding-up the energy transition for a wide range of applications, electric retrofit approach must be reinforced for both new and used machines, in addition to high runner products developed by the OEM.

This article presents a technical methodology for managing electric retrofit of an existing conventional offroad machine. Success criteria are established: performance and energy range for the user, machine modification time and cost, safety, standardization and regulation compliance.

2. Materials and Methods

Retrofitting an offroad machine with an electric battery system faces significant challenges. First challenge, assessing the use cases of the application.

The use cases knowledge is not OEM-dependent and can be appreciated by the end-user specific experience. However, it should be noted that the machine dealer and retrofit maker overall knowledge of agricultural works is a critical point to provide consistent and realistic performance targets for the agricultural machine. Those cross-experiences feed the reference duty cycle definition of the application. Therefore, the target performance and energy range from the original diesel version is not sought for limiting the retrofit cost and impact on the original machine design.

Understanding the original machine design is the second challenge, in order to get enough technical knowhow for further design, DFMEA (Design Failure Mode and Effects Analysis) analysis and regulation compliance steps.

A design process is carried out from observing the conventional machine to the final electric retrofit achievement as shown below.

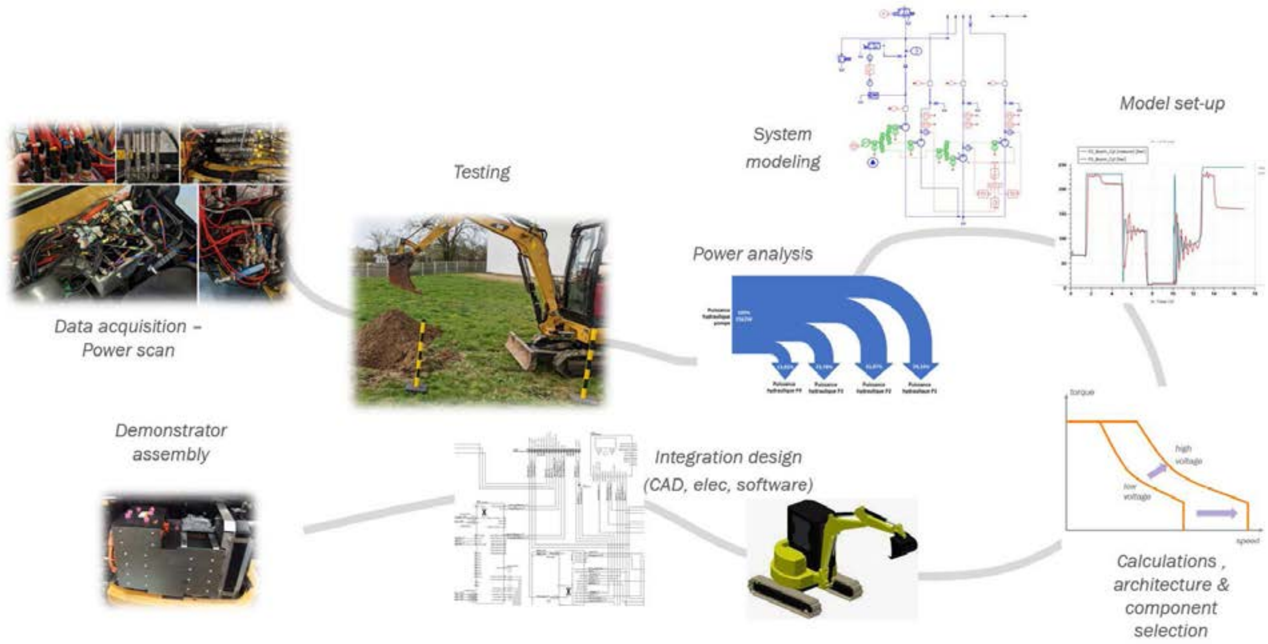

Figure 1. Electric retrofit design process.

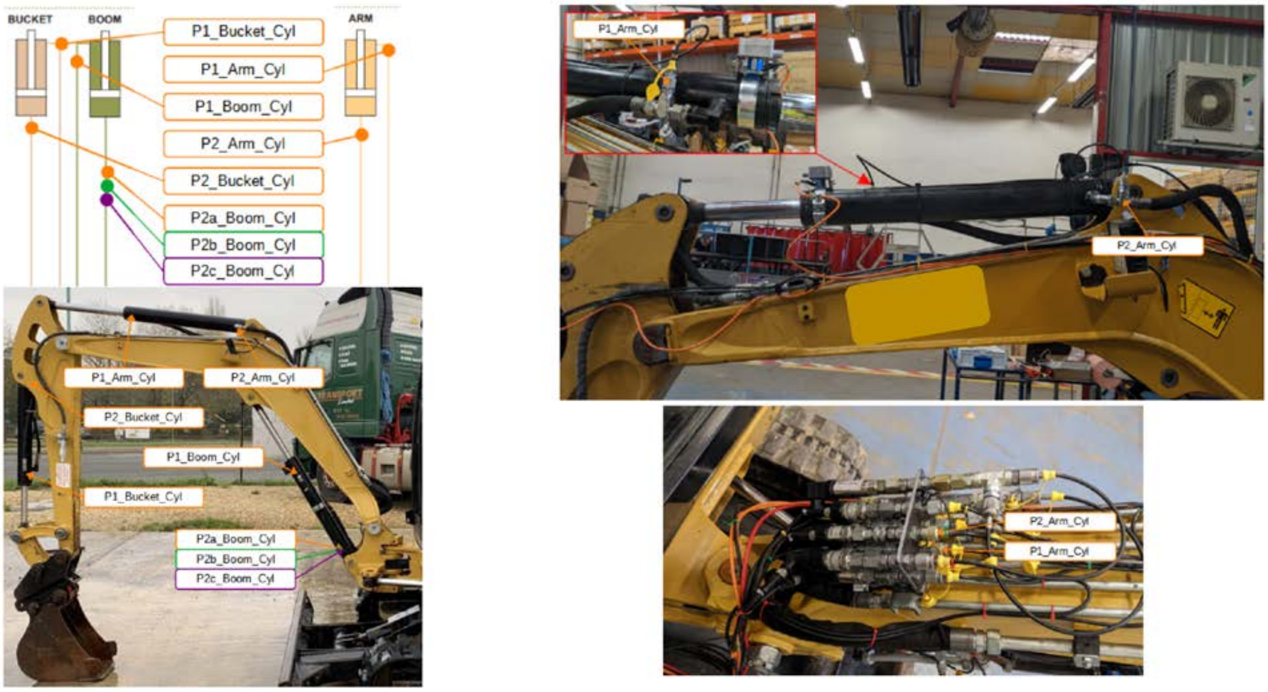

Figure 2. Test equipment used for observing the system performances during machine operations.

Removing the internal combustion engine and some covers allows to investigate deeply the mechanical, hydraulic and electric systems.

For designing the mechanical integration of the electrical powertrain, the mechanical environment is modeled with CAD based on 3D scanning performed after removing the internal combustion engine. Existing structure supports are also identified on the chassis frame, for being reused in the substitution process from the conventional engine to the battery pack; the structure and vehicle stability impacts due to the powertrain change are therefore limited.

Electrical and CAN communication systems are also investigated; based on the machine complexity, the existing electronic units could be partially or totally by-passed, in order to set HMI (Human Machine Interface) inputs for the electric system controller and to provide functional and diagnosis interfaces to the user.

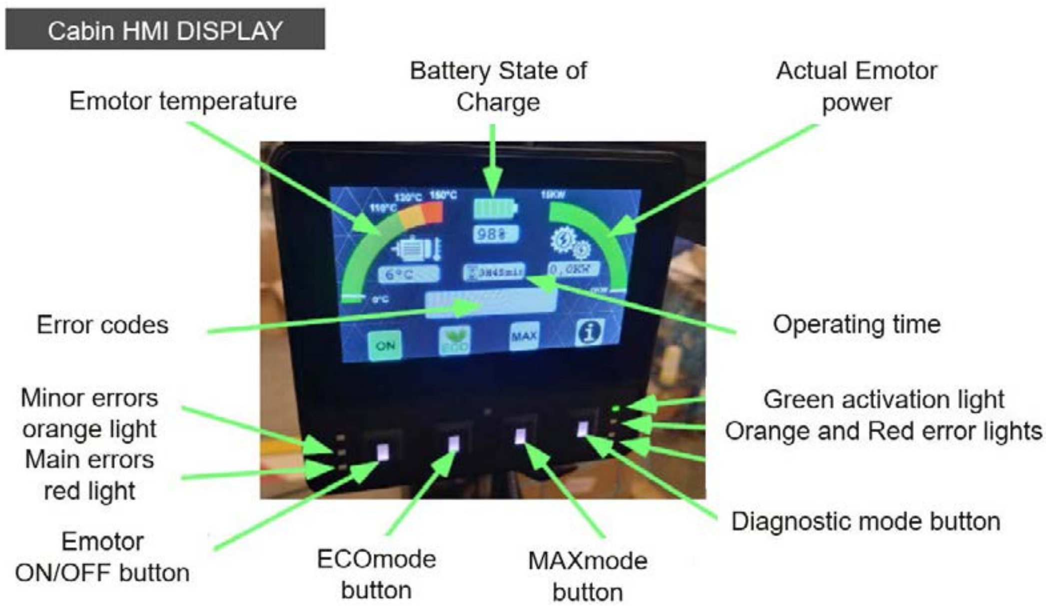

Figure 3. Example of HMI remote display of an electrification kit.

Depending on the machine software architecture, luring some vehicle controller outputs dedicated to the diesel engine (setpoint, start signal, speed feedback etc.) could also be required; this task is much easier to handle with OEM support.

Hydraulics and power systems are also numerically modeled as shown below. The purpose is first to confirm the functional assessment of the system, then to assess the power flows from the pumps to the end actuators.

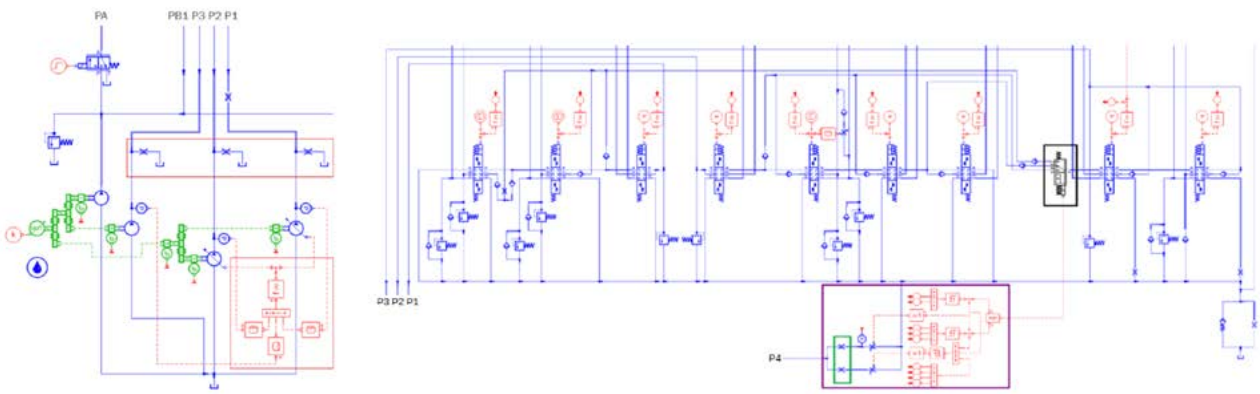

Figure 4. Power systems modelling.

Measurements performed during the initial test campaign are used for steady and dynamic set-up of the systems, within the model.

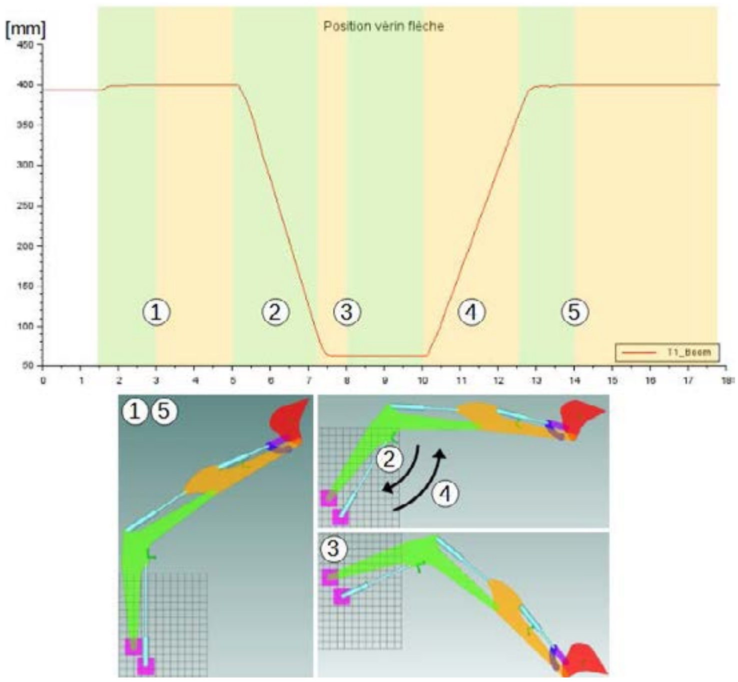

Figure 5. System model set-up based on test measurements.

As a result, hydraulic, electric and mechanicals system understanding is completed, which is requested for further safety analysis.

The next step consists in performing a conventional machine engineering process for ensuring performance, reliability, and safety goals :

- risk analysis of the machine with regards to the applied regulation
- crossed investigation of feared events and existing machine design
- electric powertrain specification
- electric powertrain DFMEA, supported by suppliers of the electric components
- integration design of electric powertrain into the machine
- testing and validating the performance, safety and regulation requirements

It should be noted that this process shows similarities with a machine upgrade engineering performed by an OEM, based on machine carry-over like an engine stage upgrade.

For safety concerns, hydraulics carry-over remains the more conservative approach for both implement hydraulics and traction system (wheel or caterpillar based), because hydraulic systems are usually able to stop the machine operation by themselves. The gravimetric analysis including the overall machine mass and the location of center of gravity, either intends to carry-over the mass distribution of the original machine or increase the overall machine stability.

On the other hand, replacing the mechanical of hydraulic driven cooling fan by an electric device provides significant energy benefits without significant safety or performance impact of the vehicle. The existing fluid/air heat exchanger can be carried over, since the heat rejection levels are lower in the systems thanks first to the remove of the internal combustion engine which is a significant heat provider to the hydraulic circuit, but also thanks to the overall improved use of the energy provided by the increase of controlled systems on-board.

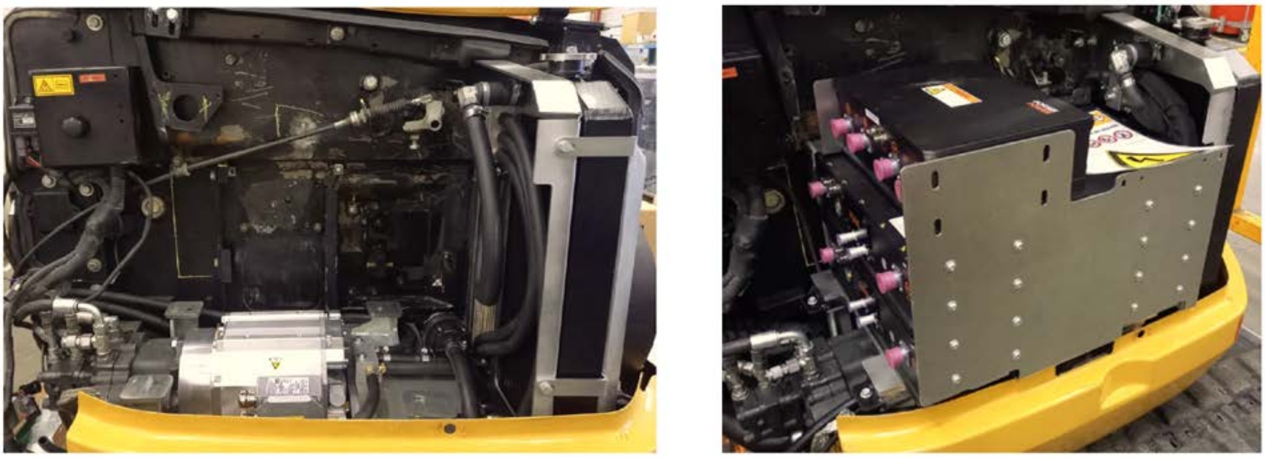

Figure 6. Example of Vensys electric retrofit system integration in machine.

The bill of material of the electric retrofit system usually consists of:

- an energy storage unit, usually a battery,
- a single electric motor and control inverter,
- a DCDC converter for low voltage network supply,
- a power distribution unit
- an overall control unit.

Figure 7. Main component change in the electric retrofit process.

Those strategic components can be effectively sourced by some retrofit maker familiar with consistent logistics and stock capabilities, like players of the aftermarket part business. In addition, on the contrary to internal combustion engines, axles or gearboxes requiring significant production volumes due to foundry processing, electric components are much scalable and standards. As a result, their technology and manufacturing process allow the retrofit maker to offer tailor made systems based on standard off-the-shelf components.

After integrating the system into the machine and starting-up, hydraulic pumps efficiencies can be easily assessed directly in the machine, because the electric drive provides input speed and torque information that are compared to measured output flow and pressure values. The overall multiple pump train can hence be operated over the entire pressure and flow range, showing the best efficiency range which is sought for optimizing the efficiency while controlling the E-motor speed.

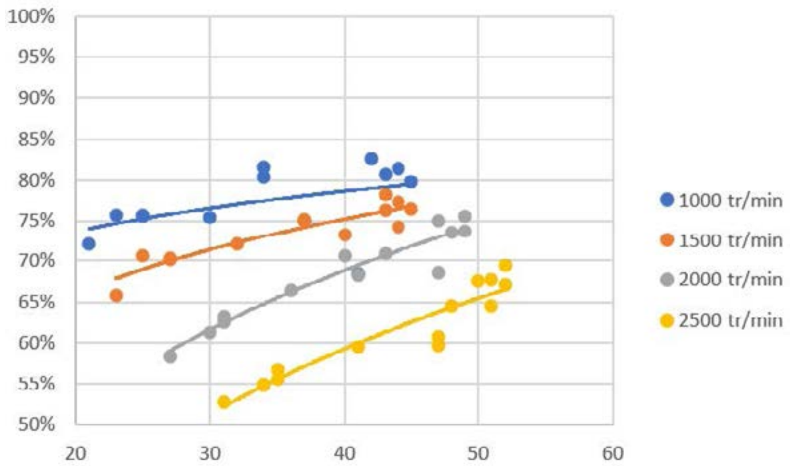

Figure 8. multiple pump train efficiency (%) over torque (Nm) and speed (rpm) range.

Last but not the least, the retrofit maker must demonstrate the machine compliance with the regulation. Regarding the offroad sector, the scope of responsibility of the retrofit maker must be differentiated considering the considered european machine directive or future machine regulation (From 14/01/2023, the European 2023/1230 new regulation replace the European 2006/42/CE Machine directive, enlarging the scope of responsibility of the change maker regarding the modification of a used machine to the entire machine, in case of substantial modification which includes electric retrofit). The retrofit maker becomes gradually a complete machine maker and shall provide required validation calculations and test results for auto-certifying the overall machine, including requirements from the machine, EMC, noise and electrical regulations.

This challenge can be faced by some retrofit makers on their own with significant engineering efforts. However, the 2027 machine regulation evolution must be considered as a real risk in terms of business and employment for aftersales players. A closer cooperation with OEM with formal agreements would support the machine change sector to contribute to the energy transition.

3. Results and Discussion

The machine energy range mostly depends on the embedded energy in the battery. Retrofit makers already demonstrated their ability to offer similar et even higher energy than new OEM machines as shown below for the mini-excavator case.

The comparison is based on energy density criteria calculated with the embedded energy and the machine weight, which is very much linked to the power need and the machine size.

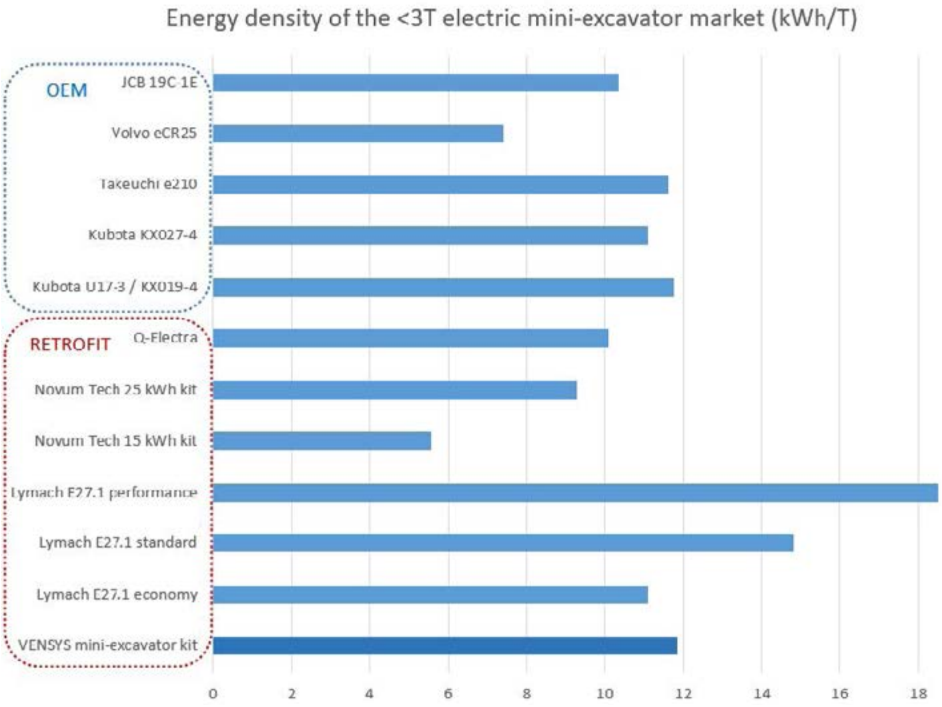

Figure 9. Energy density embedded in electric mini-excavator, both new OEM machine and retrofit.

The energy use observed during operation tests of the Vensys mini-excavator retrofit demonstrator shown mean power values close to OEM new electric excavator* : between 8 and 12 kWh used per hour for continuous work operation depending on the use case. The maximum mean power deviation of 15% was observed in the energy comparison with the OEM electric excavator, partially due to the hydraulic differences between the two different machines.

* (Statement based on comparison performed between Vensys mini-excavator demonstrator and a reference OEM new mini-excavator machine from the market. The used retrofit demonstrator was mechanically renewed before tests)

The retrofit cost efficiency is also remarkable. Indeed, an electric vehicle cost is significantly linked to the electric components (battery, motors, converters) as shown on figure below.

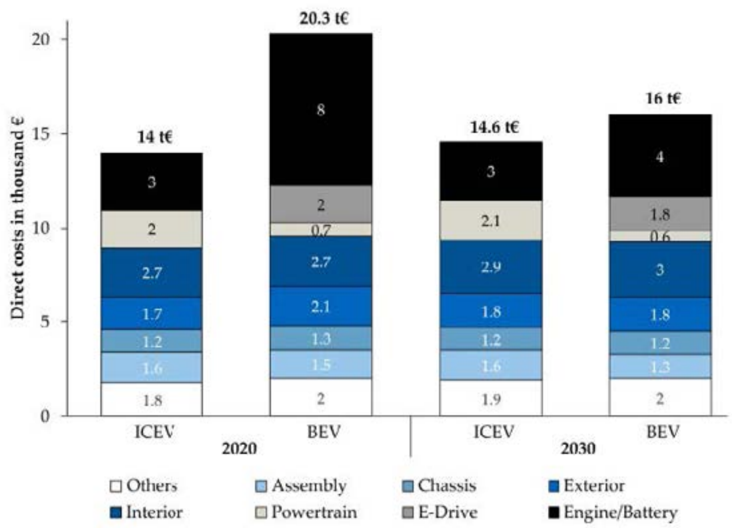

Figure 10. Cost structure of current and future BEVs compared to ICEVs.

Regarding the battery cost, the standardization of this type of product shows that competitive prices can be achieved with low quantities order thanks to cells and modules synergies obtained by the battery manufacturer with other Emobility markets like automotive or bus.

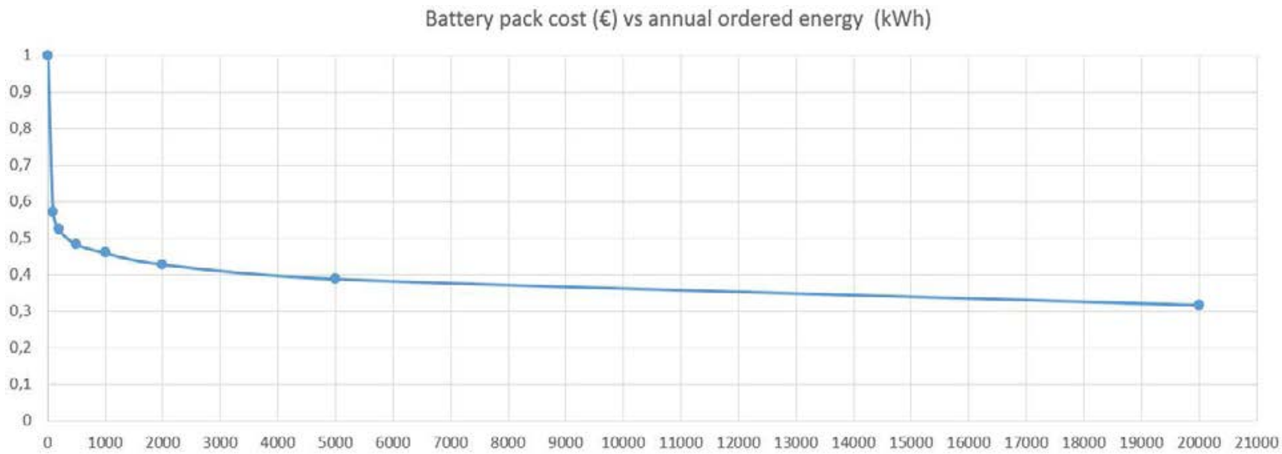

Figure 11. Benchmark of battery pack cost vs the annual ordered energy (Vensys source).

Considering the very limited battery cost deviation based on order volumes, the significant part of the battery in the total machine cost, the residual value of the aged machine used for retrofit, and the limited manufacturing investment for the retrofit process, the electric retrofit case shows significant economical advantages for enlarging the electric vehicle offer.

4. Conclusions

This paper presented the ability of retrofit makers to deliver electric machines for the offroad markets based on standard off-the-shelf electric components. A full technical retrofit process was described for succeeding design and certification challenges. It highlighted the ability of retrofit maker to ensure the cost and quality relevance of electrifying new or used machines according to conventional engineering standards. The obtained energy range can be close to brand new electric machine, thanks to the flexibility of the retrofit assembly process combined with a suitable control power of the system.

The electric retrofit cost shows a limited dependence between the machine final price and produced quantities, due to the electric component standardization and residual value of used machine. Regarding new machines retrofit business case, the retrofit operation cost must be compared to manufacturing investments that OEM must support.

New machine retrofit offers a relevant alternative option for OEMs to enter the low emission market with limited risk exposure to the demand uncertainties.

Used machine electric retrofit can reinforce the availability of low emissions offroad offer, with higher cost savings and CO_2 emissions savings (twice higher compared to brand new machines on the French market), by reusing existing equipment.

In the context of the energy transient of offroad machines, electric retrofit makers offer opportunities for OEM to speed-up their electric offer to the market, but also a solution for aftermarket players to save local employment significantly. Greater chances of success can be expected with a closer cooperation between both players.

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Does autonomy improve the environmental impacts of agricultural robots? The case of vineyard weeding robots

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Abstract

In France, the Ecophyto II+ program aims to reduce pesticide use in agriculture by 50% by 2025. Viticulture, as well as other crops, has to develop alternative solutions to chemical weed control. These alternatives can be achieved by mechanical weeding either using tractors or weeding robots. An initial Life Cycle Assessment (LCA) study conducted in 2022 showed that scenarios using weeding robots for intra row management have either greater or lower environmental impacts than conventional ones depending on the impacts considered.

This paper aims to present the updated LCA results of vineyard weeding practices with respect to two main improvements identified from the first study: (i) the transition to operating a robot with and without human intervention, (ii) the updated Life Cycle Inventory of agricultural tractors in order to have a fairer comparison with agricultural robots.

The main results show:

- a drastic reduction of acidification, eutrophication and photochemical oxidation impacts due to the depollution system of the agricultural tractor in the updated LCI
- an increase of mineral depletion and terrestrial ecotoxicity impacts due to the sensors and electronic components of the agricultural tractor in the updated LCI
- a decrease of all environmental impacts when the robot is operated in autonomous mode

These results show the added value of conducting a LCA in order to improve agricultural robot and tractor ecodesign. However, there are still methodological challenges to face with regards to the additional services and functions provided by robots that question the LCA methodology (such as increased security, less soil compaction).

Keywords : Agricultural robot, full autonomy, Life Cycle Assessment, vineyard, mechanical weeding, updated tractor Life Cycle Inventory.

1. Introduction

The agricultural sector is facing the double challenge to feed an increasing population while reducing its impact on the natural environment and human health. In consequence, crop yields need to be maintained at a high level in order to secure food supply at the same time as developing sustainable agriculture practices. It involves especially reducing chemical inputs, including pesticides and herbicides. To achieve such goals, the European Union established a framework for community action to achieve the adoption of pesticides compatible with sustainable development (i.e. Directive 2009/128/EC) in 2009. In France, this European Directive was transformed into French national law as the Ecophyto II+ program. This program aimed to reduce pesticide use in agriculture by 50% by the horizon 2025 and to phase out glyphosate use by the end of 2020 for its main uses and by 2022 at the latest for all other uses. Consequently, one of the main actions is to develop alternatives solutions to chemical weed control (French Ministry of Agriculture, 2020).

The most studied alternatives to chemical herbicide use for row crops are selective chemical spraying (that is Drop-on-Demand technologies where only the weed is sprayed and not the entire field) and mechanical weeding. Other solutions such as flaming, hot water, steam or high voltage (Blasco et al., 2002) exist, but their adoption has been low (Fountas et al., 2020; Steward et al., 2019). Cultivation tillage, often referred to as tertiary tillage, is the most adopted method for mechanical weeding in agricultural crops.

It is carried out after crop sowing and consists of shallow tillage by a variety of tools often categorized as hoes or harrows (Rueda-Ayala et al., 2010). For perennial crops, such as vineyards, the most adopted alternatives to chemical herbicides in the main wine-producing countries (Europe, United States, Australia, New Zealand, Chili) are inter-row (between the vine rows) and intra-row (between the vine plants) mechanical weeding and the use of cover crops, also known as grassing. Inter-row mechanical weeding is conducted using cultivation tillage standard tools such as disc harrows, French ploughs, or rotary cultivators while specific tools such as finger, torsion or spring-hoe weeders are used for intra-row mechanical weeding (Cloutier et al., 2007). The intra-row weed management is challenging, as accurate steering is needed to avoid damaging the vine trunks, especially the young ones, by the tools. An accurate guidance system is then required (Manzone et al., 2020; Reiser et al., 2019).

The improvement in precision agricultural tools such as navigation system, distance sensors, cameras and algorithms for weed recognition has created wide opportunities for autonomous weed management in vineyard, market gardening and arable crops and may become a key element of modern weed control (Bajwa et al., 2015; Reiser et al., 2019). Precision agriculture technologies have progressed in two broad classes: large, automated tractor with driver-assist systems such as RTK-GNSS display and autonomous robotic solutions capable of carrying out agricultural tasks with no human intervention (Basu et al., 2020; Pedersen et al., 2006). Development of robotic platforms was allowed by the convergence of precision agricultural tools and maturing mechatronics technology, making autonomous units technically feasible (Lowenberg-DeBoer et al., 2020). Autonomous units identified here have mobile machineries able to perform complex automated functions, without any interaction with humans, and being able to ensure the safety of the operations by themselves. No longer is an operator is needed during autonomous operations to ensure safety. Automation for weed control has been one major fields of research in agricultural robotics in the last few decades. Research had especially focused on the following four core technologies: guidance and perception sensors, level of weed detection and identification, precision intra-row weed removal and mapping (Bechar and Vigneault, 2016, 2017; Fennimore et al., 2016; Fountas et al., 2020; Steward et al., 2019; Utstumo et al., 2018).

Commercial agricultural robots are scarce (Fountas et al., 2020; Shamshiri et al., 2018) and face a low adoption rate in farms (Gil et al., 2023). The most recent publications by Koerhuis (2020) and Lenain et al. (2021) show that about five hundred units of field and harvest robots were commercially available in 2021. Most of the robots intend to eliminate weeds in row crops. France is the country with the most agricultural and field operational robots in use with at least hundreds of units for weed management and about fifty units being used by viticulture entrepreneurs (Koerhuis, 2020). High-added value crops such as vines appear to be the best business cases for the first generation of weeding robots. Indeed, the cultivation of vines is historically a crop that consumes the most chemical inputs compared to arable crops or market gardening. Expectations for robotic alternatives, with high investment capabilities in new technologies, are highest for this crop which explains the significant emergence of agricultural robots in vineyards these recent years. Most of the weeding robots identified within this overview rely on mechanical weed removal (75%) or on local spraying to reduce herbicide use by up to 95% (Koerhuis, 2020).

A recent study by Pradel et al (2022) was conducted to assess the environmental impacts of mechanical weeding practices in vineyards with the TED robot from Naïo Technologies. The main results showed that scenarios using weeding robots for the intra-row management have greater impacts than conventional ones on mineral resource depletion, human toxicity, freshwater ecotoxicity and marine eutrophication due to the manufacture, the lifetime (when assumed short) and the relative specialization of robots for specific tasks. However, these same scenarios have fewer impacts than conventional ones on climate change, fossil resources depletion, ozone depletion, acidification and particle formation, especially when robots are used on plots closed to the winery. This study also highlighted a need for consolidating LCI data for agricultural tractors in order to achieve equivalent comparison between the two technologies and for robot use in the field that is work performance, electrical consumption, autonomous mode.

This new study aims to present the updated LCA results of vineyard weeding practices with respect to two main improvements identified from the first study: (i) the transition to operating a robot with and without human intervention, (ii) the updated Life Cycle Inventory of agricultural tractors in order to have a more accurate comparison with agricultural robots. This study is focused on the intra-row weeding with inter vine hoe in Languedoc vineyard.

2. Materials and Methods

LCA is designed to be the most exhaustive multi-criteria assessment method reflecting the current knowledge on the environmental impacts. LCA aims to quantify all the impacts of human activities on the environment. The LCA method is described by the ISO 14040 standards (ISO, 2006a, b) and recommended by the European Union (ILCD Handbook, 2010). This method is commonly used by industries to eco-design products in various economic sectors (energy, transport, chemical industry, agriculture). LCA follows a four-step procedure that consists of goal and scope definition of the study, inventory data collection, environmental impact assessment and result interpretation according to the goal, the system boundaries, the assumptions and sensitivity analyses made.

Goal and Scope

Our study aims to provide a comparative environmental impact assessment of robotic technologies used to control weeds in vineyard compared to historically in-use technologies (i.e. tractors). As weeding practices are numerous, this study focuses on intra-row weeding practices in Languedoc vineyard for which experimental data is available.

To be consistent with the objectives of the study, the general function of the system studied is to control the development of weeds located under the row in the Languedoc vineyard. This vineyard is characterized by a density of 4,000 vines per hectare, an inter-row width of 2.50 m and an absence of plant cover, whether on the intra-row (90% of the vineyard concerned) or the inter-row (70% of the vineyard concerned). The majority of the intra-row are not grassed (90%). The management of weeds in Languedoc is therefore essentially mechanized. The function studied will therefore be as follows: **to control weeds under the rows of a vine plot in Languedoc by means of mechanized weeding.**

Mechanized weeding practices are very varied. They can be carried out by different weeding tools with different levels of performance depending on the pedoclimatic conditions of the wine-growing area and the annual meteorological variations. In view of the objectives of the study and the function of the system, the functional unit has been defined as **the weeding control under the row for 1 hectare of vines in Languedoc by means of inter vine hoe.**

The concept of temporality is absent from the functional unit because it is assumed that the technological solutions compared: (i) have the same weeding efficiency since they use the same tools (interceps), a single pass is therefore necessary to compare the solutions with each other, and (ii) are carried out under the same pedoclimatic conditions.

Two systems are compared in the study: a conventional system based on the use of a tractor and a robotic system based on the use of a vineyard-weeding robot (TED robot from Naïo Technologies). Each system uses a specific type of machine (tractor or TED robot) as well as agricultural material, energy, and human resources. The system boundaries and the studied systems are described in Figure 1.

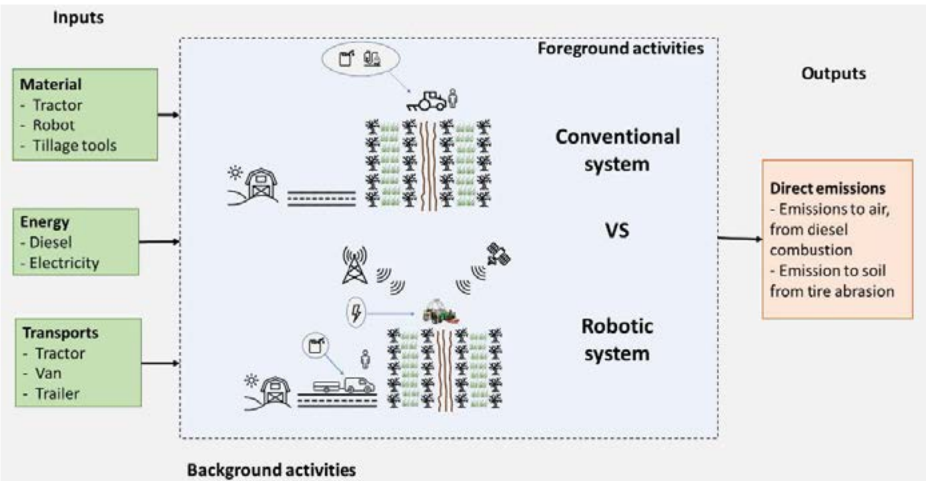

Figure 1. System boundaries and studied systems.

To carry out the intra row weeding task, tractor and inter vine hoe were used by the conventional system. When not in use, the tractor and the agricultural equipment were stored in a shed. The distance from the winery to the plot is considered to be 4km. The mounting of the implement, the filling of the tank and the maintenance operations are carried out manually (Figure 1).

TED robot equipped with inter vine hoe is used by the robotic system. The TED robot is guided in the plot by Network Real Time Kinematic Global Navigation Satellite System (NRTK-GNSS). It relies on GNSS satellites, a reference beacon and relay antennas (GSM). When not in use, the TED robot is stored in a shed. Robots are exclusive off-road machinery and are transported to the plot using a van equipped with a trailer. A same distance of 4 km is assumed. The assembly and disassembly of the robot's tools, the recharging of its battery and the maintenance operations are carried out manually (Figure 1).

We assessed three modalities in this study:

- LCI of agricultural tractor was modelled according to data from Ecoinvent database (Te) or updated data from Pradel (2023) (Ta).
- TED robot was operated with a human operator (TEDna) or without a human operator (TEDfa). The TED energy autonomy directly linked to the batteries capacity is reported to be 6h for TEDna and 12h for TEDfa.
- The weeding was carrying out on a square plot (P1: 1 ha, length = 100 m, width = 100 m) or a rectangular plot (P2: 1 ha, length = 152,15 m, width = 65,72 m). For each plot, the vines are planted in the direction of the width.

The studied scenarios are explained in Table 1

Scenario code	Scenario characteristic
TEDna_P1	TED robot operated by a human operator in plot P1 – 6 h autonomy
Te_P1	Ecoinvent data used for agricultural tractor LCI and the tractor operated in plot P1
TEDfa_P1	TED robot operated without a human operator in plot P1 – 12 h autonomy
Ta_P1	Updated data from Pradel (2023) used for agricultural tractor LCI and the tractor operated in plot P1
TEDfa_P2	TED robot operated without a human operator in plot P2 – 12 h autonomy
Ta_P2	Updated data from Pradel (2023) used for agricultural tractor LCI and the tractor operated in plot P2

Table 1. Studied scenarios.

Life Cycle Inventory (LCI) data collection:

Three main types of data were collected: data from the literature available, data from Ecoinvent database, and data provided by manufacturers developing the robotic solutions evaluated (robot composition, energy consumption).

Data for tillage tool, diesel and electricity production came from Ecoinvent V3.7.1 database. The 50-60Kw tractor was modelled based on BCS Valiant 500 AR. This model was chosen based on the availability of the specific fuel consumption among the tractor OCDE test catalogue published by Agroscope. The data for tractor manufacturing came from the Ecoinvent database (Te) or Pradel (2023) (Ta).

A lifetime of 7,200 hours was considered for the tractor and the TED robot. Data for lifetime, masses of tractor and tillage tools as well as fuel consumption come from Agribalyse V3 (Asselin-Balençon et al., 2020). Data for working operation speed came from IFV Occitanie website. Emissions of potentially toxic elements due to tire abrasion and fuel combustion were included in the LCI and came from Nemecek and Kägi (2007). Emissions reduction due to the use of the depollution system for the newly modelled tractor came from the Swiss Federal Office for the Environment (FOEN, 2015). Values used are provided in Table 2. AdBlue® consumption was estimated to be 5% of the fuel consumption.

Type of emissions	Emission stage		Reduction
	Pre-EU A (before 1995)	EUIV (from 2014)	
CO	3,62	0,5	-86%
HC	0,91	0,17	-81%
NOx	12,52	0,4	-97%
PM	0,61	0,03	-95%
CH_4	0,0218	0,0031	-86%
N_2O	0,035	0,035	0%
C_6H_6	0,0014	0,0002	-86%

Table 2. Emission reduction due to depollution system used by tractors solution.

Data for TED robot production came from its manufacturer Naïo Technologies. The robot composition is based on the material production of the robot (steel, electronic component). The electricity consumption by TED robot for a working operation was calculated based on the electricity consumption per hour of operation (limited by the battery capacity) multiplied by the operation time (h/ha).

Life Cycle Impact Assessment (LCIA):

Two methods usually used in LCA were chosen for the analysis of the results: the ReCiPe2016 method and the CML-IA method.

3. Results and Discussion

In this section, we will focus on some of CML-IA results. Results are related to intra-row weed control using inter vine hoe of a vineyard plot with an area of 1 hectare for 1 year (equal to 1 crop rotation for vineyards). The comparative results are presented on graphs based on 100%, that is for a given indicator, the most impacting scenario represents 100% and the result of the other scenarios are expressed in relation to this maximum impact.

The impact categories abbreviations are as follows: Abiotic depletion fossil (ADP Fossil), Abiotic depletion ultimate reserves (ADP UR), Acidification potential (Acid), Eutrophication potential (Eutro), Global Warming Potential 100 years (GWP), Human Toxicity Potential (HTP), Photochemical Ozone Creation Potential (POCP), and Terrestrial Ecotoxicity Potential (TETP), Particule matter formation (FPMF), freshwater consumption (FC), Freshwater ecotoxicity (Feco), Ionizing radiation (IR°, Land Use (LU), Marine eutrophication (meutro), Stratospheric ozone depletion (SOD).

Figure 2 shows the results obtained for the P1 plot with the tractor modelled either using Ecoinvent data (Te) or data from Pradel (2023) (Ta) and results obtained for the TED robots operated with or without a human operator (respectively TEDna and TEDfa).

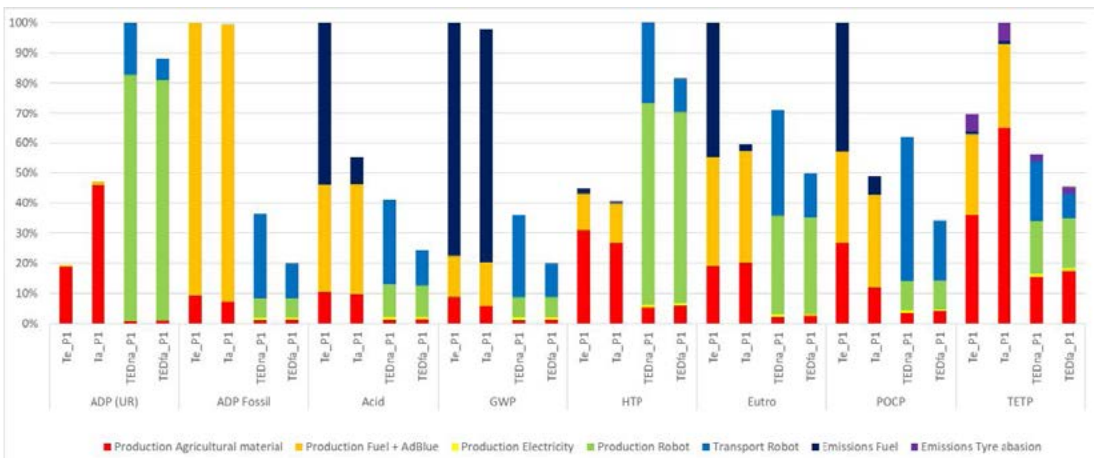

Figure 2. LCA results obtained for 1 ha of intra row weeding with inter vine hoe for P1 plot.

The impacts on the mineral resource depletion (ADP (UR)) are much greater for the robotic scenarios (TEDna_P1 and TEDfa_P1) than for the conventional scenarios (Te_P1 and Ta_P1). This difference is mainly due to the production of active electronic components, electric motors and electric cables using for the robot manufacturing. For the conventional scenarios, the impact on the mineral resource depletion is mainly due to the production of the tractor (94% for Te_P1 and 97% for Ta_P1). The LCI update for the tractor shows a 2.48 increase for the ADP(UR). This difference is mainly linked to the lead-acid battery and the on-board electronics which represent respectively 55% and 41% of the ADP(UR) impact. The same explanation is valid for the human toxicity impact category.

The impacts on the fossil resources depletion (ADP Fossil) are much greater for the conventional scenarios (Te_P1 and Ta_P1). These impacts are mainly due to the fuel production used by the tractor. For robotic scenarios, the main contributor is the transport of robots from the farm up to the plot to be weeded (17 to 58% of the impact).

Regarding the impacts on acidification (Acid), the conventional scenarios have a greater impact than the robotic scenarios. The large reduction of the emissions due to the use of a depollution system explains the significant reduction for Ta_P1 (81%). The finding is similar for the eutrophication (Eutro) and photochemical ozone (POCP) impact categories (93% and 85% respectively).

Climate change impact (GWP) is also much greater for conventional scenarios which are the emissions related to fuel combustion (78% for Te_P1 and 79% for Ta_P1). Here we observe very similar values between Te_P1 and Ta_P1 as the depollution system only reduces CH4 emissions, which is a negligible amount is compared to the amount of CO2 emitted.

Finally, the terrestrial ecotoxicity (TETP) impact category is much greater for the conventional scenarios, particularly for the Ta_P1 scenario. The main contributor is the production of agricultural equipment. The update LCI of the tractor (Ta), especially the depollution system and the electronic components, explains this increase.

The degree of variation in the impacts between Ta and Te and TEDna and TEDfa is shown in Table 3. The variation between the Ta and Te impacts are very significant for CML-ADP (UR), ReCiPe-FC and ReCiPe-Meutro and in a lesser extent for CML – TETP, ReCiPe – IR, ReCiPe – LU and SOD. For all the other impact, the Ta impacts are lower than for the Te ones. All the impacts of TEDfa are lower than those of TEDna.

Impact	Te	Ta	Variation	TEDna	TEDfa	Variation
CML – ADP (UR)	2,98E-04	7,22E-04	**142,14%**	1,54E-03	1,36E-03	-11,84%
CML – ADP Fossil	8,52E+02	8,46E+02	-0,63%	3,11E+02	1,70E+02	-45,24%
CML - Acid	2,39E-01	1,34E-01	-43,68%	9,80E-02	5,81E-02	-40,71%
CML - GWP	6,01E+01	5,88E+01	-2,18%	2,16E+01	1,20E+01	-44,47%
CML - HTP	2,00E+01	1,81E+01	-9,37%	4,47E+01	3,64E+01	-18,55%
CML - Eutro	6,53E-02	3,95E-02	-39,59%	4,65E-02	3,26E-02	-29,93%
CML - POCP	2,31E-02	1,14E-02	-50,81%	1,43E-02	7,89E-03	-44,78%
CML - TETP	2,28E-01	3,27E-01	43,36%	1,84E-01	1,48E-01	-19,17%
ReCiPe - FPMF	8,90E-02	3,87E-02	-56,49%	3,51E-02	2,13E-02	-39,33%
ReCiPe - FC	4,38E-02	2,45E-01	**458,59%**	1,08E-01	7,63E-02	-29,43%
ReCiPe - Feco	7,33E-01	7,18E-01	-2,12%	2,95E+00	2,48E+00	-15,83%
ReCiPe - IR	5,10E+00	8,56E+00	67,92%	6,31E+00	4,18E+00	-33,80%
ReCiPe - LU	2,37E-01	4,30E-01	81,62%	6,73E-01	3,95E-01	-41,26%
ReCiPe - Meutro	3,06E-04	2,22E-03	**627,12%**	1,71E-03	1,66E-03	-3,19%
ReCiPe - SOD	5,01E-05	5,45E-05	8,76%	1,71E-05	8,97E-06	-47,66%

Table 3. Impact variation according to the tested modalities Ta/Te and TEDfa/TEDna.

Figure 3 shows the sensitivity of the plot size on the LCA results for the tractor modelled using data from Pradel (2023) (Ta) and results obtained for the TED robots operated without a human operator (TEDfa).

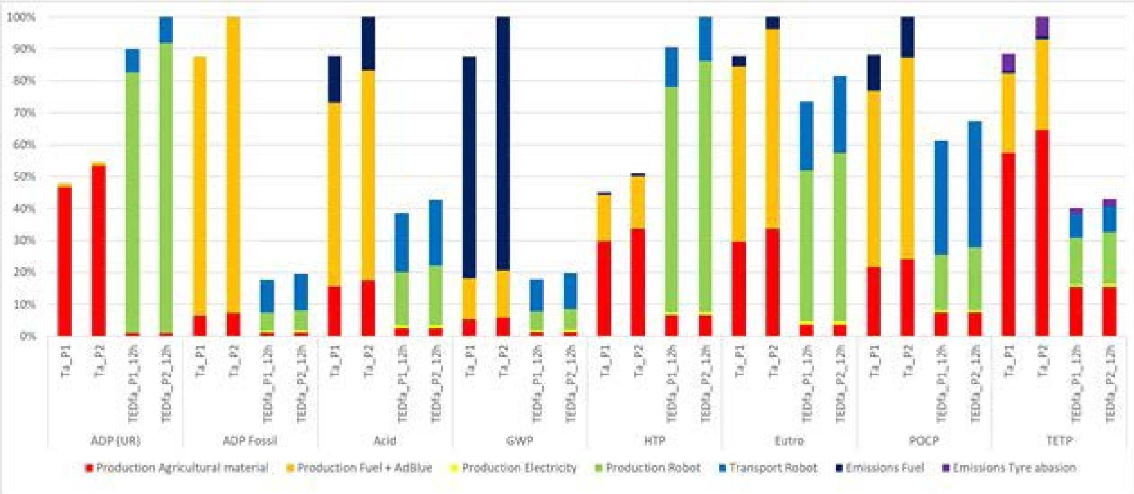

Figure 3. Comparison of LCA results regarding the type of plot weeded (P1 = square shape; P2 = rectangular shape) for 1 ha of intra row weeding with inter vine hoe.

Vines in P2 plot are planted, and therefore weeded, in the direction of the width of the plot (shorter side). In consequence, there are more rows to weed than for a square plot such as P1. Thus, the number of turns made by the robot, or the tractor in conventional scenarios, is much greater than in P1. The work performance is therefore lower in P2 than in P1 plot and induces greater impacts for weeding in P2 plot than in P1 due to a greater allocation of the mass of the robot and tractor to the mission as well as a greater consumption of fuel and electricity. A rectangular plot cultivated in the direction of its length could certainly allow a more signification reduction of environmental impacts.

Figure 4 shows the sensitivity analysis of LCA results regarding the autonomy of the TED robot operated with and without a human operator.

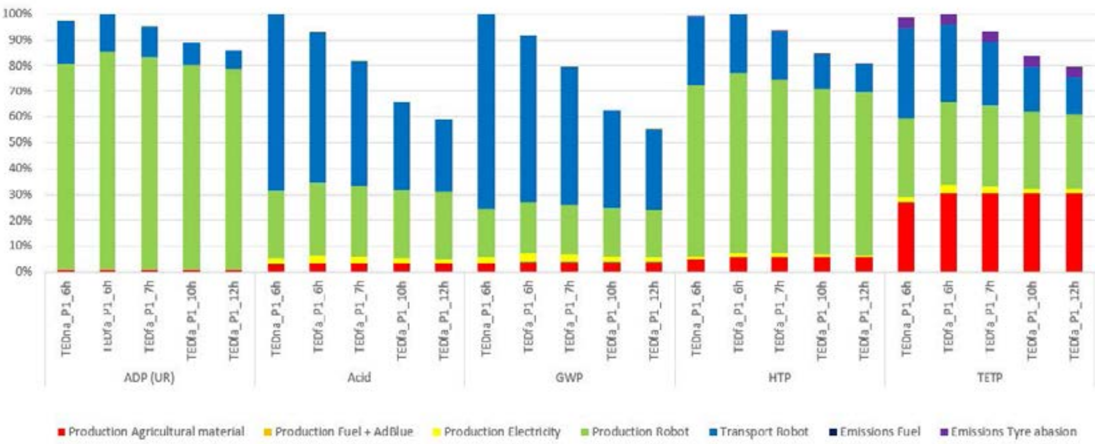

Figure 4. Sensitivity analysis of the TED autonomy with ad without a human operator for 1 ha of intra row weeding with inter vine hoe in P1 plot.

The availability of the robot has been increased up to 12 hours per day. That increase from 6 hours to 12 hours is the result of two factors: the increase of the batteries capacity, and the fact that the autonomous operations shall be performed at 0.6m/s or below, in order to ensure the safety of TED operations. In consequence, for one hour of effective work in the field, transport time is divided by two. This is highlighted by LCA results (Figure 4).

When comparing the two scenarios for which the robot's autonomy is identical (6h), we observe greater impacts for TEDfa than for TEDna regarding some impacts such as mineral abiotic depletion, human toxicity (HTP) and terrestrial ecotoxicity. However, we note that the increase in the autonomy of TEDfa (from 6h to 12h) makes it possible to globally reduce the environmental impacts. Indeed, moving from 6h to 12h autonomy allows a reduction of the environmental impacts between 9% (Marine eutrophication – RECIPE) and 46% (fossil resource depletion – CML) depending on the impact category.

4. Conclusions

This paper is aimed at focusing on the main improvements identified for agricultural robots and to answer the following questions:

1. What will be the environmental impacts of agricultural robots that become autonomous? What will be the orders of magnitude of environmental impacts changes for autonomous robots compared to those that are human-operated?

2. What will be the orders of magnitude of environmental impacts changes by using updated inventory data of agricultural tractors?

This study addressed these questions by using the TED robot as an example of technologies available on the market that can operate in an autonomous mode. Indeed, we highlight that robots operated without a human operator relies on technologies and safety strategies which result in a lower speed and work rate of robots but with a longer availability on field. It results in a reduced need to recharge the batteries and to transport the robot to the farm for recharging.

The life cycle inventory for agricultural tractors was updated by integrating the electronics devices, the sensors and the depollution system that have been mandatory for 20 years. This update highlights an increase in impact categories related to mineral depletion and terrestrial ecotoxicity due to the modelling of the electronics devices and the depollution system (that contain vanadium, rhodium and tungsten) and a decrease in impact categories related to acidification and eutrophication due to a severe decrease of air pollution thanks to the depollution system.

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360° MONITORING FOR AGRICULTURE

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Abstract

The challenges facing agriculture encompass both environmental sustainability and societal demands. Efforts are being directed towards minimizing inputs by applying the principle of targeted application in terms of timing and location and optimizing natural resources like pasture to reduce feed expenses. The agro-industrial sector is likewise focused on conserving energy and proactively addressing material issues for efficient interventions.

Society is pressing for enhanced transparency in the agricultural supply chain, necessitating comprehensive food traceability from production to consumption. This is accelerated by production standards and labels such as AOC and AOP, for which digital technology is crucial in substantiating monitoring indicators for producers and processors.

Furthermore, the monitoring and substantiation of animal welfare and ethical treatment are crucial concerns. Innovations like IoT for animal tracking, multi-modal animal surveillance (photos, videos, sounds) for behavior analysis, and AI, particularly machine learning, offer promising solutions. The integration of diverse datasets can augment their value.

The aim of this article is firstly to highlight the challenges that agriculture will face in the future, pushing for the digital transformation of agricultural enterprises. Secondly, it intends to exemplify and demystify the array of available data sources, elucidating their advantages through practical use cases and particularly two research projects.

The first one is about pasture optimization and traceability (crossing location data, remote sensing data, and weather data). The second one is related to animal welfare, specifically respiratory pathologies in young cattle (crossing analysis, imaging, and sound data).

Keywords : Monitoring, IA, Deep Learning, AgTech, Optimization.

1. Introduction

As previously mentioned, the agricultural sectors are facing major challenges. With nearly 10 billion people expected to be living on Earth by 2025, food production needs to increase dramatically, by around 70%. However, it is alarming to note that arable land is shrinking by around 33%, according to the FAO. This land has already been degraded or used for other purposes. This situation will have a significant impact on food production capacity, with an expected drop of around 12% between now and 2030. It is therefore essential to focus on preserving species and territories, particularly agricultural land, as well as animal health.

Climate change is also having a negative impact on food production, leading to a reduction in both the quantity and quality of harvests. These climate challenges are expected to reduce food production by around 10%. In addition, there is significant pressure to reduce greenhouse gas emissions, as recommended by the IPCC. Although progress has been made over the years, we have not yet reached the targets set, which means that it is imperative to accelerate these reductions.

With regard to natural resources, in particular water, it is important to note that 70% of the freshwater used is currently allocated to agriculture. This demand is set to increase by almost 20% between now and 2050. Optimizing the use of this resource is therefore crucial if we are to be able to regulate its use, directing it to the right places at the right time and in the right quantities.

At the same time, it is essential to discuss the optimisation of other natural resources, such as meadows and pastures. The aim is to maximise the use of grass capital, which can have a positive economic impact on farmers' budgets, while helping to preserve biodiversity.

It is also important to consider work in agriculture, with the aim of reducing its arduousness and automating a number of tasks. Companies are faced with a scarcity of certain types of expertise, due to factors such as the increase in geographical areas and retirements. This is giving rise to discussions about the ability of digital technology (and more specifically artificial intelligence) to factualise and reproduce the expertise that is currently in the eye of experts or advisers (remote assistance, ratings, assessments, visual checks, etc.). The resulting advantage is the ability to rate more often and more consistently.

Finally, another crucial point to address is the issue of food waste. It is estimated that around a third of the world's food production is lost and wasted every year. This represents a very powerful lever that can be exploited to improve the overall situation. Reducing food waste can make a significant contribution to food security, environmental sustainability and resource efficiency. This is a key area that requires continued attention and initiatives to reduce this unnecessary loss of food.

Digital solutions have an essential role to play in meeting these challenges. In particular, they make it possible to make the most of data, which is crucial for anticipating trends and forecasting risks thanks to the massive collection of data. In this context, we have identified three key areas that will help us to better anticipate, produce and sell.

1. **Better anticipate:** The aim is to detect animal and plant health problems at an early stage, and to anticipate production-related issues such as sowing dates, harvest dates, irrigation dates, etc.
2. **Better produce:** Better production means more accurate observation of farming environments through the collection of monitoring data, whether in the form of ambient sensors, videos, sound data, etc. It also means optimising and therefore reducing various aspects of the agricultural supply chain, such as the use of fertilisers, plant protection products, seeds, stock management, itineraries and even waste management..
3. **Better sell:** Improve customer relations by leveraging historical data to help customers on a daily basis, by providing alerts, reminders, etc. This also reduces the mental workload associated with administrative tasks. What's more, it means contacting customers at the right time, on the right subjects, such as order renewals, for example

Digital solutions, through data analysis and process automation, must play a key role in optimising agriculture and solving the major problems it faces.

Data sources are many and varied, and acquired via a variety of channels, including manual input from field tools, sensor data feedback (image, video, sound, atmosphere), and data aggregation via third parties: weather data, remote sensing (satellite) data, management data from public or institutional data sources, or enhanced data from private partners (suppliers of equipment, software of the DAD type, platforms for exchanging or marketing agricultural data).

There are many different types of data available, both in the agricultural and food sectors and in the agro-industrial sector. In the agricultural sector, the primary source of data is the farmer, who possesses a vast amount of empirical knowledge that is difficult to formalise. Their farms (buildings, plots of land) may be equipped with sensors such as abiotic sensors (temperature, humidity, ammonia), cameras and microphones. In animal production, the animals themselves are an important source of data. There is a wide range of information available about them, including production data (e.g. quality and quantity of milk from dairy cows), genetic data, data relating to their health and physiology (feed intake, ruminations, pulse, blood pressure), and also their physical activity (accelerometers, GPS, etc.).

In crop production, we can study the genetic potential of each crop, the yield and quality of the harvest, the various inputs used and the cultivation itineraries, including any irrigation, the state of health, including the plant protection strategy, the geographical location on the scale of the territory, the landscape or even to obtain information on the soil and the overall state of the plant, its phenological stage, its vigour, and so on.

These data can be supplemented by external data, such as weather data, for detection time data (i.e. remote sensing using satellites and drones).

In the agro-industry, we also have similar data, data from operators (inputs, location sensors, connected glasses, etc.), machines (consumption, sensors (atmosphere, sound, images, accelerometers, etc.), management data (ERP, business software), etc.).

It is illusory to think that a company can have all the data mentioned above at its disposal. The question is: what data do I really need in order to respond to my problem? It's obvious that making the most of historical data should enable us to anticipate better, so we can learn from the past to plan for the future. It's also obvious that there is enormous potential in making the most of cross-referencing multi-source data, to get an exhaustive view of the production environment (animal, plant).

It is against this backdrop that we are highlighting two research projects in this article. The first concerns the optimisation of animal production resources, with a specific focus on the optimisation and traceability of grazing through the CHRONOPATURE project. The 2nd concerns a CIFRE thesis project currently underway, the aim of which is to work on reducing the problems of respiratory disease in young cattle through the use of artificial intelligence: INSATIABLE (Innovating for Animal Health through Artificial Intelligence for Predictive Purposes).

CHRONOPATURE is a Research Tax Credit approved project, implemented by ADVENTIEL, SGPI which markets the solution, in collaboration with CETA 35 (farmers' technical group): The aim of this project is to enable optilisation and traceability of grazing.

INSATIABLE is a project developed as part of a CIFRE thesis thanks to collaboration between ADVENTIEL, UMR BIOEPAR in Nantes and UMR IGEPP in Rennes. INSATIABLE (INnover pour la Santé Animale au Travers de l'Intelligence Artificielle à finalité predictiBLE), is a project applied to respiratory diseases in young cattle. The aim is to combine several Artificial Intelligence methods to create effective Decision Support Tools (estimation of health status, early detection of clinical signs, prediction of disease dynamics, estimation of optimal control strategy).

2. Materials and Methods

a. Outdoor Monitoring

In CHRONOPATURE project, in order to calculate effective grazing time, position data were collected in about fifty different farms thanks to GPS sensors built with RF-TRACK, an equipment partner. These sensors are carried by two cows in each herd and display their position every 15 minutes via the LoRA network if the animal has moved. Detection of the animal's movement using an accelerometer saves the sensor battery, which can last from 12 to 24 months. Tracking the position and plot of the paddocks enables actual grazing time to be calculated.

Figure 1. GPS collars worn by cows

To optimise pasture, it is necessary to have access to information on the amount of grass available in each paddock. The information used by farmers in the field comes from a plate meter that measures grass height. Nevertheless, measuring takes times. To help farmers saving this measurement time, a model using satellite images to predict available biomass was built. The satellite data used come from Sentinel-2, a Copernicus network satellite whose data is accessible on an open access basis. Sentinel-2 is an optical satellite that takes images at different wavelengths, known as bands, from visible to infrared. The linear combination of these different bands is used to calculate vegetation indices. The most well-known, notably for its correlation with biomass, is NDVI. The satellite has a spatial resolution of 10 meters which allows a good assessment of the spatial occupation of biomass. Commercial satellites similar to Sentinel-2 have also been tested.

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

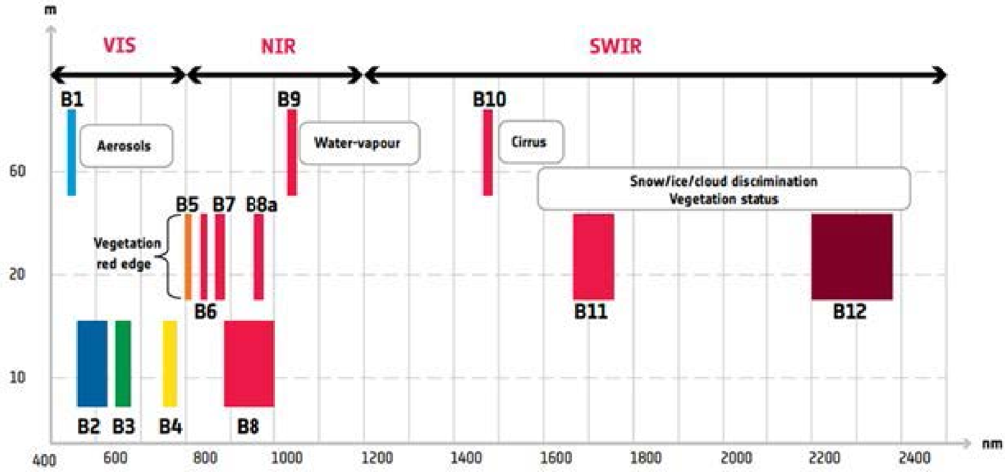

Figure 2. Positions of the Sentinel 2 satellite spectral bands and their spatial resolution in meters as a function of wavelength in nanometers. (Gatti and Bertolini, 2013).

The biomass model was built using plate meter measurements associated with GPS coordinates as field reality. Grasshopper plate meter were used, and measurements were carried out on 23 dates, on 4 farms. Measurement errors are smoothed using inverse distance weighting, and field data associated with cloudy pixels are removed. 843 clean grass height - satellite pixel associations are used to build the model. 30 vegetation indices and the 12 satellite bands from the satellite are potential candidates for its construction. During the model construction, variables were selected in a stepwise approach.

Different machine learning models built using cross-validation were tested to find the one that predicted biomass with the best performance. Since we only have field data for grass height, our biomass model is assimilated to a grass height model. In order to verify the generalizability of the best model's performance to new dates and new farms, metrics were calculated on a validation set. The metrics chosen were RMSE and Spearman's coefficient to measure both the quality of the quantitative prediction and the good relative ranking of the plots among themselves. The validation set is made up of data averaged at plot level for 4 different dates, using a different plate meter model from the one used to build the model.

b. Monitoring Indoor

In the context of the INSATIABLE research project, a comprehensive dataset was gathered from ten farms, each equipped with an array of data collection devices. The focus of this project was directed solely towards young beef bovines of the Charolais breed, as they exhibited clinical symptoms in the most discernible manner.

2 kinds of data are collected: collective and frequent data, as well as individual and occasional data. The former category included inputs from cameras, abiotic sensors, and microphones, while the latter involved a portable ultrasound scanner and an electronic stethoscope.

The cameras employed in this study were tasked with capturing video surveillance data. Possessing a wide field of view spanning 160 degrees and recording in RGB format, these cameras diligently operated during daylight hours, from 8 am to 6 pm. The recorded videos were segmented into three distinct batches, each containing approximately ten animals. The camera settings were configured to ensure high-definition recording at a resolution of 1280x1024 pixels, a frame rate of 15 frames per second (FPS), a video duration of 120 seconds, and a bitrate of 500K.

To augment their functionality, each camera was also fitted with sensors that measured carbon dioxide (CO_2) levels, ammonia (NH_3) levels, as well as both interior and exterior temperatures. These abiotic measurements were logged at two-minute intervals every day. Furthermore, the cameras were equipped with microphones to capture audio recordings of sounds generated by the animals.

Similar to the video recordings, audio data were collected daily from 8 am to 6 pm. Audio and video recordings were synchronized to commence and conclude simultaneously. In certain agricultural settings the network quality is suboptimal, so audio recordings were segmented into smaller units (each less than 100 megabytes) before transmission to the storage server. The original audio content can subsequently be reconstructed by concatenating these individual segments together.

Figure 3. Camera equipped with sensors & a microphone.

To facilitate data transmission and storage, routers were strategically installed on all ten farms. These routers played a pivotal role in facilitating the seamless transfer of data via Wi-Fi to a dedicated server designed exclusively for the INSATIABLE project.

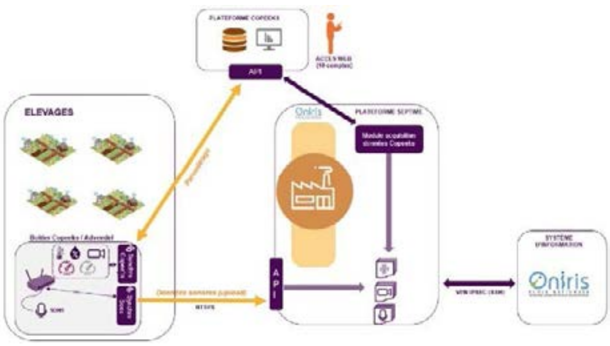

Figure 4. Pipeline created in order to collect data.

A portable ultrasound scanner was employed for the purpose of scanning the animals' lungs. The scanner generated video recordings which were conducted by a qualified veterinarian on specific days, namely Day 0, Day 2, 5, 14, 21, and 28. Subsequently, the collected ultrasound data were manually stored on a designated server for further analysis.

Figure 5. Portable ultrasound scanner.

To establish a ground truth dataset that would serve as the basis for evaluating the performance of the models, a veterinarian made regular visits to the farms to collect clinical and biological data. The clinical data encompassed temperature measurements and clinical assessments, including the nature and severity of nasal and ocular discharges, the frequency and nature of coughing episodes, and an overall clinical score. These clinical observations were conducted at a frequency of approximately every two days for each individual animal.

The biological data category encompassed blood samples and nasal swabs, which were meticulously collected on specified days (Day 0, 2, 5, 14, 21, 28). These samples were subsequently subjected to rigorous laboratory analysis to ascertain the presence or absence of pathogens associated with Bovine Respiratory Diseases and to determine the overall health status of the animals.

In sum, the INSATIABLE research project employed a multifaceted approach to data collection, leveraging advanced technologies and veterinary expertise to compile a comprehensive dataset that will underpin valuable insights into bovine health and well-being.

As for the processing methods, deep learning models are first used to extract information on the current health state of the animals. They are applied on raw data collected from the farm: lung ultrasound, video & audio records, abiotic data.

Stochastic mechanistic models will then use the information extracted by deep learning models in order to forecast the evolution of Bovine respiratory Diseases. Multiple scenarios can thus be simulated leading to the selection of the scenario having the best impact on the farm.

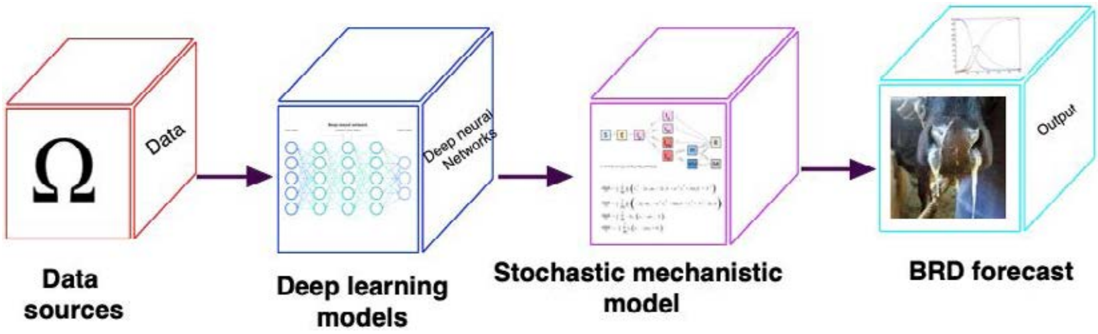

Figure 6. Pipeline to fuse deep learning with mechanistic models.

3. Results and Discussion

a. Outdoor Monitoring

The best grass height prediction model obtained has an RMSE of 2.5 cm and a Spearman coefficient of 0.65 on the validation set (Figure 7). The relative ranking of the plots is therefore quite good, and this finding is encouraged by the feedback from beta-tester farmers. Quantitative prediction is almost always underestimated and could be improved. However, this performance is encouraging, given that the validation set is slightly erroneous, due to the data being averaged at plot level and measured using a different plate meter model from that used in the training set. Furthermore, measuring grass height can be a source of error, with overestimations occurring in the presence of holes in the ground or underestimations if the grass blades are flattened. The presence of unwanted plants that are not of interest to the farmer and not measured but visible in the satellite image can also contribute to this measurement uncertainty.

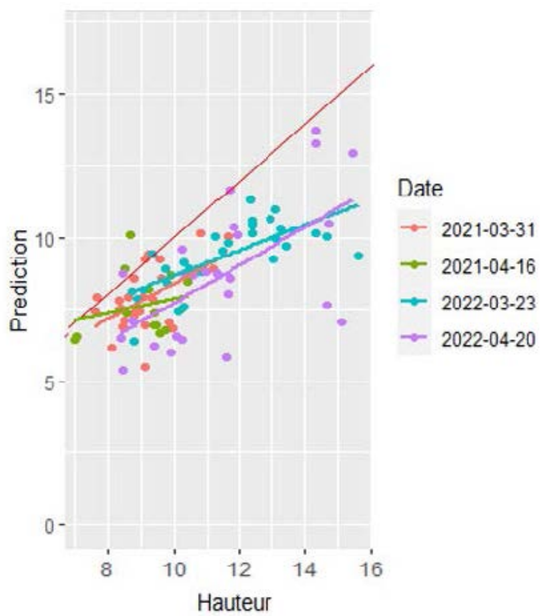

Figure 7. Performance of the best model on the validation dataset.

To improve performance, more field data are needed, as well as information on other biomass variables such as density, dry matter and floral composition. A student project in partnership with the Institut Agro Rennes Angers is currently underway to gather this missing information. In the future, grazing duration information can be combined with the results of the biomass prediction model to study the impact of grazing on biomass.

b. Indoor Monitoring

Within the framework of individual and occasional data collection, the primary objective is to harness the power of deep learning architectures for the purpose of diagnosing the health of each individual animal. Subsequently, the extracted diagnostic information will be utilized to fine-tune a stochastic mechanistic model. This calibrated model will then serve as a predictive tool to forecast the dynamic progression of Bovine Respiratory Disease (BRD) in these animals.

In the case of collective and frequent data, the methodology remains consistent with that of individual data but is applied collectively to all the animals in the study cohort. This approach seeks to leverage the wealth of data collected from multiple animals to create a holistic predictive model.

The outcomes and findings of these research efforts are not yet available. The analysis and interpretation of the collected data are ongoing, and the results will be disclosed in due course. This research endeavor holds significant promise in advancing our understanding of BRD dynamics and may have far-reaching implications for the management and health of bovine populations in the future.

4. Conclusions

This article demonstrates the growing need for the use of sensors and data collection to monitor animal welfare both indoors and outdoors. Solutions can be brought from disease prevention to monitoring compliance with specifications, as well as optimizing resource management. These technological advancements offer new perspectives for the agricultural world. By continuing this transition to digital agriculture, we can hope to improve the quality of life for animals, reduce economic losses for farmers, and contribute to the sustainability of our planet.

Acknowledgements

We would like to express our sincere appreciation to INRAE and ONIRIS for their collaboration with Adventiel on the INSATIABLE thesis project. Furthermore, we extend our gratitude to CETA35 for their invaluable support in the Chronopature project, including the generous provision of their herbometer and their valuable guidance.

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Smartbox Traceability System and Data Valorization

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Abstract

We aimed at developing control of the agricultural equipment fleet in France based on data generated in the field. The main results stand in an effective connection to Farm Management Information System such as "MesParcelles" which allows to obtain a better visibility of the use of equipment fleets so that manufacturers can offer an improved after-sales service while farmers save time in the field.

This experimentation revealed interest in automatic data collection and data sharing to serve many other use cases from input management to the granting of crop subsidies with better remuneration for farmers..

Keywords : Connected Smartbox, Automatic traceability, All-equipment compatibility, Data collection and exchange, Consent, Crossover Data Valorization.

1. Introduction

The agricultural environment is evolving with the implementation of digital means to facilitate and optimize the work of the farmer, but also to develop new uses related to agroecological transitions, traceability, logistics optimization; and to better reward sustainable practices. The market is made up of all upstream and downstream agricultural players, supported by public initiatives and the desire to develop national and European sovereignty over this agricultural economy both in terms of production and dissemination of data from the sector's activities.

The European regulatory framework guides these new solutions and aims to protect stakeholders by ensuring that everyone preserves their interests while benefiting collective projects which initiate the transformation and evolution of practices. In our activities and in the context of this experiment, we rely on the Data Governance Act* and the Data Act*, which frames data exchanges, defines the role of stakeholders and underlines the level of security of service infrastructures while paving the way for the interoperability of systems.

The French group ZeKat, specialized in the design and implementation of IOT solutions, is present in the agricultural, logistics, construction and environmental sectors.

By cross-referencing our feedback on different markets, we have highlighted recurring issues that can hinder the deployment of solutions, and keys to success related to the exploitation of shared business data by offering new high-value services. Agdatahub as a trusted third-party data intermediary offers a data exchange platform with authorization control related to data from farms. It thus connects the entire agrifood sector through efficient and secure solutions to deploy many use cases in the sector. Starting from the observation that there is no feedback on the uses of agricultural equipment resulting in a high untapped potential and poor control of the level of the active equipment fleet, we focused our experiments on the prerequisites necessary for the exchange of data on a typical fleet, the construction of information flows between the different systems and the resulting opportunities for use for the farmer and the agricultural ecosystem in the broadest sense.

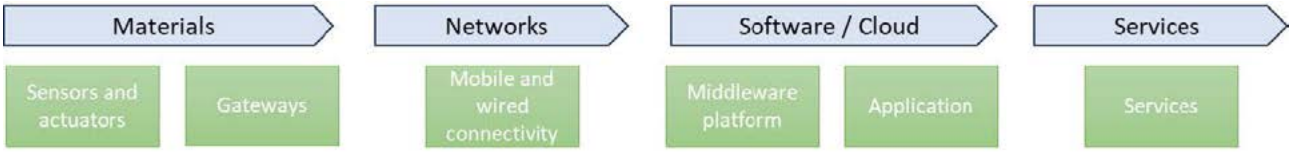
Our objectives started from a connection between a traceability solution based on the Smartbox and connected to the FMIS in order to allow automatic entry of business data from field data collection. We will see the challenges related to IoT solutions in the method part. This solution intended for the farmer can be extended to multiple use by sharing data. We wanted to build a solution that meets regulatory requirements and we therefore chose to refine our experimentation on the management of a sprayer park by promoting the development of useful services with probative value.

During this experiment, we demonstrate the optimal approach to capitalize on machine investments and develop the value of a sprayer fleet based on data sharing.

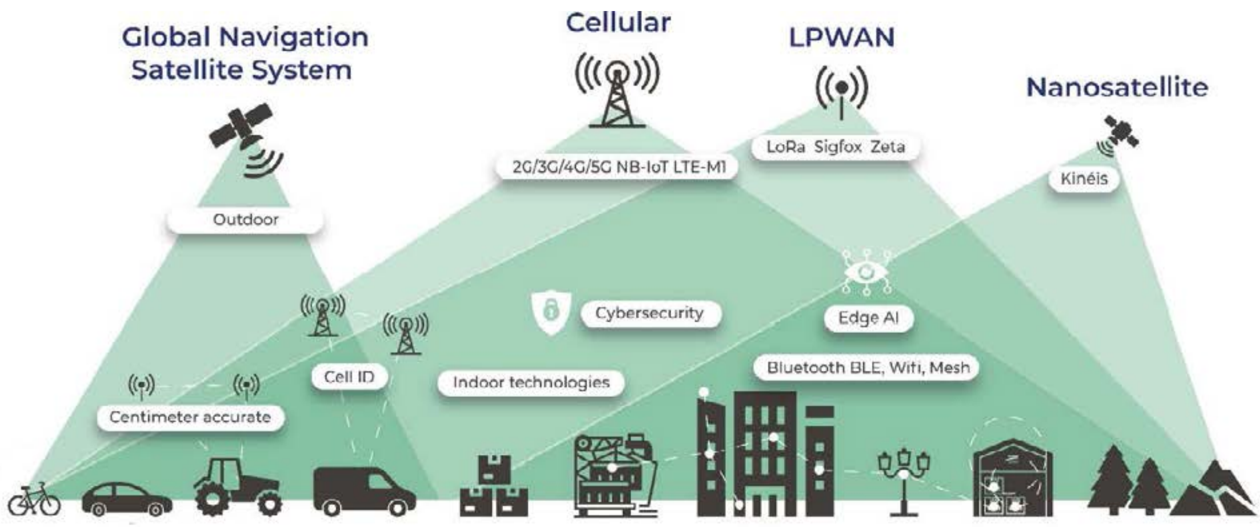
2. Materials and Methods

2.1. The data collection chain and its challenges for successful commissioning

Field data collection solutions and the provision of value-added services based on business data rely systematically on an **IOT chain**:



This IOT chain is complex because it relies on different communication networks that are constantly evolving and whose choice depends on the use, the amount of data to be transported, the frequency of collection, the network coverage, the available energy and the lifetime of the solution.



The Zekat Group designs and has solutions used in various use cases, including:

After several years of experience, we can identify all the **success factors of a solution** for a given use :

- **Mastery of** complex data collection and processing **technologies;**
- Mastery of the evolution of communication networks;
- Know-how in "device management";
- The range of **industrial products** and services available from the IOT solution provider;
- The **reliability of the IOT solution provider**
- The simplicity of commissioning and use of the solution on an existing fleet and/or on new equipment;
- Proper data separation :
  - **Operational data** of sensors / objects / network / object management platform (for example GNSS position, vibration...);
  - **Business data:** management of a fleet of equipment / management of a technical route in the context of use (plot inputs/ outputs, surface worked, tool utilization rate, inventory, etc.);
  - **Machine data** collected directly by manufacturers of connected machines (energy consumption, etc.);
  - **Available data** from the cloud (weather, parcel, tool park, etc.).
- **Compliance with data protection :**
  - **Cybersecurity**: the applicable standards according to the RED DIRECTIVE (ETSI EN 303 645), ANSSI (CSPN, EAL ...)
  - The **regulations** associated with **personal data** (GDPR) and **professional data** (Data Governance Act)
  - Data **sovereignty** in the agricultural sector
- The need to **standardize** data by business Examples: Autosar in the automobile, J1939, ISOBUS...
  - With the Numagri association and its objective to bring out a common language of agricultural data:
    - Which integrates existing standards;
    - Which makes it possible to promote **interoperability** to better exploit the **data mastered by farmers;**
    - Which commits the sectors to jointly build future standards*.
- **Creating data sharing models and new services :**
  - Identify the actors of the service;
  - Identify key business data to share;
  - Access a consented data sharing platform;
  - Determine the valorization of the data and the evaluation of an associated reliable ROI to the different actors;
  - Rely on the crossover principle to generate multiple services;
- **Interoperability between solutions** :
  - Between the FMIS and the Smartbox solution which allows automatic exchange between the 2 systems for :
    - Real-time data updates ;
    - The automatic declaration of new Smartbox on the FMIS MesParcelles;
    - Avoid double entry.
  - Interoperability at the level of the input data to the service and at the level of the data generated by the service itself: which allows the consumption of crossover data :
    - Advantage of interoperability input data: instantaneous exchanges and real-time data updates (time saving and automation);
    - Advantage of interoperability of output data: crossover through a data exchange platform and simplification of the exploitation of data in other systems.
- **Partnership of experts** on the development phase (POC phase) :
  - IOT expert: device management, choice of technologies;
  - Business expert in the field: development of the solution in the field;
  - Expert Service: identification of the business data necessary for the service.

2.2. Feedback on the SmartBox project

To illustrate the relevance of these challenges, we present a use case experienced within the ZeKat group: the automatic entry of the traceability of intervention on the plots with the SmartBox solution to the MesParcelles tool. Prior to the installation and use of this solution, the farmer subscribes to Mes-Parcelles' automatic traceability service and confirms his consent to exchange his data between Mes-Parcelles and ZeKat.

This solution consists of two parts:

1. A first part that the farmer installs and uses with his agricultural equipment:

• a "Smarbox" telemetry box that the farmer plugs into the cab of the tractor or self-propelled vehicle	
• a Bluetooth Low Energy beacon** box per tool that makes up the hitch	
• a mobile QR code reader that the farmer uses when loading inputs	

2. A second part composed of a smartphone application:

It allows the farmer during installation to declare the association between a "box identifier" and a tool "serial number"	
In real time, visualize the loading of scanned inputs	

At the end of the tour, visualize the generated interventions in the plots and validate them	
Once validated, the farmer finds his interventions automatically incorporated into his Mes-Parcelles environment	

The solution is based on the following **operational data** :

- Knowledge of the plot of the farm (data available because already informed on Mes-Parcelles by the farmer);
- The "serial numbers" of the agricultural equipment concerned (data available because already entered on Mes-Parcelles by the farmer);
- A standardized Inputs reference (phytosanitary products such as Lexagri) or codified by a third party (by Mes-Parcelles for example);
- The GPS track from the SmartBox;
- Beacon detection placed on the tool ;
- Product codes read on packaging from the hand shower to the loading of an input.

At the end of a chain composed of algorithms and management rules, it makes it possible to restore the following **business data**:

- Grouping of interventions by tour;
- The composition of the tractor coupling + tool(s) ;
- The surface worked in each plot by the tool(s);
- Working time at the plot;
- Loading with inputs (products and quantities incorporated).

The **strengths of this solution** with regard to the challenges described above are :

- Technical expertise :
  - Operation in white zone;
  - Easy installation and remote maintenance;
  - Independent of the tool and its manufacturer and therefore suitable for aftermarket equipment;
  - Good separation of operational and business data (GDPR...).
- Business expertise :
  - Business data is generated using shared identifiers between the ZeKat service cloud and the Mes-Parcelles software;
  - Learning multiple operational patterns for intervention generation during field adjustment (e.g. plots crossed and not worked for example).
- Interoperability with the FMIS Mes-parcelles through APIs, after obtaining consent :
  - Interoperability of input data to the service (i.e. parcel data, tool(s), input(s));
  - Interoperability of the interventions generated (plot area worked).

The weak points of this experience with regard to the challenges of this solution are :

- Duration of field adjustment related to diversity of practices;
- A valorization of the dataset generated by the device limited only to the traceability of interventions for the farmer;
- Data from shipments, representative of product consumption, do not enrich the stock management of the inputs concerned;
- The data from the hitch journeys do not enrich fleet management (operationally: working time

and travel time; excluding operation: equipment available for sharing);

- Deferred, the data is not anonymized to feed complementary third-party services (for example benchmarking of the farm in its reference group on economic, technical or cultural criteria).

The new multi-segment and therefore multi-service orientations :

- Identification of the uses of the different actors to develop multi-services :
  - In addition to the automatic traceability of interventions :
    - Optimize spraying operations and other cultural phases;
    - management of agricultural equipment fleets.
  - and more generally :
    - sharing data with ecosystem actors;
    - allowing the creation of complementary services.
- The publication of business data by relying on a data intermediation platform such as Agdatahub in order to share them with other actors or to feed existing data solutions to enrich them.

2.3. Data valorization

The data thus generated, whether raw or enriched by processing and cross-referencing, have a value at several levels that it is useful to circulate to benefit everyone. Agdatahub supports companies on various axes ranging from the definition of their use case, to the construction of pilots and the definition of data offers to allow an actor or an ecosystem to exchange data in order to value or monetize it. This leads to defining standards that make the use of data by other solutions or actors interoperable.

The automation of exchanges and their simplification, by avoiding double entries for example, are offered through its intermediation platform which does not store nor processes data.

By acting as a trusted third party, Agdatahub also ensures control of the data by circulating only the data consented to by farmers when it concerns them. To do this, it proposes a consent manager that facilitates the collection of authorizations for an actor who wishes to use data from farms.

3. Results

We noted several elements in our results that may be part of good practices to be repeated on future experiments that would aim to work on other agricultural practices and other materials, and which would thus promote the development of new services.

Among the best practices, we would like to highlight:

- The first questions to ask yourself before starting a project :
  - For how long the solution is planned to live ?
  - What is the cost of the investment ?
  - Calculation of ROI = value of service rendered - TCO.
- The TCO (Total Cost of Ownership) takes into account the purchase of equipment, installation, maintenance cost, support, and device management which is essential for the maintenance in operational condition of the solution.

For example, in our experience, one axis of TCO reduction lies in the remote management of boxes and software updates: planning and supervision are done on a central remote administration platform of the entire fleet. This also makes it possible to program the ramp-up in the industrialization phase to keep costs under control.

- The distinction between at least 2 professions: one associated with the management of the IoT park and the other related to the management of the equipment fleet;
- Identification of the data to be aggregated and their standardization towards a common repository :
  - For example, the harmonization of digital identity starting from the same serial number as a starting key to the sharing of data concerning a tool.
- The use of a data intermediary to extend the interoperability of data and uses by making them accessible to all.

We believe in the value of the datasets generated and the reach they can find through a platform like Agdatahub. Indeed, the project led us to work as a private group within it but, with the cross-referencing and enrichment of data that can now be done through data sharing, the publication of these results on the platform's MarketPlace allows us to appear in the public catalog and increase the visibility of data offers and services to benefit the entire agricultural ecosystem from multiple uses opportunities.

4. Discussions

We value experience on the standardization of plant protection products but we will be able to duplicate experience on other inputs. It would be interesting to deploy the exercise on seeds for example.

It might also be appropriate to create a link between the data of the different manufacturers and spray manufacturers on Agdatahub. We are moving towards a consented data sharing concerning non-personal data to ensure trust and transparency in exchanges. Data anonymization is a plus to accompany the adoption of the crossover model.

It also remains to explore the question of ownership of software publishers' formats and the creation of an international standard at the level of agricultural equipment manufacturers as it exists in other sectors, for example: Autosar for automobiles – Isobus for machine data

5. Conclusions

The single-service stage combined with a data exchange platform facilitates the development of multiservices with a repositories standardization work and a study on the business model to redistribute value.

We have thus seen the added value of a dataset in the services it feeds, and we have addressed part of the issue of the redistribution of value to the actors who support the TCO :

- Farmer: automatic entry of his interventions, quality of the advice provided for the management of his farm;
- Manufacturer: maintenance planning and optimization of after-sales service;
- CUMA: optimization of the equipment usage rate, identification of equipment and preventive maintenance;
- Cooperatives: inventory management, logistics;
- Input supplier: better forecasts of the demand for their products;
- Service providers: enrichment of Decision support tool and consulting;
- Agri-food: traceability;
- Institutional: traceability on the use of phytosanitary products and tomorrow on carbon KPIs that will be imposed via regulatory calculation methods, for example on the carbon footprint of farms.

At the same time, each actor is free to put in place trade policies that benefit farmers in return for sharing their data, such as :

- Manufacturers: financing of all or part of the deployment of the Smartbox on sprayers;
- Institutional: Greenhouse gas enhancements;- Service providers: carbon credit eligibility;
- Agri-food: more expensive purchase of crops;
- ...

In concrete terms, the farmer agrees to make his data available to various beneficiaries to the extent that he obtains remuneration, whether financial or in terms of the quality and complementarity of the additional services provided in return.

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*https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022R0868

** Beacon: Boîtier d'identification sans fil

KEEPING AN EAR ON YOUR FARM: THE BENEFITS OF SOUND MONITORING

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Abstract

ANIMAL WELFARE has gained prominence among scientists and the public. Consumers demand ethical livestock practices, necessitating effective monitoring. While video data is analyzed, audio data remains under-utilized despite its potential for assessing animal health and welfare and support systems evaluation.

Breeding livestock while managing daily tasks poses challenges. Continuous environment monitoring is vital but often involves manual labor and expertise. Animals produce diverse vocalizations conveying emotions. Real-time detection of sounds like cries, grunts, and health-related noises offers precise welfare indicators across sectors. Vocalizations also help assess mechanical activities like ventilation.

Complex sound analysis requires specific AI techniques. For most applications, annotated data is essential, involving associating audio samples with events. Adventiel aims for customizable solutions, reducing annotation time using clustering to identify distinct sounds. Annotated data trains machine learning models for real-time event detection through edge computing, addressing connectivity issues.

Data is presented via dashboards, enabling users to monitor animals and systems, enhancing management. Adventiel introduces EARWISE (Equipment & Animal Recognition With Intelligent Sound Evaluation), an adaptable technology improving monitoring through sound analysis. Sound monitoring can be extended to agri-food, pest detection, and veterinary stethoscopes.

Leveraging sound data advances animal welfare assessment and management, with applications beyond livestock.

Keywords : monitoring, sound, artificial intelligence, deep learning, animal welfare

1. Introduction

Animal welfare has emerged as a significant concern within both the scientific community and the broader society. In response to growing consumer demand for ethical practices in livestock farming (Bellassen et al., 2022), there is a heightened need to develop effective and innovative methods for monitoring and ensuring the well-being of animals. While visual surveillance has traditionally been the primary approach for assessing animal conditions, the potential of audio data in contributing to this endeavor has remained largely untapped. This paper addresses this gap by exploring the underutilized realm of audio data analysis and its implications for enhancing animal welfare assessment.

Livestock breeders face multifaceted challenges as they strive to maintain optimal health and comfort for their animals while effectively managing day-to-day operations. Central to this challenge is the requirement for continuous environmental monitoring, which, though crucial, often demands substantial manual effort and specialized expertise for data interpretation. The acoustic landscape within which animals reside is replete with a rich tapestry of vocalizations, each potentially conveying important insights into the animals' well-being and emotional states (Laurijs et al., 2021). Real-time detection and analysis of various vocalizations, such as cries, grunts, and specific health-related sounds, hold the promise of providing accurate and timely indicators of animal welfare across diverse sectors of livestock production.

This study aims to bridge the gap between the potential of audio data and its practical application in enhancing animal welfare assessment. The objectives of this work include exploring the feasibility of utilizing audio data for monitoring and interpreting animal well-being, developing robust techniques for acoustic event detection and interpretation, and investigating the potential for integrating these findings into existing animal management systems. By harnessing the power of artificial intelligence (AI) techniques, specifically tailored for audio analysis, we aim to unlock the valuable insights embedded within animal vocalizations, thereby enabling more comprehensive and nuanced monitoring strategies.

In the subsequent sections, we present the materials and methods employed in our study, offering detailed insights into our approach to data collection, annotation, and analysis. We then discuss the results of our investigations, shedding light on the efficacy of the proposed audio-based welfare assessment methodology. The implications of our findings are deliberated upon in the context of both animal welfare management and broader agricultural practices. Finally, we summarize our research outcomes and propose avenues for further research and practical implementation in the field of animal welfare assessment. Through this endeavor, we aspire to contribute to the advancement of innovative and ethically grounded approaches to livestock management and welfare monitoring.

2. Materials and Methods

The proposed solution, known as EARWISE (Equipment & Animal Recognition With Intelligent Sound Evaluation), aims to enhance animal welfare assessment and monitoring through innovative audio analysis techniques.

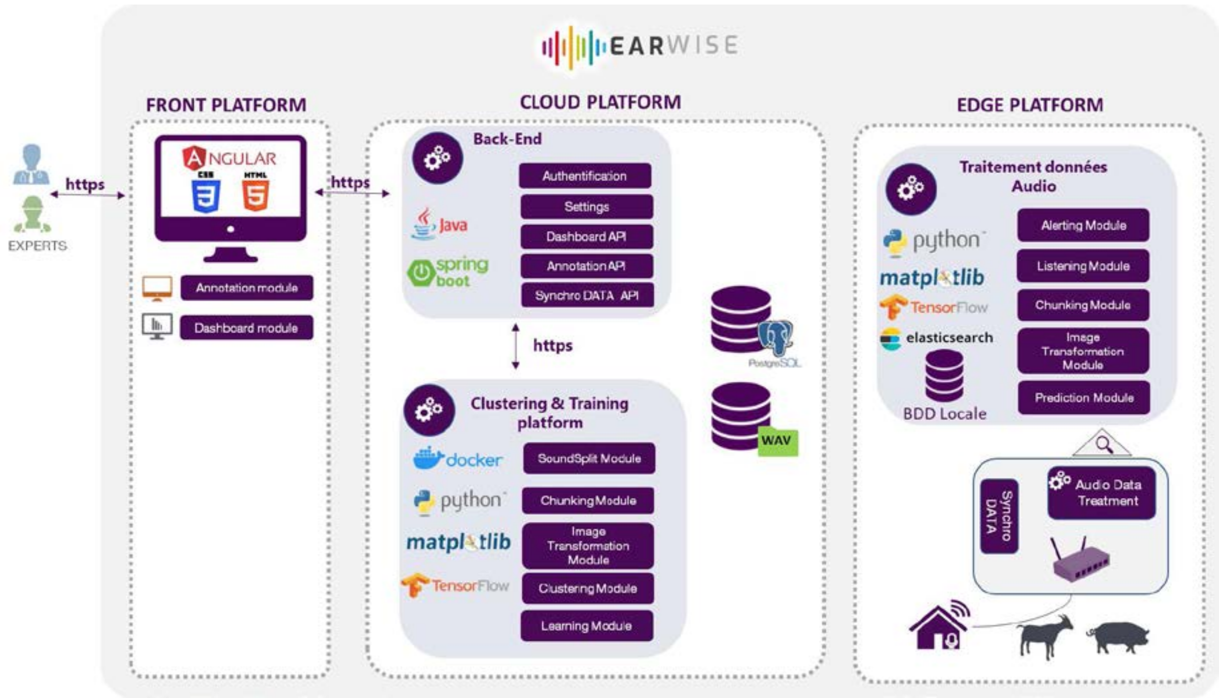

Figure 1. General architecture diagram of the EARWISE solution.

This comprehensive system as described on Fig 1, comprises four modules, each addressing distinct aspects of sound-based welfare monitoring:

Specialization-Personalization Module:
This module empowers farmers to annotate pre-selected sounds captured by algorithms, tailoring surveillance to their specific constraints and concerns. Farmers can set alert thresholds for each relevant sound event, such as coughing frequency or ventilation anomalies. Notifications are automatically sent if thresholds are exceeded or if unique and uncharacterized events occur.

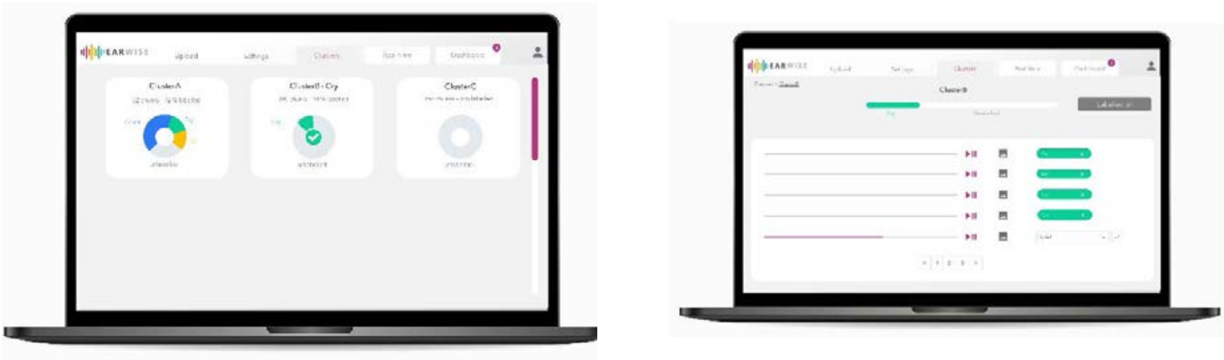

Figure 2. Two critical screens of the Specialization-Personalization Module, designed to help experts in annotating their reference sound segments.

Local and Frugal Active Listening Module:

Real-time sound event verification is achieved through in-depth analysis of sound characteristics and supervised machine learning. Event data is time-stamped and saved, and audio recordings are retained only for unrecognized or explicitly requested events. By employing edge computing and strategic data retention, the module strikes an optimal balance between effective event detection and safeguarding data privacy. This unique combination of technical and audio data analysis facilitates swift problem detection and proactive intervention.

Visualization Module:

This module enables tracking of frequency and intensity curves for each sound event. The user-friendly application interface facilitates identification of temporal anomalies and correlation with other ambient parameters measured by connected sensors, such as thermometers, hygrometers, water or electricity meters, and even ammonia sensors.

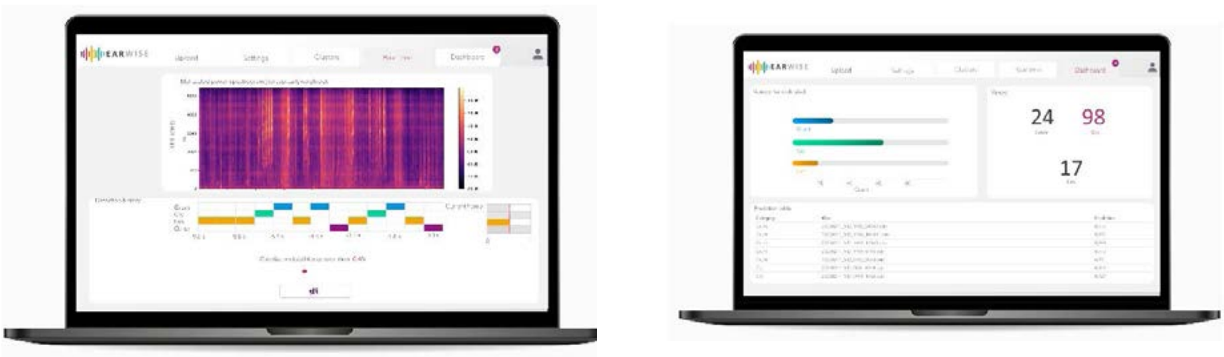

Figure 3. Two screens of the Visualization Module, designed to help farmers to monitor their animals and equipment. The first one illustrates the continuous monitoring and has not yet been developed, as Adventiel never had to upload direct sound stream as the intelligence is kept local.

Data Sharing Module:

Farmers will be, in a future version of the solution, able to share data with veterinarians or partners to establish diagnostics for complex situations. Data is of high value, particularly for cases with significant historical health or equipment-related context. Partnering veterinary laboratories can leverage the data for treatment effectiveness assessments or protocol adjustments based on evolving indicators.

The development of EARWISE involved cutting-edge technologies, including machine learning, real-time edge computing, and audio signal processing. The system was collaboratively designed with livestock experts to address practical farmer needs. It is user-friendly, configurable, and scalable.

This solution is designed to be versatile and adaptable across multiple sectors, including bovine, swine, caprine, and poultry farming. The solution also presents promising prospects in agri-food industries, pest detection, and integration with veterinary tools such as connected stethoscopes.

The sound monitoring solution is presently undergoing comprehensive testing across various sectors within ongoing projects, several of which are kept confidential due to proprietary considerations. Of notable significance, the solution is undergoing rigorous assessment within the porcine farming sector, aiming to anticipate and detect instances of caudophagia – a phenomenon characterized by tail-biting behavior in pigs. This agronomic occurrence, influenced by a multitude of factors including stress and environmental conditions, can profoundly impact animal welfare and productivity.

In this endeavor, Adventiel works for diverse stakeholders within the animal farming industry, including esteemed organizations such as IFIP. An illustrative instance is the SOLBI (**SO**unds **L**ike **BI**tting) project, led by IFIP in conjunction with INRAE and financially supported by Carnot France Futur Elevage. The overarching goal of the SOLBI project revolves around characterizing sounds associated with the manifestation of tail-biting behaviors.

Valérie Courboulay, a research engineer at IFIP and a recognized authority in animal welfare, elucidates, "Tail-biting remains a persistent challenge within pig farming operations, especially in instances where tail docking is not practiced. The paramount objective is to subsequently develop a tool that guides pig farmers towards a gradual cessation of tail docking practices within livestock operations. (Translated from French). This collaborative effort exemplifies the commitment to enhancing animal welfare and aligning industry practices with ethical considerations.

In addition, within collaborative research involving the French national research institute for Agriculture, Food, and Environment (INRAE), we are actively incorporating sound monitoring. This project, conducted as part of Theophile Eyango's PhD research and supported by Adventiel, is entitled 'INSATIABLE' (Innovating For animal Health through Artificial Intelligence for predictive purposes). The aim is to combine deep learning models with stochastic mechanistic models to automatically diagnose the health status of young cattle and also the predict the progression of respiratory diseases. Sound monitoring plays a crucial role in this study, facilitating the identification of respiratory abnormalities such as coughing, sneezing, and irregular breathing patterns.

In parallel, the specialisation-personalisation module was evaluated on a reference dataset. In the following section, we detail the results we obtained on this dataset.

3. Results and Discussion

To evaluate the effectiveness of the specialisation-personalisation module, a comprehensive test framework was set up using a reference dataset. This dataset consisted of 3 sound segments, each thoughtfully constructed by concatenating randomly selected sounds from the Animal-Sound reference database. The module was applied to this reference dataset, allowing us to rigorously evaluate our clustering algorithms.

Clustering algorithms were employed, and their relative performances were meticulously examined. 10, 20, 40 and 80 clusters were generated on the benchmark dataset. Notably, the sensitivity and specificity of each algorithm's clustering outcomes were meticulously recorded and analyzed.

The results of this evaluation provided a better understanding of the distinctiveness of the groups of sounds. It is clear that the most distinctive sounds were easily isolated within the individual groups. However, for some events (chickens and birds) perceived as acoustically close and likely to be confused by the human ear, a degree of iterative refinement was sometimes required. Sometimes, closely related species can appear in the same group, while one of the two species belongs to another group. This can be explained by the grouping on vocalizations, which brings closely related species together for low-frequency sounds representative of well-being and high-frequency sounds more representative of ill-being.

Remarkably, this iterative clustering approach showcased its practicality. By annotating only 15 % of the dataset, which equates to a time-saving of 1 hour 2 minutes and 6 seconds in manual auditory analysis for a total audio duration of 1 hour 12 minutes and 30 seconds minutes, a commendable level of reliability, the quantification of which is still under evaluation, was achieved. This efficiency-oriented methodology underpins the practicality and usefulness of the Specialization-Personalization Module in real-world applications.

The recently trained models are presently in the testing phase. This approach will be implemented using real data collected from farm buildings under real-world conditions, with the aim of carrying out real-time analysis. Moreover, it is pertinent to note that ongoing efforts include the re-evaluation of all algorithms on authentic field data derived from diverse livestock farming projects. These field data, obtained from ongoing developments in various sectors of livestock production, provide a tangible context for validating the robustness and adaptability of the algorithmic approaches.

Notably, the implementation of the solution, has yielded substantial time savings in audio data annotation. Adventiel's estimation of a time gain of approximately 80% based on the previous work on the benchmark dataset, assumes paramount significance, given the inherent challenges and resource-intensive nature of mobilizing domain experts for annotation tasks. The module's streamlined and efficient annotation process significantly contributes to the solution's overall effectiveness, particularly in situations where continuous expert availability remains unfeasible.

The evaluation of the Specialization-Personalization Module not only highlights its potential in effectively annotating and personalizing sound event detection but also uncovers the intricate interplay among clustering algorithms, iterative refinement, and the distinctive auditory attributes of livestock environments. Moreover, ongoing validation with real-world data ensures the module's adaptability and resilience across diverse agricultural scenarios.

The ongoing testing and validation of the global sound monitoring solution (EARWISE) highlights its potential to revolutionize animal welfare assessment and management. By harnessing the power of cutting-edge technologies, such as deep learning and real-time audio analysis, sound monitoring demonstrates the feasibility of proactive event detection and its implications for timely intervention. Additionally, its application across diverse sectors, including porcine and bovine farming, underscores its versatility and adaptability.

Pauline Creach - ITAVI - Precision Livestock Project Manager explains : "The prevention of diseases and behavioral deviations is crucial for ensuring the health and well-being of poultry in farming environments. Swiftly detecting the early signals of a health episode enables the application of preventive medicine, averting the worsening and spread of issues within the poultry group. Sound monitoring tools now provide access to indicators of animal activity levels or specific sound profiles associated with certain behaviors, indicative of health or behavioral problems. Collaborating with Adventiel and the Data'Stat service of the Livestock Institute, ITAVI aims to leverage acoustic analysis for the early detection of behavioral and health disorders in broiler chickens and laying hens in commercial farms. The Acoust'CHICK 2.0 project has been designed with this goal in mind and is currently awaiting funding.

Sébastien Picault - Research Associate INRAE, HDR - UMR 1300 BIOEPAR, elaborates : "The use of sound to construct indicators for animal well-being and health within farm environments is a rapidly emerging field, encompassing the identification of potential diseases (e.g., coughing, as observed in INSATIABLE for bovine respiratory diseases), the emotional state of animals (e.g., Céline Tallet's work on pig vocalizations), and abnormal behaviors (e.g., the Carnot France Futur Elevage project 'SOLBI' on tail-biting at IFIP). However, at this stage, various finalized research projects addressing these questions lack an integrated solution. Such a solution would not only provide reliable technical solutions for real-time monitoring (deployment in farming, connectivity, data management) but also integrate well-developed research outcomes or ongoing prototypes for sound data processing (annotation, learning, testing, and prediction) within a unified software environment."

These insights from Pauline Creach and Sébastien Picault serve as strong testimony to the growing importance of sound monitoring for animal health and welfare on livestock farms. The global and integrated approach of EARWISE, as discussed above, aligns with the trends and challenges highlighted by these experts. The ongoing collaborations, as illustrated by their contributions, are poised to make a significant contribution to the evolution of precision livestock management practices.

4. Conclusions

The integration of sound monitoring into current research projects demonstrates its potential to advance the fields of agronomy and veterinary science. Combining the analysis of complex sound data with epidemiological models holds promise for redefining disease surveillance and prediction, contributing to improved livestock health and welfare. Notably, the solution's iterative clustering approach has demonstrated commendable accuracy on the reference dataset that is still being evaluated, while also delivering significant time savings in data annotation - a reduction of 85% - a crucial achievement given the resource-intensive nature of expert annotation.

In summary, the ongoing testing and evaluation of EARWISE across a range of projects highlights its potential to improve animal welfare, disease prediction and overall management strategies. Offering both a high level of accuracy and efficiency, this solution opens up new avenues for effective sound-based surveillance. The modular nature of EARWISE guarantees complete customization, making it adaptable and integrable with customers' various information systems. In addition, the collaboration between ADVENTIEL and customers in the selection of hardware guarantees a tailor-made hardware configuration optimized for specific use cases.

As the study continues to evolve and the digital results consolidate, EARWISE is ready to validate its effectiveness and consolidate its role as a transformative tool. Its potential contributions to the agricultural and veterinary sectors are underlined by its ability to integrate seamlessly into existing systems, redefining the noise monitoring landscape and propelling these fields into a new era of innovation and sustainable practice.

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- Pauline Creach, Precision Livestock Project Manager at ITAVI (Technical Institute for Poultry, Rabbit, and Fish Farming), for her thoughtful contributions and perspectives. ITAVI's dedication to applied research and support for professionals in poultry, rabbit, and fish farming has greatly enriched our work.
- Sébastien Picault, Research Associate and HDR (Habilitation à Diriger des Recherches) at INRAE (National Research Institute for Agriculture, Food, and the Environment), in collaboration with ONIRIS (National Veterinary School of Nantes-Atlantic). Their combined efforts have been instrumental in advancing our research endeavors.

Their willingness to share their insights and interest in the EARWISE solution has undeniably played a pivotal role in shaping its development and potential contributions to the agricultural and veterinary sectors.

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Mandatory Inspection Database Results for Sprayer Calibration

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Abstract

The Néopulvé is a project focused on improving the performance and use of sprayers in the context of sustainable agriculture and the reduction of pesticide use based on the mandatory sprayer inspection database, which was first implemented 14 years. Up to now, about 360 000 sprayers were inspected. And the main defaults identified for each sprayer type (boom sprayer, vine sprayer, orchard sprayer, fixed and semi-mobile sprayers). Will be used to develop the training course addressed to the main stakholders likewise farmers, technicians and advisors but also students.

So far, the extracted and identified defaults fall into four main categories: those related to operator safety towards mechanical risks (shape of the chassis, boom, PTO shields and covers, etc.), those involving errors in the application of the prescribed dosage, those leading to environmental and operator hazards, and sprayer defaults related to the construction of the machine (power and turbine management, etc.).

The project is based on three main actions. 1) Exploitation of the database and quantification of impacts with the help of a group of experts Impacts may be defined through simulations or experiments. 2) The design of the training material will be disseminated to different parties through the training tutors' incentives. The upgrade of the project may also be found in digital form. 3) prospective activity with the manufacturers association in order to define, based on the list of defaults, new sprayer specifications more adapted to the application of bioproducts.

The current focus is centered on the database extraction of the type and likelihood of defaults based on age and sprayer technology, referring to the compliance of sprayers to inspection, Approximately 20% of the inspected machineries are approved only after repair, where we find that about 72% of the sprayers are fieldcrop boom sprayers, 21% of them are vine sprayers, and the rest are orchard sprayers.

Regardless of the sprayer's build date and market renewal regulations. The defaults appear with each inspection where few factors could link those defaults (or inappropriate settings) to impacts in terms of spray dosage and spray distribution on the crop from a quantitative perspective. Finally, the efficacy of liquid application of bioproducts will be strongly dependent on the precision and calibration of the sprayer settings.

Keywords : Néopulvé project, DataPulve database, sprayer defaults, operator safety, spray calibration training, mandatory sprayer inspection.

1. Introduction

Effective spray application entails the even distribution of the mixture across the entire foliage with minimal waste to the environment (air, vegetation and soil). It is typically carried out blindly, with the only monitored parameters are the indirect measures like sprayer pressure and the forward speed.

However, using an improper equipements, making poor adjustments, practicing improper treatment techniques can result in a significant amount of product being sprayed away from the targeted area, this can lead to increased health risks including exposure to: 1) pesticide handlers; 2) residents near the treated areas, including vulnerable populations such as children, the elderly, and patients; 3) compromised water quality; 4) harm to wildlife and flora; 5) degradation of air quality and soil; 6) adverse impacts on neighboring crop production; and 7) economic losses for the operator due to increased production costs resulting from excessive product consumption, which may lead to treatment resistance and eventual yield loss (CGAAER n° 16097).

In the 2017 Finance Bill, the budget section for the agriculture, food, forestry, and rural affairs mission outlined strategic goals for the 206 guidelines, which emphasize food safety and quality. These goals aim to promote practices that safeguard public health and the environment while seeking to prevent and reduce health risks throughout the production process.

Public policies serve as a crucial reminder of the significance of issues related to spraying equipment. The sprayer inspection and calibration package aligns effectively with the priorities of the ECOPHYTO plan, incorporating phytosanitary product economy certificates (CEPP) and emphasizing initial and ongoing training in the plant protection products certification program (CERTIPHYTO). Additionally, it demonstrates reduced product application through well-calibrated equipment. To this end, mandatory sprayer inspections were established in compliance with European Directives 2009/127/EC and 2009/128/EC, requiring Member States to conduct inspections at least once every three years as specified in Decree No. 2018-721. These inspections adhere to guidelines and standards ensuring impartiality, independence, confidentiality, inspector qualifications, and training, which include compliance with EN ISO 16119, ISO 16122, ISO 17020, and Directive 2006/42/EC.

The inspections were implemented 14 years ago. Up to now, about 360 000 sprayers were inspected on the classified sprayers, boom sprayer, vine sprayer, orchard sprayer, fixed and semi-mobile sprayers).

Launched by the French Ministry of agriculture, the Néopulvé focuses on improving the performance and use of sprayers for sustainable agriculture and the reduction of pesticide use by developing training material for farmers based on the sprayer inspection data (Bouchekoum et al., 2023). The project is based on three main actions. 1) Exploitation of the database by Identifying and classifying the main defaults in spraying equipment across all sectors, based on their potential impact on performance in terms of dosage or drift risk to provide quantitative data on the consequences of observed defaults with the help of a group of experts through simulations or experiments.

2) The design of the training material will be disseminated to different parties through the training tutors' incentives. The upgrade of the project may also be found in digital form. 3) Prospective activity with the manufacturers association in order to define, based on the list of defaults, new sprayer specifications more adapted to the application of bio-products.

2. Materials and Methods

The project acknowledges the existence of good agricultural practices and practical training initiatives. Provided by private inspection training centers or institutions such as the agricultural chambers and technical institutes (IFV, CTIFL, and Arvalis).

Notes that they often do not sufficiently address the risks and consequences of defaults or improper settings. Moreover, independent educational resources for sprayer use training are scarce. The project seeks to fill these gaps by leveraging the inspections' database, the DataPulvé, which is a comprehensive database containing information on sprayer conditions, equipment types, and recurring identified defaults, to classify them across all sectors based on their potential impact on performance in terms of dosage or risk of drift. To finally create a training material for the stakeholders (farmers, technicians, inspectors, advisors & students).

In addition to the interviews conducted with farmers, sprayer inspectors, and machinery experts from various regions in France across three agricultural sectors (vineyards, fruit, and field crops).

Field observations were made in order to identify the limitations faced during sprayer calibration and maintenance, as well as to gather expert advice and perspectives on sprayer settings. Furthermore, the project also sought to capture the wishes and recommendations of experts involved.

First, regarding the frequency of sprayer calibration. Every sprayer should be thoroughly calibrated and the calibration should be checked periodically during the season. In addition, the sprayer should be recalibrated every time nozzles, pressure, or travel speed is changed (Cahoon et al.(2019). In accordance with the lack of appeal for calibration, experts have identified three types of sprayer users.

1) Motivated users, who account for approximately 10% of farmers, which run multiple adjustments during the season, comply with recognized quality standards and certifications such as HVE (High Environmental Value) and GLOBAL GAP. They also strive to meet the specific social and environmental requirements imposed by suppliers and purchasing groups, often emphasizing reduced pesticide usage.

2) Vigilant users, who tend to calibrate their sprayers once a year, or more often depending on the season and disease infestation.

3) Average users, representing approximately 80-90% of the total, calibrate their sprayers only once during the equipment's working life. Tend to stick with the initial settings and do not make any adjustments.

Secondly, experts have highlighted various challenges that users encounter in the process of crop protection. These challenges include a lack of readily available answers or information sources, insufficient knowledge about machinery and its maintenance, limited information about calibration (usually restricted to the initial setup offered by manufacturers), and a general lack of awareness regarding regulatory information, such as guidelines related to drift.

The experts have shared their expectations for the project, which encompass conducting experiments to quantify defaults and identify optimal settings for various crops and machine technologies. They also emphasize the need to standardize training materials to ensure consistency across the public and private stakeholders. Furthermore, there is a call to improve the professionalism of programs related to spraying, particularly in initial training. Experts suggest incorporating training on machinery knowledge and settings into various aspects, including Certiphyto renewal training for sprayer inspectors, user manuals provided by manufacturers, and machine setup performed by dealership technicians.

Since the beginning of the inspection, about 360,000 sprayers have been inspected based on the mandatory sprayer inspection database representing 236 000 individual sprayers currently in use. These inspections cover 13 types of sprayer technology, which are identified by age, manufacturer, model, options, and are associated with a specific cropping system or sprayer architecture (table 2). In total, around 2,230,698 defaults have been inspected, listed in 259 potential default codes.

Growing sector	Types of sprayers
Field Crops	Field Crops Boom Sprayers
	Palisade HortiCrop Sprayers
	Weeding Orchard Sprayers
	Weeding Vine Boom Sprayers
Vine Crops	Vine Mistblower Sprayer
	Vine Air-Assisted Side-by-Side Sprayers
	Vine Self-propelled Side-by-Side Sprayers
	Vine Pneumatic Side-by-Side Sprayers
	Vine Pneumatic Sprayers
Tree crops	Orchard Sprayers
Other sprayers	Combined Sprayers
	Fixed and Semi-Mobile Sprayers
	Other Boom Sprayers

Table 1. The 13 types of sprayer technology inspected.

3. Results and Discussion

The initial findings highlight the most noteworthy discoveries. Key aspects covered include the impact of age on re-inspection rates, as well as the primary defaults identified and their implications in terms of compliance. The database contains approximately 236,000 sprayers from different technologies. Around 20% of the inspected could only be approved after repair and most of these sprayers ages range between 10 and 20 years old.

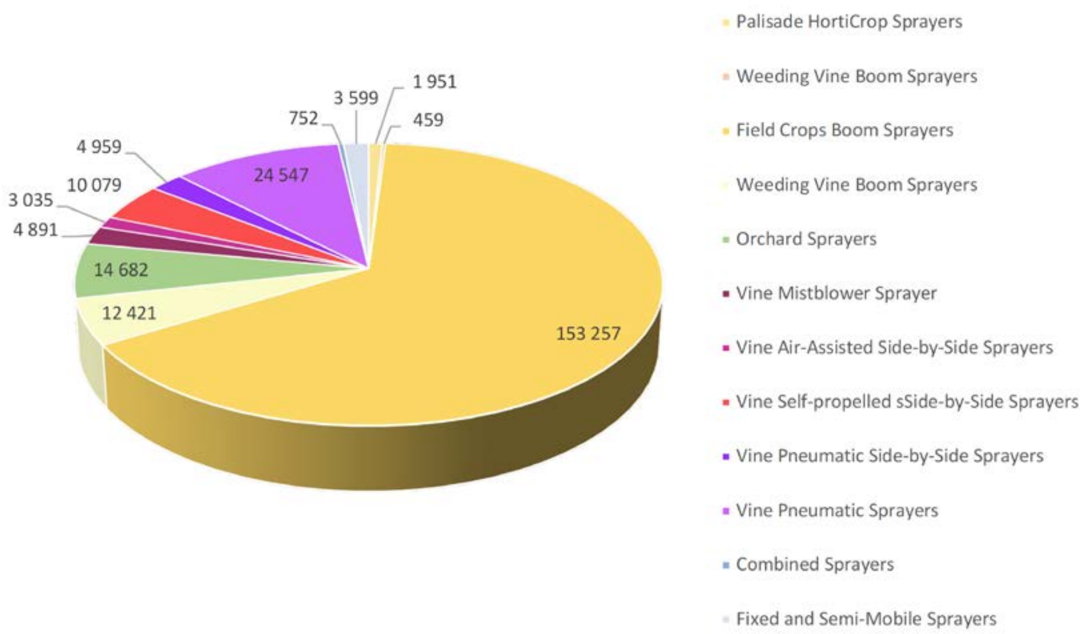
Out of the 360,000 sprayer inspections conducted on field crop, orchard and vineyard and other types of sprayers, more than 50,000 field crop sprayers required repairs. Additionally, 5,052 orchard and 14,682 vineyard sprayers were found to be partially or totally non-compliant.

Approximately 20% of the inspected machinery received approval only after repair., This reveals that about 71% of the sprayers are field crop boom sprayers, while 26% of them are vine and orchard sprayers (see graph 1).

In the analysis of the data, several categories of defaults were identified. The first category pertains to "Defaults without Re-Inspection," which predominantly involve issues related to filters and account for 49.13% of the total. The second category involves "Partial Re-Inspections," with defaults often associated with pressure gauge inaccuracies, making up approximately 10.4% of the total. Lastly, the third category includes "Full Re-Inspections," which are necessitated by defaults related to the safety components of sprayers and represent 2.4% of the total.

Default without reinspection	Defaults with partial reinspection	Defaults with full reinspection
Filters (49%)	Pressure indicator accuracy (10%)	Fan clutch (2%)
Pb tank level indicator (43%)	Absence of mixing device (7%)	Absence/damage PTO shaft protection (2%)
Absence of cleaning/rinsing (33%)	Pressure level between nozzle holders (6%)	Dirty sprayer (0.2%)
Absence of induction bowl (29%)	Global nozzle wear (5%)	Major leaks (0.1%)
Lights/road compliance (28%)	Absence tank level indicator (3%)	Non-functioning sprayer (0.1%)
Absence of compensation control (27%)	Absence anti-dripping (2%)	

Table 2. Example of defaults observed for sprayers use in viticulture.



Graph 1. Typology of the sprayers inspected inspected since 2009.

4. Conclusions

An intriguing pattern emerges when considering the influence of machinery age on re-inspections. Specifically, for boom sprayers, the data reveals that as these machines grow older, the likelihood of requiring re-inspections increases. This emphasizes the critical importance of regular maintenance and updates for aging boom sprayers, ensuring their ongoing compliance and safe functioning.

In contrast, when it comes to vineyard sprayers, the re-inspection rate remains relatively stable across different age groups. This suggests that vineyard sprayers may possess distinctive characteristics or maintenance practices that contribute to their consistent performance over time, regardless of their age.

Furthermore, the study also delves into the primary defaults, revealing instances of defaults increasing with machinery age, while in some cases, even newly acquired machines exhibit defaults.

In conclusion, The connection between the NéoPulvé project and the training course will be established with the assistance of experts to quantify the impact of the primary defaults on spray dosage and spray distribution on crop but also from environmental, health, and safety perspectives, where which we will employ experiments, where we will simulate the most common defaults encountered on the EvaSprayViti test bench to demonstrate accurately the results of using a defaulted sprayer, to quantify their impact and suggest the proper calibration for it.

This approach ensures the creation of a cohesive, homogeneous training resource.

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Flashes of UV-C light, a physical plant resistance inducer and biostimulant that can be effectively used in cropping conditions

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Abstract

Low intensity UV-C light, when delivered several times a week, can control powdery mildew by exerting a surface disinfecting effect. High intensity flashes of UV-C light, for their part, are effective against a much larger range of diseases in several plants of economic importance. They are typically delivered every 10-15 days and act by stimulating plant natural defenses. The flash technology is already applied by the UV Boosting company for reducing symptom severity and fungicide use, and increasing yield in commercial vineyards. Transcriptome data show that flashes of UV-C light stimulate expression of genes of the salicylic acid/NPR1 pathway, as well as genes involved in systemic acquired resistance, notably synthesis of N-hydroxy-pipecolic acid. Field data are also provided, as an example; they show that a strong decrease in fungicide use can be achieved by supplying flashes of UV-C light to 'Merlot' grapevine inoculated by downy mildew in a commercial vineyard.

Keywords : abiotic stress, fungal diseases, salicylic acid, systemic acquired resistance, vineyard

1. Introduction

In addition to resistance issues, pesticides have well-documented negative effects on the environment and human health (Rani et al., 2021). In addition to resistant or tolerant cultivars, biological control of pests and the development of complex cropping systems that are intrinsically less fragile and more resilient when confronted with aggressors and stressing conditions, plant resistance inducers (PRIs), alias elicitors, are on the rise (Marolleau et al., 2017). Whereas techniques of biological control are more specifically designed for replacing insecticides and acaricides, PRIs represent the alternative to fungicides, including copper and sulfur. Several PRIs have moreover been found to be effective not only against fungi and oomycetes but also bacteria and viruses (Tripathi et al., 2019). On the contrary to fungicides, PRIs generally act as a preventive, not a curative measure against pathogens.

Besides chemical and biological PRIs, physical PRIs (light, mechanical stress mainly) are attracting more and more interest thanks to their unique features: they can be applied even in the presence of rain and wind, they do not need to be formulated and they do not leave any residues on plants or in the soil. Lengthy procedures of homologation do not apply to physical PRIs, basically because they do not exert any toxic effects on humans and the environment. All the same, some of them, UV radiations notably, have to be applied by following safety rules. But these rules are easy to define and follow (Urban et al. 2022b).

The potential of some wavelengths to act as physical PRIs is now acknowledged (Huché-Thélier et al., 2016), which includes blue and red light, as well as UV-B and UV-C radiations (Ballaré, 2014, Urban et al., 2018). Pulsed light from xenon lamps was found to stimulate plant defense against Fusarium pallidoroseum in melon (Filho et al., 2020). Pulsed light consists in flashes of light of 300 to 500 µs encompassing wavelengths from 200 to 1100 nm, but it is generally believed to act thanks to its high proportion of UV-C light. UV-B radiation is proven to be a positive regulator of plant defenses (Demkura and Ballaré, 2012). But on the dark side of UV-B light there is a since long-documented negative impact on photosynthesis and growth (Teramura and Sullivan, 1994).

UV-C light was also observed to stimulate plant defenses, the first time of tobacco against tobacco mosaic virus (Yalpani et al., 1994). Since then, UV-C light under the form of exposures of one to several minutes was found to be effective for stimulating plant defenses against fungal diseases in several crops (Urban et al. 2018), but the need to expose plants for one minute or more, makes the use of low intensity UV-C light practicable only in greenhouse conditions. Currently there is growing interest for robots carrying low intensity UV-C lamps, but then only for surface disinfection of greenhouse crops against powdery mildew. Robots are generally considered as unavoidable because efficient crop surface disinfection requires very frequent treatments, at least twice a week, ideally made during nightime (Patel et al. 2020, Onofre et al. 2021).

The pioneering observations of (Urban et al. 2019, Aarrouf and Urban 2020a) have established that flashes of UV-C light (less than 2s) not only are capable to stimulate defenses of lettuce and tomato against Botrytis cinerea, pepper against Phytophthora capsici and grapevine against Plasmopara viticola, but to do so better than conventional exposures (60 s) for the same amount of energy (J m^{-2}) delivered and the same wavelength, paving the way for the use of flashes of UV-C as a physical PRI in field conditions. Interestingly frequent treatments are not required when considering high intensity flashes of UV-C light as a PRI and daytime treatments using a tractor at normal speed is all what is needed besides specific lamps. Also, there is no need to treat whole plants as with low intensity UV-C because of the existence of a strong systemic effect triggered by high intensity flashes. See table 1 for a summary of high intensity flashes of UV-C light in comparison to low intensity UV-C light, PRIs of chemical origin and fungicides. These findings about high intensity flashes were at the origin of the creation of UV Boosting company in 2017, which designs, develops and commercializes UV-C lamp systems than can be used in commercial cropping conditions, notably in vineyards.

	Flashes of UV-C light	*Low intensity UV-C light*	*Chemical PRIs*	*Fungicides*
Major effect on disease development	**Stimulation of plant defenses**	Direct crop surface disinfection	Stimulation of plant defenses	Destruction of the pathogen
Scope	**Very broad range of diseases on potentially all plants and crops**	Powdery mildew in greenhouse crops	Limited because of homologation issues	Limited because of homologation procedures
Biostimulant effect	**yes**	Not documented	Limited evidence for some of them	Not documented
Negative effect on growth	**Only when applied to severely stressed plants**	Observable in certain conditions	For some of the SA-based PRIs	No negative effects when application rules are followed
Importance of the dose	**medium**	medium	Depends on PRIs'	high
Preventive effect	**yes**	no	yes	no
Curative effect	**limited**	yes (powdery mildew only)	no	yes
Specific equipment required	**yes**	yes	no	no
Treatments before pathogen presence	**Highly recommended for best efficacy**	no	Generally recommended	no
Frequency of treatments	**10-15 days or more**	2-3 times a week	Typically 10-15 days	Typically 10-15 days
Restrictions for the total number of treatments	**no**	no	Depends on PRIs'	yes
Need to treat the whole canopy	**no**	yes	Not documented	yes

Importance of meteorological conditions at the time of treatments	**Not important**	Not relevant (greenhouse conditions)	Important	Important
Residues on crops	**no**	no	Yes but may be of no concern depending on PRIS'	yes
Appearance of resistances	**no**	Not documented	no	yes
Homologation procedures	**no**	no	Depends on PRIs	yes
Safety procedures for applications	**yes**	yes	Depends on PRIs	yes

Table 1. Comparison of flashes of high intensity UV-C light, low intensity UV-C light, chemical PRIs and fungicides. Note that flashes of UV-C light combine very easily with the others and even with biological PRIs stimulating the jasmonic acid pathway (see Urban et al. 2022b for a review).

Since then, confirming scientific evidence has been accumulated, demonstrating that flashes of UV-C light are indeed better perceived than conventional exposures (Aarrouf et al. 2022) and numerous field observations made by UV Boosting, Avignon Université and their partners have confirmed that they strongly stimulate grapevine defenses against powdery mildew, among others, in conditions of commercial production (Ledermann et al., 2021). Strong reductions of disease symptoms were also observed, among others, on strawberry, tomato and rose plants inoculated by powdery mildew in greenhouses similar to commercial greenhouses (Aarrouf et al. 2020b, Urban et al. 2022a, Urban et al. 2023b). Preliminary evidence was gathered about efficacy against some bacteria and viruses (data not published). Ungoing research aims at increasing our understanding of the way flashes of UV-C light are perceived by plants and of the signaling and regulatory pathways they trigger or stimulate.

The objectives of this paper are: 1) to provide evidence that flashes of UV-C light stimulate expression of the genes of the salicylic acid (SA)/NPR1 pathway, as well as genes involved in systemic acquired resistance (SAR), and notably synthesis of N-hydroxy-pipecolic acid; 2) to supply field efficacy data on downy mildew in vineyard conditions.

2. Materials and Methods

1. Effect of flashes of UV-C light on *Arabidopsis thaliana* L. transcriptome

Plants of *Arabidopsis thaliana* L. were grown for 5 weeks in a phytotron at constant conditions: photosynthetically active radiation of 50 µmol photons m^{-2} s^{-1}, photoperiod of 12h/12h, day/night temperatures of 21°C/20°C. Based on preliminary trials, we found that a dose of 200 J m^{-2} s^{-1} UV-C in phytotron were effective for stimulating plant defenses. Treated plants were submitted to this dose delivered under the form of a 1 s flash. Leaves from UV-C-treated and untreated plants were harvested 4 hours after the UV-C treatment and frozen immediately in liquid nitrogen before storage at - 80°C. Frozen samples were pulverized in a sterile mortar using liquid nitrogen. Total RNAs were extracted from ground leaves using the RNeasy Plant kit (QIAGEN France S.A.S, Courtaboeuf, France), following the manufacturer's protocol. RNAs were quantified with Qbit 4 Fluorometer (Thermo Scientific, Wilmington, NC, USA) and RNA quality was assessed on a Fragment Analyzer (Agilent Technologies, Santa Clara, CA, USA). All RNAs had an RNA integrity number (RIN) score of ≥7. Library preparation and RNA-seq were performed by BGI Tech Solution (Hong Kong, China) using an DNB-SEQ platform. RNAseq data were analyzed using Dr Tom tools (BGI Genomics, Shenzhen, China).

2. Effect of flashes of UV-C light against *Plasmopara viticola* on *Vitis vinifera* L. 'Merlot' in vineyard conditions

UV-C light was produced by a system made UV-C amalgam lamps (OSRAM HNSL, 95 W, 254 nm) in a 60x60 cm aluminium frame, specifically designed to supply 1-sec flashes under greenhouse and field conditions (UV Boosting, Boulogne-Billancourt, France). The spectrum was measured by a UV sensor (OSI UV-20 TO-8 photodiode) and confirmed a major peak at 254 nm. The energy perceived by plants depends on the distance between the source of UV-C and the plants and light energy measurements were performed with a portable joulemeter (Gentec Electro-optics Inc., Québec city, Canada). In order to ensure that the effect of UV-C could not be attributed to a disinfecting effect, the first three UV-C treatments were carried out before disease development and repeated every 10 ± 1 days.

Figure 1. A two-row stimulation system of the UV Boosting company. This system is also suited for full grown grapevine plants.

Treatments and observations were conducted from April to July 2018 on 'Merlot' grapevines grown in an experimental vineyard located in Tourne (Gironde, France). Vines were spaced 2.5 m x 1 m with limited weed control. No fertilization programme was applied, and there was no irrigation. The conditions during the growing season were as follows: minimal temperature between minimal temperature 11.1°C , 11.5°C and 16.1 °C in April, May and June respectively, maximal temperature 18.9°C , 21.9°C and 26.1 °C in April, May and June respectively, and relative humidity between 45% and 90% (https://www.wofrance.fr/weather/maps/city). The experimental design consisted of two plots. 75 plants per plot were treated with flashes of UV-C light every 10 ± 1 days between April and July 2018, 75 plants per plot were treated with a standard fungicide programme, and 75 plants per plot were left untreated. All plants were randomly distributed. Severity symptoms were assessed on 200 leaves and 100 fruit clusters per plot on 25 July. Severity represents the percentage of cluster or foliage area covered by disease. It was assessed by the same expert and expressed as a percentage.

The Kruskal-Wallis non-parametric statistical test was applied because the data do not meet the assumptions about the population sample, and notably do no follow a normal distribution. The data were expressed as the means ± standard error, and statistical significance was set at $P < 0.05$. All statistical analyses were performed using XLSTAT software (Addinsoft, Andernach, Germany).

3. Results and Discussion

1. Flashes of UV-C light stimulate the SA/NPR1 pathway and Systemic Acquired Resistance, the major immunity system in plants.

Four hours after plants were treated with flashes of UV-C light, several key genes of SA synthesis were upregulated (Table 1), including ISOCHORISMATE SYNTHASE (*ICS1*) and ENHANCED DISEASE SUSCEPTIBILITY 5 (*EDS5*) (Ding and Ding, 2020). Genes associated with methylation, hydroxylation, glycosylation and sulfonation were also strongly upregulated, arguably reflecting the need to deal with high concentrations in SA in UV-C treated plants. *NPR1* gene expression was moderately upregulated. *PR2, PR4* and *PR5* gene expressions were clearly increased. The observed transcriptional changes show that the SA signaling pathway was stimulated by flashes of UV-C light. This is all the more obvious when considering the genes associated with N-hydroxy-pipecolic acid synthesis, *ALD1* (AGD2-LIKE DEFENSE PROTEIN 1) and *SARD4* (SYSTEMIC ACQUIRED RESISTANCE DEFICIENT 4), and SAR (Table 1). These findings confirm lab and field observations that already suggested that

flashes of UV-C light stimulate SA production and SAR in plants (Urban et al. 2023a).
There is increasing evidence that the NPR1 protein not only constitutes a hub in immune responses triggered by SA but orchestrates in addition plant tolerance to different forms of abiotic stress, including suboptimal temperatures, frost, drought and high salinity (Tajima et al. 2020). Based on preliminary observations made on grapevine (unpublished), we consider that flashes of UV-C light act not only as a physical PRI but also as a biostimulant. Therefore, they have a strong potential for helping growers and farmers to address the upcoming challenges of increased disease pressure and climatic change, and their interactions.

Gene	Locus	*Full name*	*Log_2 Fold Change*	*Q value*	*Biological process*
SID2 (ICS1)	AT1G74710	ISOCHORISMATE SYNTHASE	1.07	$2.7\ 10^{-8}$	Synthesis of SA
EDS5	AT4G39030	ENHANCED DISEASE SUS-CEPTIBILITY 5	1.40	$6.3\ 10^{-13}$	Synthesis of SA
	AT1G15125	S-ADENOSYL-L-METHIO-NINE-DEPENDENT METHYL-TRANSFERASE	1.98	$1.0\ 10^{-4}$	Synthesis of MeSA
DMR6	AT5G24530	DOWNY MILDEW RESIS-TANCE 6	0.69	0.01	SA-5 hydrolase
DLO1	AT4G10500	DMR6-LIKE OXYGENASE 1	2.33	$8.3\ 10^{-11}$	SA-3 hydrolase
UGT73C1	AT2G36750	UDP-DEPENDENT GLY-CO-SYLTRANSFERASE 73C1	2.26	$1.7\ 10^{-10}$	SA glycosylation (see also UGT76B1 below)
SOT12	AT2G03760	ARABIDOPSIS THALI-ANA SULFOTRANSFER-ASE 1	2.57	$6.6\ 10^{-63}$	SA sulfonation
NPR1	AT1G64280	ARABIDOPSIS NON EXPRES-SER OF PR GENES 1	0.31	0.001	Hub for defense and tole-rance re-sponses
PR2	AT3G57260	PATHOGENESIS RELATED 2	1.50	$6.9\ 10^{-7}$	Response to cold, SAR
PR4	AT3G04720	PATHOGENESIS RELATED 4	1.32	$8.7\ 10^{-4}$	Defense respons-es, SAR
PR5	AT1G75040	PATHOGENESIS RELATED 5	2.09	$7.0\ 10^{-16}$	Defense respons-es, SAR
ALD1	AT2G13810	AGD2-LIKE DEFENSE PROTEIN 1	2.52	$3.4\ 10^{-4}$	Synthesis of N-hydroxy-pi-pecolic acid
SARD4	AT5G52810	SYSTEMIC ACQUIRED RESIS-TANCE DEFICIENT 4	0.58	$3.9\ 10^{-5}$	Synthesis of N-hydroxy-pi-pecolic acid
UGT76B1	AT3G11340	UDP-DEPENDENT GLYCOSYL-TRANSFERASE 76B1	2.80	$1.6\ 10^{-20}$	N-hydroxy-pipecolic acid homeostasis

Table 2. Summary of some of the transcriptional changes induced by flashes of UV-C light in *Arabidopsis thaliana* L.

2. Field treatments against downy mildew on 'Merlot' grapevine are effective for reducing severity of symptoms and pesticide use

The standard and the 50 % reduced fungicide treatment programs were found to reduce severity of downy mildew symptoms on leaves and clusters by 92% and 97% %, respectively (Fig. 2). Flashes of UV-C light were found to reduce severity by 45% on leaves and by 39% on clusters in plants untreated by fungicides (Fig. 2). Similarly, flashes of UV-C light were found to reduce severity by 92% on leaves and by 98% on clusters of plants under the 50 % reduced fungicide program (Fig. 2). Flashes of UV-C light combined with the 50 % reduced fungicide treatment program proved as performing as the standard program (100%) and proved better than the 50 % reduced fungicide treatment program (Fig. 2).

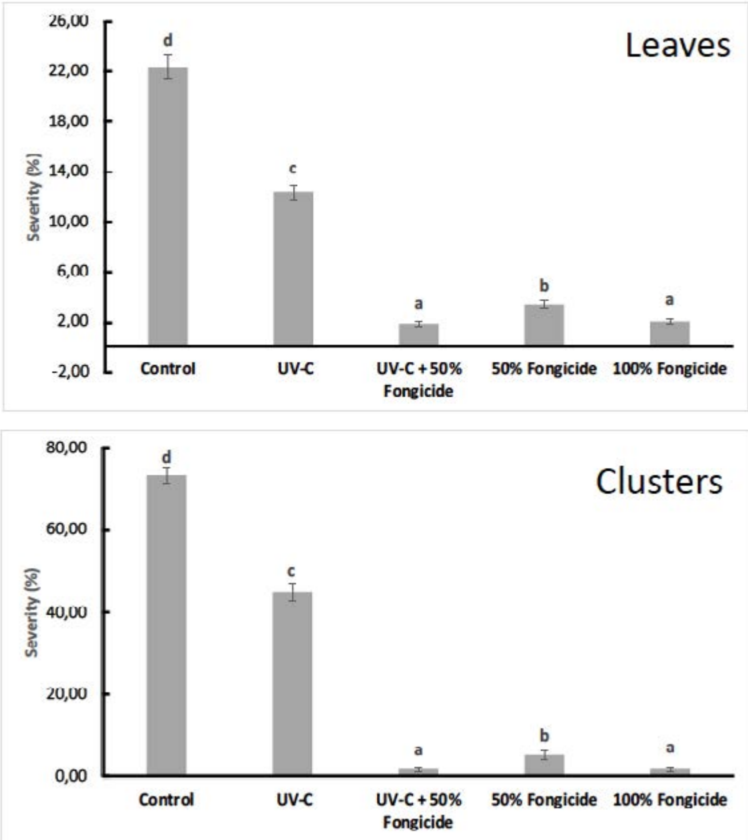

Figure 2. Effect of flashes of UV-C light on the severity of symptoms of downy mildew on leaves and clusters of 'Merlot' plants grown under vineyard conditions in Tourne (Gironde, France). Data represent means and bars denote standard errors. Different letters on the same date indicate significant differences at the P = 5%.

Flashes of UV-C light can be used to increase resistance of grapevine against downy mildew as it was observed on isolated and then inoculated leaves taken from 'Cabernet Sauvignon' plants grown in pots in greenhouse conditions (Aarrouf and Urban 2020a). Here we supply evidence that flashes of UV-C light are also effective in vineyard conditions against downy mildew on 'Merlot'. UV-C light treatments were more efficient on clusters than on leaves. The issue of differences in susceptibility between leaves and clusters, namely towards powdery mildew, was discussed by Ledermann et al. (2021). As for downy mildew, it is known moreover that berries become less susceptible during ontogenesis when stomata are replaced by lenticels (Kennelly et al. 2005). A possible explanation for the superior effect of flashes of UV-C light on clusters than on leaves is that availability of resources for defense is higher in fruits than in leaves (Ledermann et al. 2021). This suggests also that the limiting factor of stimulation of defenses is possibly not so much the perception of the stimulus and downstream signaling than availability of resources for synthesis of defense structures and compounds. The importance of this issue and the lack of scientific studies dealing with it were stressed by Walters and Heil (2007). To improve efficiency of flashes of UV-C light we should arguably pay more attention in the future to the resource status of organs that need to be protected.

The observations we made suggest that flashes of UV-C light could be beneficially included in reduced fungicide treatment programs to increase their efficiency. It is highly probable that not all forms of association with protection treatments are equally efficient. Here we have associated UV-C light treatments with fungicide treatments whereas it could be more efficient to target specific development phases with UV-C light treatments and others with fungicide treatments. It is also likely that flashes of UV-C light do better in combination with some specific fungicides than with others. Flashes of UV-C efficiency could also benefit from an association with other forms of elicitors (Urban et al. 2022b). Aarrouf et al. (2020a) found that flashes of UV-C light when associated with laminarin, a storage glucan with elicitor properties, provided strawberry plants with a level of protection against powdery mildew far better than laminarin alone and as good as the standard fungicide treatment program.

4. Conclusions

Flashes of UV-C light stimulate the SA/NPR1 pathway, therefore triggering Systemic Acquired Resistance, the major immunity system in plants, which explains why flashes of UV-C light do not require to be supplied to full canopies for being efficient and that they have a very broad action spectrum. Preliminary observations, not shown here, even suggest that they have the potential for stimulating plant tolerance against different forms of abiotic stress, which is consistent with what is known about the hub role of NPR1 in immune and tolerance responses triggered by SA. Stress tolerance is a major issue to farmers and growers, as much as resistance to pathogens, since stress episodes have started to increase in frequency, intensity and duration as a consequence of the climate change. Further steps will consist in deepening our understanding of the mechanisms of UV-C light perception and of the signaling and regulatory pathways stimulated downstream, which is of paramount importance as they may be influenced by the physiological status of plants and environmental cues. Besides, UV Boosting will continue to make field trials in collaboration with its partners, like the one that has provided the results about downy mildew presented in this paper, with the objective of accumulating expertise and evidence of the multiple agronomic benefits of the flash technology. We are confident that experience sharing and joint thinking among plant physiologists and agronomists will play a pivotal role in the development of its full potential in the future, all for the benefit of farmers and growers worldwide.

Acknowledgements

The transcriptome analysis was conducted with financial support from the French Ministry of Agriculture and Food as part of the CASDAR programme (OïdUV project). We thank Douae Ben Hdech for participating in the outline of this analysis and the preparation of the plant material. We thank Enigma for carrying out the GEP trial.

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ADDI Spray Drift: A spray drift model for vine sprayers

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Abstract

THE PREDICTION of sedimentation and airborne spray drift at different distance ranges from a vineyard was developed using ADDI Spray drift model. This model also predicts infield soil deposition and canopy interception. This 3D model is based on a random walk approach considering droplet size and air emission profiles as input parameters but also considering their fate in terms of droplet evaporation, atmospheric stability status, interactions between canopy and atmospheric turbulences, ground deposition and canopy interception. Different sprayer locations were considered (e.g. in the middle of the field or close to field boundary spray applications) as well as in terms of interaction between them. Sedimentation spray drift reference values (Ganzelmeier et al. (1995) obtained in vineyard conditions were used for comparison. Sedimentary spray drift decay along with the downwind distance was predicted with less than 1 % deviation at medium-range distances, and a maximum deviation reached 2.56% at shorter distances. Interestingly, according to the sensitivity analysis, the model appeared much more sensitive to spraying conditions, especially droplet ejection velocities that are not often easy to measure in practice.

The potential of ADDI-SprayDrift model is to assess and compare the efficiency of application techniques, quantify losses and the mitigation measures efficiency or bystanders/residents exposure to pesticides.

Keywords : Vineyard sprayers, spray drift modelling

1. Introduction

Spray drift modelling was studied for a long time because of the difficulty to conduct field measurements. Three levels of variability are observed i) due to local wind conditions ii) due range of settings of sprayers and iii) due to the variability of vineyards vigor and development. Different types of models are existing. Empirical models are based on the statistical analysis of field tests. Their advantage is the practical correspondence with field tests but the main drawback is that they cannot predict the result of any modification concerning the type of sprayer, the settings nor the wind and atmospheric conditions. Mechanistic models are based on the physical description of the phenomenon (Chahine, 2011, Hong et al., 2018). In most cases, particle transport models in the atmosphere are used. Specific empirical models were developed for bystanders exposure through droplet spray drift like the German model (Martin et al., 2008) or the Browse model (Butler Ellis et al., 2017). This work aimed at developing a new model able to consider outfield spray drift, bystander exposure and the infield distribution of plant protection products (PPP) at the moment of the application. The model might be simple, mechanistic, generic, shall represent spray drift key processes and shall consider ground application.

2. Materials and Methods

The model includes three main parts including the emission of droplets, the atmospheric dispersion and the deposition on target and on the ground (Figure 1).

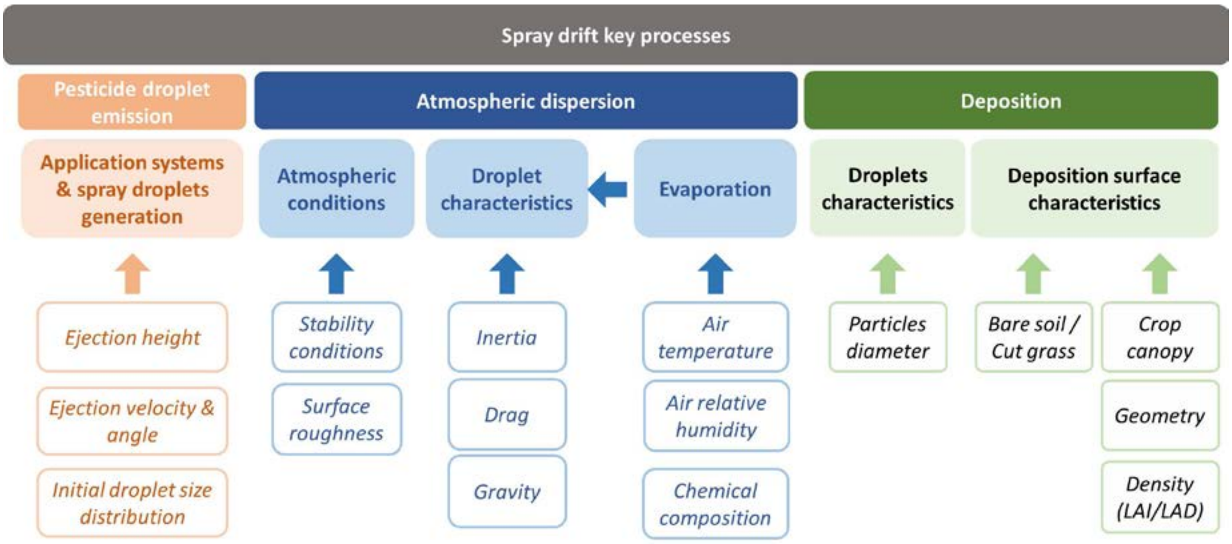

Figure 1. Components of the ADDI Spray Drift model.

A Lagrangian Random Walk model was developed takes into account the droplet size, droplet direction and evaporation during the transport phase. During transport, the fraction intercepted by the canopy is calculated and the remaining fraction is considered as transported in the atmosphere. Outputs are defined in terms of in-field and out-field ground deposition, crop interception and airborne concentration (Figure 2).

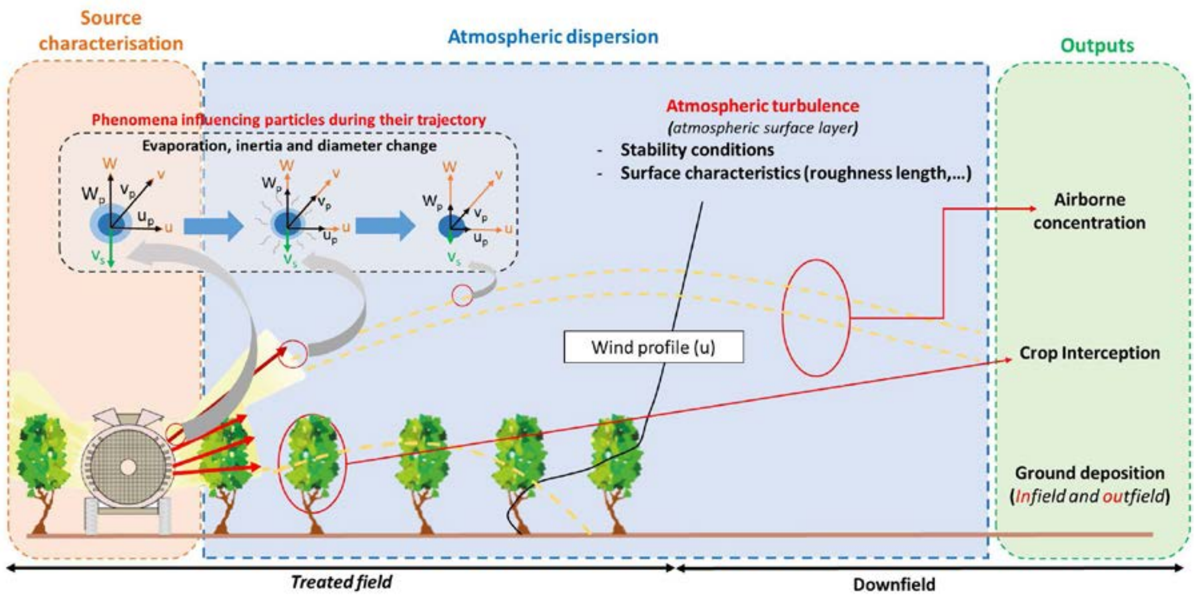

Figure 2. ADDI-Spray drift model principle.

Several vineyard sprayers were considered for modelling representing different designs present on the market (Figure 3).

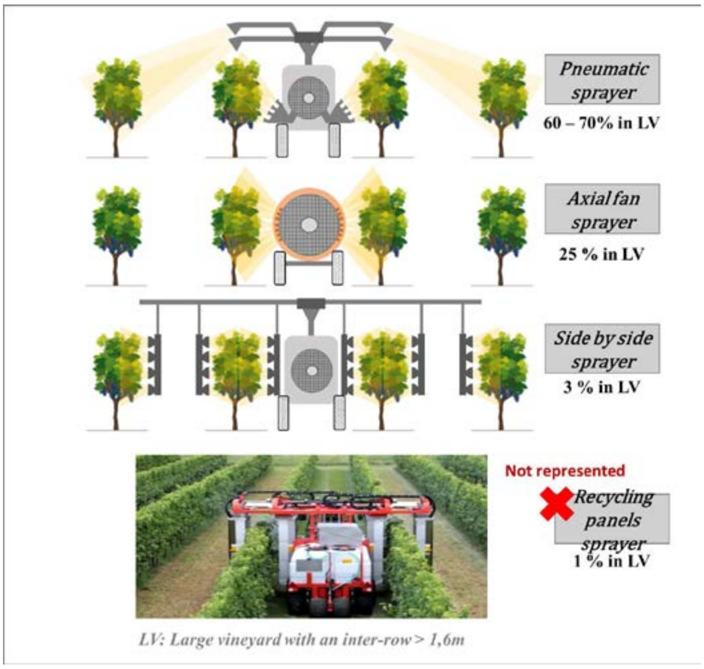

Figure 3. Typologies of vineyard sprayers tested with the model.

The evaporation model is based on Trayford and Welsh (1977) squared diameter law where the diameter is function of the time.

Different atmospheric stability conditions were considered but the turbulence was considered homogeneous in the domain of study. An important point is that although all studied sprayers have air assistance, the system was not considering an air co-flow with the similar speed of droplets but droplets are ejected at a speed corresponding to the air speed of the air assistance. Furthermore, the influence of this air co-flow in the close atmosphere around the sprayer was not considered.

3. Results and Discussion

First a global distribution of the spray is evaluated considering the 3 compartments in-field (crop-air-soil) for an axial fan with hollow cone nozzles. Inside the vegetation, or at the boundary of the field, the percentage of deposition on the crop is almost similar but the main differences are observed for ground and air deposition (Figure 4).

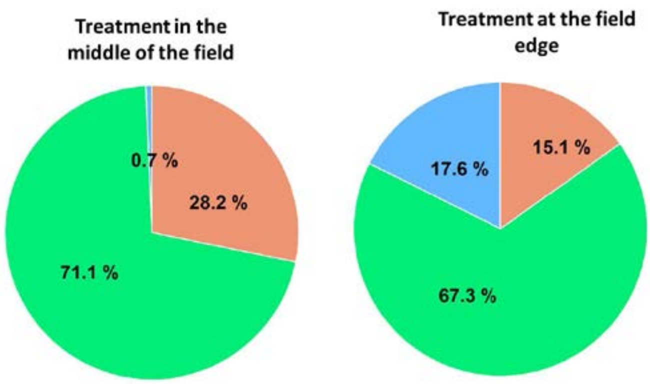

Figure 4. Pesticide distribution of the spray in the middle or at the boundary of the field.

The sedimentation drift simulated for an axial fan sprayer was compared with data obtained by Ganzelmeier et al (1995). In the following figure. At distance greater than 10m, the correspondence between the model output and the experiment looks quite similar (Figure 5). However, the data obtained at closer distance from the field edge appear overestimated.

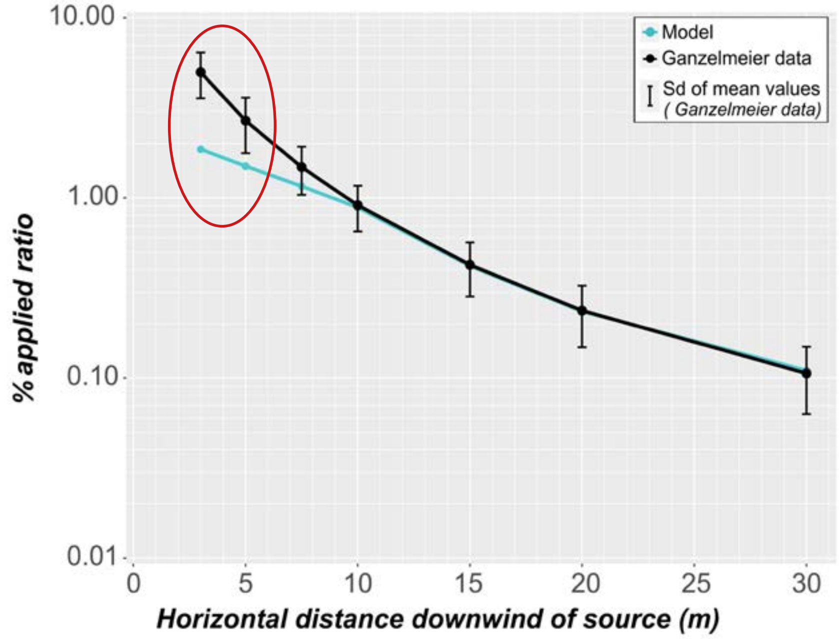

Figure 5. Comparison of experimental drift data and modelling.

The pesticide distribution for different sprayer technologies is introduced on Figure 6. The ranking between machines follows the results of experimental tests in terms of deposition in the canopy and percentage of the air fraction that is correlated to spray drift. Indeed side by side sprayer with low drift nozzles (case 5 from the left) appears to be the most effective sprayer in practice compare to the axial fan with hollow cone nozzles (case 2 from the left). Interestingly, the use of low drift nozzle with an axial fan sprayer does not modify significantly the average deposition in the canopy but increase the variability of both crop and soil deposition (Djouhri et al, 2023).

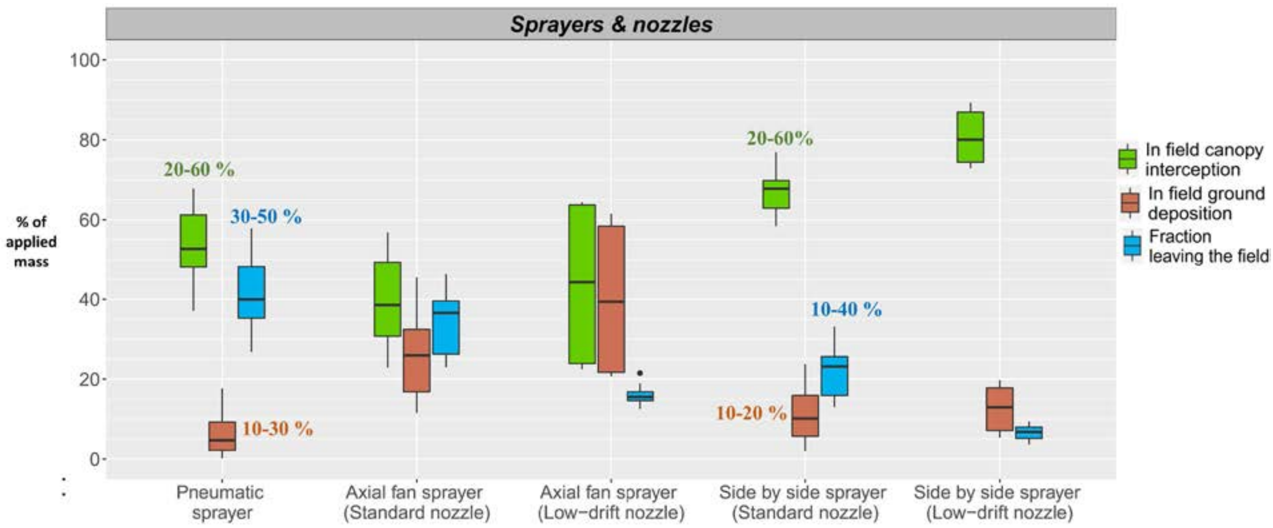

Figure 6. Pesticide distribution evaluated for five sprayer typologies.

4. Conclusions

ADDI-SprayDrift is a mechanistic model but with limited complexity. It is rather generic for various spray application techniques, crop stage and structure and atmospheric conditions. It is able to model the pesticide in-field distribution during the application, spray drift and resident exposure (not presented here). Order of magnitude of the pesticide distribution are consistent with experimental results as well as the ranking between spray application technologies. Improvements of the model are mainly needed on the consideration of the air assistance effect in the close environment of the sprayer.

Acknowledgements

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Evaluation of the guidance accuracy of non-chemical weeding robots in crop production

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Abstract

ROBOTICS is undergoing rapid development in the agricultural sector. New solutions are emerging to meet the challenges of reducing herbicide use and manpower for manual weeding in organic vegetable farming. The quality of guidance is an essential element for weeding robots to make them autonomous, to ensure the weeding quality as close to the row as possible, and avoid costly and time-consuming manual weeding afterwards, while limiting the impact on the crop. This article proposes a methodology to assess the guidance accuracy on field of weeding robots. This evaluation was carried out on four robots (Anatis, Dino, Oz and Toutilo).

The guidance systems of the four robots evaluated are based on different technologies (GPS, camera or a combination of both). The results highlight the strengths and weaknesses of this technology. The median distance between the weeding tool (weeder, tine) mounted on the robot and the crop is less than 4 cm, all robots combined. An analysis of the distribution of robot guidance accuracy data (in particular the 95th percentile) clearly shows that there is room for improvement. Given the real precision of robot guidance, it would be possible to improve the adjustment of weeding tools to position them as close as possible to the crop. This would substantially improve the quality of weed control, without causing damage to the crop. Nevertheless, further improvements are still needed to drastically refine tool settings around the row.

Keywords : precision agriculture, autonomous system, geospatial technol ogy , robotization, weed control

1. Introduction

In the agricultural machinery sector, the automation of repetitive and time-consuming tasks meets a societal demand for the reduction of inputs of all kinds (manpower, pesticides, fuel, etc.) (Young et al, 2014, Rubrecht et al, 2017). This project aims to explore the potential offered by the robotization of mechanical weeding. These meet the societal challenges of (i) reducing the use of herbicides, as required by international and national regulations (e.g. European Framework Directive 2009/128/EC; Walloon Pesticide Reduction Program (PwRP) 2023-2027), and (ii) shortages of manual weeding in organic vegetable production.

The degree of maturity, reliability and adaptability to the Walloon Region (Belgium) conditions of weeding robots currently on the market or in pre-production is poorly documented. The trials carried out from 2021 to 2023 aim at evaluating 4 weeding robots and identifying the levers and obstacles to the development of this technology in the Walloon Region.

The quality of guidance is an essential element for weeding robots to make them fully autonomous, to ensure the weeding quality as close to the row as possible and to avoid costly and time-consuming manual weeding afterwards. Guidance is generally based on the use of Real-time Kinematic Global Positioning System (RTK GPS) and/or machine vision. In addition to in-depth studies of each of the core technologies, studies of complete systems in real-life conditions are still needed to validate the information exchange and synchronization capabilities of the components (Slaughter et al, 2008). This paper proposes a methodology to assess the guidance accuracy on field. This methodology is based on the gps positions of the robot and its tools measured with a gps tracking antenna. In the following sections, we focused on the field trial of 2021.

2. Materials and Methods

2.1. Robots

The four robots evaluated are already on the market or are being offered in pre-production (Figure 1). They have been specifically developed for mechanical weeding of market garden crops planted in beds. Oz and Toutilo also offer planting and harvesting assistance. All robots are electrically powered and have four-wheels drive, except for Toutilo with two idler front wheels. The Table 1 shows the main characteristics of the robots.

Row guidance systems of the robots and their tools are different and representative of the existing variability (Slaughter, 2008). Oz relies solely on RTK GPS and Toutilo solely on a camera. Dino is guided by RTK GPS and can adjust its tools using a camera (machine vision based automatic row guidance). Anatis is guided by RTK GPS and camera, and adjusts its tools using an additional rear camera. In contrast to the Anatis, Dino and Oz robots, Toutilo is a cobot corresponding to the collaboration between a human and a semi-automated robot. It moves around the plot autonomously, following a physical colored guideline, but requires an operator to make half-turns and to lower weeding tools.

GPS systems require the use of an RTK GPS guided planting system or the crop row mapping using georeferenced mapping technique (Slaughter, 2008). Anatis uses simplified straight-line mapping, as the camera corrects the guidance. Dino and Oz use detailed mapping carried out during sowing or planting.

Robot	Anatis V2	Dino	Oz	Toutilo
Company	Carré	Naïo	Naïo	Toutiterre
Weight	1500 kg	1000 kg	150 kg	400 kg
Track width	1.45 m	1.5 m	/	1.6 m
Working speed	≈ 3 km/h	≈ 3 km/h	≈ 1.4 km/h	≈ 1.9 km/h
Guidance system	GPS RTK + camera	GPS RTK	GPS RTK	Camera on line/ cord
Tool fitting	Translation with a rear camera	Translation non usable on coliflower	/	/

Table 1. List of robots evaluated during the project.

Figure 1. Robots evaluated during the project: (1) Anatis, (2) Dino, (3) Oz et Toutilo (4).

2.2. Field trial

The field trial was carried out on a cauliflower crop planted, with a row space of 75cm and an intra-row space of 40cm. The weed control program aimed to achieve zero weeds. Therefore, frequent passes were made to control weeds in their early stages of development. Four weeding operations were carried out with the robots during the growing season of 2 months. Most of the weeding was performed in ideal conditions, with dry weather. As weedings were done at different stages of crop development, weeding tools settings were adapted. The tools used were supplied by the robots manufacturers, and consisted of paired hoeing shares with Lelièvre blades for Anatis, torsion springs for Oz and wheel-track claws for Toutilo.

The experimental design is illustrated in the Figure 2. The trial area is divided into 2 blocks (B1 and B2), within which each modality is arranged randomly. Modalities are made up of 3 crop beds of 1.5m wide and 50m long, enabling to evaluate the robots on 3 passes and 2 half-turns. As Oz passes between each row of crops, this modality is made up of 2 beds rather than 3.

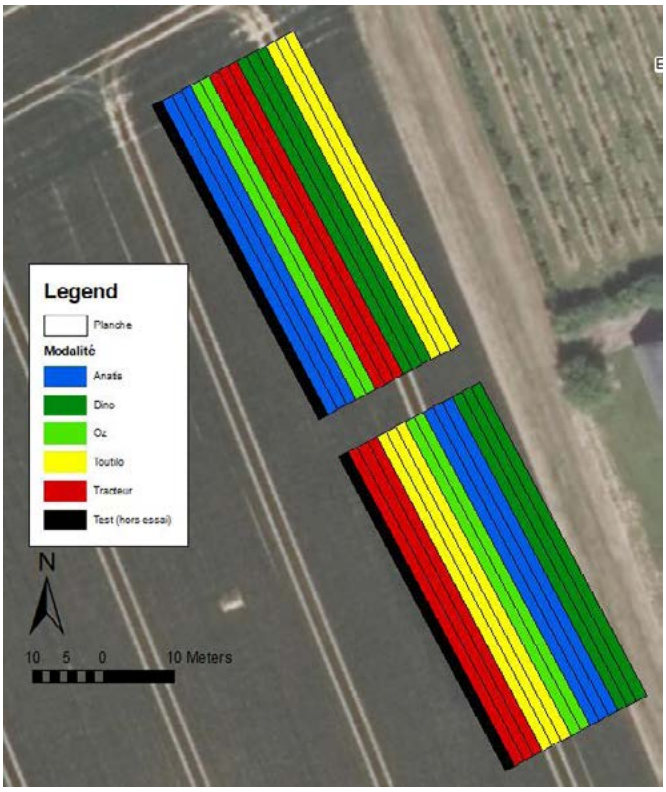


Figure 2. Experimental disign presenting the four robot modalities evaluated in two blocks (B1 and B2).

2.3. Data collection

Evaluation of the quality of guidance is based on a comparison between the actual position of the weeding tool and its expected position. Therefore, two sets of geolocalized information were registered and compared (i) the position of the planting line and (ii) the geographical coordinates correspon-ding to the trajectory of the tools during weeding.

A datalogger recorded, at a frequency of 1 Hz, the NMEA GGA frame of the robot's antenna, the NMEA GGA frame of the tracking antenna. The datalogger consists of a Siemens S7-1200 PLC and two screens, one of which is a SOCOMEC display.

A RTK-corrected tracking antenna was positoned on the robot during working and displacement. This antenna is a Sokkia GRX3 using the GPS, GLONASS and Galileo networks. The WALCORS (Wallonia Continously Operating Reference System) network is used to provide RTK correction with centimetric accuracy. It comprises 22 GNSS reference stations spread across Wallonia and 13 neighboring stations. The tracking antenna is positioned (Figure 3) at different points depending on the robot, its architecture, its guidance and the position of its weeding tools.

For Anatis, the tracking antenna is placed on the tool beam, in line with the rear camera and tools. For Dino, the tracking antenna is positioned just above the front axle, aligned with the robot antenna in the forward axis, 74 cm in front of the center of the robot and therefore in the front of the tools. For Oz, the tracking antenna is positioned just above the tool beam, aligned with the robot's antenna in the forward axis. For Toutilo, the tracking antenna is positioned in the axis of the optical camera, plumb with the tools and plumb with the left side row of the board.

Figure 2. Illustration of the positioning of the tracking antenna on each robot (Anatis, Dino, Oz, Toutilo).

The cauliflower field was fully mapped during planting using the Sokkia antenna and datalogger. The Figure 4 illustrates the set-up of the planting machine. The Sokkia antenna is aligned with the planting row and a Septentrio antenna was also used to generate maps for the Naïo robots (Oz and Dino). Lateral and directional offset data from the center of the plantation are measured.

Figure 4. Plantation GPS data acquisition set-up with Sokkia antenna, Septentrio antenna and datalogger.

2.4. Data analysis

Cartographic processing of the data was carried out using ArcMap software. Statistical analyses were performed using SAS software (SAS 9.4; SAS/STAT 13.1 analytical product).

The planting data, transformed into a Lambert 72 map projection and shifted to the center of the crop bed via an ArcMap script developed in-house, were cleaned to retain only the beds (removal of half-turns and repositioning of the tractor). Points were transformed into reference lines.

The weeding data recorded during each pass of robots were transformed into a Lambert 72 map projection, shifted to the center of the weeding tool and cleaned. Since the recordings have a frequency of 1 Hz, the distance between two recorded points varies according to the robot's forward speed. It is around 75 cm for Anatis, 85 cm for Dino, 40 cm for Oz and 30 cm for Toutilo at normal working speed.

Robot weeding tool positioning accuracy was assessed by calculating the distance between each recorded point and its reference line. The ArcMap Near analysis function was used. To analyze the results, two zones were defined: (i) the work area or plot, and (ii) the plot entrance and exit. In the second zone, defined by the first three and last three meters of the plots, accuracy can be impacted by the initial position of the robot start-up in autonomous work, automatic or manual half-turns, and the end-of-field exit.

Figure 5 shows an example of results where each positioning point has a color which is associated with a guidance error class (cm).

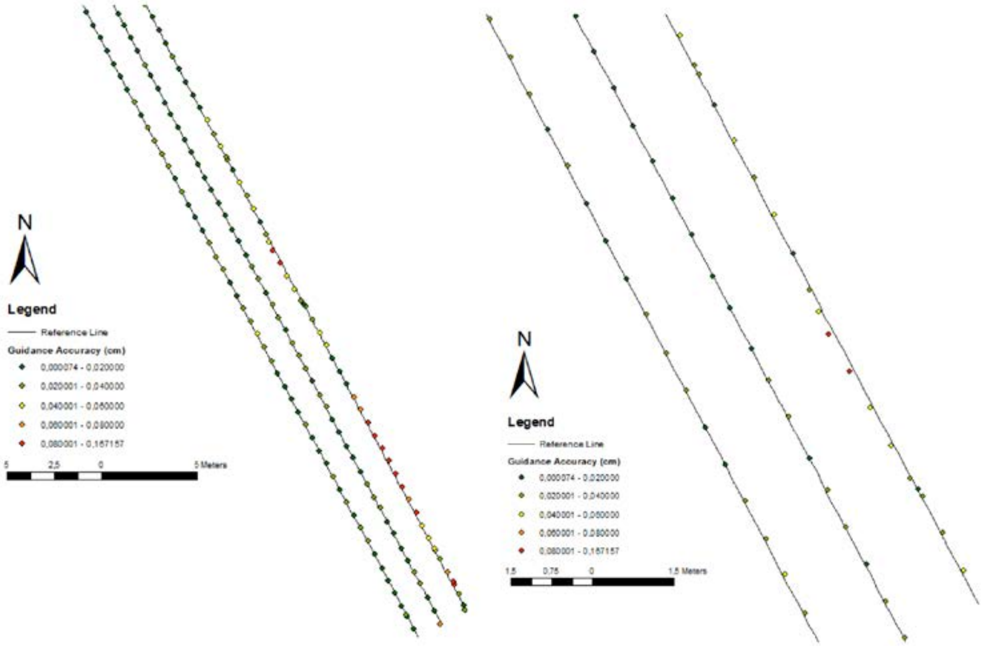


Figure 5. Cartographic representation, global and zoomed-in, of robot positioning errors during autonomous weeding along the reference line (crop line). Color indicates the error class to which the data belongs.

3. Results and Discussion

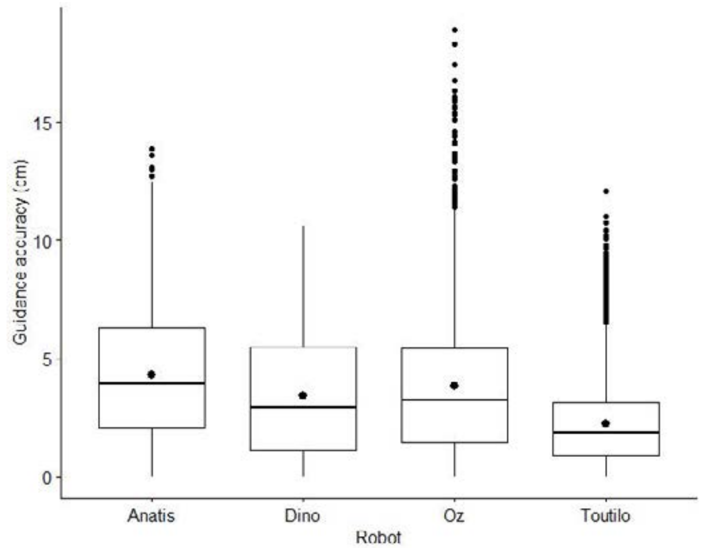
3.1. Work area – Plot

The mean and median accuracies of the robot weeding tools range from 1.88 to 4.31 cm, depending on the robot (see Table 2). As a reminder, the theoretical accuracy of the GPS with RTK correction is 2 cm. The results obtained are therefore satisfactory on average. The 95th percentile is 5.51 cm for Toutilo and between 8 and 10 cm for the other robots. There is therefore still a room for improvement to ensure constantly high quality guidance.

Accuracy (cm)	Modality			
	Anatis	Dino	Oz	Toutilo
N	1659	978	2814	3341
Maximum	13.84	10.60	18.89	12.09
Minimum	0.00	0.00	0.00	0.00
Mean	4.31	3.44	3.83	2.24
Median	3.93	2.94	3.22	1.88
Percentile 95	9.45	8.05	9.58	5.51
Standard deviation	2.82	2.58	2.98	1.78
Coef of variation	65.50	75.01	77.64	79.52
Variance	7.96	6.67	8.86	3.17

Table 2. Positioning accuracy of tools in cm for each robot.

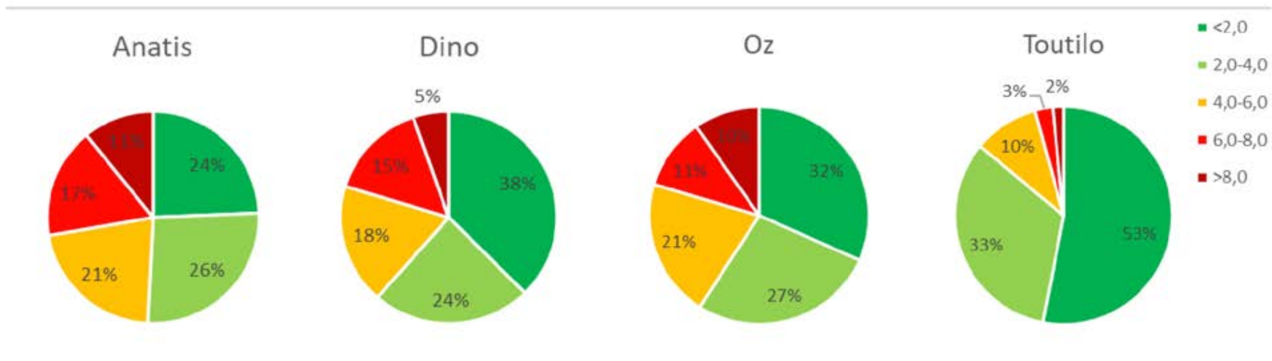
Graph 1 shows the weeding tool positioning accuracy for each robot, for all weed control operations combined. Oz and Toutilo have some values well above the third quartile. Although these few data have little impact on the mean and median, they generate considerable variability. For Oz, these values can be explained by significant lateral displacements when the robot returns to its course following a deviation. For Toutilo, these values are linked to the correction of robot positioning by the operator when the deviation is significant or the camera signal is lost. As Toutilo has two rear drive wheels and two front idle wheels, the correction can result in a strong displacement of the front where the tools and the tracking antenna are located.



Graph 1. Positioning accuracy of tools in cm for each robot. Median, min and max accuracy, quartile 1 and 3 and the mean represented by a star.

Graphs 2 show the percentage frequency of weeding tool positioning accuracy for each robot, for 5 distance classes. The good results obtained with Toutilo can be explained by the quality of the camera, but also by the less autonomous guidance principle based on i) physical marking on the plot (line/cord) and ii) manual turning and positioning by the operator. Dino and Oz show similar results, which can be explained by their identical mapping methodology and the use of similar algorithms for these two robots from Naïo. For Dino, Oz and Anatis, there is still a room for improvement.

These results are nonetheless positive, and allow us to take more risks when adjusting the tools, by bringing them as close as possible to the crop. In the trials, an a priori safety margin of 6 cm was maintained between the tools and the crop. On the basis of the quality of robot guidance actually observed, this margin could be reduced to 4 cm. This would further improve the quality of weeding outside the row and reduce the area of weed in the row, without causing damage to the crop.



Graph 2. Percentage distribution of errors by class of distance for each robot. The classes are, from dark green to dark red: <2cm; between 2 and 4cm; between 4 and 6cm; between 6 and 8cm and >8cm.

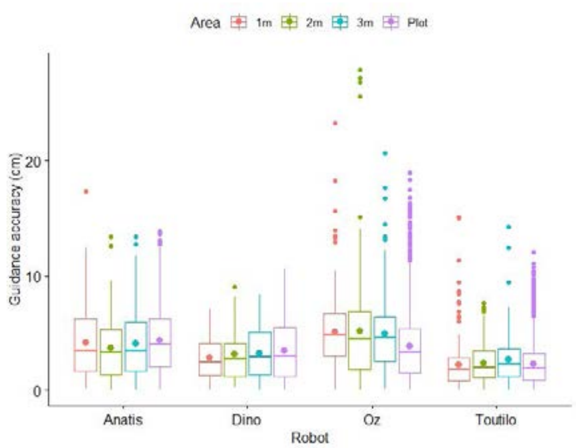
3.2. Plot entrance and exit

Graph 3 shows the tool positioning accuracy for the first and last three meters of the plot for each robot, broken down by zone (1, 2, 3m). In the graphs, plot data enables easy comparison of entry and exit zones with the precision measured within the plot.

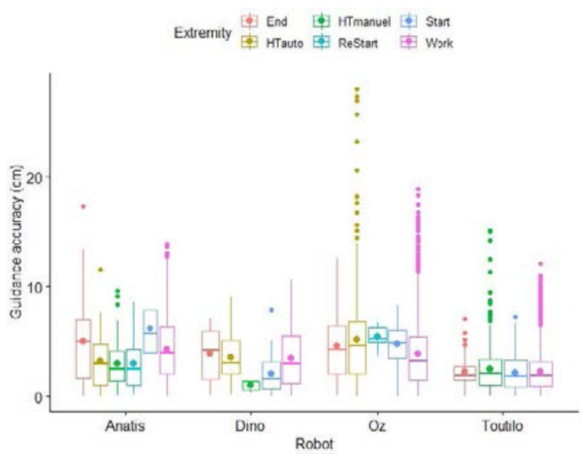
Accuracy in the first and last 3m of the plot is equivalent to that in the working area of the plot. Overall, there was no deterioration or improvement in guidance in these zones, except for Oz, where average precision was less good.

Graph 4 shows the weeding tool positioning accuracy for the first and last three meters of the plot for each robot, broken down by type of plot entrance or exit ("start", "restart", "automatic half-turn", "manual half-turn", " end"). For Anatis, Dino and Oz, an operator carried out "restarts" and "manual half-turns" after technical problems requiring intervention. In the graph, the Work data enable easy comparison of the entrance and exit zones with the accuracies measured within the plot.

Results are highly variable for each robot. Nevertheless, autonomous actions (work, autonomous half-turn, end) tend to have an average precision over the first and last three meters equivalent to the precision of work in the plot. Operator actions, on the other hand, have a greater impact on guidance quality in the first and last meters. This impact is positive or negative, depending on the attention paid by the operator to the execution of the task.



Graph 3. Tool positioning accuracy for the first and last 3 metres of the plot for each robot. Median, min and max accuracy, quartile 1 and 3 and the average represented by a star.



Graph 4. Accuracy of tool positioning according to plot entry and exit for each robot. Median, min and max accuracy, quartile 1 and 3 and the average represented by a star.

4. Conclusions

The project aims to explore the potential offered by robotized mechanical weeding. On the other hand, this new technology should also provide solutions to the challenges of laborious work and the heavy reliance on manual labor in organic vegetable farming.

During the 2021 trial, four robots (Anatis, Dino, Oz and Toutilo) were evaluated on a cauliflower crop in a weed control program targeting zero-weeds. The guidance quality was evaluated based on the positioning precision of the weeding tool compared to the planting line.

Median guidance accuracy is less than 4cm, with values ranging from 1.88cm to 3.93 for all robots evaluated. In 95% of cases, accuracy is less than 5.51 cm for Toutilo and between 8 and 10 cm for the other robots. There is therefore still a room for improvement of the guidance systems. The good results obtained with Toutilo can be explained by the quality of the camera, but also by the less autonomous guidance principle based i) on physical marking on the plot (line/cord) and ii) on manual turning and positioning by the operator. Based on actual guidance quality, the 6 cm safety margin for tool adjustment could be reduced to 4 cm; this would further improve the quality of out-of-row weeding, without causing damage to the crop.

Autonomous actions (work, autonomous half-turn, end) tend to have an average precision over the first and last three meters equivalent to the precision of work in the plot. Operator actions, on the other hand, have a greater impact on guidance quality in the first and last meters. This impact is positive or negative, depending on the attention paid by the operator to the execution of the task.

In addition, it would be interesting to complete this evaluation with trials in different soil and topographical contexts.

Acknowledgements

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Spray drift measurements with herbicide application trains: methodological issues and results

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Abstract

Weed control on railways and surroundings is a key factor for safety and is typically operated using dedicated herbicide application trains. In France, the annual distance area covered by such trains corresponds to about 60 000 km of railways tracks (e.g. 30 000 km of railway lines) plus amenities for about 34 000 ha in France covered by both national high speed trains and regional low speed trains. The recent changes in French regulation introducing safety distances towards residential areas required the test of train applications in terms of spray drift mitigation as compared to a standard herbicide application with a boom sprayer. For this purpose, two train sprayer categories (national and regional) were tested in situ and using a dye tracer (no herbicide) considering ground deposition measurement using Petri dishes placed at various distances from 1 to 10m. A second protocol mimics dermal deposition onto 2D mannequins (adults and child size) equipped with cotton garments mainly placed at 3 and 5m downwind. The international standard for spray drift measurement has quite severe weather constrains and two tests were rejected; although samples were analyzed for further comparison with validated tests.

After analysis, spray drift measured in terms of ground deposition and resident exposure at various distances from the treated area showed a significant drift reduction above 90% for both trains compared to the reference boom sprayer.

Keywords : Train sprayers, spray drift, resident exposure

1. Introduction

Trains sprayers are employed to prevent the development of weeds on railways, rail infrastructures and amenities (Wygoda et al., 2006). In France, the number of train sprayers is limited (26 in France), but they cover a surface area of about 30 000 ha of railways (30 000 km x 10 m) plus 34 000 ha of amenities. Since train sprayers may work close to residential areas, the definition of adapted safety distances depending on the herbicide profile is a critical issue. Any surface area not being sprayed by train might be sprayed by other means, mostly manually with portable sprayers, that represents a laborious task for operators that also can be subjected to contamination. Since 2022, the national railway company has launched a new generation of train sprayers equipped with digital maps of each km of rails, a GPS aided control system for buffer zone management as well as direct injection of herbicides and adjuvants. Two main train types are employed. "National trains" – G&G design (Hungary) named TDGR (Train Désherbeur Grand Rendement) were set to deliver 300 L/ha @ a rated speed of 60 km/h and "Regional trains" – CTD design (France), named TDR (Train Desherbeur Regional) deliver 400 L/ha @ a rated speed of 40 km/h. Since 2021, glyphosate was banned and the main herbicide applied corresponds to pelargonic acid sometimes mixed with an antigerminative product and an adjuvant.

Trains may treat a variable width depending on the type railway (single track – Spray swath of 7m or double track, spray swath of about 11m). Trains sprayers consider several sections corresponding to the following Fig 1 for both systems.

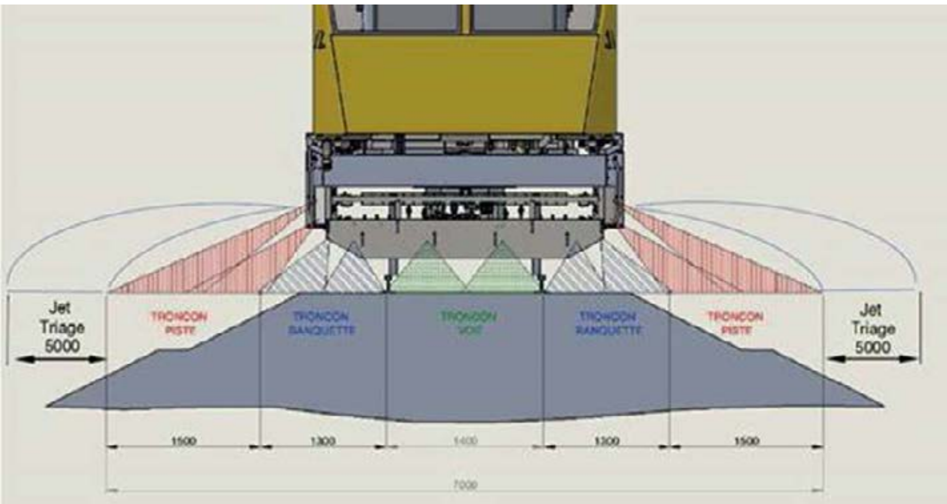

Figure 1. Spray sections defined for a single track system.

In order to consider a wide range of travel speed, each section is fed with clusters of up to 4 boomless stainless steel nozzles, of different size. The system may combine several nozzles of the same section in order to deliver the rated dose according to the effective travel speed (Fig 2). The same dosage is applied by each section, nozzle flow and angle are adapted to each section.

Figure 2. Nozzles clusters for each section.

According to the French Law, herbicide application by train is considered with regards to a boom spraying operation and spray drift might be ranked according to a filed crop sprayer model. Due to the absence of national or European model, the very few studies from other EU countries were first analyzed. Wydoga et al., (2006) revealed that, under the German conditions of application rate, travel speed and train settings, a drift reduction of 90 % was possible for trains sprayers in comparison with the German drift reference curves (Rautmann et al., 2001).

The national railway company asked INRAE to conduct a specific study in order to 1) quantify the sedimentation spray drift at short distances from the treated area as well as the resident (bystander) exposure and 2) to classify both train types as a potential spray drift reducing technique compared to the reference boom sprayer.

2. Materials and Methods

Trains

Both types of trains (TDGR and TDR) (Fig 3) were tested priory to the experiments. A virtual travel speed of 60 or 40 km/h respectively was set, the flowrate and the dye concentration of the spray mix was then checked on a static position.

Figure 3. Left: TDR sprayer – right: TDGR sprayer.

Experimental plots

Experimental plots were identified considering several constrains:

- Open area of 500 m minimum along tracks without obstacles (trees, buildings, bridges…);
- An obstacle free distance of 10 m minimum perpendicular to tracks (typically cultivated land);
- The railway shall be preferably elevated of about 1m above the ground; places where the railway is above the ground were not considered;
- Tracks shall be perpendicular to the main wind direction;
- Test plot shall be far away to nearest railway crossing (spray application are automatically shut down).

Several plots were considered and presented in Table 1.

Test	Location	Dates	Application Volume (L/ha)	Speed (km/h)	Main wind direction	Protocol
TDR 1	Brazey en Plaine 21	10/09/2021 To 14/09/2021	400	40	NE	Sedimentary spray drift @ 3m and 5m
TDGR	Rouziers de Touraine 37	20/10/2021 To 25/10/2021	300	60	W	Sedimentary spray drift @ 1 to 10m and mannequins
TDR 2	Ouges 21	27/10/2021 To 31/10/2021	400	40	NW	Sedimentary spray drift @ 3m and 5m and mannequins
TDR 3	Couffouleux 81	04/07/22 To 06/07/22	300	40	NW	Sedimentary spray drift @ 1 to 10m and mannequins

Table 1. Description of experimental plots and conditions.

Figure 4. Examples of an experimental plots (Left : Rouziers de Touraine Right: Couffouleux)

Experimental setup

Sedimentary spray drift is the reference protocol for spray rift measurement. Following ISO 22866 (2005) and ISO 22368-1 (2008), the protocol consisted of a series of plastic Petri dishes placed on the ground at 3 and 5m, in general 60 dishes were used with an interval of 2m. Mannequins (adult and child) were equipped with cotton T-shirts and pants and EFSA (2014) recommendations were followed.

By convention, the limit of the sprayed area was defined at the end of the path ("Piste") which is the normal limit for standard herbicide application by trains. For a better consistency and precision, all distances downwind were measured from the external rail, under the supervision of SNCF safety personnel.

A weather station composed of 2 x 2D anemometers (Gill, Maximet GMX 200, Alliance Technologie, Dierre, France) is placed downwind to check the conformity of wind speed and direction according to ISO 22866 :

- Minimum recording frequency of 1 Hz
- Minimum 90% of the total wind speed data higher than 1 m/s
- Average wind direction is perpendicular to the application direction +/- 30°
- Maximum 30% of the total number of data are out of the range +/- 45°
- Maximum average wind speed below 5 m/s

Remark 1: In general, a global appreciation of the weather conditions is made before the test, but the tests can only be validated afterwards, after the weather data are analyzed.

Remark 2: Since tests were conducted on commercial railways, the definition of time slots for spray applications were fixed about 2 weeks in advance, without knowing the weather conditions. In practice, a maximum of time slots were proposed per day in order to cope with both demanding weather conditions and safety rules regarding railway regulation.

Collectors

Round Petri dishes of 8cm diameter were used as sedimentary drift samplers. In general 60 collectors were placed at 3m ad 5m and for TDGR and TDR3, 10 additional Petri dishes were placed at 1m, 7m and 10m. The evaluation of resident exposure was achieved using 2D mannequins made of wood of 1.80m (adult) and 1.20m (child). These 2D body shape were covered with cotton T-shirts and pants (only adults) were used for the evaluation of resident exposure

The extraction of dye tracer (limit of quantification) was defined for both collectors.

Spray Mix

For practical reasons, no herbicide was used in this study. A fluorescent dye (Sulforhodamine B) was used at a concentration of 1 g/l (0.1% w/w) in the final mix. Considering the direct injection system, a premix of concentrate dye solution was incorporated at a rate of 3% in water. After spraying, the dried collectors are picked up and stored in a dark and dry place. Cotton T-shirts and pants are cut directly on the 2D mannequins according to the different body parts: legs, torso, back, arms.

Each sample is wrapped with aluminium and stored. The head and hands of the mannequins are individually washed using wet tissues, also analysed as collectors. When back to the laboratory, collectors are washed with a known volume of deionized water. The reading with a spectrofluorimeter is proportional to the dye concentration. Using Sulforhodamine B, the limit of quantification is about 0.1 µg/L e.g. 0.1 ppm compared to the initial concentration of 1 g/L.

Samples of the spray mix are taken in order to evaluate the initial concentration; this helps to calibrate the readings of the spectrofluorimeter.

The general equation used for to convert reading to concentration is the following:

$$ID = \frac{IF \times Vdil \times 10^{-3} \times b}{s \times V} \times 10^{6}$$

Where

ID: Drift Index (% of application rate)

IF : Fluorescence reading (no unit)

Vdil: volume of dilution in mL

b: slope of the calibration curve (concentration vs fluorescence)

s: surface area of the collector (m^2)

V: (Volume) Application rate (L/ha)

3. Results and Discussion

Validation of tests

Two out the four tests were finally not validated due to non-complying wind direction (TDR 1 and TDR2). However all collectors were analyzed.

Sedimentary spray drift

Results from Table 2 showed a logical deposition decrease from 1m to 10m along the downwind distance. A large variability was also obtained at 3m and 5 m (not shown here) due to both the air movements during and after the train passes and the natural wind turbulences.

Distance	TDR 1 90ème centile	TDGR 90ème centile	TDR 2 90ème centile	TDR 3 90ème centile
1m		0.204%		0.100%
3m	0.191%	0.028%	0.173%	0.022%
5m	0.242%	0.018%	0.034%	0.045%
7m		0.015%		0.015%
10m		0.018%		0.012%

Table 2. Sedimentary drift results expressed as % of the application rate (90th percentile). TDR 1 and TDR 2 correspond to non-validated data; TDGR and TDR3 were validated.

Globally, the order of magnitude for both invalidated tests (Table 2) was about 10 times higher than validated tests at the distances of 3m and 5m. This highlights the importance of the wind speed and direction, combined with air movements close to the train, especially when sampling at short distances downwind.

Distance (m)	TDGR 90th percentile	TDR 3 90th percentile	Test Train JKI 90th percentile	Basic drift values 90th percentile
1m	0.204%	0.100%	-	2.77%
3m	0.028%	0.022%	0.019%	0.95%
5m	0.018%	0.045%	0.014%	0.57%
10m	0.018%	0.012%	0.010%	0.29%

Table 3. Comparison with reference data.

According to Table 3, the drift values obtained from TDGR and TDR3 wer every close to those measured in Germany. Comparatively, the values obtained by the different trains and the Basic Drift Values (Rautmann et al, 2001) for boom sprayers shows differences of more than one order of magnitude. After cacalculation, the drift reducing percentage is between 90 and 95 depending on the distance and the train e.g. a drift reduction of a factor 10 up to 20 in value.

Deposition on mannequins

	TDR 2		TDGR		TDR 3	
Distance	3m	5m	3m	5m	3m	5m
Total deposition /adult	3.49 µg	2.97 µg	2.25 µg	3.03 µg	4.88 µg	3.44 µg
Total deposition 95th percentile adult	5.15 µg	4.74 µg	5.49 µg	6.68 µg	8.008 µg	0.89 µg
Total deposition /child	2.20 µg	2.02 µg	-	-	0.96 µg	1.28 µg
Total deposition 95th percentile/child	3.36 µg	3.76 µg			3.28 µg	2.70 µg
Conditions	0.5 g/L and 300 L/ha		0.5 g/L and 300 L/ha		0.5 g/L and 400 L/ha	

Table 4. Deposition on mannequins.

Table 4 shows the deposition values extracted from all body parts that are cumulated. Since children had no pants, the values for child is logically lower than for adult. Compared to sedimentation data, the difference between invalidated and validated tests is less visible. Moreover, values obtained at 3m and 5m are almost comparable (excepted TDR 3 – 5m) demonstrating that mannequins may intercept a droplet flux that probably stays in the atmosphere on higher distances.

	Kuster et al., 2021 (standard nozzles boom sprayer)			Mercier al., 2020 (66% drift reducing technique – viticulture)		
Distance	2m – av	5m – av	8m - av	3m (95th)	5m (95th)	10m (95th)
Total Deposition adult	~120 µg	~40 µg	~20 µg	22.4 µg	15.36 µg	10.48 µg
Total deposition child	~40 µg	~20µg	~20µg	9.07 µg	5.96 µg	3.53 µg
conditions	2.00 mg PTZ/ml (200 g/ha and 100L/ha)			1.6 mg/ml cymoxanil (120 g/ha and 75 L/ha) averages		

Table 5. Reference data for mannequins.

Table 5 shows some reference data obtained in the literature for boom sprayer (Kuster et al, 2021) or vineyard sprayer (Mercier, 2020). Here again, the total deposition on adult and child are much greater than for trains at similar distances. The calculation of the drift reducing percentage led to the same result as for sedimentation spray drift.

4. Conclusions

The measurement of spray drift for train sprayers was a real challenge. The combination of both meteorological and railway regulations imposed a good preparation and coordination be-tween partners. Despite the invalidation of two tests, the results revealed that spray drift from train sprayer is 10 times lower than for a boom sprayer, as demonstrated through sedimentation spray drift and resident exposure measurements. These data also correspond to the definition of basic drift curves for trains in France.

Acknowledgements

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4PTH and Weeder Pilot design, Inspired by User Centered Design method

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Abstract

THE 4PTH (4th hydraulic point) associated with the Weeder Pilot limits the use of phytosanitary weed control products. The concept gives access to the precision of guiding hoeers and any other tool that must follow crop lines. The objective of this project is to propose simpler solutions than those already existing.

The development of these solutions was based on User Centered Design. This article is a testimony to our approach.

The method deployed focuses on understanding the usage environment expressed by the real user: What are their tasks, their working environment, their mental load, their relationship to optimizing the use of their tools, etc. The real user is also multiple.

The multidisciplinary team designs by also integrating the notion of criteria attached to the repairability index. Validation and continuous improvement are carried out in several stages with user support.

These innovative developments contribute to the development of sustainable agriculture. Using the hoe is made easier. At the same time, the use of lower-power tractors remains possible, due to their limited mass and lower energy consumption. These systems make it possible to transform a classic tool into a modern tool controlled by row monitoring, to extend the period of obsolescence and to limit the carbon impact that new equipment would have caused. They also solve the labor problem because they eliminate the need for experienced drivers.

The method used proved satisfactory for the team and allowed the creation of popular and effective systems.

Keywords : Mechanical weeding, Side shift, Camera guide, sustainable agriculture

1. Introduction

The deployment of agroecology faces many obstacles. The challenge of limiting the use of agrochemical products, particularly for weeding crops, is one of the many areas to which agriculture is gradually committing. The practice of mechanical weeding requires the farmer to have the most efficient tools adapted to his farm. The Bournigal report[(1)], published nearly 10 years ago, sets out the challenges of triple-efficient agriculture from the point of view of agricultural equipment. Among other things, this report presents recommendations to integrate users into the design thinking process in order to provide them with particularly suitable agricultural equipment.

The design and development of the Weeder Pilot (Cormiers) and the 4 PTH (Hydrokit) were carried out in full awareness of the three pillars of sustainable development with the aim of offering solutions that meet the real needs of users. Several tools strongly inspired the approach implemented by the design and development teams :

- Standards ISO13407-1999[(2)] (Human-centred design process for interactive systems) and then ISO 9241-210[(3)].
- The items of the repairability index proposed in France for household electrical appliance[(4)].

This state of mind (because it was much more a state of mind than a line-by-line follow-up of the standards mentioned) made it possible to achieve fairly quickly and with limited resources, products that were highly appreciated by users, reliable and durable.

The pre-marketing study is not presented in this document.

2. Materials and Methods

1. User-centered design (Weeder Pilot)

User-centered design is based on the following criteria :

- Active user involvement.
- Designed by a multidisciplinary team to optimize the user experience.
- Taking into account users, their tasks, their environment,
- Division of functions between user and technology.
- Iteration of the design until user needs and requirements are met.

At the same time and/or successively, visits to numerous weeding sites "in the tractor – and with the user – and in the diversity of plots / crops causing a hot expression".

Experience sharing also includes the opportunity given by the user to delegate their driver's seat to us.

"Extraordinary" users have been defined

A follow-up of "pilot" users is deployed during the season.

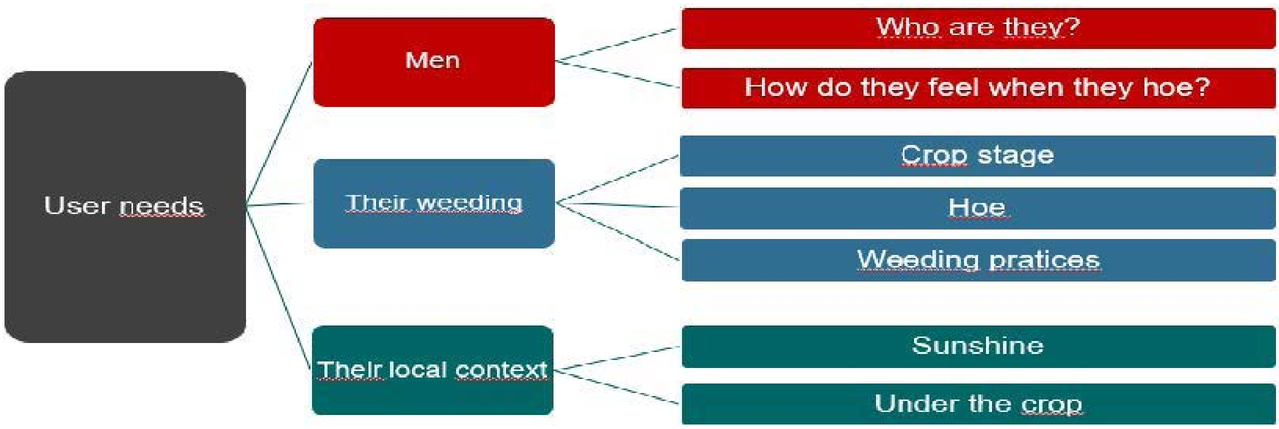
1.1. Active user involvement :

No "form" survey was conducted. Listening to the users' free expression on both open-ended and closed-ended questions broadens the scope and makes it possible to detect perceived interactions in the problematic that are more difficult to access by means of a questionnaire

Users are co-opted and involved at different stages of the process. In the first place, feedback is collected during visits "to the user base of competing systems.

1.2. Design by a multidisciplinary team :

The following know-how is present in the team: Agricultural, agronomic, industrial and applied research, mechanical weeding and other field work, hardware and software development, mechanical design. Incoming developers, if they do not know agriculture, are inserted into an integration course leading them to exchange with farmers about their practices, to learn how to drive a tractor and then to practice mechanical weeding in a real situation.



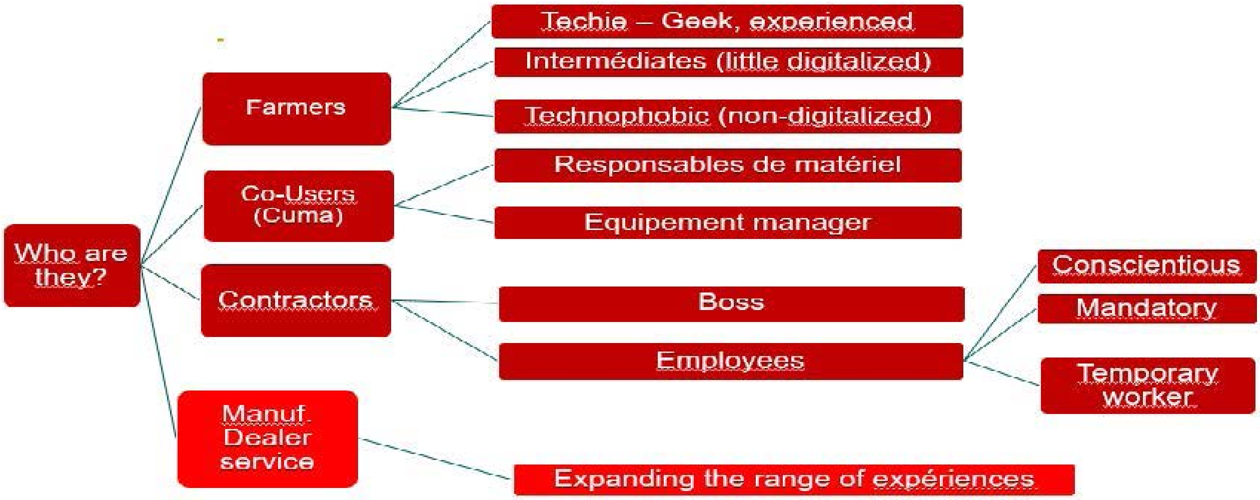
1.3. Consideration of users and their environment

The consideration of users' needs is divided into three main categories :

- Humans: Who are they, what are their responsibilities, their postures, their dispositions?
- Their weeding: This aspect focuses on their work and the means used to carry it out.
- Their local context: mechanical weeding in Brittany or Drôme confronts the user with conditions that can be significantly different.

1.3.1. Humans

1.3.1.1. Who are the users?

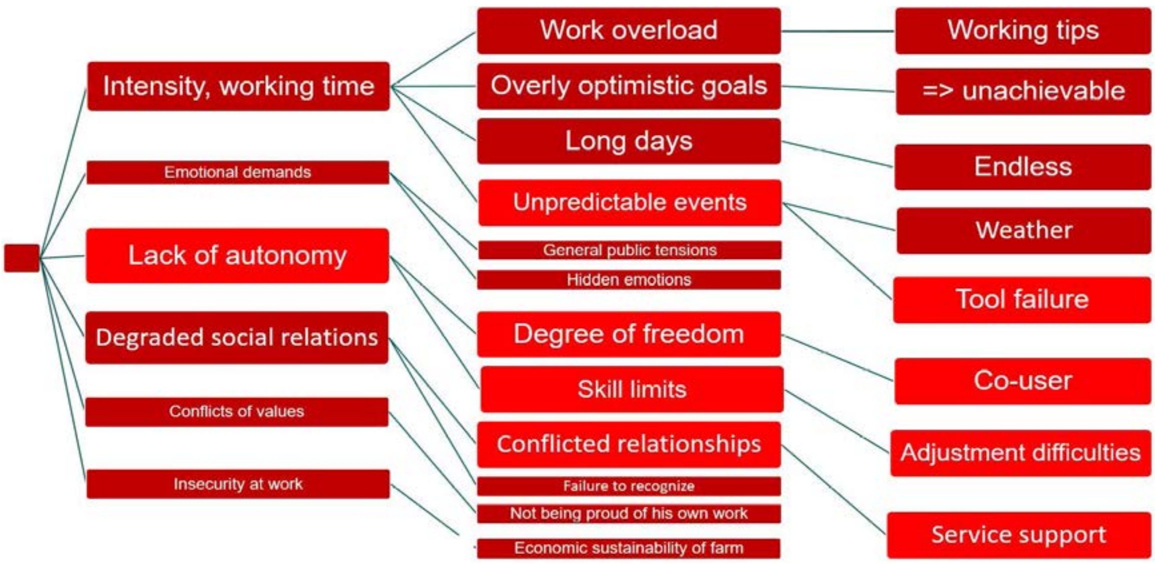


Depending on the responsibilities and skills of the users, their relationship with technology is very different. If, in the long term, the objective is to allow each of these categories to satisfactorily apprehend the product to be developed, distinguishing between these profiles makes it possible to define the target targeted for each development iteration.

1.3.1.2. How do users feel?

Anyone who works is potentially at risk of psychosocial risks. The INRS (National Institut of Health at Work) classifies these risks into six categories[5].

The purpose of the presentation of these categories and their variations (adapted for comprehension) is not to define the level of psychosocial risk of each user. It is to integrate the consideration of the mental load resulting from these risks in the work phase and to define ambitious objectives for the development of solutions that maximize the avoidance of hardware breakdowns and the autonomy of the user. Facilitate co-use, pay extreme attention to ergonomics and simplicity of adjustment, avoid as much as possible the need for after-sales service. For this last point, the training of the intermediaries involved in start-ups and after-sales service interventions is a decisive element.



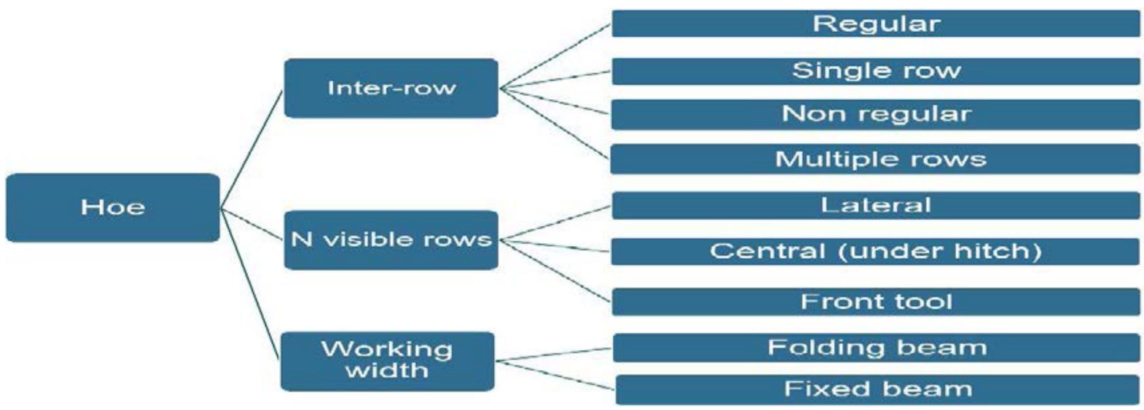
1.3.2. Weeding

1.3.2.1. Cultures and steps …

Crops	Colour	Row spacing Cm ?	Use. x
Maize	Green Yellow -> Green	75-80	✔
Beet	Green	45-50	✔
Sunflower	Green -> Green White	50-80	✔
Grain	Green	12,5-30	
Soybean…	Green	18-50	
Peas/beans	Green	12,5-35/ 45-50	
Cabbage	Green White	60-90	
Endive	Green	36	
Onions	Blue green, thin stems	Ex 180 (4x25)	
Carrots	Green, very fine	Ex 60 (3X5)	
….			
PPAM ex lavender	Wood -> Purple	150-180	
…			

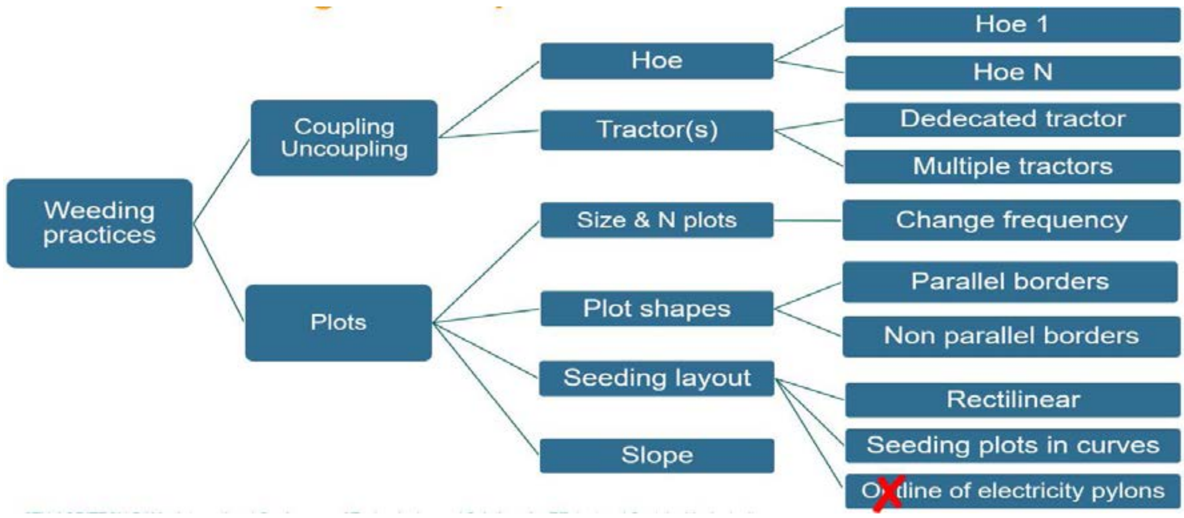
1.3.2.2. Weeding/hoeing

The expressed need to "read irregular/multiple row spacing" leads to the inclusion of this possibility, even though it is a very rare need. This satisfied need is converted into a selling point.



1.3.2.3. Their weeding/weeding practices

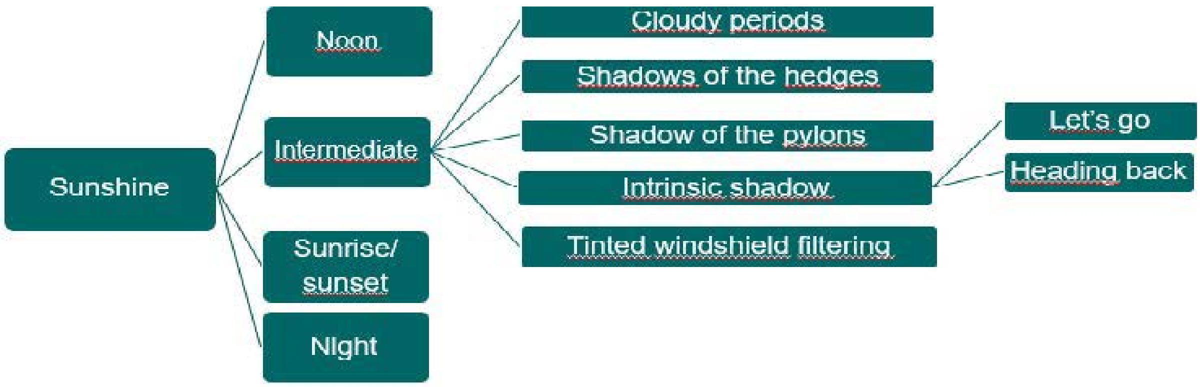
Visiting users' sites in real situations in different regions significantly broadens the scope of our perception of certain needs to be met compared to our initial vision (e.g. certain slope conditions). This also makes it possible to set limits on the performance to be achieved (e.g. winding contours, etc.).



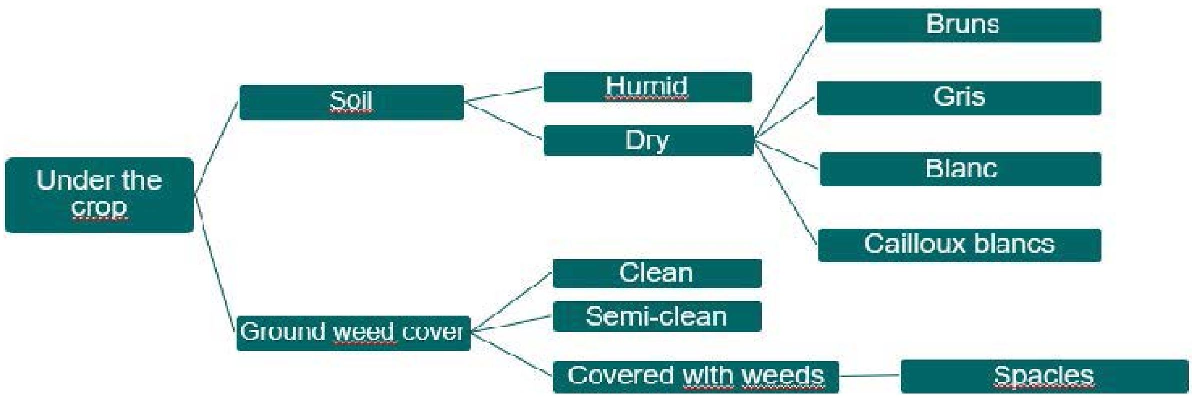
1.3.3. Their local context

1.3.3.1. Their local context/sunshine

Similarly, construction sites have particularly bright sunshine or unpredictable situations (e.g. tinted windshield filtering).



1.3.3.2. Their local context / under culture



1.4. Distribution of functions between users and technologies

Goal Setting

Define an interface, an application

- Usable by intermediate (not very digitized), occasional and multiple users;
- Allowing spontaneous autonomy for these users;
- Limiting the necessary settings to the equivalent of the best bidder of the competitors.

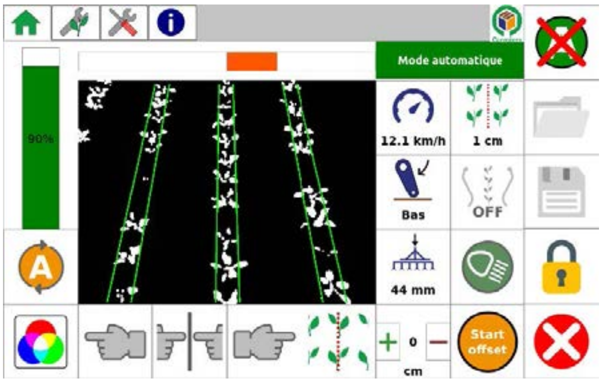
Define a system

- Evolutionary;
- Capable of handling all root crops (in rows);
- "Portable" by several different cultivators from th-same farm;
- Robust to strong variations in brightness;
- Robust to different soil types and levels of grass cover;
- Precise.

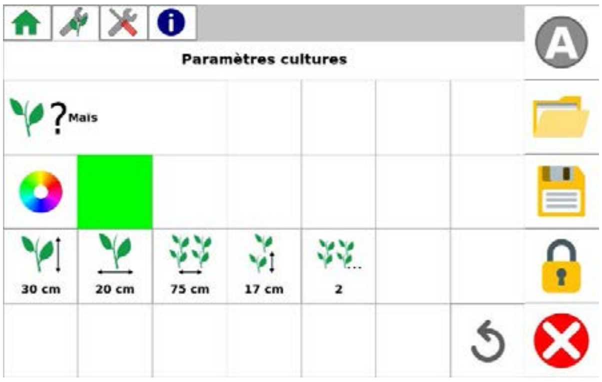
1.5. Design iterations

1.5.1. First iteration :

- Easy-to-read and user-friendly interface;
- Operational system on the most hoed crops (maize, beetroot, etc.) with classic (regular) row spacing configurations ;
- The system is robust to strong variations in light and robust to the main situations of soil types and grass cover levels corresponding to these crops.

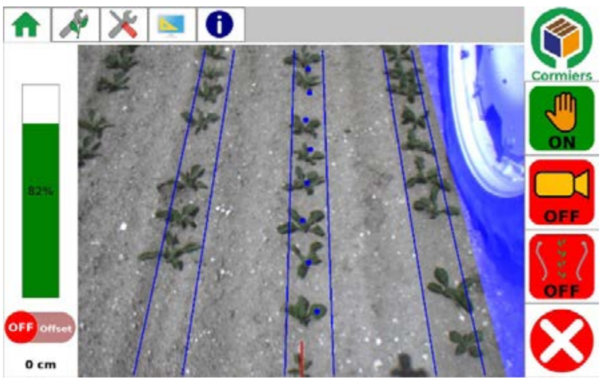


One of the important features of the Weeder Pilot is that it presents either the color image or the segmented image (white crop on a black background) on the video monitor. This possibility reassures the user considerably, which will knows exactly what the trajectory correction calculation is based on at all times



1.5.2. Subsequent Iterations

Active listening to users and monitoring machines in the field make it possible to prioritize iteration objectives. They also make it possible to develop new branches.



Optimized the readability of certain icons and their placement

Broadening video feedback,

More and more types of crops

Irregular row spacing

Image Mask

Servo optimization – sensitivity, dedicated hydraulics

… and many other possibilities

2. Repairability Index *****

The repairability index was implemented in France in 2021 by the Ministry of Ecology, Energy and Territories. It is composed of the following five criteria :

2.1. Documentation (length of time technical documentation is available and advice on operation and maintenance)

The documentation covers five main aspects beyond the presentation of the leaflet and safety instructions. It will soon be available online.

2.1.1. User: Product Description - Using the Console - Getting Started (Field Use).

2.1.2. Constructeurs / concessionnaires: Installation / Etalonnage / Paramétrage / Dépannage.

2.2. Disassemble ability (ease of disassembly, tools needed, characteristics of the fasteners).

Disassembly does not require any product-specific tools.

2.3. Availability of spare parts (duration, delivery time)

A minimum stock of spare parts is established. However, the supply period is potentially subject to availability from our own suppliers (for some parts). Planned storage over 10 years. Lead time (Stock of after-sales service parts at our manufacturer customers under consideration).

2.4. Spare parts prices.

The price of spare parts is set by the dealers. Cormiers suggests a piece rate with a coefficient of 1.22 (Culture Price)

2.5. Specific Criteria:

Up to date: Users have the opportunity to update the program of their material every year free of charge through online access.

3. The design of the 4 PTH

A similar but independent approach has been implemented. Main elements

3.1. Taking into account users and their environment (Summary with synthesized needs)

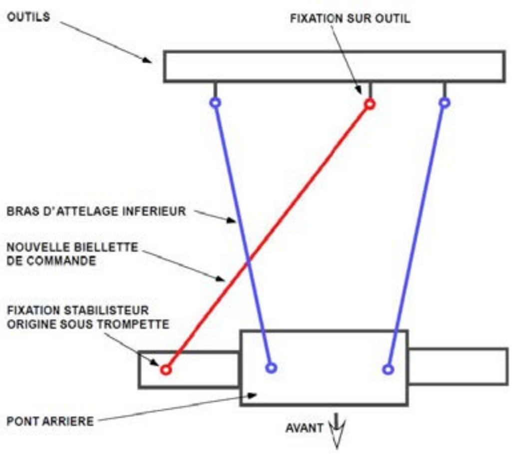
Have a trajectory correction interface :

- Cheaper than other interfaces on the market,
- Not requiring the use of a more powerful, heavier tractor to do the same job,
  - Light.
  - Doesn't move the center of gravity of the tool being carried.
- Allowing a very good working precision and a range of motion of around 400 mm.
- Compatible with different tools (hoe, seeder, etc.).
- Compatible with different types of piloting.
  - Guiding camera,
  - Dual Antenna RTK GPS,
  - Followers
  - Joystick or orbitrol.

3.2. Design iterations

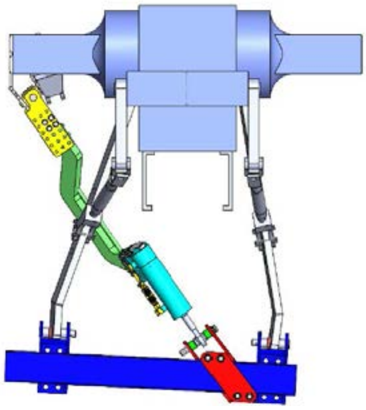
3.2.1. First iteration (prototyping)

The principle adopted is to enhance the degree of freedom of transverse movement of the 3-point hitch *(Thank you Mr Ferguson)* while avoiding any additional constraint on the coupling arms.



3.2.2. Subsequent iterations (pre-series and series)

Redesign of a fastening device including a clevis compatible with the stabilizer of the tractor equipped and allowing easy hooking/unhooking for users with several implements (triangle agreement).



3. Results and Discussion

1. Users

The participation of users is crucial for the correct definition of a product. From our point of view, this approach is very different from a simple inventory of needs, however exhaustive it may be, if it is devoid of the confrontation with the LIVE of the use.

It is the fact of experiencing the site, of practicing the site, with the user that reveals the critical points to be resolved, especially since some of these points are multifactorial.

2. Distribution of the project:

Downstream of these exchanges, the project appears to be particularly vast. The definition of the objectives to be achieved covers a large area which should be circumscribed by

- a large "eventual" scope: This scope makes it possible to define the hardware architecture which must be almost fixed for the commercial life of the product (Supplies/spare parts/after-sales service, etc.).
- The initial scope of development (development time/cost/time to market, target addressed).
- The intermediate perimeters of iterations. The latter are not fixed perimeters but perimeters adapted to the outcome of each work campaign during which user feedback is produced

3. The Design Team

No one on the design team – in all its diversity – is exempt :

- Contact with users;
- Driving the tractor and the implement in a real construction site situation, especially during the testing of iterations.

The relationship between the developed system and the user purpose is the primary basis of the vocabulary shared by the team. These experiences shared by the team make it possible to define the choices of objectives for future iterations with relative consensus.

4. Conclusions

The use of a design method strongly inspired by User-Centered Design has made it possible to develop two very operational systems that differ in their markets in terms of efficiency but above all in terms of ergonomics for the Weeder Pilot and its simplicity and sobriety for the 4PTH.

The expressions of needs have been analysed in a framework that is always connected to the human user and the context in which he has to use his equipment.

Targeting "non-tech-savvy" extraordinary users has made it possible to set ambitious usability and simplicity goals for Weeder Pilot's HMI. In addition to the performance of the system, this gives it a real competitive advantage.

It is this approach that has made it possible to develop very competitive solutions relatively quickly in a market that has been occupied by other players for the past twenty years.

5. References

(1) Bournigal, Jean-Marc. "Defining together the future of the agricultural equipment sector." Report of the agricultural equipment mission, Irstea (2014).

(2) ISO13407-1999, Human-Centered Design Process for Interactive Systems

(3) ISO 9241-210:2010, Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems

(4) Consumer Information/ Repairability Index,(2021) Ministries Ecology, Energy, Territory (link updated 2023)

(5) Gautier Marie-Anne, Langevin Valérie, Brochure: Psychosocial risks. 9 tips for taking action on a daily basis; Inrs (2016)

TIM, Rear Top Linkage and Spreader developments

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Abstract

Spreading fertilizer is all about precision and getting the best yield from the crop: an optimal and accurate distribution of the material (determined by the optimal spreading pattern parameters) is highly desired in order to cut back waste, reduce input costs/maximize return on the crop and minimize the impact on the environment.

Spreading parameters not properly configured or badly adapted while spreading will determine a bad spreading pattern with underdosing and overdosing situations.

Key parameters for an optimal spreading are, amongst others: dosing opening, spreading release point control, spreading height, spreading inclination and disks rotation speed. The necessary initial setting and continuous tuning of these parameters by the operator, due to the dynamic evolution of the spreading conditions, is quite challenging and takes usually to a corruption of the final results.

In addition to the already existing automated features like dosing opening control and spreading release point control, TIM technology was added both on the tractor and spreader side to complete the parterre of spreading parameters automatically adjusted by the system.

Two existing TIM functions were implemented to utilize TIM Rear PTO for the disks rotation speed and TIM Rear Hitch for the spreading height, meanwhile a new TIM-like function was developed to have a Rear Top Linkage control for the spreading inclination. Some challenges are still on the table but the tests demonstrated that the target to complete the automation of the spreading task was achieved: this will further allow future developments towards full autonomous spreading.

Keywords : TIM, top link length control, inclination control, fertilizer spreading, autonomous spreading, pitch control.

1. Introduction

1.1. Spreading and related problems

Accurate and even distribution of the fertilizer while spreading is a key aspect of this activity and the key parameters to achieve the best results, still manually tuned by the operator, are correct height and inclination of the spreader compared to the crop surface and disks rotating speed. These parameters are connected to tractor functions like Rear Hitch (height), Rear Top Linkage (inclination), tractor Rear PTO (spreader disks rotating speed)

Currently, the operator is supposed to set all the initial parameters and to continuously tune some of them during the spreading phase in order to keep the optimal values. On the spreader side, the automatic adjustment of some of these parameters (like dosing opening) is already existing but, due to the changing weight in the hopper, the main problem is to keep the height and inclination of the spreader optimal compared to the crop; this is something still not automated.

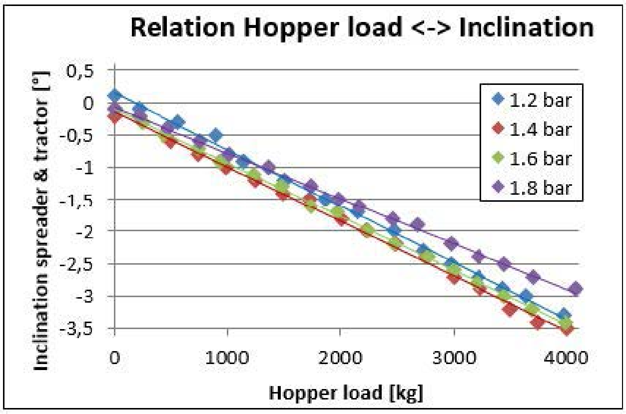
Figure 1.1. Result of wrong spreading settings with the spreader inappropriately inclined towards the back generating under dosing at the border between two passes (yellow) and overdosing on the passes (dark green).

If the spreader is higher and tilted forward more than desired, this will create a more trapezium spreading pattern which will cause overdosing between two passes; if the spreader is lower and tilted backward than the desired position, this will create a more triangular spreading pattern which will lead to under dosing between two tracks.

In the figure 1.1, a typical case of wrong spreading settings where the green/yellow stripes between the passes are clearly indicating a mistake in the adjustment of the spreading settings.

During the spreading phase, the so called "hinge effect" can be observed: due to the fertilizer decrease in the hopper, the weight and weight distribution on the tractor wheels is significantly changed. The loading capacity of a spreader can be up to 3900 kg at the same time: with a flow rate up to 540 kg/min, the hopper can be completely emptied within a few minutes.

The following pictures show two aspects of this hinge effect, related to spreader inclination and spreading height above the crop.



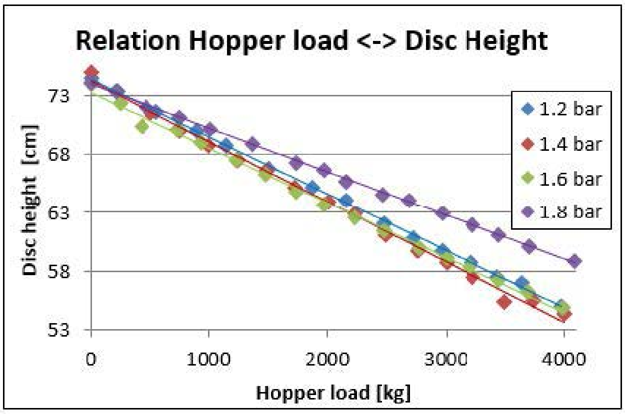


Figure 1.2. example of hinge effect in test environment with different tractor tires pressure. The relation between the hopper weight and the hopper inclination and disks height depends on tires conditions, front load, tractor mass and it is mainly linear. A load of about 4000 kg can result in 16-20 cm disks height decrease and 2.9° – 3.5° deviation on the spreader inclination.

The main challenge of the hinge effect is to understand when to do the initial spreading settings and how to keep the settings optimal while spreading. The following picture shows the ideal initial and final conditions of the spreader parameters involved in the hinge effect, taking into account that the spreader is fully loaded at the beginning and empty at the end of the spreading operations.

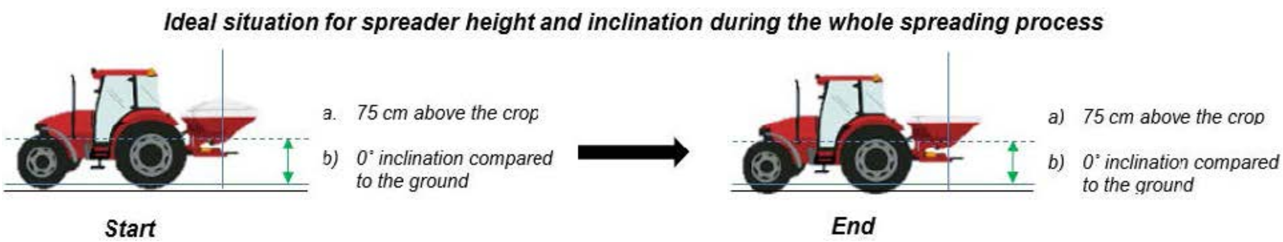


Figure 1.3. Ideal situation where the spreader parameters like height and inclination are kept constant during the spreading process.

A typical problem, just before to start spreading, is to decide if the initial parameters (e.g spreader height and inclination) must be adjusted after filling the hopper or before to fill it.

The following picture demonstrates that both methods have a side effect if a continuous tuning of the parameters is not properly done.

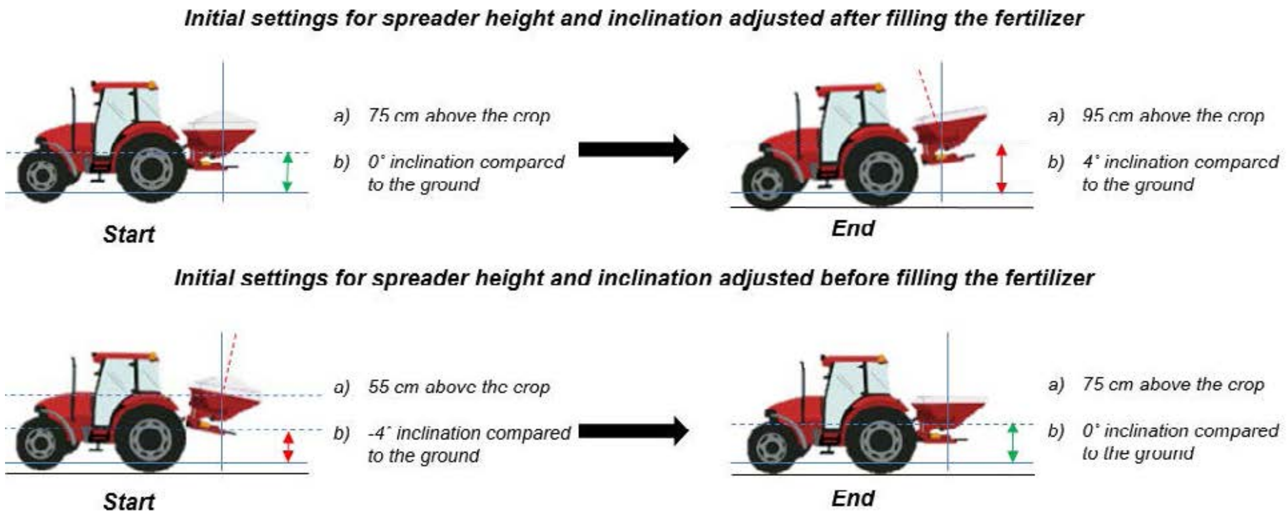


Figure 1.4. Effects on spreader parameters of different methods to set the initial settings like height and inclination. Settings done before (upper figure) or after (lower figure) filling the hopper with the fertilizer.

If the initial settings are done after loading the spreader, the right configuration will be the initial one (e.g 75 cm above the crop and 0° inclination) but, while the hopper content decreases, the hinge effect will act moving the spreader up and towards the tractor (up to 95 cm above the crop and +4° on inclination).

If the initial settings are done before to load the spreader and then the spreader is loaded, the wrong configuration will be the initial one (e.g 55 cm above the crop and -4° of inclination) but, while the hopper content decreases, the hinge effect will act moving the spreader up and towards the tractor and coming back to the initial proper configuration with the empty spreader.

It is therefore desired to develop a system able to adjust the spreading parameters throughout the spreading process, without human interference.

In Tab 1.1 there is a clear resume of the main parameters impacting the spreader settings and the associated current automation level status.

Spreading parameters	Ideal parameters	Currently tuned by	Impact, if not well tuned
Dosing opening	Dynamically tuned by the system following the spreading chart	Spreader	Wrong amount of fertiliser applied
Spreading release point	Dynamically tuned by the system following the spreading chart	Spreader	Wrong working width resulting in over and underdosing
Disks rotation speed [rpm]	Fixed setpoint depending on field location (main field / border area)	Operator	Wrong working width resulting in over and underdosing
Spreading height [cm]	75 cm from the crop	Operator	Over and underdosing
Spreading inclination [degree]	0° compared to the ground	Operator	Over and underdosing

Table 1.2. Main factors impacting the spreading pattern and their current automation level.

1.2. Main directions to solve the problem and objectives

The main idea is to use the TIM technology to integrate the already existing automatic tunings (dosing opening and spreading release point) and to allow the spreader, that has the best knowledge about the situation into the field, to directly manage the resources of the tractor in order to keep always all the optimal parameters. To proceed in this direction, two already existing TIM functions, TIM Rear PTO and TIM Rear Hitch, were implemented both on tractor and spreader side. Additionally, a new necessary TIM-like function, able to manage the Rear Top Linkage, had to be developed and integrated with the other 2 TIM functions. This TIM-like Rear Top Linkage function is currently in discussion in the AEF TIM group and potentially candidate to be officially introduced in TIM Norm Gen 2.

Spreading parameters	Method	TIM Function	TIM-like addition
Dosing opening	-	-	-
Spreading release point	-	-	-
Disks rotation speed [rpm]	The spreader commands the tractor Rear PTO rpm to get the correct disks rotation speed (also when changing from main field to border area)	Rear PTO	-
Spreading height [cm]	The spreader commands the right Rear Hitch height, in order to maintain correct spreading height above crop.	Rear Hitch	-
Spreading inclination [degree]	The spreader commands the right Rear Top Linkage length, in order to maintain correct spreading inclination.	-	Rear Top Linkage

Table 2. TIM strategy applied to the tractor/spreader couple.

Resuming, the main objectives of the developments were to reduce the operator interactions with the system and to optimize the yield of the crop through a really accurate spreading. The direction of the developments was, then, to increase the global level of automation of the couple and the intelligence on the spreader side, allowing it to develop and drive the best spreading strategy.

The main directions used for these developments were to fit the current technologies already available on the market (TIM) to the spreader and to generate the necessary improvements (TIM- like Rear Top Linkage) in order to get the optimal set of features.

2. Materials and Methods

2.1. Developing the necessary TIM functions on the tractor and the spreader

The first necessary step was to develop the TIM normed Rear Hitch and Rear PTO functions for a TIM Server (tractor) and the TIM Client (spreader) in order to allow the spreader to manage these resources through ISOBUS. These functions are allowing the spreader to control the following features using the AEF TIM norm and had to pass the AEF TIM conformance test in order to get the necessary AEF certificates:

TIM Function	TIM Function Facility	Development necessary to allow the spreader to:	Impacted spreader parameter
Rear Power Take Off (Rear PTO)	PTO engagement clockwise	Engage the Rear PTO when a spreading action is needed	Disks rpm management
Rear Power Take Off (Rear PTO)	PTO disengagement	Disengage the Rear PTO when a spreading action is not needed anymore	Disks rpm management
Rear Power Take Off (Rear PTO)	PTO shaft speed Clockwise	Manage the speed of the Rear PTO shaft while the fertilizer is spread	Disks rpm management
Rear Hitch	Rear Hitch motion	Raise until stop request/lower until stop request/Float and Stop the Rear Hitch without a specific setpoint (%)	Height of the disks from the crop
Rear Hitch	Rear Hitch position	Request a specific setpoint position (%) for the Rear Hitch	Height of the disks from the crop

Table 2.1. TIM functions developed both on the tractor and the spreader side.

In addition to these official TIM functions, another function, the TIM-like Rear Top Linkage , had to be developed on both tractor and spreader side in order to manage the missing parameters.

The last missing step done was, then, to develop the internal algorithm of the spreader able to handle all these functions at the same time keeping all the parameters properly harmonized.

2.2. Developing the TIM-like Rear Top Linkage function

A completely new function able to manage the spreader inclination was a clear necessity: a Rear Top Linkage function that allows to set the Rear Top Linkage length was then developed, allowing settings like Float, Stop, Raise, Lower, specific % position (completely new).

This function was developed as a basic tractor function and then, on the top of it, adapted to the TIM structure, allowing an external source command (the spreader) to command it. The basic idea was to get a Rear Top Linkage that is behaving like a TIM Rear Hitch

TIM-like Function	TIM-like Function Facility	Development necessary to allow the spreader to:	Impacted spreader parameter
Rear Top Linkage	Rear Top Linkage motion	Raise until stop request/lower until stop request/Float and Stop the Rear Top Linkage without a specific setpoint (%)	Inclination of the spreader compared to the ground
Rear Top Linkage	Rear Top Linkage position	Request a specific setpoint position (%) for the Rear Top Linkage	Inclination of the spreader compared to the ground

Table 2.2. TIM-like Rear Top Linkage function developed both on the tractor and the spreader side.

2.2.1. Developing the TIM- like Rear Top Linkage on the tractor

The target was to develop a system able to get some position commands from ISOBUS (Raise, Lower, Float, Stop, % position) and to actuate them through the valve connected to the Rear Top Linkage.

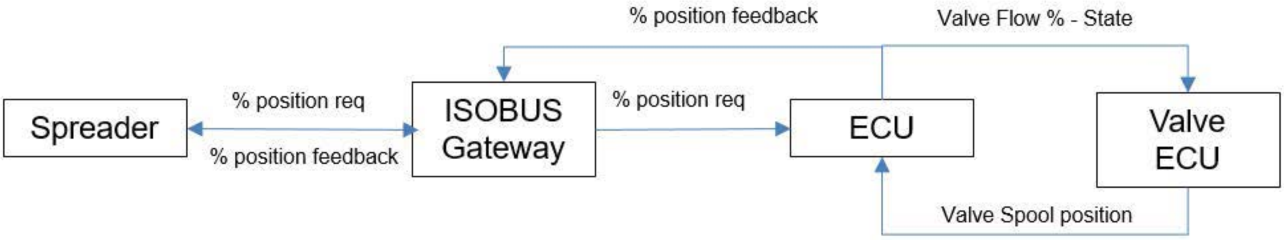


Figure 2.1. System scheme of the TIM-like Rear Top Linkage management on the tractor.

The most challenging part was to reach the proper specific % position of the rear top linkage in a reasonable time, avoiding too much overshooting and undershooting while allowing different loads on the toplink. Main areas of research and developments were:

Engine minimal rpm to get enough oil flow for the rear top linkage: it was necessary to measure the real flow for the valve connected to the Rear Top Linkage in relation with the engine rpm to understand if there was a lower limit for the engine rpm in order to guarantee a proper response of the system for the requested flow. In the graph we can see that, when the engine rpms are not enough, not all the flow commands are executed. However, due to the fact that the engine rpms are mainly set to get the proper Rear PTO rpm and that only little slow regulations (5-10% length, flow always below 30%) are requested to the Rear Top Linkage these limits did not impact the developments at this stage.

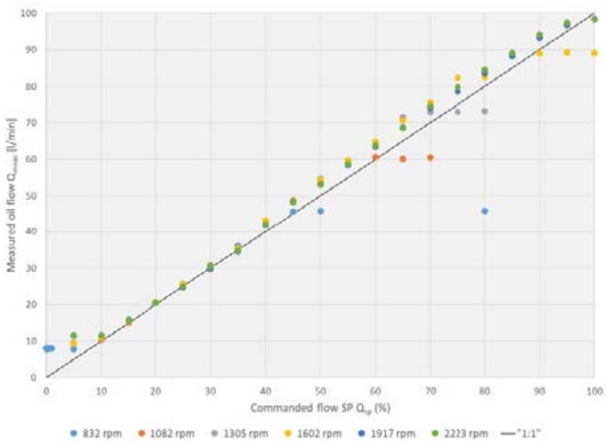


Figure 2.2. Relation between engine rpm (X-axis) and measured (not estimated) oil flow (Y-axis).

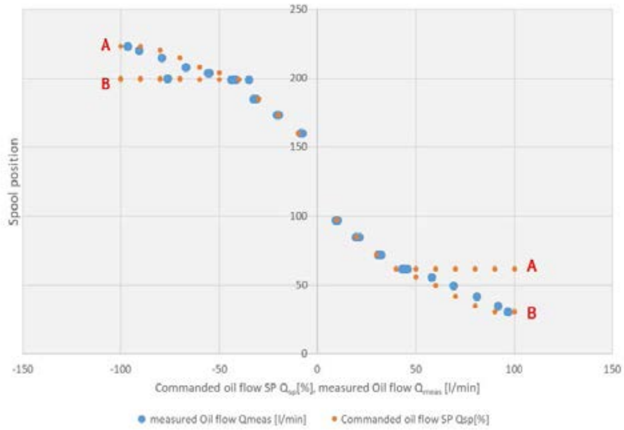


Figure 2.3. Spool displacement vs measured oil flow for different engine rpms.

Valve Spool displacement for a suitable feedback for the PID controller: to create a reasonable control loop with the PID controller that manages the valve connected to the rear top linkage, experiments and measurements about the communicated valve spool position were conducted, comparing the results with the current method used on the tractor to report the estimated flow (connected to the fingertips). When the engine rpms are not enough to guarantee the requested flow, the spool position reported by the valve does not change, meanwhile, if the rpms are enough, the spool position has a clear relation with the flow as shown in the graph.

These results corroborated the idea to use the spool position and its relation with the flow as a suitable parameter for the PID control algorithm.

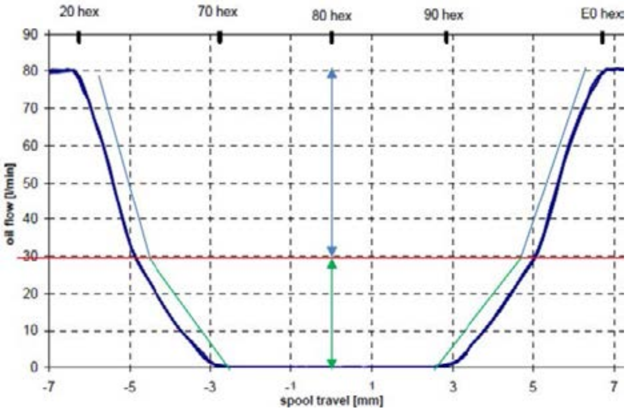


Figure 2.4. Spool displacement relation with the oil flow. Two different working areas can be defined, above and below 30% flow.

Spool displacement movement range: following the measurements (that confirmed what is reported in the data sheet of the valves), the spool displacement relation with the oil flow has two main working areas (green and blue) and, into these areas, the relation is suitable for a closed loop control. Due to the nature of the requested adjustment while spreading, the spreader requires a relatively slow rear top linkage control; consequently, the lower range (0-30% oil flow) has been chosen to implement the control.

Tuning the PID parameters: the experimental tests corroborated the simulations and different P values to extend and retract the Rear Top Linkage were used, while I and D parameters did not have a big influence for the kind of performances that were requested (quite slow and limited movements).

	P	I	D	Dead band	Weight	Qmax°	Step-size	Overshoot	SP reaching time
Extend	1500	0	0	0.15%**	2300 kg	10%	30%	3.35%	1.56s
Retract	2000	0	0	0.15%**	2300 kg	10%	30%	0.48%	2.26s

** 1% position change in the toplink length result in about 0.2 degrees inclination movement, so 0.15% deadband means a maximum deviation of 0.03 degrees in the inclination.
° Flow command sensitivity

Table 2.3. Optimal PID parameters selected at the end of the test session to tune the PID controller for the Rear Top Linkge.

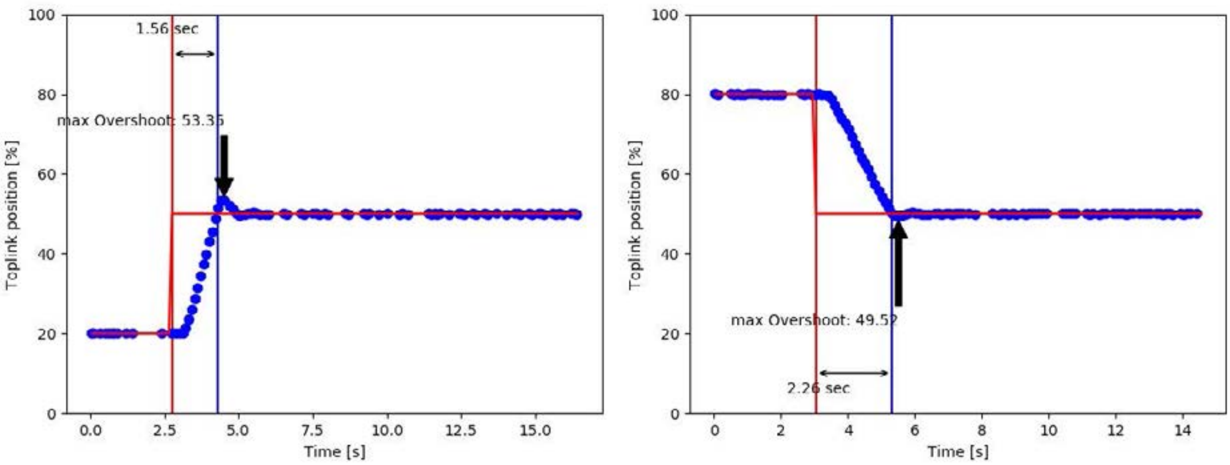


Figure 2.5. Extend (left) and retract (right) performances of the rear top linkage with the optimal parameters mentioned in Tab 2.3.

2.2.2. Introduction of the Rear Top Linkage into the TIM AEF norm

The TIM norm Gen 1.0 currently does not contain any TIM Rear Top Linkage function, so the discussion was triggered into the specific AEF Tractor Implement Management working group. Themes on the table were to discuss the potential use cases and benefits of this function, the timings, the technical proposal and the test implementation. This job was shared among the different manufacturers in the

AEF group and the Rear Top Linkage is a potential candidate to be part of the TIM Gen 2.0 norm as an official TIM function. In the current implementation of the system described in this paper, the function is handled as a proprietary function on ISOBUS in parallel with the existing TIM ones and with the same kind of protocol and closed control loop.

2.3. Developing the TIM spreader internal algorithm to manage all the functions

All the 3 functions used for spreading are managed by the spreader at the same time using an algorithm that mixes the commands together and harmonizes them.

Disks speed control (Tractor Rear PTO control): a straight forward control based of the tractor Rear PTO was developed: based on the spreading job and specific location into the filed, different disks rotation speed setpoints are defined.

One fixed rotation speed is defined for the main field meanwhile a different rotation speed is defined, while going into border areas, depending on the type of border spreading application.

In the spreader, the disks necessary speed is converted into rear PTO speed and communicated via TIM protocol to the tractor. When reaching the border areas, border spreading unit is hydraulically moved into the spreading flow, then the disks speed setpoint is automatically adjusted accordingly.

Spreader height control (Tractor Rear Hitch control): since this parameter is heavily influenced by the huge load variation in the spreader and the crop height, a control system was developed using ultrasonic distance sensors mounted on the spreader (one per side). A PID control strategy manages hitch height control setpoints via TIM protocol to the tractor, allowing the system to react to hopper content and crop height variations.

Spreader inclination (Tractor Rear Top Link control): the geometry of a common tractor hitch defines the relation between the hitch height, toplink length and spreader inclination. In Figure 2.6 the measurements explain the required toplink length during deviating hitch height for various spreading angles.

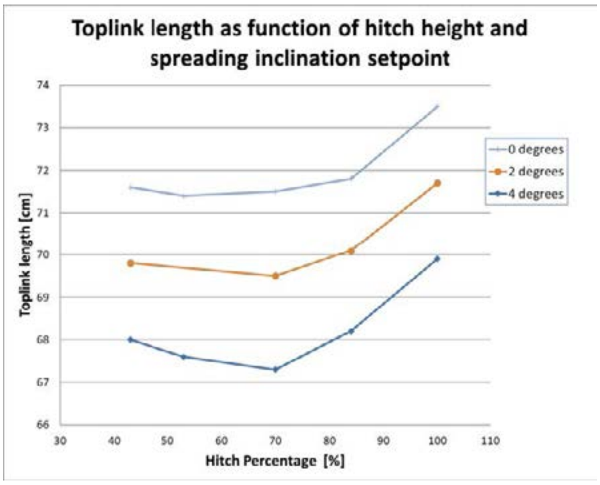


Figure 2.6. Relation between the rear hitch position and the top link lenght.

Since the hitch height is continuously controlled by the height control, this needs to be taken into account to control the toplink length.

Additionally, due to the nature of fertilizer spreading, driving on hilly conditions requires a spreader inclination control referred to the field slope and not to earth horizon. This means that, in these conditions, it is not possible to generate a control based on an inclination sensor on the spreader.

Mounting a secondary inclination sensor on a tractor could resolve the relation problem with the rear hitch height while driving under hilly conditions. However, since the tractor itself will also incline due to varying load in the spreader (look at figure 1.2), a new control strategy was defined where the toplink length is controlled based on spreading inclination setpoint, actual hitch height and actual hopper content.

3. Results and Discussion

Based on the aforementioned developments, an extensive spreading test was performed into the field in real spreading conditions in Q1 2023. A M7 KBT tractor and a DSX-W2550 GEOSPREAD were equipped with TIM control technology and TIM-Like Rear Top Linkage functions. The spreader was loaded with 2200 kg fertilizer, working width defined at 36m and driving speed maintained at 18 km/h.

Based on the spreading charts, the required spreading inclination was set to 0^0 and the required spreading height was defined at 75cm above crop. Finally the rear PTO speed was defined at 524 rpm; no boundary spreading was performed during the test.

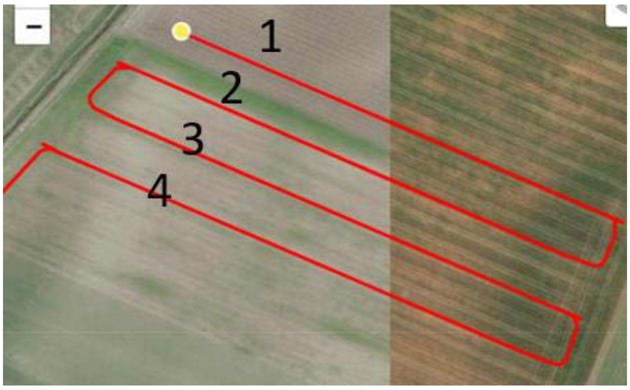


Figure 3.1. Relation between the rear hitch position and the top link lenght.

Figure 3.1 shows the GPS track where 4 typical field tracks are identified: spreading was only done on the main field, no spreading was carried out when turning on the headlands and TIM control stayed active for all 3 functions during the complete duration of the test; a total application of 1928 Kg was performed.

In figure 3.2, the resulting spreader inclination is represented in relation with the hopper weight over time. Due to the slight inclination of the field ($0.5\ ^0$) the inclination can be compared between pass 1 and 3, and 2 and 4. Additionally a slight inclination adaption can be noted at the east side of the field. While having inclination control enabled, the variation between the passes is limited to $<0.5\ ^0$, which is very much acceptable for accurate spreading. According to figure 1.2, without inclination control this would have a deviation of 1.5° – 1.9^0.

Figure 3.2. Hopper content and spreading inclination as function over time including track number.

In a similar way, in figure 3.3, the height measurement for left and right height sensor show a very consistent height regulation.

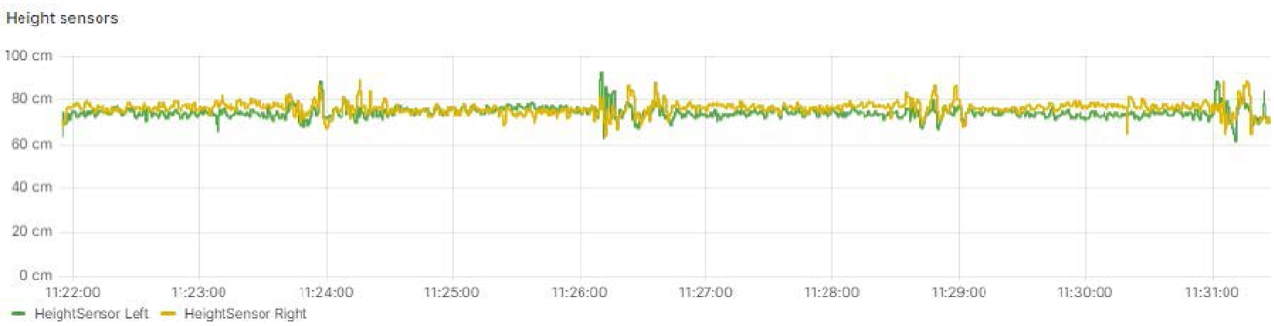


Figure 3.3. Spreader height sensor measurements as function over the time.

Figure 3.4 shows the requested set point and actual measurement both toplink and rear hitch: maximum deviation from the actual measurement to the requested setpoint is seen to be 2%.

Due to the weight decrease over time, the tractor is tilting forward and an average decrease of the hitch setpoint of 12% (height adaption of ~9 cm) can be observed: this adaption is closely matching with the loading tests performed in laboratory conditions and shown in figure 1.2

Figure 3.4. Measurements and setpoint for the TIM rear hitch and TIM-like Rear toplink.

Finally, part of this test was dedicated to the Rear PTO control. The system was able to keep the accuracy of ± 5 Rear PTO rpm (± 20 Rear PTO rpm in specific corner cases): as the spreading process in combination with the requested speed and the filed slope have an influence on the tractor engine load, a slight deviation from requested rpm occurs. Works are carried out to overcome this phenomenon.

Figure 3.5. Measurements and setpoint for the TIM Rear PTO.

4. Conclusions

Starting from basic field needs, some developments were identified on both tractor and spreader side. The developments and connected tests in real conditions demonstrated that the idea to automate the spreading tasks using TIM technology with an additional function TIM-like (the rear top linkage) goes in the right direction, allowing the operator to really avoid to have a continuous active monitoring of the spreading job.

A Rear Top Linkage function was fully developed on the tractor side in addition to the basic TIM developments for the Rear PTO and Rear Hitch control, while a 3 function control algorithm and TIM compliancy was developed on the spreader generating a system able to have a very consistent spreader height and inclination regulation in association with a suitable Rear PTO management.

The main challenge on the table is still a very fine tuning of the Rear PTO management on the tractors side in corner cases in relation with the tractor speed and field slope (overall the definition of the acceptable slope ranges).

Acknowledgements

- Different departments of Kubota Corporation for the close synergy on extended projects involving both tractor and implement.
- AEF for the usual fruitful discussions to continuously improve the TIM norm into the Tractor Implement Management project group through open and challenging discussions on several topics.

5. References

"AEF 023 ISOBUS –ISOBUS Automation Principles" summarizes the AEF security concept and the TIM related processes and methods. The document can be obtained on www.aef-online.org.

An overview of agROBOfood: Achievements and Future Outlook

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Abstract

THE PURPOSE of this paper is to provide an overview of the project agROBOfood that has been funded by the European Commission's research and innovation programme Horizon 2020. The project was selected for funding through the H2020-DT-2018-2020 Call for Proposals "Digitising and transforming European industry and services: digital innovation hubs and platforms" and responding the Topic: DT-ICT-02-2018 - Robotics - Digital Innovation Hubs (DIH). A brief overview of the context of the agROBOfood project is outlined, followed by an illustration of the main achievements, lessons learned and sustainability of such a pan-European network of Digital Innovation Hubs for robotics in agri-food

After analysis, spray drift measured in terms of ground deposition and resident exposure at various distances from the treated area showed a significant drift reduction above 90% for both trains compared to the reference boom sprayer.

Keywords : Agriculture, Food production and processing, Robotics, Agricultural Robotics, Digital Europe Programme, Digital Innovation Hubs, Cascade Funding

1. Introduction

The specific challenge proposed by the EU Call for proposals that led to agROBOfood project was to "provide a sustainable ecosystem of robotics stakeholders covering the entire value network to facilitate and accelerate a broad uptake and integration of robotic technologies, and supporting the digitisation of industry through robotics." The aforementioned challenge addressed four prioritised sectorial application areas of: Healthcare; Infrastructure Inspection and Maintenance; Agile Production and Agri-Food.

Figure 1. AgROBOfood consortium, budget and duration.

The agROBOfood project started its activities in 2019 and brought together 37 diverse interna-tional partners with an overall budget of 16 million Euros (Figure 1). The overall objective of the agROBOfood project has been to: *establish and expand a network of mature, agri-food robotics DIHs to make the European agri-food sector more efficient and competitive.*

To achieve this, it provides a sustainable ecosystem of agri-food and robotics stakeholders with shared interests and expectations. Specific goals accomplished in the project are: ONE-STOP SHOPS: Establishment of a network of DIHs capable of offering complete service portfolio to companies in their proximities. A web portal gives each DIH access to both the local facility and the entire network of robotics agri-food hubs across Europe offering technological, business and brokerage (ecosystem) services.

SERVICES: Supporting the industry's digitization and robotization through: Demonstrating to the end users how robots can help them while promoting their deployment and use; 2. Supporting smaller organisations engaged or interested in developing new robotic products or solutions through technical, business and training support and 3; Contributing to common system platforms and industry-led standards.

VALUE DEMONSTRATION: Demonstration of the value of agri-food robotics applications by:

1. Promotion of how a system can be tailored to unique agri-food business needs; 2. end users acquiring hands-on experience by participating in highly-innovative cross-border experiments; 3. Demonstrating added value of DIH services.

GROWTH of the ECOSYSTEM: Stimulating growth of the eco-system by attracting new DIHs and Competence Centres (CCs) to the network, collaborating within the broader ecosystem while engaging with the end users across the value chain, and stimulating business growth.

NETWORK SUSTAINABILITY: Ensure the long-term sustainability of the agROBOfood network, through developing business models that generate sufficient income to safeguard the network's viability beyond contractual duration of the project.

2. Materials and Methods

At its core, the project has had two main threads of contributions and impact: 1. Related to the establishment of the network and 2. Related to the distribution of financial support to innovators with pertinent ideas and solutions to open innovation calls or to address identified challenges.

2.1. Establishment of DIHs for robotics in agri-food:

The concept of a network of DIHs has been proposed for robotics in the agri-food domain. These organisation are to fulfil the role of **one-stop-shops** in their ecosystems that help companies become more competitive with regards to their business/production processes, products or services using digital technologies, by providing access to technical expertise and experimentation, such that the innovator companies can benefit from the opportunities of "test before invest". They also provide innovation services, such as business and financing advice, training and skills development that are needed for a successful digital transformation[1].

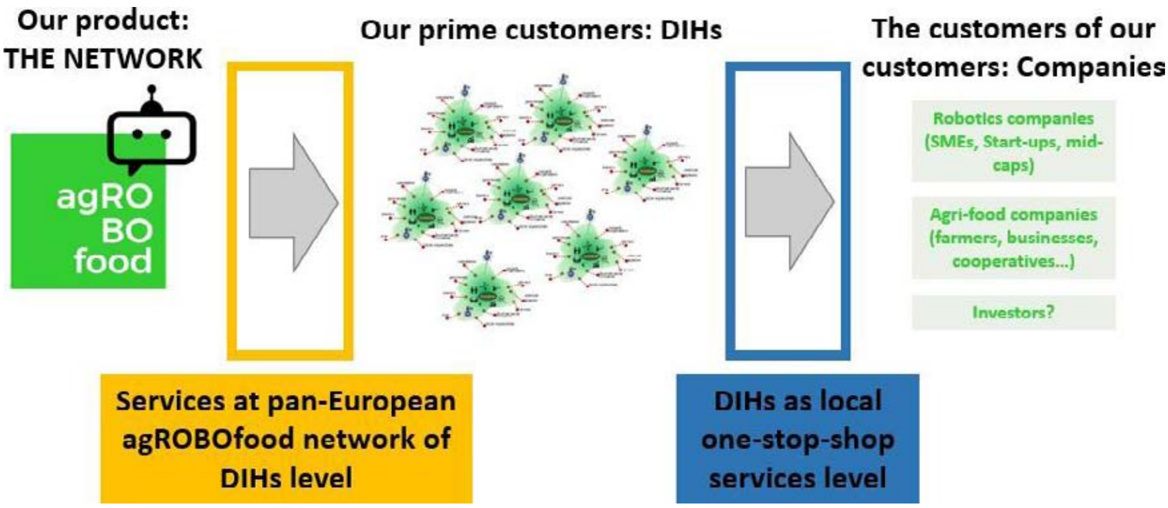


Figure 2. An illustration of our service ecosystem.

As such, the network is to provide services to the DIHs as its first level clients, and in turn, the DIHs are to provide services to their regional customers (see Figure 2). Considering local specifities and language considerations, the network is structured into 7 regional clusters that are meant to be first-level points of contact, a kind of doorways to the innovation ecosystem. A DIH is therefore a regional multi-partner cooperation between Research and Technology Organisations (RTOs), universities, industry associations, incubator/accelerators, regional development agencies and governments[2]. DIHs can therefore play an enabling role and create synergies among end-users, technology providers, and integrators, facilities for testing and experimentation, public administrations etc.

SMEs and family-owned farms, considered as the backbone of the EU economy, need to introduce innovative ways of working, and adopting new business models and more disruptive products. DIHs having by definition the role to support SMEs in benefiting from advanced digital technologies (including Robotics, Artificial Intelligence, Cyber-security and digital skills) are powerful tools and structures for national/regional policy makers that search ways to support competitive and sustainable farming.

2.1.1. Regional approach:

To maximise complementarity, the seven regional clusters of agROBOfood work together within the network at different levels and for the same main objectives (Figure 3). The strength of the network and its positioning and coverage across the EU provides the opportunity to involve the needed expertise while promoting at national levels synergies and alignment of activities. In this sense the DIHs assume the role of the national contact point to represent the country in the pan-European network.

The DIH services are expected to be offered not only in their own specific regions but also to the other regions of the network. One of the DIHs in each Regional Cluster coordinates actions in that region in liaison with the network's coordinator of all regional clusters.

Figure 3. Seven regional clusters of agROBOfood network.

To gain an understanding of the evolution of the network (in terms of number of involved DIHs, CCs and SMEs), Figure 4 illustrates the growth of the membership in the network. The agROBOfood website and the members' portal contain the latest DIH members providing possibilities to search per country and sector.

2.1.2. Networking and synergy making:

To support communication across the network and more widely, variety of communication tools were implemented such as: Website and portal[3]; Newsletter[4], Social media channels (YouTube[5]; Twitter, now X[6]; LinkedIn[7] etc.). Other examples of the actions, tools and outreach created were:

Events: The agROBOfood project organized a variety of events, namely: Pitch your Robot event where start-ups and SMEs introduced their robotic solutions to representatives of different funding organisations; conference held in May 2023 "Unlocking the Power of Robotics in Agri-Food[8]". Besides organizing own events, agROBOfood also participated in events organized by others e.g. FIRA, EIMA, European Robotic Forum, ERF workshops. An upcoming policy related event is a joint agROBOfood- JRC scoping workshop to prepare grounds for a foresight exercise looking into the longer terms scenarios of robotics in agriculture.

Github and technology mapping: To support researchers and engineers we created a Github[9] page were different case studies are presented. This platform also provides background and training information on robotic software platforms such as ROS(2), YARP, ROCK and OROCOS, development of ROS2 components, and interfacing between ROS2 and field busses like CANopen, EtherCAT and ISOBUS. Robot security issues are also discussed with respect to attack targets and attack vectors along with some common security measures to put in place.

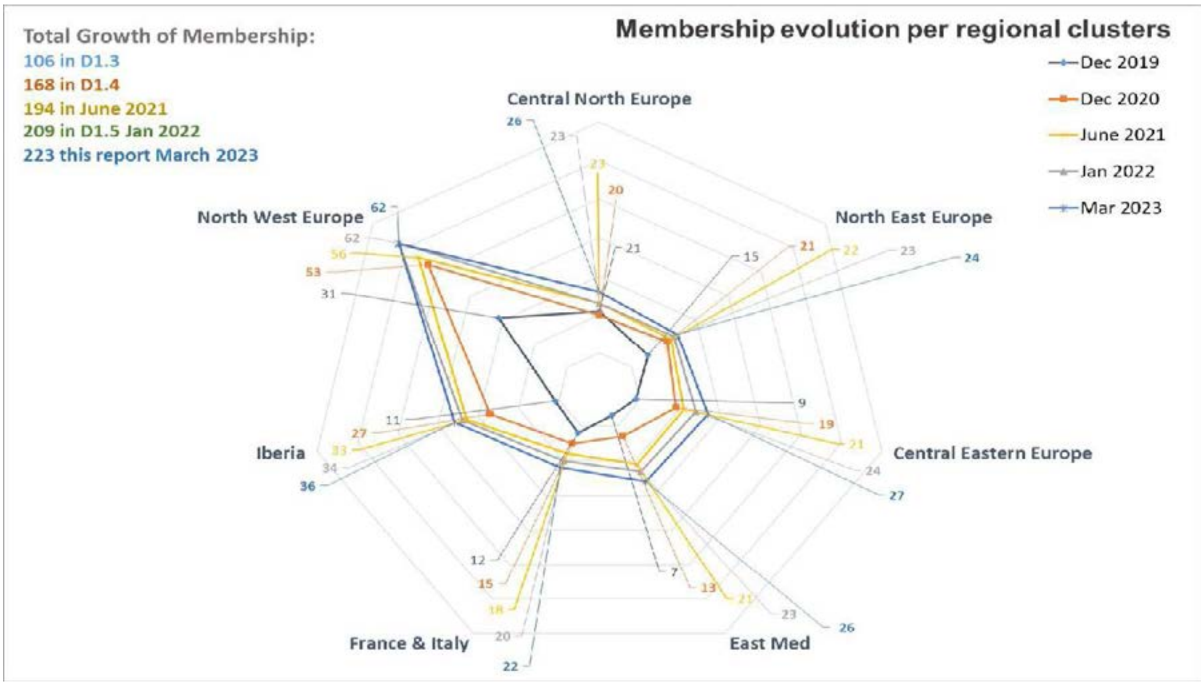


Figure 4. Growth of the network's membership across the regional clusters.

Information on Funding opportunities: To help the SMEs in searching risk-sharing funding opportunities and investments, agROBOfood provides access to Venture Capitals (VC) and other EU- and regional funding opportunities and info-sessions. To help them improve their chances of achieving success with grant applications and other kinds of fundraisings agROBOfood's deliverable 'General guide on potential funding opportunities[10] provides a comprehensive overview of the financing options available to agROBOfood beneficiaries.

Catalogue of services: AgROBOfood aspires to be a "catalyser" and cohesive actor of the ecosystem so that every stakeholder from farmers and agri-businesses owner to robotic SMEs and investors will have access to the services of a DIH (one-stop-shop). The hubs use business principles and a consolidated service model to respond to the needs of their clients. More detailed insights on the services provided in the agROBOfood network can be found in 'Updated plan and results for service delivery[11] and on the agROBOfood website and portal.

2.2. Technology development and maturation through Experiments[12]:

About half of the resources available to the project and the collaborative actions in the network have been dedicated to the promotion, selection, funding and mentoring of innovation experiments proposed by European SMEs. In addition to the 20 projects selected through three different open calls for proposals (to be described in more details in the following sections), the agROBOfood project also supported seven initial innovation experiments carried out by the partners in the consortium which are briefly outlined below. More detailed information on these experiments and their contributions to the project can be found in specific deliverables to the European Commission (with Public accessibility).

2.2.1. Initial Innovation Experiments (IIEs) carried out within the project:

To prepare the grounds for the innovation projects funded Financial Support to Third Parties (FSTP) or cascade funding, the core partners DIHs in the network proposed seven Initial Innovation experiments (IIEs). These seven experiments are outlined below including links to some of their video demonstrations – details are available in the public Deliverables of the project. All IIEs succeeded in most of their objectives despite the COVID-19 restrictions on work and travel and this affected severely some of the envisaged Field tests and cross-border field trials.

Main beneficiaries in the project including Universities, RTOs and SMEs, implemented the IIEs. Four end-users as well as ten technology providers collaborated in these projects either, directly as main partners or as external providers. All ten tech providers as well as one systems integrator were SMEs.

The key generated results included 3 new sensors (two based on deep learning), 3 new actuators, 2 significant applications, 3 test and safety protocols and 4 mechanical prototypes. Four of these outputs are expected to become commercially viable within few years.

Soil nitrogen monitoring and mapping, led by BioSense Institute, Serbia. This experiment developed a robot that could take a soil sample, analyse the nitrate content of the sample onboard the robot and report the result. https://www.youtube.com/watch?v=ENiPefYwMD0

Robotic olfactometry for detecting and controlling ochratoxins in maize, led by Agriculture University of Athens (AUA). Aflatoxins are carcinogens and mutagens produced by certain moulds. They must not enter the food chain. This experiment developed a test for aflatoxins and adapted a Husky robot to carry a sensor suite and adjustable sprayer. https://www.youtube.com/watch?v=BDTpGPgI8XU

Monitoring vineyards by drone, led by EURECAT, Spain. A vision and software package attached to a mobile robot to image each side of each row of vines, use deep learning to detect grape bunches, and then count and map the grape bunches. https://www.youtube.com/watch?v=QU-J3hIS8sk

Maximizing olive yield with a mobile sensor platform, led by Fraunhofer-Gesellschaft, Germany. Reliable 3D mapping and compensation for frequent wheel slippage enabled an adapted Summit XL robot from Robotnik to navigate on slopes of up to 80%. Tests with real data showed that trees show up well in the map. https://www.youtube.com/watch?v=BTuyutsoP30

Greenhouse cucumber leaf removal, led by Wageningen University & Research, Netherlands. This experiment developed a new mobile robot capable of removing cucumber leaves without damaging the plant stem. https://www.youtube.com/watch?v=MKIT2u5IvjY

Agricultural robot performance assessment, led by INRAE, France. This experiment defined protocols for assessing agricultural robot safety in line with international norms and standards. Three protocols were developed for obstacle detection, perception system performance under difficult environment conditions and safety tests of devices that prevent agricultural robots leave their defined work area. https://www.youtube.com/watch?v=tE-90qFyMVXY&list=PL5GgoLmRKwrkHXop5laUG-dK05lWWvpmHa&index=9

Robot mixed palletising in a freezer room, led by Danish Technological Institute. A collaborative robotic arm equipped with flexible adaptive gripper, robot skin and vision system to handle cabbages in the food industry. https://www.youtube.com/watch?v=-YtBRvDWqGw

2.2.2. Experiments carried out by third parties through cascade funding:

With a budget of 8 million Euros, three open calls for proposals were developed, and executed by agROBOfood on new innovation experiments and industrial challenges proposed in particular by SMEs and start-ups with robotics capabilities and solutions and with the interest in the agri-food sector. The goal was to share the financial risk in the sectorial robotic transformation, through demonstrators and platform development, technology transfer experiments and mentoring services by the DIHs. It also provided the opportunity to the European agricultural machine industry for guiding, supporting and teaming up with start-ups and SMEs from the robotics sector.

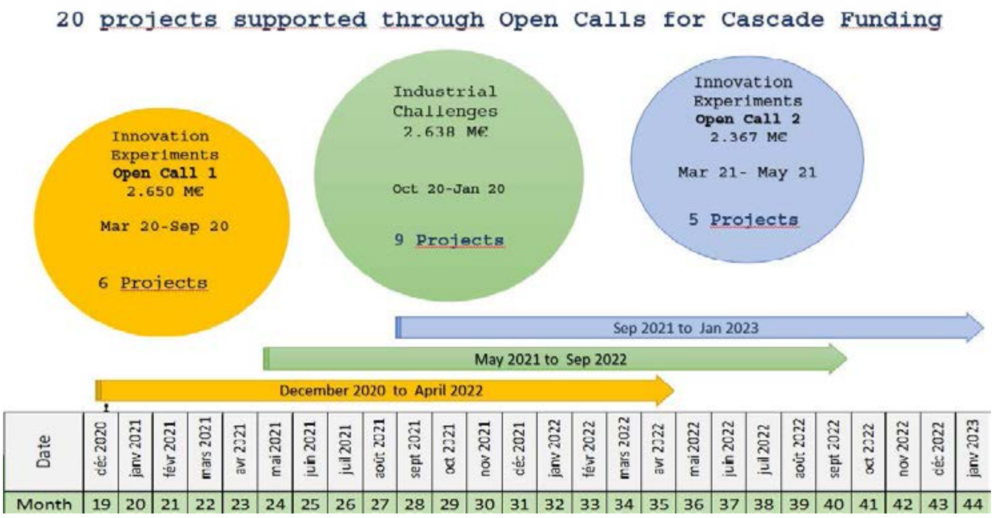


Figure 4. Main features of the three open calls for proposals.

Two types of open calls (three different calls) were organized (as summarised in Figure 5). There were two open calls for Innovation Experiments and one Open Call for Industrial Challenges. In the Innovation Experiments small consortia of three to five organizations with one SME as end-user and another SME or industrial partner as technology provider proposed innovative experiments. The IEs aimed to stimulate collaboration between European countries; therefore at least two different European countries eligible for EU funding were included in each consortium. Each Innovation Experiment had to meet predefined selection criteria. Innovation Experiments were supported through a variety of technological, ecosystem and business services, and they demonstrate the technology usefulness from an end-user perspective.

In summary, the open calls attracted 605 organisations mostly based in Spain with 88, Italy 77, Netherlands 43, Greece 42, France 30 and other countries with 325 companies.

Results of the First Call for Proposals: Innovation Experiments (IE-1):

This first call led to 93 applications submitted by the consortia of minimum 2 and maximum 5 partners. The average number of partners in consortia was 3.35. The average requested grant was 445.505€.

The IE-1 Call ran from March to Sep 2020 93 proposals were evaluated during Sep-Oct 2020 by 30 evaluators 12 were short-listed for interviews by the IAB **Nine** experiments selected for funding Implementations started in Dec 2020

The list of funded projects are given in Table 1.

	Projects supported under first call for Innovation Experiments **With Links to some of the experiment's videos**	**Lead SME**	**N° of partners**	**Country**
1	**HONEY.AI:** improve time efficiency, costs and accuracy of honey quality analysis during processing.	Sonicat Systems S.L	4	Spain
	Automating the tedious work of pollen analysis for honey's floral source authentication with higher accuracy, using artificial intelligence and robotized low-cost microscopy https://www.youtube.com/watch?v=jswkz18XFxs			
2	**I-CATCH:** Insect Capture Automation TeCHnology	PATS-DRONES	3	The Netherlands
	Drone and computer vision system for automated monitoring and mechanical elimination of flying pests in greenhouses with AI-based software. https://www.youtube.com/watch?v=7nv9mszllus			

3	**ACROCrop:** Aerial permanent Crop Robotics for ma-nage-ment Operations	Alpha Unmanned Systems S.L	5	Spain
	Gasoline-powered, autonomous helicopter drones in combination with IoT sensors and a complete software service support, to provide Frost Protection and General Crop Scouting service https://www.youtube.com/watch?v=f-TdVmUJvU9o			
4	**H3O-SpotOn:** Healthy Crop-Environment-Farmers' through Optimized Spot On Spraying Robotics	Pulverizadores Fede S.L.	5	Spain
	Optimized Spraying – Robotics paired with satellite navigation and AI enabled machine vision to reduce the amount of pesticides used in orchards, and vineyards by over 50%. https://www.youtube.com/watch?v=RGcYI-3MO-jE			
5	**MM-ROWER:** Multi-row Modular Robotic Weed Remover	Dahlia Robot-ics GmbH	3	Germany
	Mechanical intra-row weed removal through a solar-powered autonomous platform which uses AI-based on-board im-age processing to segment a video stream into crops vs. weeds on pixel-level.			
6	**NEWMAN:** Non-chemical Weeding MAchiNe	ULLMANNA s.r.o.	5	Czech republic
	Weeding robotics equipped with AI capable of intra-row non-chemical weeding even at the earliest stages of the crop growth. https://www.youtube.com/watch?v=rKmjl7ZBVvU			

Table 1. List of Projects, with brief description and links their videos funded under 1st Innovation Experiments Call.

Results of the Industrial Challenges (IC) Call for Proposals:

The IC call ran from Oct 2020 to Jan 2021 61 proposals evaluated during Feb-Mar 2021 by 19 evaluators 20 were short-listed for interviews Nine experiments selected for funding Implementations started in May 2021

Region	Proposals
North East Europe	3
North West Europe	7
France & Italy	15
Iberia (South West)	17
Central Eastern Europe	5
Central North Europe	6
East Mediterranean Europe	8

Table 2. Key figures about IC Call.

The key figures describing the outcome of the Industrial Challenges Call for proposals are summarised in Table 2. The overall concept of the IC Call was driven by "real" industry needs, seeking mature technology solutions. The agROBOfood consortium in consultation with its Industrial Advisory Board identified target challenges/problems and then invited SMEs and start-ups to propose solutions for addressing these problems under this Call.

The industry was thereby given the opportunity to coach the formulation and execution of the solutions by SMEs. The SMEs in return were to gain access to funding, utilize DIHs services, and have the opportunity to seek further funding through private resources in the form of contracts either with larger customers or in the form of equity investment/takeover. The topics defining the industrial challenges are shown in Table 3 while the supported projects under this Call, including links to some of their demonstrations are listed in Table 4 below.

For more information visit: https://agrobofood.eu/innovation-demonstrators

Industrial Challenges and Technical Component	proposals received
Challenge 1: Can optimized spraying lead to improved environmental conditions? **Technical component:** Robots for spot spraying	34
Challenge 2: Can robots improve working conditions in the labour force in the fresh and processed food industry? **Technical component:** Robots for logistics picking, packing and palletizing	12
Challenge 3: Are robots in the livestock industry posing ethical challenges by replacing human labour with machines? **Technical component:** Robots for logistics picking, packing and palletizing	1
Challenge 4: What added value can harvesting robots bring compared to existing machinery solutions? **Technical component:** Robots for selective harvesting	9
Challenge 5: What new business opportunities do robots for cleaning livestock farms bring? **Technical component:** Robots for cleaning	5

Table 3. Technical Challenges defining the scope of the call and number of proposals.

	Projects supported under Industrial Challenge Call for Proposals	Lead SME	Challenge	Country
1	**TOMMIE:** Automating Crop Load Management In Apple Or-chards	Aigritec S.r.l.	Challenge 1	Italy
	A robot that improves crop load management in apple orchards by automatically counting, monitoring and thin-ning flow-ers at precisely targeted locations using customised dosages of chemical spraying, using AI. https://www.youtube.com/watch?v=WhekilDUqeg&t=38s			
2	**FLOX LitterBot:** Poultry Robotics to improve Bird Welfare and Perfor-mance through improved Litter Management	FLOX Sp. Z o.o.	Challenge 5	Poland
	Commercial agribot system to monitor and physically manage poultry litter through aeration and spraying neutra-lising agents. It combines the litter management abilities with a litter quality algorithm (LQ-AI). https://www.youtube.com/watch?v=t3nerUM4ulY&t=22s			
3	**Farmer JoeBot:** Autonomous viticulture robotics	Rperception	Challenge 1	Israel
	Autonomous robotic vehicle for precision viticulture, expands on the typical autonomous monitoring concept and aims to provide a solution that combines treatment-centric monitoring with site-specific spraying, targeting major grapevine stressors.			
4	**GreenSprayer:**	IKH SA	Challenge 1	Greece
	GreenSprayer is a robotic solution for preventive 3D spot spraying, based on an autonomous ground robotic plat-form and an AI-powered computer vision system attached to an open hardware co-bot arm. https://www.youtube.com/watch?v=RGcYI3MO-jE			
5	**AHR: Automato Harvest Robot,**	Automato Robotics	Challenge 4	Israel
	Affordable robot for harvesting single tomatoes in passive greenhouses. https://www.youtube.com/watch?v=Ji1V_6t_9hk			

6	**HyFlexyBot: Hygenic Flexible Robot**	Automa-tionware SRL	Challenge 2	Italy
	Fully integrated Autonomous Mobile Manipulation Robot (AMMR), combining an autonomous robotic arm with an autonomous mobile robot (AMR), for a full non-contaminating production and palletisation food process. https://www.youtube.com/watch?v=d_IF_HG5iy0&list=UULPosQLDFzC6Zh-Xrpxm2xYFg&index=9			
7	ScaFo: Implementation of a fleet of human-aware robots for the food processing industry	PAL Robotics SL	Challenge 2	Spain
	Fleet of Autonomous Mobile Robots (AMRs) based on developments to the TIAGo Base robot model to perform food transportation tasks in the unstructured and dynamic environment of the food processing industry. https://www.youtube.com/watch?v=1GzSNprMzNo			
8	BioSpray: organic spraying with high precision spot spray and AI	ecoRobotix SA	Challenge 1	Switzer-land
	Ultra-high resolution spot spraying systems using high-performance AI-based plant classifiers. https://ecorobotix.prowly.com/231421-ecorobotixs-ultra-high-precision-sprayer-ara-a-game-changer-for-sustai-nable- crop-protection			
9	QualiSpot: Quality Assurance in Lean Production of Spot Spraying Robots	Ambimetrics S.L.	Challenge 1	Spain
	Quality Assurance for Lean Production of Spot Spraying Robots: https://www.youtube.com/watch?v=D08E-pjJ0wc&list=UULPosQLDFzC6Zh-Xrpxm2xYFg&index=28			

Table 4. List of 9 projects supported under Industrial Challenge Call for Proposals.

Results of the Second Call for Proposal on Innovation Experiments (IE-2):

IE-2 Call from 1 March to end May 2021 69 proposals evaluated during June-July 2021 by 21 evaluators 14 proposal short-listed for interviews Five experiments selected for funding Implementations started in Sep 2021

This Second Call led to 69 applications submitted by the consortia of minimum 2 and maximum 5 partners with an average of 3.8, while the average requested grant was 472 619€. Key information about the call and the selection of the 5 experiments are given in the insert box and the list of funded projects in Table 5 below.

To see brief description of all funded projects visit: https://agrobofood.eu/innovation-demonstrators

	Projects supported under first call for Innovation Experiments	Lead SME	Consortium Countries Coordinating*
1	**Zerotoxvine:** non-chemical robotic solution to eliminate weeds and pests in vineyards.	Green Killer Weeds	Spain*; Ukraine; Poland; Romania
	100% non-chemical robotic solution to eliminate weeds and pests in vineyards, by monitoring crops and using artificial intelligence (AI) the elimination is done directing electromagnetic microwaves to the targeted areas of 5x5 cm in the field: https://www.youtube.com/watch?v=wsVGCxbfwcU		
2	**CROVER:** 'underground drone', to autonomously scan and sample grains in bulk storage	Crover Ltd	UK*; Italy
	The world's first 'underground drone', to autonomously scan and sample grains in bulk storage (e.g. in grain bins and sheds), in order to provide early detection of potential spoilage. https://www.youtube.com/watch?v=li1WAlzNE58		

3	**Oenobotics:** needs of wine-producing vineyards locat-ed in hilly sloppy elevated locations	Hellenic Drones	Greece*; Romania; Cy-prus
	Drone platform for disease and water-stress diagnostics, precise spot-spraying for treatment of downy mildew, powdery mildew and grey mould/botrytis enabled by machine vision. Wireless drone charging via a smart charging dock: https://www.youtube.com/watch?v=GYlmYL3sBPg		
4	**FullPheno:** machine intelligence for high-resolution, full canopy obser-vation in phenotyping and monitoring	Yield Systems Oy	Finland*, Germany, Italy
	Machine intelligence for high-resolution, full canopy observation in phenotyping and monitoring, to be licenced as an interoperable software (SW) component for customers in crop R&D and robotics companies. Providing an interoperable machine vision component for full canopy phenotyping and monitoring to be integrated with any field robot platform: https://www.youtube.com/watch?v=PfCiciUnMB4&t=119s		
5	**MIRAGE:** Make it Rain and Grow Efficiently automate and optimize irri-gation of industrial crop fields such as potatoes, carrots, or beans	Osiris Agriculture	France*; Belgium
	Robot, OSCAR, will automatically irrigate daily, following the needs of the plants and soil moisture status. Oscar will be equipped with advanced ground-penetrating radar (GPR) technology and other sensors to reduce the water input without reducing yield. https://www.youtube.com/watch?v=-0qU6ykogAU		

Table 5. List of five Project supported under second call for Innovation Experiments.

3. Concluding Remarks and future perspectives

3.1. Main Conclusions

The agROBOfood project has been able to make the network of DIHs with common interests in agri-food robotics more informed and better engaged actors in responding to the needs of their ecosystems through the tailoring of their business, ecosystem and technical services. Stronger adoptions of AI-Powered automation and robotics in agri-food sectors require a multitude of technical and non-technical issues and interests of diverse communities to be aligned or reconciled into concrete strategies, policies and actions. agROBOfood network has strongly contributed to these under the two major thrusts of its activities, i.e., 1- establishment and growth of the network of DIHs as "one- stop-shops" offering services and 2-technology development and maturation through collaborative innovation projects and experiments by means of cascade funding through FSTP and relying on mentoring contributions of the DIHs.

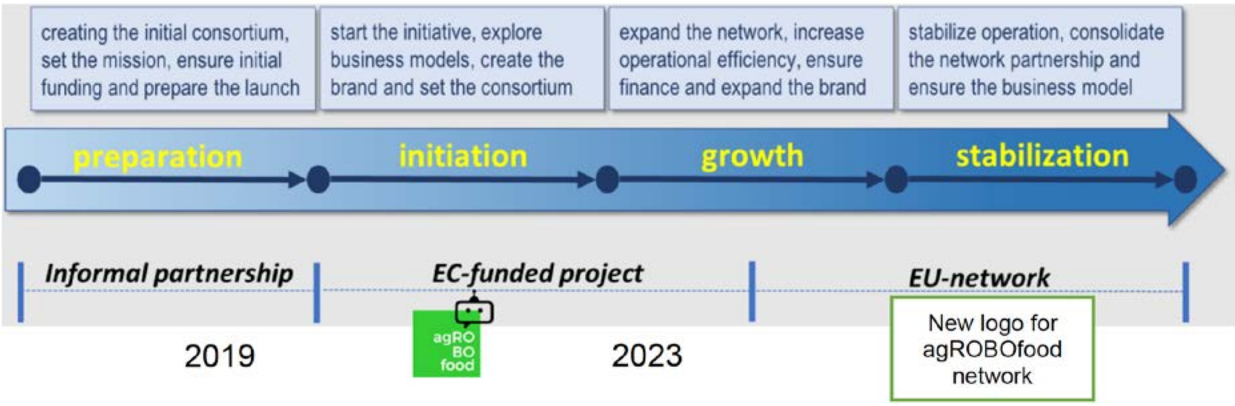
The mentoring and supporting of companies that propose and develop robotic solutions stimulated the collective capacity and added value of the DIHs in our network. The main focus was on companies with the potential to market robotics products or services to end users. Moreover, having end users involved in the innovation experiments meant ad-ditional impact on market readiness of innovative solutions. Specifically, there are dedicated DIHs who are engaged in standardization and platform activities which are essential components for field deployments.

The network's catalogue having reached 105 member DIHs and their services (technical, ecosystem, bu-siness) offer a strong foundation for the continua-tion and further growth of the network beyond its contractual mandate. Many aspects of both the working of the network and its support to marketable innovation have been scrutinised and weak spots have been identified. These in the form of "lessons learned" will help fine tune ambitions, trajectories and execution of a sustainable network beyond the current agROBOfood project.

3.2. Future outlook for agROBOfood network

The agROBOfood[13] journey started to be one of the Innovation Actions projects in the Horizon Europe programme on robotics. The network is organised around 7 regional clusters with national DIH contact points in 30 EU countries, with more than a 100 DIH members and around 100 business members. The EU-funded project agROBOfood contributes to the development of a stable and sustainable pan- European network of DIHs for Robotics in the agri-food sector.

We are in a transition to go from the agROBOfood project to the **agROBOfood network** with a time-line illustrated.



Various scenarios were investigated as to the legal form and mandate of a future self-sustained expert network with a pan-European focus. For a transition from the current project to a pan-European expert group and a self-sustained network, the **value proposition** outlined below are being considered:

I. The network facilitates **easy access to vital information and experts** in agri-food robotics;

II. The network facilitates **leading-edge robotic technologies, skills and expertise** that can be applied in the European agri-food context to accelerate their digital transformation;

III. The network supports existing—and identifies new—**business opportunities** and **policy recommendations** by providing market insight through its established community;

IV. The network stimulates and supports **services to seek various types of investments.**

To conclude **agROBOfood project**, aimed at **maximising the return of EU investment in robotics agri-food technologies**, and advance Europe to become the vanguard in providing safe and adequate food for the generations to come in a sustainable way. To do so, **agROBOfood achieved a multiplying network effect** by developing an expanded open ecosystem **bringing together the world of Robotics and Agriculture, involving the multiple dimensions** (technical, human, financial) **actors and stakeholders** (DIHs and CCs, SMEs, farmers and agribusiness suppliers, traders and technology providers, Research, Government, Investors, the Public) towards a common vision. These elements are being crystallised into a transitional roadmap to connect the current project to its next phase of a unique purposeful and self-sustainable expert network.

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4. References

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[10] D2.6 Best Practices for funding Robotics in Agri-Food activities by Tatjana Knezevic, Stavros Tsitouras, Dragana Petkovic, Milana Vitas

[11] D2.8: Updated plan and results for service delivery v2 by Pau Vallès, Samuel Rodríguez, Laura Arribas, Kees Lokhorst, Natalie Hotrum, Mireille van Hilten, Miriam Strous, Ahmad Issa, Dragana Petkovic.

[12] All information provided in this paper and the accompanying poster are in public domain. Due to space limitation only a very few number of images as examples could be included. More information on other projects can be obtained through the provided links.

[13] agROBOfood: Business-Oriented support to the European Robotics and Agri-food Sector, towards a network of Digital Innovation Hubs in Robotics, Horizon 202 Framework Programme project 825395

THANKS

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The AXEMA organization team looks forward to seeing you all in 2024 for the 7th AGRITECH DAY.

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