Les rendez-vous Techniques AXEMA

EurAgEng

2019 EDITION

3rd Rendez-Vous Techniques AXEMA

Sustainable agriculture : An opportunity for innovation in machinery and systems

THE CONFERENCE OF INNOVATIONS IN AGRICULTURAL ENGINEERING AS AN INTRODUCTION TO THE SIMA SHOW 2019

APS
Axema Promotion & Services

AXEMA,
THE REFERENCE ASSOCIATION AT THE SERVICE OF AGRICULTURAL EQUIPMENT

BUILDING THE FUTURE AND RESPONDING TO YOUR AMBITIONS

AXEMA is the French Association for agricultural equipment manufacturers and agricultural environment providers. Its 230 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. It also brings together the sector's economic actors, equipment providers, service companies, and establishments that work with manufacturers.

A DIVERSE SECTOR

The agricultural equipment sector includes businesses that produce, market equipment and distribute machinery, fixed and rolling, intended for various users: arable crop farmers, livestock farmers, wine growers, horticultural producers, and vegetable farmers. This equipment may also be used by 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 AND 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 16-person team organised by unit and responds to members' requests:

- Technical Department
- Economic Department
- Training and Employment Department
- International Department
- Membership and Communication Department
- Administrative and Accounting Department

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

Axema, in partnership with the COMEXPOSIUM group, organises the SIMA (Paris International Agri Business Show) and SITEVI (International exhibition for the vine-wine, fruit-vegetable, and olive growing sectors) trade fairs through the joint venture, EXPOSIMA.

The Association is involved in defining strategies and policies and proposes developments to promote trade fairs, render them more attractive and increase business volumes.

These trade fairs are essential for the French image of the agricultural equipment sector. AXEMA's objective is to show that the sector is innovative and offers growth prospects in the context of efficient and sustainable agriculture.

This initiative extends beyond our borders with the development of international trade fairs, such as SITEVINITECH China or Argentina, SIMA Asean in Bangkok and SIMA-SIPSA Algeria.

Axema is building the future for agricultural equipment and Agricultural Environment to ensure sustainable agriculture and responsible territorial development.

FOREWORD,

The edition of the 3rd Rendez-Vous Techniques AXEMA gathered all the Agricultural Equipment researc & innovation actors on February 23, 2019, on the Parc des expositions, Paris Nord Villepinte.

Agricultural Equipment supports the transformation of Agriculture and takes part in developing new agricultural models more respectful of ecosystems.

AXEMA created Les Rendez-vous Techniques to promote direct exchanges with Agricultural Equipment research & innovation actors and inform on ongoing developments.

The strong mobilisation for this second edition is a testimony to the sector's vitality and expectations. Agriculture issues challenge many scientific and technological experts.

This event spotlighted thirty five presentations under the form of plenary sessions, thematic 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 Les Rendez-Vous Techniques AXEMA has become the privileged event in France for innovation and research around the agricultural equipment sector.

Our ambition is to continue to strengthen ties between all the actors working in the different fields for sustainable agriculture.

COMPOSITION OF THE SCIENTIFIC COMMITTEE

- **Dr. Philippe Colacicco**, Kubota Corporation, Director Farm Machinery Engineering Europe and AXEMA Technical Committee Chairman
- **Christian Adler**, KUHN Group, Head of the electronic Department
- **Dr.Thomas Anken**, Agroscope, Agronomist
- **Dr. Paolo Balsari**, Department of Agricultural, Forestry and Food Sciences, UNITO, Professor
- **Dr. Nils Bjugstad**, Norwegian University of Life Sciences, Professor
- **Olivier Croix**, MONROC, CEO
- **Dr. Peter Groot Koerkamp** (prof. dr. ir. P.W.G.) Professor in Biosystems Engineering / Agrotechnology
- **Franz Handler**, HBLFA Francisco Josephinum, Head of Department, Agricultural process engineering
- **Dr Martin Kremmer**, Deere & Company World Headquarters, Manager Integrated Solutions Technology Strategy
- **Dr. Peter Schulze Lammers**, Universität Bonn, Professor
- **Dr. Roland Lenain**, IRSTEA, Research fellow on the topic of off-road mobile robotics
- **Lionel Leveillé**, SULKY-BUREL, Head of R&D Department
- **Dr. Eberhard Nacke**, CLAAS KGaA mbH, Head of Product Strategy
- **Dr. Florentino Juste Pérez**, Universitat Politècnica de València, Professor
- **Dr. Claus Aage Grøn Sørensen**, Department of Engineering Aarhus University – Denmark, Head of Research Unit - Head of Smart Farming Centre
- **Dr. Sylvain Villette**, AGROSUP Dijon, Unité Pédagogique Agroéquipements
- **Dr. Andrii Yatskul**, UniLaSalle, Associate Professor in Agricultural Machinery

PROGRAM

8:45	**CONFERENCE OPENING -** *Peter Groot Koerkamp (prof. dr. ir. P.W.G.) - EurAgEng president*	
9:00	**PLENARY SESSION**	
	EIP AGRI - THE AGRICULTURAL EUROPEAN INNOVATION PARTNERSHIP *Peter Pickel - John Deere GmbH & Co. KG*	
9:25	**POSTERS PRESENTATION**	
	SMART AGRICULTURE	SUSTAINABLE AGRICULTURE
10:00	***Wireless In-Field Communication – AEF guideline for interoperable agrarian M2M communication*** Franz Fuchshummer – AGCO GmbH Johann Witte – Claas GmbH Saverio Zuccotti – CNHi AG&CE Manuel Gorius – John DEERE GmbH & Co.KG	***The GridCON - Tractor - Concept*** Peter Pickel – John Deere GmbH & Co. KG
10:30	***2019 the year of TIM – Vision, system and infrastructure for Tractor Implement Management*** Georg Happich – AGCO GmbH (Fendt) Hans-Jürgen Nissen – John Deere GmbH & Co. KG	***Environmental impact assessment of tractors equipped with different devices for reducing the exhaust gases emissions*** Jacopo Bacenetti, Daniela Lovarelli, Davide Facchinetti, Domenico Pessina – Università degli studi di Milano
11:00	***Development of TIM tractor*** Ryo Kurata, Fulvio Zerbinoa, Koichi Fujimoto – KUBOTA Corporation	***Measurement of Ammonia emission in practical dairy farm environment*** Hannu Haapala – Agrinnotech Maarit Hellstedt – Natural Resources Institute Finland
11:30	**POSTER BREAK**	
12:00	***Cyber security in the field*** Alain Ribault, Yannick Guyomarch – KEREVAL Lionel Léveillé, Emeric Leclair – SULKY	***Viticulture sprayer, efficiency, spray deposition, test bed, classification*** A. Vergès, S. Codis, X. Delpuech. – IVF J.F. Bonicel, G. Diouloufet, J.P. Douzals, P. Montegano, X. Ribeyrolles, B. Ruelle, M. Carra – IRSTEA
12:30	***Mundi Web Services – A digital platform providing better access and use of earth observation data to create and operate innovative apps particularly in agriculture market*** Christophe Brizot, Cédric Couget, Laurent Clergue – ATOS	***Smartomizer – Smart and connected speciality crop protection*** Cruz Garcerá – Instituto Valenciano de Investigaciones Agrarias Emilio Gil – Universitat Politécnica de Catalunya Lars Berguer – Pulverizadores Fede S.L., Cheste Patricia Chueca – Instituto Valenciano de Investigaciones Agrarias

PROGRAM

13:00	**LUNCH BREAK**	
	SMART AGRICULTURE	SUSTAINABLE AGRICULTURE
14:00	***Machine Vision in Silage Bale Digitalized Management*** Quoc-Bao Tran, Katariina Penttilä, Ilpo Pölönen – Häme University of Applied Sicences	***Herbicide site specific spraying: use of simulations to study the impact of section width*** Villette Sylvain, Maillot Thibault – Agroécologie, AgroSup Dijon, INRA Douzals Jean-Paul – IRSTEA
	ROBOTICS	SUSTAINABLE AGRICULTURE
14:30	***Some challenges to address in order to target the second generation of agricultural robots*** Michel Berducat – IRSTEA (National Research Institute of Science and Technology for Environment and Agriculture)	***Evolution of Agricultural Tire technologies and their impact on soil compaction*** P. Vervaet, F. Pinet – Manufacture Française des Pneumatiques Michelin M. Stettler – Bern University of Applied Sciences, School of Agricultural
15:00	***Development of the AgriRobo Tractor*** Tomofumi Fukunaga, Kotaro Yamaguchi, Takashi Fujiwara – Kubota Tractor Corporation	***Evaluating the quality of work for single chisel plow tines*** Amer Khalid Ahmed Al-Neama – College of Agriculture, University of Diyala, Iraq Thomas Herlitzius – Technische Universität Dresden, Germany
15:30	**POSTER BREAK**	
	INNOVATION	SUSTAINABLE AGRICULTURE
16:00	***H2L – The new generation of hydraulic trailer brake system*** Guggisberg Erich, Paul Forrer AG	***New KUHN Conservation Tillage solutions*** Philippe Potier, Vincent Hazenberg – Kuhn SA
16:30	***Pneumatic distribution of straw from within a Straw blower impeller to the ground, a predicting tool*** T. Aiouaz – LEDITH, CETIM J.M. Buchlin, A. Bardin – LEDITH	***Sustainable Development, Digital Revolution and Human Change - A new Ecology of Work and Life, from Industry to Agriculture*** Sylvain Lavelle - Icam / EHESS - Paris
17:00	**PLENARY SESSION**	
	TRAINING IN AGRICULTURAL TECHNOLOGIES: A NEW PREREQUISITE FOR SMART FARMING *Simon Ritz, Davide Rizzo – Chaire Agro-Machinisme et Nouvelles Technologies, UniLaSalle, Beauvais* *Fatma Fourati, Jérôme Dantan, Anne Combaud, Michel Dubois – InTerACT research unit, UniLaSalle, Beauvais-Rouen*	
17:30	**CONFERENCE CONCLUSION -** *Philippe Colacicco - AXEMA Technical Committee President* *KUBOTA Corporation*	

POSTERS

INNOSETA a new European thematic network for innovation in application techniques, spraying practices and training

Codis Sébastien, Eirios Hugo, Adrien Verges, Xavier Delpuech – IFV
Montserrat Gallart, Emilio Gil – UPC / Ivo Hostens – CEMA

PulvéLab : an experimental vineyard for the development and evaluation of innovative digital solutions for precision spraying

Xavier Delpuech, Adrien Verges, Adrien Lienard, Anice Cheraiet, Sébastien Codis – IFV
Mathilde Carra, Xavier Ribeyrolles, Olivier Naud, Jean-Paul Douzals – IRSTEA

Boosting agricultural scientific research and innovation through challenges: the ROSE challenge example

Avrin Guillaume, Delaborde Agnes, Galibert Olivier – LNE
Boffety Daniel – IRSTEA

Spot spraying in oil seeds and protein crops

F. Vuillemin, JL. Lucas, Olivier Mangenot – Terres Inovia / C. Chalon – Groupe CAL
F. Marechal – Société MARECHAL / C. Gée – AgroSup Dijon

Equipment for evaluating agricultural machinery impacts on soil physical and mechanical properties

Carolina Ugarte, Matthieu Forster – UniLaSalle, Aghyle Research Unit
Andrii Yatskul, Simon Ritz – UniLaSalle

How to optimize your tillage with a better and cheaper approach

Michel-P Damiani – ACTIA

Connectivity of Agriculture Equipment

Christophe Gossard – John Deere GmbH & Co. KG

Machine to machine system for integral management of a farm

Rafael R. Sola-Guirado, Sergio Bayano-Tejero, Gregorio Blanco-Roldan, Sergio Castro-García, Jesus Gil-Ribes – University of Cordoba

Software Development : Improve your efficiency with new MATCH tool chain

Philippe Gross, Anthony Perrino – HYDAC

Smart hydraulics for autonomous vehicle

Clément Chassagne, Jean Heren, André Prigent – POCLAIN Hydraulics

The design and development of three planters (Marks 1, 2 and 3) to plant daffodil bulbs under agricultural upland grassland and a harvester to collect the above ground biomass

D R White, I J Loynes, S E Cooper – Harper Adams University
K Stephens, S Head – Agroceutical Products Ltd,
M D Fraser, H Vallin and J R T Davies – Pwllpeiran Upland Research Centre

Novel technological framework for digitalizing silage bale life cycle management

Katariina Penttilä, Ilpo Pölönen – Häme University of Applied Sciences
Antti Suokannas – Natural Resources Institute Finland

Simulation model development for advanced powertrains in agricultural Tractors

Antti Lajunen – University of Helsinki

Application of CFD technology for performance optimization of fan and cleaning system in a combine harvester

Daniele Speziani, Lorenzo Vagnetti – Phitec Ingegneria Srl
Mattia Mariani – Same Deutz-Fahr

Digital tools for a biomass prediction from a plant-growth model. Application to a weed control in wheat crop.

J. Merienne, A. Larmure, Ch. Gée – AgroSup Dijon

ICAM : A reference model to improve agro-equipment companies Development of a hybrid vegetable dryer

Paul-Eric Dossou – Icam, Université Paris-Est
Sylvain Lavelle – Icam, EHESS / Sylvain Morel – Icam

SUMMARY

SUMMARY

THE SPEAKERS

PLENARY SESSIONS

PHILIPPE COLACICCO

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.

PETER GROOT KOERKAMP

Peter Groot Koerkamp take over the reins of EurAgEng as President of the European Society of Agricultural Engineers in 2018.

Peter is also a leading academic and is currently professor and chair holder at the Farm Technology Group of Wageningen University and senior scientist at Wageningen Livestock Research. His fields of expertise are agricultural & biosystems engineering, agricultural systems, animal and plant production systems, environmental engineering & technology, and design of sustainable production systems. His career started with an MSc in agricultural engineering in 1990, followed by a PhD in 1998. Nowadays he supervises 10 PhD students, is an author in many key publications, as well as all the other demands of his post and his international connections through editing and reviewing for a range of journals and his membership of international boards such as EurAgEng, IRCAEW,Agro-Food of SMK and more.

PETER PICKEL

Prof. Dr.-Ing. Peter Pickel is employed at John Deere GmbH & Co. KG (JD) which belongs to the John Deere group. As the Deputy Director of the JD European Technology Innovation Center (JD ETIC, Kaiserslautern, Germany), Prof. Dr. Pickel manages research and advanced technology. Within John Deere Peter Pickel and his team lead all publicly funded R&D activities in EU zone and external technology relationships.

Peter Pickel studied mechanical engineering with a focus on production technology at the Technical University of Berlin and holds a PhD from the same university. His PhD thesis focused on agricultural machinery. In 2000 (till 2010) he became a full tenured professor for agricultural engineering, communal machinery and environmental technologies at the Martin-Luther-University Halle-Wittenberg (Saxony Anhalt, Germany) where he also was the dean of the Agricultural Faculty from 2003 to 2006. Peter Pickel is the Chair of the MANUFUTURE Sub-ETP Agricultural Engineering & Technologies and since 2015 he is the chairman of the VDI Max-Eyth-Gesellschaft for Agricultural Engineering (German society of engineers, department Agricultural Engineering). As an expert for agricultural engineering he has been a member of the Bioeconomy Panel of the European Commission from 2013 to 2015. Since 2009 he is a full member of the Club of Bologna (CoB). Herein he has been being a member of management committee since 2016.

The focus of his research and development activities is on integrated sustainability concepts including sustainable energy production and energy supply concepts for rural areas and including the development of electrification concepts for mobile off-road machinery. Further Prof. Pickel is working in the field of automation and communication technology for agricultural equipment.

SIMON RITZ

Chairholder of the Agricultural Machinery and New Technologies (AMNT) Chair at UniLaSalle Polytechnical Institute, Simon Ritz came from a farm machinery technical background before graduating from Agrocampus Ouest and from IGR-IAE (Rennes) in 2011.

After several years working internationally (Office for Sciences and Technology, French Embassy in the U.S.A.; engineering and development of large-scale farms in arid environments) Simon Ritz focuses now his activities in developing the AMNT Chair for promoting research and education in agricultural machinery, in direct connection with the farming equipment industry, with an orientation towards agricultural technologies and smart farming.

Simon Ritz also teach graduate students in various fields linked to international supply chains in farm equipment.

THEMATIC SESSIONS

SMART AGRICULTURE

LAURENT CLERGUE

Senior Consultant and Solutions Manager in Earth Observation activities for ATOS Integration France

In charge of Agricultural Business Activities on Copernicus Mundi DIAS (Data and Information Access Services)

With a postgraduate degree in Biology of Organisms and Populations, a specialization in Agronomy, GIS and Remote Sensing, he started his professional life in 1998 within the French Army in Communications and Computer Science at the Gendarmerie National Training Center to perfect its knowledge in applied computing and the protocols of civil and military communications.

At the end of this military period, he joined the City of Auch (Gers - France) as project manager on the implementation of a GIS pooling for the services of the City and Agglomeration. This mission continued for 6 years during which he cumulated the functions of Manager of the GIS unit, the Planning and Prospects Department and finally Project Manager on the creation of the Local Internet Backbone.

All these skills have found a global application within GEOSIGWEB (SaaS GIS Editor) where he has worked for 12 years, first for two years as a distributor in southwestern France and then internally as Deputy Director and finally Director for 7 years.

His duties included managing the strategic development of the GEOSIGWEB Group's companies in France and abroad and a priority intervention on innovative subjects to steer them from the incubation stage to the implementation of a finished product.

KOICHI FUJIMOTO

Koichi Fujimoto was born in Osaka, Japan, in 1985. He received the B.E., M.E., in information science and technology from the Ritsumeikan University, Japan, in 2010. In 2010, he joined Toshiba Digital Solutions, Kanagawa, Japan as software developer and system architect. Since 2018, he joined Kubota, Osaka, Japan as information security specialist. His main areas are development of IoT system and information security. Registered Information Security Specialist (Registration number: 009712 in Japan).

YANNICK GUYOMARCH

Yannick Guyomarch, manager of the activity " bus of communication" in KEREVAL since 2012, with an experience of more than 15 years in the CAN and ISOBUS bus.

After to working, for 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.

GEORG HAPPICH

Dr.-Ing. Georg Happich studied mechanical Engineering at Braunschweig Institute of Technology (TUBS), graduated with a Dipl.-Ing. on Vehicle Systems in 2006. He joined the the Institute of Agricultural Machinery and Fluid Technology at TUBS, leaded the Team Assistance Systems and Cooperative Machinery, and earned his doctoral degree on Automatic Loading of Silage Crops in February 2012. In 2011 he started at AGCO Fendt as a Software Systems Engineer. Since that Georg is leading several project teams on – partly global – ISOBUS development topics. Nowadays he is forming a team of Systems Engineers on general E/E development.

By end of 2012 he joined the AEF project team "ISOBUS Automation", serving as its deputy team lead since 2015. Meanwhile he became member of the AEF project teams "Engineering and Implementation" and "Wireless Infield Communication", and of ISO/TC23/SC19 WG1.

Georg has a strong cross functional mindset with excellent analytical skills, combined with distinctive personal soft skills enabling high emphasis, straight communication and solution-oriented coordination of systems' development.

LIONEL LÉVEILLÉ

Lionel Léveillé is a son of farmer in the French Brittany region and is passionate in designing machines.

Lionel studied at the University of Rennes in mechanical engineering where he built his technical background. The professional meeting with SULKY was in 2001, since then he has held several positions within the SULKY R&D teams.

Since 2016, Lionel is in charge of the Research and Development department for SULKY products and also for part of the SKY agriculture range. Lionel is in charge of the design, prototype, testing and validation activities, intellectual property, continuous product improvement, standards and approvals.

Lionel works with his teams on advanced engineering projects and product improvement.

Since November 2017, Lionel is the vice president of AXEMA's Technical Committee. He was especially the leader of the ISOBUS working group which led to the creation of the AEF approved center at KEREVAL.

QUOC-BAO TRAN

Quoc-Bao Tran is a student in the Electrical and Automation Engineering degree program at Häme University of Applied Sciences (HAMK) since 2016. He also works as student assistant at Energy Efficiency Research Group, HAMK Tech Research Unit.

His research interests include IoT-based smart agriculture, machine learning applications, and building energy applications.

JOHANN WITTE

Johann Witte is at the Head of AD Electronics for CLAAS Selbstfahrende Erntemaschinen GmbH

Following Johann's short biography:

2002 to 2006 University of Appiled Sciences Cologne, Dipl.-Ing(FH) Mechnical Engineering for agricultural machines

2006 to 2008 University of Appiled Sciences Cologne, Master of Science Mechatronics

2008 to 2014 Company HJS Emission Technology, Development engineer for diesel particular filters and sensors for off high way machinery

2014 to 2018 Müller Elektronik /Trimble, Head of Application Software Development for Implements and Sensors

2018 ongoing Claas Selbstfahrende Erntemaschinen, Head of Advanced Development Electronics

And from 2016 ongoing Team Lead of AEF Project Team 11 for Wireless In-field Communication.

FULVIO ZERBINO

Fulvio Zerbino was born in Avellino (Italy) in 1983. He obtained B.D. and M.D. in Electronic Engineering at the University of Pisa (2012). In 2013, he was enrolled in Re-Lab (Reggio Emilia, Italy) as firmware engineer. He deepened the ISO11783 norm and worked on both its implementation in C and its porting on several hardware platforms.

In the early 2014, he moved to Bergamo (Italy) for working in SDF R&D as software and system engineer within the TIM project. Furthermore, he has joined the new AEF cross manufacturer PT5 group dedicated to the definition of the TIM norm. Since July 2018, he has worked for the Kubota R&D Center (Paris) on the TIM project as system engineer. Currently, he also represents Kubota in the AEF PT5 group and is the technical coordinator of the electronic department. His main areas are ISO11783, TIM, automation, safety, embedded software, and off-road vehicles

ROBOTICS

MICHEL BERDUCAT

Michel Berducat is a senior Research Engineer (59 year old). Since 1985 he is working to the Cemagref, called now Irstea, the French Research Institute in Science and Technology for Environment and Agriculture.

He has a great experience in project management in automation and robotic equipment's for out-door applications with national and international industrial partners (example: Renault Agriculture, CLAAS, John-Deere, AGCO...).

In 2007 he introduced the concept of "the third way" based on the cooperation of medium size agricultural machines in order to propose some alternative to the "bigger and bigger" machine evolution tendency.

From 2008-2013 he participated as French representative to the European Eranet ICTAGRI governing board.

In 2016, he managed the Organization of MCG2016 conference at VICHY

In 2017 he was engaged in the creation of the RobAgri French Association. Gathering more sixty founders from Private and Publics sectors, the purpose of the association is to accelerate the agricultural robotic in France.

Currently he is Deputy Director of the TSCF Research Laboratory at Clermont-Ferrand Irstea Centre, in charge more specifically of innovation and industrial partnerships. He is particularly involving in the construction of the AgroTechnoPôle Innovative Platform gathering Public and Private Partnerships for the development of innovative technologies and services for the agriculture of the future.

TOMOFUMI FUKUNAGA

Tomofumi Fukunaga joined Kubota Corporation in 2005 and was assigned to the Tractor Engineering Department in Sakai Plant located at Osaka in Japan. In early days, he worked on lowering oscillation noise of compact tractors as a performance evaluation team engineer. In 2007, he moved to the design team and took in charge of the development of compact tractors for the United States market, as a design team engineer of power train. For domestic product development in Japan, he took in charge of improvement of transmission efficiency for variable speed transmission, and vehicle chassis design of the AgriRobo tractor which has a feature of unattended and autonomous operation.

In March of 2018, he was dispatched to the R&D Department at Kubota Tractor Corporation located at Dallas in the United States.

Now he conducts the United States market research and development of new function collaborating with the implement maker.

INNOVATION

TAYEB AIOUAZ

Experienced Research Engineer with a demonstrated history of working in the mechanical or industrial engineering industry. Skilled in Numerical Simulation, Computational Fluid Dynamics (CFD), Statistical Data Analysis, Spectroscopy, and Magnetohydrodynamics (MHD). Strong engineering professional with a Ph.D. focused in Computational Fluid Dynamics (CFD) & Plasma physics from "Université Paris-Sud" (Paris XI).

Currently working at CETIM as a project manager on following subject: Optimization of pipework systems, performance assessment of wind turbine and pumps, cavitation, erosion, Development of dedicated CFD applications for industrial needs with ANSYS CFX, FLUENT, and OpenFOAM.

ERICH GUGGISBERG

Erich Guggisberg comes from a family farm with arable farming and dairy farming in the Swiss Midlands.

After completing my regular school time, Erich became an apprentice as an agricultural machinery mechanic. Subsequently, he completed various commercial and business management courses. His professional specialisations were expanded with supplementary training in the fields of mechanical engineering, hydraulics and vehicle technology and expanded over the many years with professional practice.

Erich Guggisberg professional experience in mobile hydraulics and agricultural engineering :

- 1983- 1986 Mechanic for agricultural machinery, service technician, customer service representative
- 1986- 1991 technical customer consultant, application engineer, team leader
- 1991-1998 application engineer, product manager, key customer consultant, product development
- 1998 - 2019 Technical Director (CTO) and Member of the Executive Board of Paul Forrer AG

SUSTAINABLE AGRICULTURE

AMER A. K. AL-NEAMA

Dr.-Ing. Amer A. K. Al-Neama has been a lecturer at the Soil Science and Water Resources Department, College of Agriculture, Diyala University, Iraq since 2006 and till now. In 2018 he finished his Dr. degree at the Chair of Agricultural Systems and Technology, TU Dresden, Germany. His scientific interests focus on tillage equipment design and test

PATRICIA CHUECA

Patricia's training:

- 2001: Agronomist. Polytechnic University of Valencia (UPV).
- 2007: Doctor Agronomist in Agricultural Mechanization (UPV).
- 2014: Degree in Environmental Sciences (UPV).

Patricia's professional experience:

- 2000-2002: Sanz Brothers. Company of machinery for application of phytosanitary ware. R & D Engineer
- 2003: Iberian Roda. Machinery company for horticultural plants. R & D Engineer
- 2003-2007: Valencian Institute of Agrarian Research (IVIA). Predoctoral Fellow
- 2007-2009: IVIA. Researcher
- 2009-2013: Agroalimed Foundation. Researcher
- 2013-2018: IVIA. Researcher
- 2018-Actuality: IVIA. INIA postdoctoral contract.

Since 2014, Patricia is in charge of the Mechanization Laboratory of the Agro-Engineering Center of the IVIA. She has participated in more than 5 European and national projects related to agricultural mechanization, precision agriculture and spray technology, and has collaborated with numerous companies in the sector. Author of 25 articles in international scientific journals and 40 articles of dissemination in national journals, and participate in more than 50 national and international conferences.

JEAN-PAUL DOUZALS

Dr Jean-Paul Douzals, 53, specialized himself in spray application techniques at Irstea Montpellier since 2009 after 18 years of involvement in higher education and research in agricultural engineering in Dijon and Toulouse. He is curerntly working on the optimization of pesticide application while maximizing deposits on targets and minimizing off target compartment contamination in the framework of Reducpol experimental plateform and collaborative projects with agricultural technical institutes. These five last years, he co-published 9 scientific papers and 20 communications in international congresses.

HANNU E. S. HAAPALA

Hannu E. S. Haapala is a Doctor of Science in Agricultural Engineering, University of Helsinki.

Career :

- Researcher in Finnish Academy of Sciences
- Professor of Agrotechnology at University of Helsinki
- Research Professor / Director in MTT (Agrifood Research Finland)
- Research Director at Seinäjoki University of Applied Sciences
- CEO at ProAgria Advisory Services
- CEO at Agrinnotech

Hannu is Vice President in EurAgEng and President in ENGAGE, the strategic network of EurAgEng.

VINCENT HAZENBERG

Vincent is 41 years old and grew up on a mixed farm in Normandie. Passionate about Agriculture and farm machineries, he graduated as "Ingénieur en Agriculture" from the Institut Supérieur d'Agriculture in Lille.

Vincent has had a career in different Product Marketing and Product Management positions in the tractor business for over 15 years of which he spend 10 years abroad in UK and Austria. In June 2018, he joined Kuhn as Commercial and Marketing Manager for KUHN S.A.

SYLVAIN LAVELLE

Sylvain Lavelle, born in 1969, is professor and researcher in philosophy, epistemology and ethics at ICAM Paris-Sénart. He has a PhD in Philosophy from the University of Paris-Sorbonne (2000) and also studied social sciences and natural sciences. From 1998 to 2000, he was an assistant professor and researcher at the University of Paris-Sorbonne before joining the Department of Humanities at ICAM. He is currently Director of the Centre for Ethics, Technology and Society (ICAM, CETS) and associate researcher at the Ecole des Hautes Etudes en Sciences Sociales in Paris (EHESS, GSPR). His research program in contrast to some approaches derived from Kant's Critique is focused on the philosophy of mediation - *Science, morals and art in a democratic society*. In addition to his research work in logic and dialectics, he is currently exploring in methodology another part of the philosophy of mediation - *Human change and ecological transition* ('After Habermas and Latour': Transformation of Proceduralism, Post-dialogical Thought, Actor-Network-Framework). He has been involved in several European and French projects (TRUSTNET, COWAM, EGAIS, PARTHAGE) and is the author of numerous publications: *Science, technologie et éthique* (2006), *Technique, communication et société* (2007), *Ethical governance of emerging technologies development* (2013), *La société en action* (2013), *Critiques du dialogue* (2016).

DANIELA LOVARELLI

Daniela Lovarelli currently has a post-doctoral research position at the Department of Agricultural and Environmental Sciences at the University of Milan (Italy). During her PhD she researched on the environmental impact assessment by means of Life Cycle Assessment of agricultural field operations, studying on the comparison of alternative solutions for performing field operations, on exhaust gases emissions from agricultural tractors and the technologies for their abatement and on the related environmental impact. She is currently working on the environmental sustainability of agro-food productions and author of more than 15 scientific publications.

PHILIPPE POTIER

Philippe Potier has a degree of Higher Technological Studies specialized in design and manufacturing assisted by computer at the University of Valenciennes, he started his career professional in the field of designing tooling type molding in the home appliance and automotive industries. He works then

for the PTC company (Parametric Technology Corp) as an application engineer for setting up design and manufacturing solutions for various companies.

Coming from the agricultural world and with his university degree, Philippe Potier joined the KUHN Group in 2002 at the Saverne site as the leader for setting up the 3D design tools for all the R&D group and then he leads the support services for the management of technical data and technical documentation.

At the end of 2007, he tooks over the head of the department for the development of the soil work / Seedling on the site of KUHN Saverne.

ADRIEN VERGÈS

Adrien Vergès works in the French Institute of Vine and Wine (IFV), he is an agronomist and member of the mixt unit EcoTech (IFV / IRSTEA).

PATRICK VERVAET

Chemistry Engineer at the Catholic University of Louvain (Belgium -1989), Patrick VERVAET works for the Michelin group since 1991 (Clermont-Ferrand, France).

Patrick's main functions were the quality of production, the management of project for Innovative Processes, innovations for civil engineering tires, advanced research.

Since 2007 in the Agricultural Product Line, Patrick has been efficiency project manager from 2012 and then director of innovation from 2017.

Since the beginning of 2018, he has been in charge of innovation for the Business Line 'Off Highway Transportation' (Agricultural, Construction, Logistics, Military, ...).

SYLVAIN VILLETTE

Sylvain Villette (47 years old) received his engineering degree in agronomic sciences in 1994. He obtained his PhD in signal and image processing from the University of Burgundy, France, in 2006. He is currently an assistant professor of agricultural machinery engineering at Agrosup Dijon (higher educational institute of agronomy of Dijon), France. His research work takes place in the "Precision Agriculture" team of the Agroecology joint research unit (UMR Agroécologie, AgroSup Dijon - INRA - University of Burgundy, France). His research activities deal with the optimization of agricultural equipment for the application and reduction of chemical inputs.

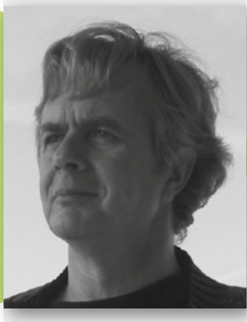
POSTERS PRESENTATION

CLÉMENT CHASSAGNE

Clément Chassagne is Agriculture Platform Manager at POCLAIN HYDRAULICS within the Markets, Systems & Electronics department.

After 6 years providing technical support to the sales team in China and in the UK, he is in charge of promoting solutions worldwide for agriculture machinery and, understanding the trends and needs of this market.

He graduated from the French Institute of Advanced Mechanics (SIGMA, Clermont-Ferrand) in 2010.



MICHEL-PHILIPPE DAMIANI

Michel-Philippe DAMIANI works in the ACTIA AUTOMOTIVE Head Quarter – Toulouse - On board electronic and diagnostic solutions for vehicles.

His Main customer in Agricultural market : CNHI (worlwide - hydraulic Controller and Telematic Units).

He is Marketing and sales Manager – Off Highway Department- In charge of Innovation for Agricultural market.

His Degrees :
- DESTC – Montpellier University
- Project Director – Siemens Technic Akademie Erlagen
- Judge Business School of Cambrigde
- Michel-Philippe main experiences :
- Project Management, International support for Actia Subsidiaries (Asia and MercoSur)

AGNES DELABORDE

Dr. Agnes Delaborde received training in computer sciences, social robotics and data analysis from the South Paris University. She joined the LNE National laboratory for metrology and testing in 2017 as a researcher. Her research activities aim the evaluation of intelligent systems through a multidisciplinary approach, without limitation on the nature or function of the object: natural language processing systems (LNE scientific coordinator for the national ANR project VoxCrim), agricultural robots (in charge of datasets processing for the national ANR project Challenge ROSE; LNE scientific representative for the French national association for agricultural robotics RobAgri); she also takes part to several projects and collaborations in industrial and service robotics and smart medical devices, and represents the LNE in the French standardization committee for robotics.

XAVIER DELPUECH

Xavier Delpuech works for the French Wine and Vine Institute (IFV) in the Mixt Research Unit ECOTECH (Montpellier, France) and is the coordinator of the PulvéLab project.

PAUL-ERIC DOSSOU

Paul-Eric Dossou holds a Phd in Automatic, Productive, Signal and Image of the University of Bordeaux.

He worked in a transfer company of research as a Project Engineer.

He has been teaching industrial engineering and logistics at the Icam University since 2003, and

in other schools (Audencia, IUT de Sénart, ESB, ...).

Researcher in business modeling and improvement of logistics performance and supply chain, Paul-Eric DOSSOU is associate researcher in the IFSTTAR SPLOTT team.

He is also the research manager of the Icam site of Paris Sénart and leads the transversal axis of Icam: Societal Transitions and Business Technologies.

CHRISTELLE GÉE

Christelle Gée was born in Dijon (France) in 1969. After a Master degree in physical chemistry at Paris Saclay University, she received a PhD degree in chemical physics with the same university (1995-1997). She joined the Cergy-Pontoise University the same year as an assistant professor in Astrophysics during 5 years. In early 2002 she moved to AgroSup Dijon where she established the Precision Agriculture Team. She became Full Professor in Precision Agriculture in 2008 with the Joint Research Unit in Agroecology (INRA/ AgroSup Dijon/Burgundy University). She devoted her research to the characterization of crop fields with remote sensors (optical and multispectral imaging systems) to reducing herbicide use. In this context, she developed innovative strategies for a sustainable agriculture. She now serves as Head of the Department of Agronomy, Agricultural Engineering, Lifestock farming and Environment at AgroSup Dijon.

CHRISTOPHE GOSSARD

Christophe Gossard started his career as a consultant and joined Deere in 1996 in France as a computer sciences engineer. Internal SAP consultant for John Deere for 3 years at the Headquarters in the US, he completed during his assignment his background with a MBA from Tippie Management School at the University of Iowa. In 2010, he started to work with the European commission as the European Emission Coordinator. Since 2012, he is the Regional Strategic Standards Manager at the Regional Center in Mannheim, Germany, in charge of regulatory subjects. He is providing support for the relevant regional issues for strategic standards and regional governmental affairs. Responsible of the data mapping proposition for the development of the agri-food eco-system based on existing standards and regulatory requirements for Europe, he has been engaged in the AIOTI, AEF, ETSI, and CEMA associations on this specific subject for the last two years.

PHILIPPE GROSS

Philippe GROSS has a degree of Mechanical engineer, associated with a Master in Management and Administration of Companies. He works for more than 20 years in the HYDAC France company based in Forbach (Moselle), he successively held the positions of Product Manager and Product Group Manager, before taking the management of the Mobile Division.

Within HYDAC France, Philippe GROSS oversees a multidisciplinary team, composed among others of Project Managers, Responsible business, Software Developers and a Mechanical Design Office, whose mission is the development of innovative solutions and customized for Mobile Machine Manufacturers.

ANTTI LAJUNEN

Antti Lajunen received the M.Sc. degree in Mechanical Engineering from Helsinki University of Technology, Finland, in 2005 and Master of Advanced Studies degree in Industrial Engineering from Ecole Centrale Paris (ECP), France, in 2007. He received his D.Sc. degree in 2014 from Aalto University, Finland. He is currently working as an Assistant Professor in Agricultural Engineering at the University of Helsinki, Finland. His main research interests are electrification of agricultural vehicles and machinery, automation in agriculture, and high fidelity modeling of off-road vehicles.

KATARIINA PENTTILÄ

Dr. Katariina Penttilä holds PhD degree in Electrical Engineering from Tampere University of Technology, Finland (2006). Currently she acts as Principal Research Scientist in Häme University of Applied Sciences (HAMK), Finland, leads Energy Efficiency Research Group in HAMK Tech Research Unit and teaches metrology in multiple engineering degree programmes in HAMK. In 2006 – 2013, she acted as RFID specialist in UPM Raflatac and Smartrac, being responsible of R&D project portfolio, including all new product design projects, new measurement systems' design and implementation against ETSI standardization, and technology expert on patenting, trade marking and antenna design. In 2002-2006, she conducted her PhD research on performance parametrization and analysis of RFID technology with 9 peer-reviewed articles, 6 scholarships and 2 personal awards. Her current research focuses on metrology and ecological technology solutions, energy efficiency, utilization of passive energy, adaptive and regenerative building. Her research work has been published among such peer-reviewed forums as *International Journal on Robotics and Automation, International Journal on Advances in Manufacturing Technology, International Journal on Logistics: Research and Applications, and Journal of Agricultural Science and Technology.*

RAFAEL R. SOLA-GUIRADO

Dr. Rafael R. Sola-Guirado is an Industrial engineer specialist in product development and design. He is researcher in the University of Cordoba where has been working in the field of rural development and contributing with more than forty papers, seven patents and thirty conferences whose main topic are the new technologies for improving the agricultural mechanization of woody crops.

CAROLINA UGARTE

PhD in soil science of the University of Burgundy, France. Carolina Ugarte is an assistant professor in soil science at the UniLaSalle Polytechnical Institute, she is member of the Agricultural Machinery and New Technologies (AMNT) Chair and the AGHYLE Research Unit (AGroecology, HYdrogeochemistry, miLieu & rEsources, UP 2018. C101).

Her research and teaching activities focus on the interaction of soil and agricultural machinery, particularly the impact of mechanized agricultural interventions on the physical and mechanical quality of soils, including soil degradation processes and levers to preserve the soil quality. Her teaching activities are mainly given to the students enrolled in the Agromachinery and New Technologies specialized courses carried by the AMNT Chair.

LORENZO VAGNETTI

Lorenzo Vagnetti is a mechanical engineer, graduated from the University of Bolton in the UK, with over twenty years of international experience in the development of new products for the automotive, agricultural machinery, industrial and consumption goods sectors.

From 1996 to today, he has been involved, as an R&D engineer, project manager and Business Unit Manager, in numerous projects for major global brands.

Over the past three years, he has worked on the technical and commercial development of PHITEC Ingegneria, a consulting company based in Turin specialized in structural simulation and computational fluid dynamics.

DAVID WHITE

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Member of the Institution of Mechanical Engineers.
Claas Stiftung Helmut Claas scholarship jury panel member.
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FULL PAPERS

Training in agricultural technologies: a new prerequisite for smart farming

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Abstract

Most of the technological innovations in agriculture enter the farm through agricultural equipment, to ease farmers' decision-making processes. The ultimate goal of smart farming is to make a better use of natural resources to reduce farming trade-offs, thus meeting the society's expectations for sustainable development. The continuously growing number of agricultural technologies aims to contribute to achieving this goal, yet deeply changing the human-machine interactions. This opens new opportunities and challenges for both equipment manufacturers and farmers. They are therefore required to expand their knowledge to master smart farming tools, currently underused. Two complementary questions shall then be answered: first, what are the available tools for farmers with limited time, variable education level and when decision-making occurs in a context of bounded rationality and framed capacity for action? Second, on a more prospective note, which direction should take initial and vocational trainings about AgTech in view of the above? This paper uses the French example to discuss available tools within the education ecosystem and propose some recommendations to facilitate deployment of smart farming, with a focus on the need to reconnect education and training about technological solutions and their use on the farm. Altogether, we discuss how the deployment of smart farming requires positive, inventive and integrated vision for the appropriate use of all technical and scientific means, promoting an open collaboration between all actors, with a culture of innovation and entrepreneurship.

Keywords: Sustainable agriculture, agricultural equipment, vocational training, farmer education, precision farming, agronomy

1. Introduction

Leading to what is called a Third Green Revolution, Smart Farming represents the application of modern Information and Communication Technologies (ICT) into agriculture. Smart farming is strongly related to three interconnected technology fields: management information systems, precision agriculture, and agricultural automation and robotics (Kernecker *et al.*, 2016). The link between technologies and agriculture is important. Bellon Maurel & Huyghe (2017) used agroecology to demonstrate the complementarity between practices and resources: agroecology is a set of practices which are not stabilized and need more knowledge about the ecosystems and their use for production (Berthet, 2014), while farming equipment and AgTech (agricultural technologies: precision agriculture tools, automation and robotics) are a set of resources to be mobilized, to achieve the agroecological objectives of the farmer. Smart farming becomes then one of the possible ways to sustainable agriculture, using AgTech to shift from intuitive to fact-based farming practices.

From this perspective, farm equipment is a vector for technological innovation in agriculture towards sustainability, AgTech a tool for implementation of smart farming practices. For example: produce more with less inputs through precision farming; use of sensors, information transfer and data processing as decision support tools; robots or specialized machines to manage soil cover and weeds. The list of technological answers to the new needs in agriculture gets longer every day and the pace of technology evolution is improving. One of the indicators is the number of proposals for using new technologies in agriculture, which is quickly growing (Brun & Haezebrouck, 2017; Wolfert *et al.*, 2017; Janssen *et al.*, 2017).

Seeing beyond immediate solutions and benefits, it is likely that external factors such as regulatory framework, insurance, or market expectations (traceability) will induce mandatory use of AgTech in some areas, in the near future, forcing their mass adoption by farmers.

As such, "agriculture is challenged by breakthrough changes that require farmers to expand their knowledge to be able to master recent farming innovations such as digital machine control, embedded sensors, big data management, etc. Thanks to the lowering cost and miniaturization of advanced technologies, farmers are pushed and eager to shift from intuitive to fact-based farming practices: chemical inputs, genetic responses and environmental condition can finally be controlled and accounted for at the intra-field level (Aqeel-ur-Rehman *et al.* 2014; Bencini *et al.* 2012). The increased data collection and monitoring capacities are indeed answering the need for a better use of natural resources to reduce farming trade-offs, thus meeting the society expectations for sustainable development." (Dantan *et al.*, 2018)

However, many researches focused on low diffusion or appropriation of new technologies (timing of adoption by some farmers), as adoption levels of AgTech are generally found low (Barnes *et al.*, 2019). Among other possible negative factors for adoption, Bellon Maurel & Huyghe (2017) identified deficit of the demand from farmers and the complexity − either real or perceived − of innovative equipment; Barnes *et al.* (2019) found economic cost barrier to adoption, behavioral component, impact of subsidy and taxation framework, industry bias perceived by farmers; Zhang *et al.* (2002) identified the lack of development of agronomic and ecological principles for optimized recommendations for inputs at the localized level. Synthesizing 10 studies on the matter, Tey & Brindal (2012) identified eventually 34 factors influencing adoption of precisions technologies, notably pointing that the implementation of AgTech require substantial technological and informationally driven analytical skills and knowledge-based interpretation.

This questions the required skill set of farmers in order to integrate innovative technologies in their farming practices (from adoption to adaptation and appropriation, Orlikowski, 2000; Carroll *et al.* 2003) for smart farming deployment, knowing that formal education and age have been found to be "common indicators of innovative behavior for most studies of technology adoption and seem to support the notion that younger and formally educated farmers are more likely to adopt precision agricultural technologies. This is further evidenced by the lack of training and technical support perceived as an adoption constraint to uptake of precision agricultural technologies." (Barnes *et al.*, 2019)

Farmers' education and tools for training becomes a key element of analysis, object of this paper: education to innovation is a component of both attitude towards innovative technologies and their appropriation on the farm (Barnes *et al.*, 2019; Knight *et al.*, 2010). Two complementary questions shall then be answered: first, what are the available tools for farmers with limited time, variable education level and when decision-making occurs in a context of bounded rationality and framed capacity for action? Second, on a more prospective note, which direction should take initial and vocational trainings about AgTech in view of the above?

Or, to sum it up, how to support today and tomorrow's farmers and agricultural equipment manufacturers to realize their new technological and digital transition? This paper uses the French example to discuss available tools within the education ecosystem and propose some recommendations to facilitate deployment of smart farming.

2. Materials and Methods

2.1. Panorama of initial trainings promoted by farmers with an AgTech component in France

Identification of AgTech oriented training courses is the linchpin for assessing available tools for deployment of smart farming. In France, most of the training courses in agriculture are under the supervision of the Ministry of Agriculture. They are carried by 824 either public or private institutions which are spread over the whole country (Fig. 1): 806 educational institutions from French level 3 to level 5 (high schools) and 18 higher education institutions of levels 6 and 7. Higher education in agriculture includes a short cycle leading to level 5 and a longer cycle leading to level 7. The 80 degrees of levels 3 to 5 (Tab. 1) are also supervised by the National Education Ministry (distinct from the Ministry of Higher Education and Research). The reattachment of training courses to the Ministry of Agriculture is dictated by the following principles:

- They are directly connected with changes in both agricultural/rural areas and agricultural/rural professional qualifications;
- The exercises of the missions defined by the 8th book of the rural and sea fishing code are federated in the educational institution project, in particular to contribute to development, experimentation and innovation activities linked with agriculture and agribusiness.

The link between agricultural trainings and the Ministry of Agriculture is thus supposed to guarantee the adequacy between education and the professional sector.

A few training courses of level 5 to 8 in both universities and IUT (French Institutes of technologies) are supervised only by the Ministry of Higher Education and Research. Indistinctively from the supervising Ministry, only some training courses are recognized as conferring the "CPA" ("Capacité Professionnelle Agricole" in French i.e. Agricultural Professional Capacity), required legally for starting a farm as farmer and benefit from start-up loans and start-up allowance. The CPA is accessible from Level 4.

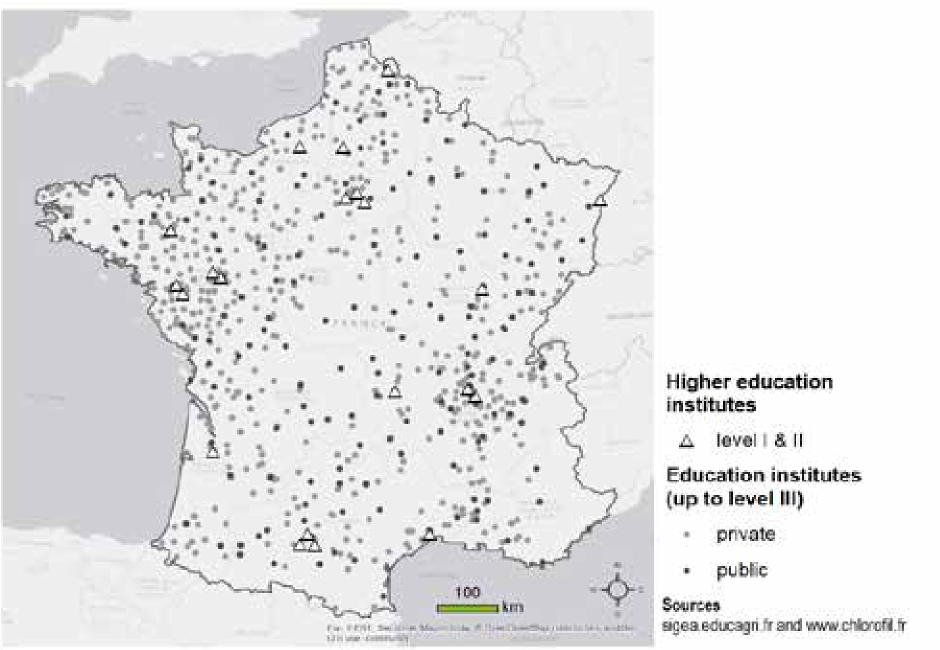

Figure 1 map of French agricultural education institutes

Training courses conferring the CPA have been studied more particularly, in order to:

- Identify the main training courses followed by farmers or agricultural employees (Tab. 1);
- Analyze the frequency of themes linked to smart farming in those courses (Tab 2 and 3).

The final purpose is to assess the farmers' preparation for smart farming.

Table 1: Number of degrees available per French education level (international standard classification (ISCED 2011) between brackets).

	French (international) educational level					Source
	3 (4)	**4 (3)**	**5 (5)**	**6 (6)**	**7 (7)**	
Ministry of HE	NA	NA	NC	NC	NC	A
Of which delivering CPA			2	2	5	A
Ministry of agriculture	35	29	16	1	*18* §	B
Of which delivering CPA	/	15	16	1	*16* §	A
Professional integration* (% of graduated per year)		64 to 83	40 to 60	NA	4,2	C, D, E

* as a farmer and farm worker

§ number of institutes (instead of number of degrees)

A http://daaf.reunion.agriculture.gouv.fr/IMG/pdf/Arrete_CPA_29-10-2012_LISTE_DES_DIPLOMES_cle01badf-1.pdf

B http://www.chlorofil.fr/diplomes-et-referentiels.html

C http://www.chlorofil.fr/fileadmin/user_upload/stats/statea/statea-2017-05-insertion-bacpro-2012.pdf

D http://www.chlorofil.fr/fileadmin/user_upload/stats/statea/statea-devenir-btsa-scol-2007.pdf

E http://www.chlorofil.fr/fileadmin/user_upload/stats/statea/statea-2018-02-esavp.pdf

Note: for Levels 6 & 7, number of institutes are indicated in italics, instead of number of degrees.

The frequency of themes linked to smart farming in the programs is studied by a search of keywords in the degree references and RNCP (Répertoire National des Certifications Professionnelles in French i.e. National Register of Professional Certifications) sheets for both levels 4 and 5 degrees. Keywords searched aim to characterize agricultural technologies / smart farming: data, AgTech, new technologies, robots, AI (Agro-Industry), drone, PFT (Precision Farming Techniques), precision agriculture.

Table 2: Terms identified linked to keywords per education level

	French (international) educational level	
	4 (3)	5 (5)
Keywords found (translated)	DSS, GPS, digital technologies, innovative technologies, new on-board technologies	New technologies, technological innovations

It shall be noted that the program sheets listed in the RNCP for Level 4 are either recent (2017) or in the process of consultation for an implementation in September 2019. This update follows the overall reform of the baccalaureate in France. The BTSA ("Brevet de Technicien Supérieur Agricole" technician certificate) sheets, which are relatively old with regard to the mutation of agriculture (2009 to 2014) should logically be updated too. Adaptations of programs with inclusion of AgTech components can thus be expected in the coming years.

Concerning Levels 6 and 7 diplomas, the titles of specializations courses taught in the engineering schools, as well as the master's degrees approved by the Conférence des Grandes Ecoles (CGE) have been studied, to draft a panorama of Levels 6 & 7 trainings related to AgTech. Such trainings may have two dominant features: one is more agricultural machinery-oriented, which is generally associated with technical trainings in agricultural equipment such as professional baccalaureate or technician certificate, the other is oriented more on data processing (computer and statistics), usually associated with higher education trainings. Thus, we provide higher education courses in connection with the AgTech taught by main engineering schools (Tab. 3).

Table 3: French higher education courses with an AgTech component

a. Level 6

Educational institute/ University, city	Course title	Degree / duration / opening
Bourgogne University / Agrosup Dijon	Agronomie spécialité agriculture, nouvelles technologies, durabilité (Agronomy specialty agriculture, new technologies, sustainability)	Bachelor / 1 year
ISA, Lille	Numérique et Biologie (Digital and biology)	Bachelor / 3 years / 2019

b. Level 7

Educational institute/ University, city	Course title	Degree / duration / opening
AgroCampus Ouest, Rennes	Mathématiques appliquées, statistiques - Parcours Data science pour la biologie (Applied Mathematics, Statistics - Data Science for biology)	Master 2 / 1 year
	Ingénieur agronome, Option Statistiques appliquées - Sciences des données (Agricultural Engineer, Applied Statistics - Data Science course)	Engineer / 1 year
Agrosup, Dijon	Gestion des Entreprises et Technologies Innovantes pour l'Agroéquipement - GETIA (Enterprise Management and Innovative Technologies for Agro-equipment)	Master / 2 years
	Sciences et Techniques des Equipements agricoles (Agroequipment)	Engineer / 1 year
ESA, Angers – in partnership with ESEO	AgTech : Innovation numérique et connectée pour la création de valeur en agriculture et agroalimentaire (AgTech: digital and connected innovation)	Master / 15 months / 2019
Montpellier Sup Agro, Montpellier	Ingénieur agronome, Option - AgroTIC (AgroICT) - Data sciences pour l'agronomie et l'agroalimentaire (Agricultural Engineer, AgroTIC and data science course)	Engineer / 1 year
Bordeaux Sciences Agro, Bordeaux – in partnership with Montpellier	Ingénieur agronome, Option AgroTIC (Agricultural Engineer, AgroTIC course)	Engineer / 1 year
UniLaSalle, Beauvais or Rouen	Ingénieur agronome, Option Agroéquipements et nouvelles technologies (Agricultural Engineer, agro-equipment and new technologies course)	Engineer / 2 years
UniLaSalle Rouen	Master of Science Agricultural and Food data Management	Master of Science / oct 2018
ISA Lille – YNCREA, Lille	Ingénieur agronome, Option Agriculture durable & Smart Farming (Agricultural Engineer, sustainable agriculture and smart farming course)	Engineer / 1 year
ENSAT, Toulouse	Ingénieur agronome, Option Agrogéomatique (Agricultural Engineer, GIS course)	Engineer / 1 year

Complementary to initial training, in vocational training (or lifelong learning), the skills related to AgTech (both machinery and digital) are increasingly necessary with the digital transition as well as more and more complex machines in agriculture. Actors of the supply chain are asking for lifelong learning. An analysis of the complete offer in this sector should be carried out to add a new dimension to the present article. Yet, researches are made difficult by the multiplication of actors involved and the subjectivity that would generate a partial analysis. However, we can mention the Certificates of professional qualification (e.g. those delivered by AXEMA), promoted by the private sector for the targeted topics which are covered, also in connection with the French chambers of agriculture network. There are also short courses on mechanization dedicated to farmers proposed by agricultural organizations such as technical institutes like Arvalis, training organizations in agriculture such as Résolia and manufacturers such as AGCO. Finally, some short courses in statistics and data processing are proposed by peripheral actors of the farming equipment supply chain; these generally require solid foundations in both mathematics and computer science (e.g. statistics courses proposed by both Idele breeding institute and French Modelling and Data Analysis for Agriculture Network).

2.2. Current impact of skills and knowledges in AgTech acquired in initial training in France

In absence of a detailed analysis of the offer and impacts of lifelong learning in AgTech fields, it is interesting to assess potentiality of diffusion of AgTech in the current farming population, based on education level of farmers and age. As highlighted above, trainings in smart farming are recent in France, and limited to higher education: it can thus be expected that initial education including references to smart farming have only been accessible to a small number of students and a very limited number of professionals yet. Crossed indicators to verify this are the level of education of the farming population and its age, keeping in mind that the French farming population is aging, quickly: from an average age of 49 years old in 2000, the farming population went to 52.5 years old average in 2016 (Agreste, 2018).

France is among the best ratios in Europe for the initial training of farmers. In line with other sectors, the overall education level of farmers rose significantly in the last 20 years, with the democratization of education and the modernization of farms. In 2016, more than 50% of the farmers possess a secondary education degree. The main variation factor among the farming population is the age: 20% of farmers above 60 years old only have a primary education level, while 85% of the farmers under 40 years old have at least a secondary education degree. Education of young farmers has made a significant jump in the last 15 years: the proportion of farmers under 40 years old with a secondary education degree went from 45% in 2000 to 85% in 2016 (Agreste, 2018).

The level of education of farmers is thus rising, also induced in part by subsidies programs (CPA as referred above) targeting young farmers, requiring a minimal initial secondary education level validated to benefit from the start-up aid scheme (start-up loans for young farmers and start-up allowance). Proportion of higher education degrees among the farmers' population grows in the same proportion, although for a smaller number.

Indeed, in 2016, the proportion of farmers who possessed a higher education degree of all types falls at 24% (11% in 2000), and only at 14% with a specialization in agriculture. Once again, age is predominant factor of variation: 43% of farmers under 40 years old have a higher education diploma while only 14% of farmers above 60 years old have one, which demonstrate a great potential for developing smart farming in the future.

However, for the time being, the limited number of farmers with a higher education degree and the aging farming population complexifies deployment of smart farming, whose adoption by farmers can be associated to many factors.

2.3. Relation of farmers to AgTech and innovation

In the literature, various factors have been identified to describe how farmers relate to AgTech and innovation. For instance, the review by Tey & Brindal (2012) identified 34 significant factors to explain the adoptive decision making of precision agriculture technologies (PATs), further grouped in seven categories: socio-economic factors, agro-ecological factors, institutional factors, informational factors, farmer perception, behavioral factors and technological factors. The authors finally pointed out some levers to bridge the information gap, which emerged among the key limiting factors in the adoption of PATs. Knight *et al.* (2010) demonstrated that farmers' education encourages innovation. In their recent study Barnes *et al.* (2019) highlighted that the educational status is not a clear predictor of adoption of PATs. However, education, advisory services and other information mechanisms might help changing how farmers relate to AgTech and their inclination towards innovation and the shift towards information intensive technologies.

In this regard, connections and infrastructures emerge as underpinning factors influencing the information mechanisms, especially in rural areas within a context of digitalization of information. Unfortunately, few data exist on the real access and use of web-related devices. A remarkable exception is the Agrinautes survey for France (Boiteau *et al.*, 2018), last edition of which reached 1210 equipped farmers. Weather and banking services, as well as classified advertising and farm data were the main reason of connection for almost all the respondents, 85% of which use internet at least once a day. Regarding social networks, 60% of them use social networks, the most used being Facebook and Youtube, including to view tutorials related to their daily work. Of notice, the farmers having at least a connected equipment almost doubled in a couple of years: respectively 24.7% in 2016 and 39.4% in 2018. These figures suggest that the population of connected farmers is already using information technologies in the day-to-day farm management, eventually shifting towards the adoption of AgTech devices. In this vein, the connection availability widens the opportunities to explore innovation and filling the information needs. This endogenous interest of the profession is illustrated below with the analysis of the recent orientation of professional events toward AgTech and the multiplication of experimentation sites.

2.4. Multiplication of professional initiatives to facilitate new technologies diffusion / appropriation

Several factors can illustrate the interest of a sector to facilitate diffusion / appropriation of a specific topic: orientation of professional events, number of experimentation structures involving users (i.e. the topic does not interest only innovation actors but generates interest of the end-users in view of a possible adoption), or multiplication of training sessions or informative communications for end-users (specialized press), etc. The research of the current paper is focused on the first two factors.

First, an extensive research has been carried out to list all professional events involving a specific dimension in agricultural technologies / smart farming in most recent years, from 2014 to 2018. Keywords used were: data, AgTech, new technologies, robots, AI, drone, PFT, precision agriculture. However, the team faced a lack of indexing for events which occurred more than two years before date of research: for recurring events, pages were updated to the last or coming version of the event, and for one-time events, websites were missing, or at best present with partial information. A shift was made towards social networks and their records to identify the said events. Altogether we identified 79 events between 2016 and 2018, unevenly distributed (Fig. 2).

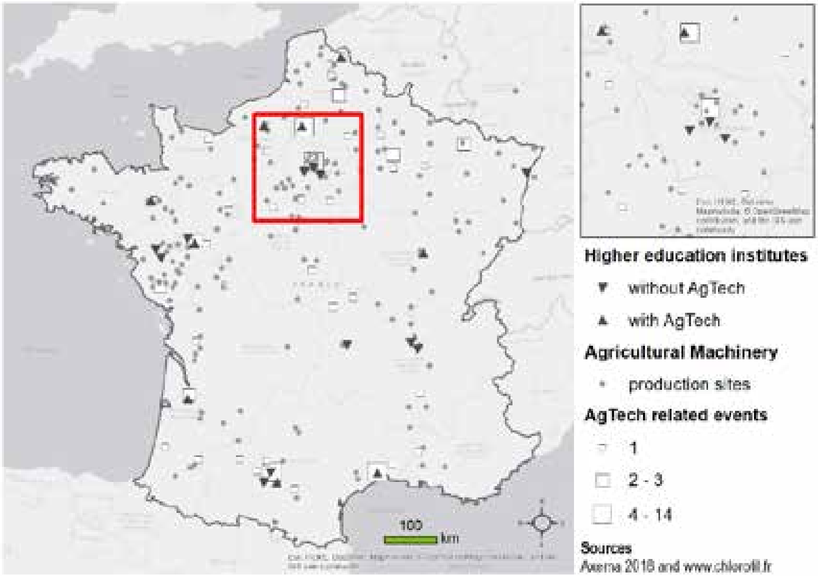

Figure 2. Spatial distribution in France of professional events with an AgTech orientation compared to higher education institutes and farm equipment manufacturers

The following points can be listed after reviewing the data:

(1) All main agricultural professional events in France (>30 000 visitors) developed an orientation towards AgTech. For example, the Paris International Show increased five-fold the area dedicated to AgTech in 3 shows. Additionally, events dedicated specifically to AgTech begin to appear (FIRA, LFDay, e-Day, CoFarming Fest).

(2) Unbalanced distribution at the scale of the country, benefiting to the north-western half, concentration of events around research poles: out of 46 location identified, Paris, Montpellier, Beauvais, Angers and Toulouse concentrate 38% of the events, highlighting a possible impact of research centers in the dynamism of the regions.

(3) Events in Paris emphasize the interest generated by AgTech of peripheral actors: several events non-specific to agricultural topics (data, finance, technology) had an orientation towards AgTech, representing a link with technological/financial sectors which identify agriculture as an opportunity for development.

(4) Link between AgTech and FoodTech: AgTech is very often associated to FoodTech, which seem to place AgTech as one of the possible links from field (the farmer) to fork (the consumer), useful for traceability of agricultural products concerns, consumers' education and positive reinforcement of farmers' image.

Second, also represented on the map, the team observed since 2015 the set-up of 20 distinct experimental structures, aiming to support the development of AgTech. With some differences in the type of organization and functioning, all of them carry the mission to contribute, often on a learning-by-doing approach, to the adoption of AgTech by farmers.

Noticeably, the network Digifermes (Arvalis) uses existing 13 farms to deploy AgTech, by placing the farmers at the center of the development of projects with high technical readiness levels. The Ferme 3.0 (Chambre d'Agriculture Hauts-de-France), the oldest of those experimental structures oriented towards AgTech, describes itself as a living lab for agronomic, technological and robotic solutions. AgriLab (UniLaSalle), on the other end, places open innovation as a prerequisite for the farmers who want to develop an innovative project.

Eventually, all those initiatives target explicitly the end-users (the farmers) and are distinguishable from profit-oriented enterprises, illustrating the genuine interest of the sector for the diffusion of AgTech.

3. Results and Discussion

3.1. The rising need of an AgTech learning ecosystem

As demonstrated above, AgTech notions beyond initiation are taught only in higher education courses in France, despites efforts of the profession for diffusing technologies. This is favorable to the deployment of AgTech in the future when linked to the raise of education level of farmers. However, the raise of education level of farmers faces a structural standstill with the lack of accessible options within the French education system for farming-oriented higher education level diploma for future farmers. Until today, the vast majority of farmers-to-be choose the levels 4 & 5 degree path, which are dead-end paths in the education ecosystem and only allow few continuations. There is no obvious link between those 2-years courses and further studies at license / master level. The education system should allow the future farmers to reach easily any level and facilitate transfers from a level to the next one. This missing link between technically-oriented trainings, largely endorsed by farmers-to-be, and masters' level degree has to be created to allow a deeper mastering of AgTech, before usage on farms. Higher education institutions should have the legislative capacity to build those bridges and to develop them with the idea of valuating technical assets of the students, while providing them with the required technological and informationally driven analytical skills and knowledge-based interpretation capacities.

In terms of content, it is necessary to value agricultural technologies as a tool, in the context of agronomy. Training courses should be designed with this distinction and avoid nowadays trends: in most of the training courses referenced above, the AgTech orientation of the trainings is made at the expense of agronomy, leading to AgTech as a precept being opposed to historical fields of agronomy.

Modality of training in AgTech are important: a support farm and a technological workshop are required as support tools for pedagogy and experimentations, in line with the French Ministry of Agriculture recommendations. The overall objective is eventually to set up a full ecosystem dedicated to train future farmers and existing farmers in AgTech:

- License and master degrees accessible from technical training courses,
- Facilitate the articulation between agronomy and AgTech in all level of training with the support of:
  - A dedicated farm for field experimentation,
  - A technological workshop conceived with the purpose of designing farming tools using AgTech, based on a project-based learning approach.

Eventually, based on the learners' profiles and aspirations, training courses and their content should be tailored and proportion in agronomy / AgTech balanced in view of specific objectives. Links with technological training course should be envisaged and mobilized upon need with the option to graduate with two diplomas jointly, from several institutions if need be. Same approach should be used for vocational training for farmers' or other professionals: the connection between technological solutions and their use on the farm should be in the heart of the training with an appropriate mix of pedagogical modalities.

3.2. Vocational education and training of smart farming: the need of an active learning approach

Farmers constantly take complex decisions that needs to account for multiple variables. For the greatest share of these decisions, they must face the uncertainty alone and in a short lapse of time. As so, they learn by doing and continuously observing the results of their decisions (e.g. Casagrande *et al.*, 2012). Therefore, vocational education and training programs aiming to unlock the appropriation of smart farming technologies will benefit from an active learning approach. The active learning implies learners to engage in meaning-making inquiry, action, and personal reflection (Lima *et al.*, 2017), thus in a similar mood of the typical farmer's decision-making process. More in general, this follows the experiential learning cycle that relates concrete experience and abstract conceptualization as modes of grasping experience, then transformed through either reflective observation and/or active experimentation (Kolb 2014, p. 51).

The active learning may take various complementary forms, such as (1) the project-based learning, (2) the dual vocational training and apprenticeship, (3) the makerspaces and similar. The project-based learning targets a self-directed learning processes starting from sound and realistic problems, thus including the uncertainty of the real-life decision-making process (Abbey *et al.*, 2016). In this sense, project-based learning generally provides an interface between academia and practitioners, so facilitating the hybridization of knowledge. This might help to build trust in smart farming technologies, as these are for the most coming from a non-agricultural background. In the same vein, the vocational education and training in smart farming could also be developed through the dual learning or apprenticeship programs. These combine on-the-job training and academic instruction, with the learners spending alternatively their time in a hosting enterprise and in the academia (cf. Mulder 2018). Finally, the training in agricultural technologies could specifically benefit from the makerspaces and similar. Makerspaces are inspired by the do-it-yourself approach, thus supporting an informal creative ecosystem equipped with a variety of rapid prototyping and low-tech tools and a meeting space for design teams. This approach was further formalized by the Fab Lab foundation (an outreach project from MIT's Center for Bits and Atoms) that federate an open and collaborative global network of places sharing a common set of tools and processes (http://www.fabfoundation.org/). For instance, in France recently opened AgriLab®, a makerspace entirely dedicated to agriculture and drawn upon the three Fab Lab pillars: doing, sharing, and learning. This platform promotes the culture of open innovation and knowledge sharing by and for farmers about agricultural equipment and new technologies for a more sustainable agriculture. It already hosted a couple of intensive workshops for farmers and students in agronomy to identify relevant technologies to support their field observations (Dantan *et al.*, 2018).

In conclusion, it is also important to consider that farmers entrust their peers as the ultimate reference to legitimate new knowledge acquired through direct or learning experiences, even against the availability of other references such as extension services, agricultural research and other media (Phillips *et al.,* 2018). Hence, the vocational education and training approaches in agricultural technologies will be more effective if developed within a learning community, as claimed for instance in agroecology (Francis *et al.,* 2011) and livestock innovative education (Sewell *et al.,* 2017).

3.3. Training centers: a possible interface between top-down and bottom-up innovations?

Eventually, and to go beyond the farmer-targeted approach, mostly promoting the diffusion of top-down innovation, training solutions should be conceived allowing and promoting the expression of bottom-up innovation, endogenously vouching for a better adoption, appropriation and eventually adaptation of AgTech and smart farming practices. This raises the question of the interface required for the expression of bottom up innovation and its valorization, or more generally of the missing link between bottom-up and top down innovations. The disconnection between bottom-up movement and top-down movement, in technology innovation, is not a fact which can be easily modified. It is the consequence of a fundamental dissymmetry.

A top-down organization, inside a company but also at the level of the society, is built on presumptions, rightly or wrongly, that knowledge is produced at top level, through research by scientists; then knowledge is transformed in formalized know-how by the engineers, and finally it is taught to farmers by specific teachers and consultants. It is a consequence of a classic vision in Western Culture coming from Francis Bacon (1561-1626) and René Descartes (1596-1650) with the aim that science should lead technique. No doubt that this new vision has changed and increased the rhythm of invention. This means that know-how is a consequence of knowledge, as research is divided in fundamental research and applied research. So, this logical hierarchy has easily transformed in a hierarchy of value. Even for action, it appeared that knowledge was a way to achieve dominance. And finally, a scientist does not want to discuss with a farmer who is supposed not to understand. The only possible relation is teaching. “As a result of these asymmetries, farmers’ own particular needs and rights may be ignored, and inequalities are at risk of growing due to data-driven insights, rather than be reduced” (Kritikos, 2017).

Indeed, current solutions, such as service providers where data is retrieved by reselling companies either as decision support systems or to other companies for marketing / commercial purposes, are unsatisfactory to the farmers:

(1) Such solutions are based exclusively on technological advances, yet the farmers’ participation in the innovation process and the technology customization on their needs appear to be quite limited.

(2) Farmers have generally to adapt to standard solutions suited for the greatest market share. Consequently, the proposed solutions do not fully suit the local heterogeneous agricultural needs. Even more, the customized solutions realized by businesses would be too expensive.

(3) The role of farmers in the innovation process is not clearly defined, or even denied. Proposed solutions (software, innovations, data involved, and decisions via a “black box”) are often proprietary. The farmer is just considered as end-user more than an innovation actor, which would promote their autonomy.

(4) Farmers’ collaboration/participatory control on hardware, data, knowledge sharing, and decision support is then low. Indeed, providers follow a general design which centralizes both data and “black box” decision tools, without collaboration between farmers of same regions.

Now, as the technical and cultural farmers’ level is growing, also grow their awareness and concerns about the access to and the use of their farm data (American Farm Bureau Federation, 2018) and the related major shift in role and power relations.

On the other hand, a bottom-up organization is built on presumptions, rightly or wrongly, that know-how has its own autonomy and as innovation is always done at the level of know-how, the practitioners know what they need and so they ask to the scientists to answer to their questions. Fundamental research is thought as an activity to answer to questions of knowledge by the innovative farmers looking for a change of practice. This could look very naïve, but research has now shown that naivety is on the other size, when top-down is applied to complex social systems, such as healthcare or modern agriculture (Braithwaite *et al.,* 2018).

An interface is thus needed. The interface to build is conceptual, but not only. It needs that the scientists presume that the questions of farmers are legitimate. It needs also that the farmers accept or at least understand the different representations, proposed by the scientists, and assume the dual role of expert and learner. The research days in UniLaSalle, from which have been published two books (Dubois and Sauvee, 2016; Caroux *et al.*,

2018) are examples of possible interactions between practitioners, engineers, scientists and philosophers. Another example is to implement farmer-oriented innovation (e.g. Dantan *et al.*, 2018), through for example a chair fostering design and development of research, education and training in AgTech by acting at the interface between students, industry sector and farmers (Rizzo *et al.*, 2018). The Bec Hellouin organic farm is also a fine example of inventor farmer of precision tools for permaculture (Caroux *et al.*, 2018, p. 59). The co-construction of new technical systems between farmers, research institutions and equipment manufacturers, is now valued in order to restore the creative and inventor role of the farmer (Caroux *et al.*, 2018, p. 93). Finally, the start-up Agrifind develops a marketplace for the agricultural world, allowing the connection between farmers wishing to enhance their experience with other farmers seeking to acquire more knowledge and know-how. This web platform dedicated to the transfer of skills has been officially launched at the SIMA 2017. These examples, again, show that the farmers just need to be considered as inventors or co-inventors, involved in the local transformation of their activity.

Transforming agriculture into a complex adaptive system implies that a routine practice through a step-by-step model, from top to bottom, is less and less used. "Complexity science forces us to consider the dynamic properties of systems and the varying characteristics that are deeply enmeshed in social practices." (Braithwaite *et al.,* 2018). We have to learn by doing and "to accept that multiple forces, variables, and influences must be factored into any change process" and that "unpredictability and uncertainty are normal properties of multi-part, intricate systems."

4. Conclusions

Deployment of smart farming will only be possible with the combined inputs of initial training for tomorrow's farmers and vocational training for the current farming populations. Many drawbacks will slow down the process, but coordinated efforts of academics, private sector, peripheral actors of the supply chain and of the farmers themselves will eventually pay off, to avoid counter-productive accelerated concentration of farming capacities in large-scale farms at the expense of agricultural diversity.

For the initial training, the involvement of the Ministry of Agriculture in supervising agricultural educational programs aim at this coordination of actors and overall guidance in including AgTech components within trainings, as seen with the last revision of program sheets of the National Register of Professional Certifications. Ongoing revision of short higher education programs should naturally reflect this trend as well. Same approach with the support of public institutions should be adopted to ensure consistency and limit dispersion of initiatives, especially for farmers-to-be in the framework of obtention of the Agricultural Professional Capacity.

However, mechanisms of dynamic update of training programs are required to adjust trainings to current usages. This requires resources: AgTech are constantly evolving, and the time required to build a consistent training program and identify academics with required skills to teach it often overpasses usages. One option for compensating differences in temporalities is that trainings in at higher education level in AgTech could be envisaged not focused on technologies, but on their usages, implication in agronomic programs, benefits, consequences on the cultural cycles, on the farms, on the supply chain. A clear focus of numerous students, whether technological, practical or organizational, would be detrimental to agronomy and would lead to a lack of hindsight when assessing technical, economical and sociological impacts on farming practices.

On the other end, useful project-oriented trainings for end-users, could promote this technological focus and provide to nowadays' farming population required skills for using, at least, before adapting, i.e. being part of the design or update of the technologies. Efforts shall be undertaken by the all supply chain to place farmers at the center of the innovation process. Moreiro (2016) and Hostiou *et al.* (2017) concluded their papers by highlighting the step of adapting the use of technologies to farmers' need and skills; or to a set of farming practices: "Significant research and development efforts will be needed to adapt such technologies to the particular requirements of farm machinery that will support the transition to agroecology" (Bellon Maurel & Huyghe, 2017). Equipment manufacturers have thus also a key role in leading farming innovations deployment by easing farmers' decision-making processes with the support of agricultural technologies.

Finally, the role of the peripheral actors of the farming equipment supply chain is a key for scalability of intervention: training of the whole farming population is neither required nor possible. However, ensuring that vocational trainings conferred benefit from a large impact by involving communication relays is a key aspect for successful development of smart farming.

Altogether, this new data intensive farming requires positive, inventive and integrated vision for the appropriate use of all technical and scientific means. Eventually, this vision of tomorrow's agriculture will allow for the emergence of digitally augmented farmers. This is the moment to undertake a technical revolution and to promote collaboration between farmers, engineering schools, students, farm equipment manufacturers and experts in agronomy, ICT, and research, with a culture of innovation and entrepreneurship.

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References

1. Abbey, Lord, Dowsett, E., Sullivan, J. 2017. *Use of problem-based learning in the teaching and learning of horticultural production*. The Journal of Agricultural Education and Extension, volume 23, n° 1. p. 61-78
2. Agreste, 2018. Population agricole, formation et recherche, GraphAgri, http://agreste.agriculture.gouv.fr/IMG/pdf/Graf1815_-_Formation_initiale.pdf
3. American Farm Bureau Federation. 2018. *Data Privacy*. https://www.fb.org/issues/technology/data-privacy/
4. Aqeel-ur-Rehman, Abbasi AZ, Islam N, Shaikh ZA, 2014, *A review of wireless sensors and networks' applications in agriculture*, Comput Stand Interfaces, 36: 263–270. https://doi.org/10.1016/j.csi.2011.03.004
5. Barnes A.P., Soto I., Eory V., Beck B., Balafoutis A., Sánchez B., Vangeyte J., Fountas S., van der Wal T., Gómez-Barbero M., 2019. *Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers*. Land Use Policy, Elsevier https://doi.org/10.1016/j.landusepol.2018.10.004
6. Bellon Maurel V, Huyghe C., 2017, *Putting agricultural equipment and digital technologies at the cutting edge of agroecolog*y. Oils and fats Crops Lipids, 24: D307. https://doi.org/10.1051/ocl/2017028

7. Bencini L, Maddio S, Collodi G, Palma DD, Manes G, Manes A., 2012, *Development of Wireless Sensor Networks for Agricultural Monitoring*, Smart Sensing Technology for Agriculture and Environmental Monitoring. Springer, Berlin, Heidelberg, pp. 157–186. https://doi.org/10.1007/978-3-642-27638-5_9

8. Berthet E., 2014. *Concevoir l'écosystème, un nouveau défi pour l'agriculture*. Presses des Mines. Paris

9. Boiteau P., Ménager M., Sauget N. (2018). Etude Agrinautes 2018 réalisée par BVA pour Terre-net Média et Hyltel.

10. Braithwaite J., Churruca K., Long J. C., Ellis L. A. and Herkes J. 2018. *When complexity science meets implementation science: a theoretical and empirical analysis of systems change*. BMC Medicine, 16:63. DOI: 10.1186/s12916-018-1057-z

11. Braun A-T, Colangelo E, Steckel T., 2018, *Farming in the Era of Industrie 4.0*, Procedia CIRP, 72: 979–984. https://doi.org/10.1016/j.procir.2018.03.176

12. Brun F. & Haezebrouck T.-P. AgTech – Digital *Agriculture Current development in France*. Conference Big Data and sustainability – Food and agriculture – September 20-21, 2017, Copenhagen, Denmark

13. Casagrande, M., Joly, N., Jeuffroy, M.-H., Bouchard, C., et David, C. 2012. *Evidence for weed quantity as the major information gathered by organic farmers for weed management. Agronomy for sustainable development*, volume 32, n° 3. p. 715–726

14. Caroux, D., Dubois, M. J. F., & Sauvée, L. (2018). *Evolution agro-technique contemporaine II. Transformations de l'agro-machinisme: fonction, puissance, information, invention*. Ed. UTBM Belfort, 252p.

15. Carroll, J., Howard, S., Peck., J. and Murphy, J., 2003, *From adoption to use: the process of appropriating a mobile phone*, Australian Journal of Information Systems, 10:2, 38-38. http://dx.doi.org/10.3127/ajis.v10i2.151

16. Dantan J., Rizzo D., Fourati F., Dubois M., & Jaber M., 2018., *Farmer-Oriented Innovation: Outcomes from a First Bootcamp,* 3rd Abbé Grégoire Innovation Days International Conference. https://www.researchgate.net/publication/327269621_Farmers-oriented_innovation_outcomes_from_a_first_bootcamp

17. Dubois, M. J. F. & Sauvée L., 2016. *Evolution agro-technique contemporaine. Les transformations de la culture technique agricole*. Ed. UTBM Belfort, 235p.

18. Francis, C.A., Jordan, N., Porter, P., Breland, T.A., Lieblein, G., Salomonsson, L., Sriskandarajah, N., Wiedenhoeft, M., DeHaan, R., Braden, I., et Langer, V. 2011. *Innovative Education in Agroecology: Experiential Learning for a Sustainable Agriculture*. Critical Reviews in Plant Sciences, volume 30, n° 1-2. p. 226-237

19. Hostiou, N., Fagon, J., Chauvat, S., Turlot, A., Kling-Eveillard F., Boivin, X., Allain, C., 2017, *Impact of precision livestock farming on work and human animal interactions on dairy farms*. A review, Biotechnol. Agron. Soc. Environ, 21(4): 268-275. <hal-01563608>

20. Janssen S. J. C., Porter C. H., Moore A. D., Athanasiadis I. N., Foster I., Jones J.W., M. Antle J. M., 2017, *Towards a new generation of agricultural system data, models and knowledge products: Information and communication technology*, *Agricultural Systems,* 155: 200–212. https://doi.org/10.1016/j.agsy.2016.09.017

21. Kernecker, M., Knierim, A., Wurbs, A. (2016). *Report on farmer's needs, innovative ideas and interests*. Deliverable 2.2. Smart-AKIS https://www.smart-akis.com/wp-content/uploads/2017/02/D2.2.-Report-on-farmers-needs.pdf

22. Knight, J., Weir, S., Woldehanna, T. (2003) *The role of education in facilitating risk-taking and innovation in agriculture*, The Journal of Development Studies, 39:6, 1-22, DOI: 10.1080/00220380312331293567

23. Kolb, D.A. 2014. *Experiential Learning: Experience as the Source of Learning and Developmen*t. FT Press, 417 p. ISBN 978-0-13-389250-5.

24. Kritikos, M., 2017, *Precision agriculture in Europe. Legal, social and ethical considerations*. Report No.: PE 603.207. European Parliamentary Research Service. doi:10.2861/278

25. Le Méhaute, A., Raynal, S., Chédru, M., et Pormente, S. 2007. *L'acteur du projet « pour une économie de la connaissance »:* La Revue des Sciences de Gestion, volume 226-227, n° 4. p. 65-75

26. Lima, R.M., Andersson, P.H., Saalman, E.2017. *Active Learning in Engineering Education: a (re)introduction*. European Journal of Engineering Education, volume 42, n° 1. p. 1-4

27. Moreiro, L., 2016, *L'appropriation d'une technologie peut-elle entraîner le développement d'une compétence distribuée entre l'homme et la technologie ? Le cas de la viticulture de précisio*n. Thèse soutenue à l'Université Paris Sud. DOI: 10.3917/vse.202.0071

28. Mulder, M. 2018. *New investment in international vocational education research by the German federal government.* The Journal of Agricultural Education and Extension, volume 24, n° 2. p. 115-119

29. Orlokowski, W.J., 2000, *Using technology and constituting structures: A practice lens for studying technology in organizations*, Organization science, 11(4): 404-428. https://doi.org/10.1287/orsc.11.4.404.14600

30. Phillips, T., Klerkx, L., and McEntee, M. 2018. *An Investigation of Social Media's Roles in Knowledge Exchange by Farmers*. In 13th European IFSA Symposium. 1 Juillet 2018, Chania, Crete, Greece. p. 20.

31. Rizzo D., Fourati F., Ceapraz L., Ostapchuk M., Randrianasolo H., Combaud A. Ritz S., Jaber M., Dubois M., 2018. *Identifying the stakeholders' interactions within an agricultural innovation system towards sustainability*, SISA International Workshop, 3rd Edition, Riga

32. Rogers, E.M., 1995, *Diffusion of Innovations*, The Free Press, 3rd Edition, New York.

33. Sewell, A.M., Hartnett, M.K., Gray, D.I., Blair, H.T., Kemp, P.D., Kenyon, P.R., Morris, S.T., et Wood, B.A. 2017. *Using educational theory and research to refine agricultural extension: affordances and barriers for farmers' learning and practice change*. The Journal of Agricultural Education and Extension, volume 23, n° 4. p. 313-333

34. Sivertsson, O., & Tell, J., 2015, *Barriers to Business Model innovation in Swedish agriculture*, Sustainability, 7(2), 1957–1969. doi:10.3390u7021957.

35. Tey Y. & Brindal M. (2012). *Factors influencing the adoption of precision agricultural technologies: A review for policy implications*. Precision Agriculture. 13. 10.1007/s11119-012-9273-6.

36. Wolfert S., Ge L., Verdouw C., Marc-Jeroen Bogaardt M.-J., 2017, *Big Data in Smart Farming* – A review, Agricultural systems. 153:69–80. https://doi.org/10.1016/j.agsy.2017.01.023

37. Zhang N., Wang M., Wang N., 2002. *Precision agriculture – a worldwide overview*, Computers and Electronics in Agriculture, 36 (2–3): 113-132. https://doi.org/10.1016/S0168-1699(02)00096-0

Wireless In-Field communication – AEF guideline for interoperable agrarian M2M communication

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Abstract

The agricultural industry is supplying a diverse market and is driven by innovations of numerous manufacturers. The objective of the Agricultural Industry Electronics Foundation (AEF) [1] is the interoperability of different manufacturer's equipment via common guidelines and standards.

AEF Project Team 11 handles wireless in-field communication (WIC). PT 11's focus spans from technology decisions for suitable radio standards to create a manufacturer-independent middleware providing a common communication layer to applications for wireless in-field communication.

Standardized M2M communication between equipment of different manufacturers in the agricultural domain creates high value opportunities for customers worldwide. It will enlarge efficiency of processes performed on the field by avoiding doing work twice on the same piece of soil, but also give benefits to automation efforts in cooperating fleets of machines and will enhance also safety in on and off-road scenarios.

After performing field tests and clarifying regulative aspects ITS G5 802.11p was chosen as radio technology and will tailored for agrarian M2M communication. PT11 will provide a software supporting wireless networks, which will be capable to be used as a safe and secure communication channel for application like process data exchange, or platooning. Also high volume data transmission tasks are in the focus of the project team, even there could be the need to use another technology for this use case.

To minimize integration efforts and shorten time to market availability PT11 plan is to provide a middleware ready for integration into existing communication modules and providing it's functionality as a set of services.

Keywords: Intelligent transport systems, radio technology, process data exchange, platooning, 802.11p

1. Introduction

The agricultural industry is supplying a diverse market and is driven by innovations of numerous manufacturers. The objective of the Agricultural Industry Electronics Foundation (AEF) [1] is the interoperability of different manufacturer's equipment via common standards. This is being facilitated by joint approaches of the industry to technical challenges around electrical systems, electronics and software in agricultural technology and farming.

Initially established in order to create guidelines for the standardization of ISO 11783 (commonly known as ISOBUS [2]) systems, the AEF's focus was expanded to a wider range of topics including electrification, camera systems, farm management information systems (FMIS), Ethernet communication and wireless in-field communication (WIC). Specifically, Project Team 11 (PT 11) handles wireless in-field communication. PT 11's focus spans from technology decisions for suitable radio standards to corresponding transport layer protocols for machine-to-machine (M2M) communication and secure communication methods. M2M standards enable direct communication between cooperating machines. Potential remote control scenarios require authentication and secure communication. A certain level of privacy must be applied as well to logistic information such as position, speed and tank level. WIC's safety considerations rely on PT 02 "Functional Safety". By adhering to PT 02's Guidelines 005 and 007, safety functions can communicate via WIC in case they implement approved authentication methods.

Standardized M2M communication between equipment of different manufacturers in the agricultural domain creates high value opportunities for customers worldwide. Via creation of this guideline, several use cases are being formulated as a basis for a broader range of applications. PT 11 is pursuing the intention to create a manufacturer-independent middleware providing a common communication layer to applications for wireless in-field communication.

2. Objectives

PT 11's goal is the publication of a set of guidelines that cover the following topics:

- Radio standard
- Specification of WIC core middleware and API
- Functional safety for WIC as a communication channel
- WIC security concept
- Conformance test
- WIC application guideline including usage example

A central component of PT 11's guideline is a managed gateway that publishes vehicle functionality via wireless network technologies. Remote WIC gateways may obtain access to the published API. This access is conditional and requires proper authentication via the WIC security infrastructure. Compliance with the communication standard as well as the safety and security guidelines will be approved by a conformance test [3]. As a final stage the AEF guideline is planned to be transformed into ISO 16867 - Tractors and machinery for agriculture and forestry - wireless communication in agriculture [4].

3. Scope

PT 11 limits the scope to the definition of a middleware for secure machine-to-machine communication. For the physical communication layer it intends to adopt existing industry standards of the telecommunication and vehicular communication domain. Specific demands in terms of reliability, safety, security and responsiveness of a WIC connection will require the project team to determine sophisticated transport and session layer protocols. Role models for such protocols have evolved in industry automation [5] and large-scale IoT pilots [6], which both might develop interfaces to WIC for the integration of agricultural equipment into larger ecosystems of smart farming solutions. This might above all include mandatory diagnostic interfaces according to emerging European Standards.

4. Market Drivers & Visions

The diversity of the agricultural equipment market leads customers to operate heterogeneous fleets with choices for various manufacturers based on their individual preferences. As a matter of the digital evolution in the agricultural industry, connectivity and data exchange between cooperating machines is essential. This includes local information flow in terms of machine synchronization, guidance line and coverage sharing as well as end-to-end communication of high-definition sensor data all the way through the network cloud down to analysis and management software tools. In the field domain, this data exchange fuels solutions for operator assistance and converges into fully automated workflows. In future the global connectivity will be the basis for remote implementations of agronomic decisions as well as autonomous field operations. At the boundaries of the agricultural domain, WIC systems will be in touch with Intelligent Transport Systems [7] [8] in order to provide road safety information. Based on several car manufacturers' announcements, the corresponding technology is about to enter the market with their upcoming models[1,2]. This creates significant potential for the avoidance of severe road accidents involving agricultural equipment.

5. Parties & Stakeholders

PT 11 includes representatives from most major manufacturers in the domain of agricultural equipment and precision farming solutions. Vendors of electronics and radio components joined the team as well as certification labs. Inside the AEF, PT 11 is expected to benefit from strong synergies with PT 02 "Functional Safety", PT 03 "Engineering & Implementation", PT 04 Service & Diagnostics, PT 05 "ISOBUS Automation", PT 09 "Farm Management Information Systems" and PT 10 "High Speed ISOBUS". External communication and partnering is being established with ISO TC 23 SC19 "Agricultural Electronics" – WG5 "Wireless Communication in Agriculture", the Car2Car Consortium [8] as well as the European Telecommunications Standards Institute (ETSI) [9]. In order to establish a strong foundation of expertise inside PT 11, additional participation and consultancy of industrial and academic partners in the field of radio technology, communication and vehicular networks, security solutions and distributed software systems is highly welcome.

6. Key Scenario and Use Cases

PT 11's work is mostly summarized by the key scenario in Figure 1. The scenario comprises four layers of communication with their specific ranges and group definitions. The smallest unit defines a pair of machines working in close cooperation via exchange of real-time control data. A typical use case for this communication layer is parallel platooning between a harvester and a trailer in order to unload grains. As a matter of their spatial proximity and in order to limit interference with additional WIC equipment, the underlying radio standard would operate in a shorter range. The next layer in the hierarchy covers a whole working group performing cooperative work on one or more fields in a mid-range distance of up to few kilometers. This group would exchange process data such as guidance lines and coverage maps. All equipment of the same farm or contractor is part of a global communication group in order to exchange logistic information with a Farm Management Information System. This level of communication requires connectivity to the Internet, which is out of the scope of PT 11. WIC equipment may as well participate in specific scenarios of Intelligent Transport Systems. This communication layer is ideally compatible with car-to-car networking standards and shares road safety information with on-highway traffic. An essential use case for this layer is a slow-moving agricultural machine informing the remaining traffic about its intention to enter the road.

1 www.volkswagenag.com/en/news/2017/06/pwlan.html

2 http://corporatenews.pressroom.toyota.com/releases/toyota+and+lexus+to+launch+technology+connect+vehicles+infrastructure+in+u+s+2021.htm

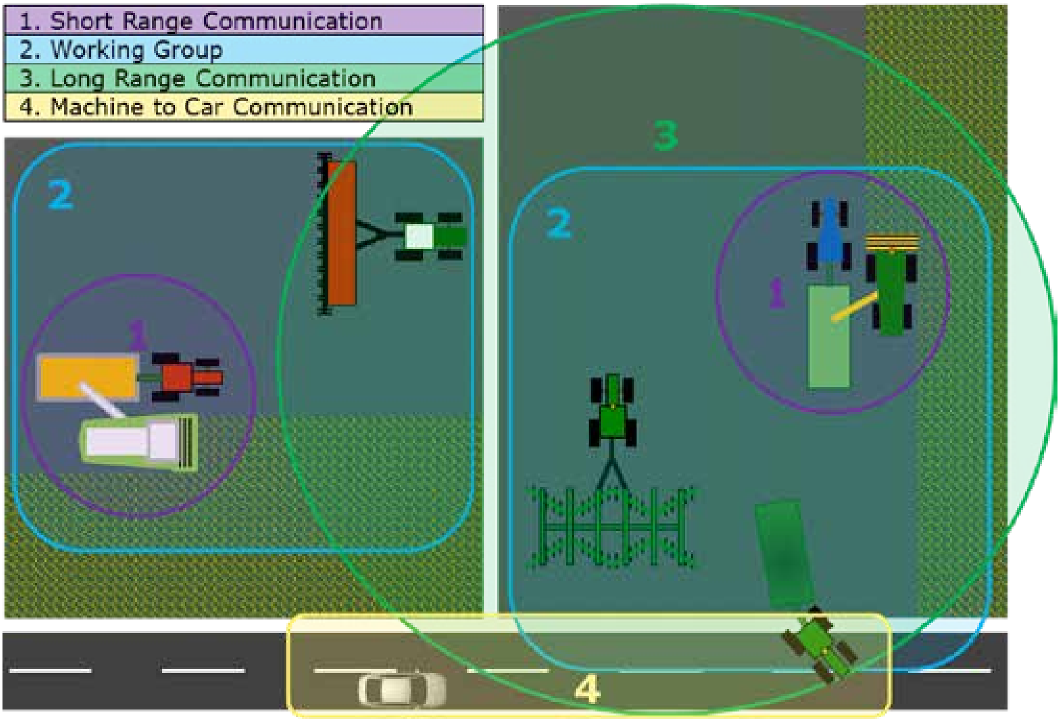


Figure 1: WIC Key Scenario

WIC use cases under the above key scenario are outlined in the following.

6.1. Real-time Machine-to-Machine Control

Use cases in the real-time control category include assistance systems for unloading grains during a harvesting process or additional scenarios where cooperative machines join pairwise in a leader-follower setup. These scenarios are concluded under the terms virtual drawbar or longitudinal and parallel platooning. Real-time exchange of control data is essential for these applications, which determines strict latency constraints. A short-range radio standard is required whereas the desired throughput is at least fairly above the data rate of a CAN bus.

Range:	Low (up to 100 m)
Bandwidth:	Low
Latency:	Low
Relationship:	1 to 1

6.2. Streaming Service

Specific use cases are based on the point-to-point transmission of continuous high-volume and low-latency data. This is a main characteristic of real-time video streams as they might be produced by a remote camera or a remote display session. Similarly, high-definition sensor information, which may include camera sources as well as other types of data, can be sent to a remote participant in the WIC working group for data analysis or processing. Ideally, these use cases are possible to be established via a medium-range radio technology.

Range:	Medium (few 100 m)
Bandwidth:	High
Latency:	Low
Relationship:	1 to 1

6.3. Process data exchange

Working groups of cooperative machines have an intrinsic demand to share recorded work progress. This in particular includes communication of coverage data so as to avoid multiple operations on the same area and consolidate the distributed work state into consistent application maps. This is particularly important for pesticide applications, which are subject to strict regulations. A pre-condition for efficient cooperative work in the same field is the exchange of guidance lines and coverage maps in order to optimize the field operation under consideration of the equipment's working width. A viable approach for the exchange of the relevant ISO 11783-10 data would be the Extended FMIS Data Interface[3]. For the use cases of this category, the range of the radio standard is the dominant factor. Since distances within a single field might span several kilometers in some regions, a long-range physical layer technology is desirable. A store-and-forward propagation approach for the process data might be required in order to synchronize equipment that is temporarily out of range. In order to allow for quick exchange of the medium-sized data packages, a transfer rate in the range of few Mbps is required. Latencies of a few seconds are tolerable. The network standard of choice should allow for one-to-many and many-to-many topologies.

Range:	High (1 to 2 km)
Bandwidth:	Medium
Latency:	Average
Relationship:	n to m

6.4. Fleet Management & Logistics

Timely access to process data of the entire fleet is crucial for economic and agronomic decisions within a farming or contractor business. Farm Management Information Systems provide the tools to accumulate the required information and plan the field work. Communication with such systems relies on the availability of Internet connectivity, which might not be continuously present in the field environment. As of 2017 hardly a third of the world's landmass is covered with mobile network provisioning. Instant connection to FMIS might integrate the management of WIC working groups into the crop planning process and could identify equipment that is eligible for any of the above cooperation scenarios.

In terms of Quality of Service (QoS) the fleet management and logistics use cases are among the least demanding applications. Transmissions are delay-tolerant and might expand in time depending on the network's current data rate. Network coverage is clearly the limiting factor for these use cases.

6.5. Road Safety

Participation of agricultural equipment in road safety use cases is key to the avoidance of a large number of traffic accidents since slow moving vehicles increase the risk of sudden traffic jams and collisions. In addition farm equipment entering traffic after field work might cover the road surface with dirt. This information would significantly improve the safety of motorcyclists.

3 Under development inside AEF PT 09

Based on international consensus, the Cooperative Intelligent Transport System (C-ITS) [7] obtained a dedicated frequency range located in the 5.9 GHz domain. C-ITS is based on IEEE 802.11p [10]. With the extended range of up to 1000 m it is a promising option for the mid- to long-range communication of the PT 11 key scenario, under the condition that agricultural applications will be provided access to the reserved spectrum.

Recently, however, LTE V2x [11] is being driven by few manufacturers as a competing approach to enable vehicle-to-vehicle and vehicle-to-infrastructure communication on the road. LTE V2x intends to formulate a space claim in the same spectrum. Both radio standards are designed to operate without centralized network infrastructure.

7. Field test, prototypes and technology decision

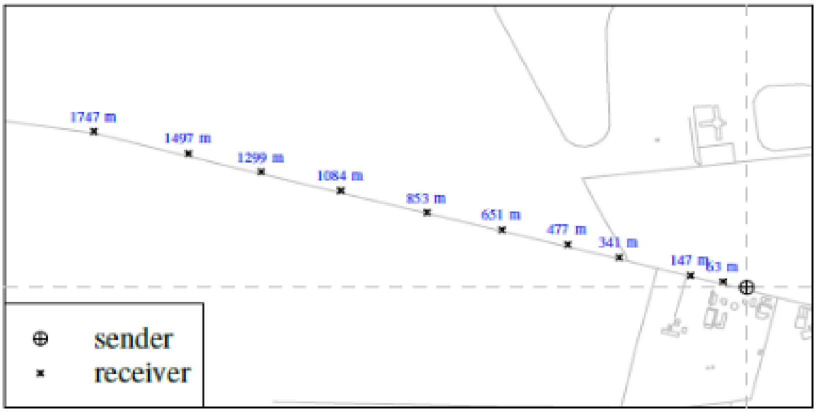
To prove the suitability of WiFi based communication for agrarian use cases the University of Paderborn and the company Autotalks performed a field test in Warendorf at the Deula site. Both parties equipped a forage harvester and a tractor with 802.11p radio equipment.

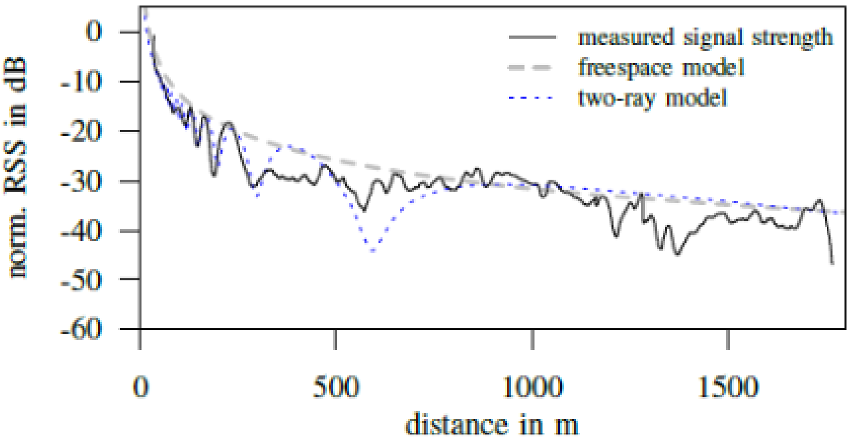
The test was separated in a range, a coverage and a multi vehicle scenario.

1) Range scenario

The tractor was placed static on the road while the forage harvester started to move away sending all the time a test message.

Signal strength and possible data throughput was measured all the time.



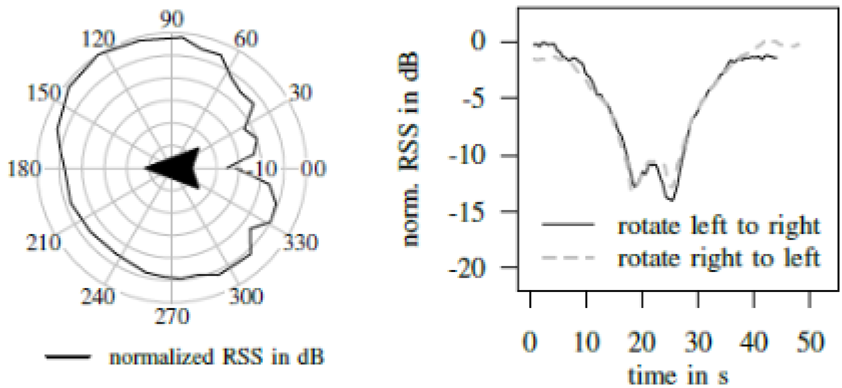


Summing up results a range of 1700m was reached without loosing connection. Due to limitation in road length it was not possible to test maximum range, according to signal strength a line of sight range of 2000m seems to be feasible.

2) Circular scenario

The forage harvester was placed static on a field with rise discharge chute while the tractor was moved circular with a distance of 20m around the forage harvester sending all the time a test message. Also the influence of rotating the chute was under investigations.

Signal strength was measured all the time.



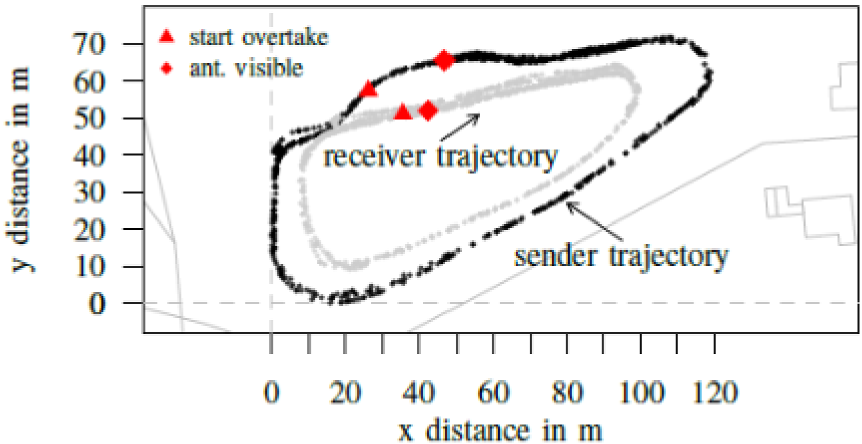
(a) Antenna pattern (b) Signal strenth

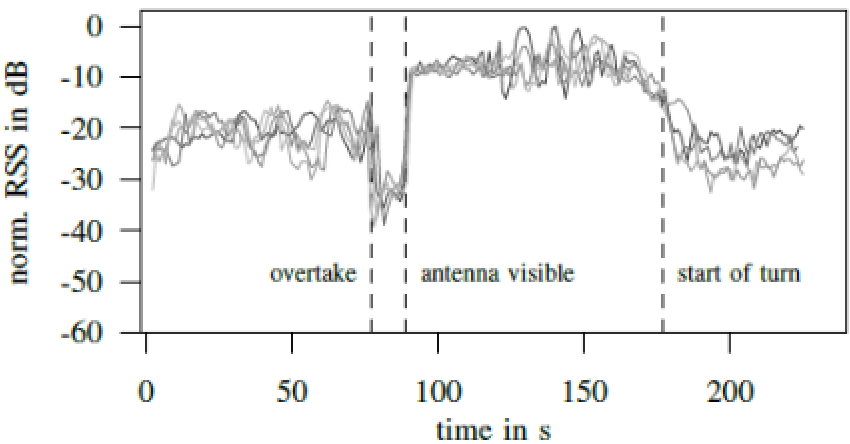
Summing up the communication was never lost but the chute have a signifcant impact on sgnal strength with the choosen one antenna design in the scenario.

3) Multi vehicle scenario

Goal was to simulate a harvest scenario in the moment where unloading must be switched from the first trailer to the second.

Therefore unloading simulation from forage harvester in trailer one was simulated while the second tractor approaches behind the first trailer. Then the first trailer accelerate and the second tractor with trailer moves closer toward the forage harvester. Main goal was to gather information about signal strength reduction due to having the trailer one in line of sight.





As a result using 802.11p it was possible to have all the time a valid connection, even with a trailer between sender and reciever.

Neverthenless the loss in singnal strength while hiding the reciever behind the trailer is in the range of total transmitting power of a commercial availabe WiFi system.

802.11p tractor prototyp

The focus of the field-test was to show on physical layer level that 802.11p is feasible for most of our use cases. To proof this on higher layers as well AEF and John Deere were involved in an ETSI showcase [2] showing up how that data gathered on the ISOBUS could be used to fill messages required for 802.11p G5 ITS systems.

8. Results and Discussion

AEF PT 11 aims at the specification of common guidelines for wireless communication in the domain of agricultural equipment. The underlying key scenario includes several use cases for data synchronization and remote control of cooperating machines. Besides low-latency communication at reasonable data rates, authenticated and secure network access as well as safety and reliability are crucial components of PT 11's efforts. This requires the consideration of cutting-edge industry standards, engineering solutions but also research results in the field of wireless communications, machine-to-machine communication, industry automation and Internet of Things.

Using 802.11p radio communication, which was designed for ITS applications, will give us the best ratio between range and data throughput within a today available technology. This was shown in a field test and as well in an ETSI founded project proofing the general compatibility of ITS and ISOBUS communication.

Next steps will be to align our use cases with existing radio standards and closing gaps by generating an AEF guideline tackling this issues.

9. Conclusions

AEF project team 11 will work on to define a common software providing communication capabilities based on 802.11p technology to any functionality which want to use M2M communication in a safe and secure way. This will also help to minimize conformance test efforts to ensure interoperability.

Project team 11 of AEF will also take action in enhancing existing ETSI standards to add ag specific functionality to 802.11p.

Acknowledgements

Many thanks to all members of PT11 contributing our work and ensure success of AEF Wireless in-Field communication.

References

[1] "Agricultural Equipment Electronics Foundation", [Online]. Available: www.aef-online.org.

[2] "https://www.etsi.org/deliver/etsi_tr/103500_103599/103545/01.01.01_60/tr_103545v010101p.pdf", ETSI, SOFIA Antipolis, 2018.

[3] "AEF ISOBUS", [Online]. Available: www.aef-online.org/the-aef/isobus.html.

[4] "Cooperative, connected and automated mobility (C-ITS)", [Online]. Available: https://ec.europa.eu/transport/themes/its/c-its_en.

[5] "IEEE 802.11p", [Online]. Available: http://grouper.ieee.org/groups/802/11.

[6] "LTE V2x", [Online]. Available: www.3gpp.org/release-14.

[7] "Car 2 Car - Communication Consortium", [Online]. Available: www.car-2-car.org.

[8] "European Telecommunications Standards Institute", [Online]. Available: www.etsi.org.

[9] "OPC Foundation - Unified Architecture", [Online]. Available: www.opcfoundation.org.

[10] "oneM2M Partnership", [Online]. Available: www.onem2m.org.

[11] "AEF Conformance Test", [Online]. Available: www.aef-online.org/products/conformance-test.html.

[12] "ISO 16867", [Online]. Available: www.iso.org/committee/47156.html.

[13] "Agricultural Equipment Electronics Foundation", [Online]. Available: www.aef.org.

[14] J. B. F. D. Florian Klingler, "Agriculture meets IEEE 802.11p: A Feasibility Study", 15th IEEE International Symposium on Wireless Communication Systems, Lisbon, 2018.

2019 the year of TIM
Vision, system and infrastructure for Tractor Implement Management

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Abstract

Introducing an open Tractor Implement Management (TIM) system, whereby the implement is given the control to set tractor functions (e.g. the implement requests a specific ground speed, hitch position, hydraulic valves oil flow, …), seems to be a major step for the whole Ag industry and Ag customers. The Agricultural Industry Electronics Foundation (AEF) has taken the challenge to lead this discussion towards a standardized solution based on ISOBUS protocols and technologies. After presenting the general concepts of the open Tractor Implement Control system during conferences in 2013, 2014 and 2017([5], [6], [7]) the following paper presents the actual state of work of this AEF Project.

1. Motivation and Introduction

While ISOBUS [2] enables interoperability of electronic-based products across manufacturers in the agricultural market, the focus of the industry today is to reach a higher level of automation in such open multi-brand systems. This automation allows further process optimization and/or reduction of operator fatigue in this rapidly growing system complexity. Tractors provide multiple energy outlets like hydraulic valves or PTOs, but also ground speed, steering and hitches. While attachments and implements bring process specific knowledge utilizing the power of the tractors. A natural next step is of course to have the implements control the power outlets. More and more manufacturers started to provide proprietary solutions in past years, for example balers control the ground speed and hydraulic valves. Even when they utilize the ISOBUS messaging to give the implements access to the tractor functions, they still do not provide open usage across manufacturers. This is driven by safety and liability aspects in combination with missing or unclear specification. Product-liability forces the manufacturers to ensure that only known and well tested product combinations can be used in the field. Therefore manufacturers perform joint testing with each possible counterpart to ensure safe operation before they release a product to the market.

In 2012 the AEF took the challenge to standardize the interaction between tractors and attachments towards a modular self-propelled machine in an open ISOBUS solution that meets the safety and liability concerns of the individual participants. While the definition of the required ISOBUS messaging and safety requirements appear to be known, it is the standardisation work to provide the means to ensure only known and trusted equipment can work together in the field which is a new challenge for the AEF experts.

2. Vision – objectives to the AEF project team

TIM systems are destined to be distributed on a wide scale as automated systems assisting the operator in the effective use of the machinery. Such system architecture brings a new level of complexity and responsibility with respect to safety and liability, as more than one manufacturer is involved in the overall system. The AEF Project Team “Functional Safety” encountered several areas of liability risks, once manufacturers enter such a multi-brand automation system. Based on this identification the AEF decided to create the project team “ISOBUS Automation” to develop and define methods and processes, to ensure that the industry wide liability risk for the manufacturers is reduced to an acceptable level. The processes and methods are formulated in an AEF Guideline [4], and shall include all needed aspects of state-of-the-art normative and several AEF Guidelines [1].

In the meantime the scope of project team “ISOBUS Automation” has been enlarged, as the overall concept of reducing liability risks affects the work of other AEF project teams, such as the “Conformance Test”, “Engineering and Implementation”, “Service and Diagnostics”, “Communication and Marketing”, and “Wireless Infield Communication”. Driving the coordination of TIM relevant attributes within these project teams requires the need for open lines of communication between teams.

3. System – AEF defined technical concept

The technical concept implies that products ensure AEF compliance with usage of a digital authentication process.

3.1. General Concept

Each TIM product must perform and pass an AEF Conformance Test in order to get a digital certificate from the AEF. The digital certificate will be included into the production software payload of each series components’ electronic control unit (ECU). The digital certificate ensures that the TIM counterpart of each component can check for AEF conformance as well as the AEF tested functions that the component supports. Therefore the certificate contains the tested SW-Version of the ECU’s payload.

To reduce the system start-up time the related authentication checks need to take two different options:

- Full weight Authentication (FwA): When two TIM components get plugged together for the first time, a complete authentication needs to be executed to introduce the products to each other.
- Light weight Authentication (LwA): With the FwA both components share a specific secret, so that on additional start-ups both only validate this secret. While the FwA takes several seconds (up to a minute), the LwA brings the system back to operation within a few seconds (e.g. after an unintended engine stall).

Once a component’s certificate needs to be revoked due to e.g. functional misbehaviour, responsible manufacturers have means to revoke the certificate with usage of the so called Certificate Revocation List (CRL). The CRL may be placed as part of the software payload of each component. Once a certificate is listed on the CRL of an ECU, this specific ECU will not work with a component containing the revoked certificate. The CRL is managed and generated by the AEF, while the manufacturers include it in their products.

3.2. Certificate Hierarchy and Public Key Infrastructure

In detail, when a FwA is performed, each counterpart is not only checking the validity of one single certificate, but of a complete certificate chain. This mechanism ensures via a given certificate hierarchy, that only instances approved by the AEF (so called Certificate Authorities, CA's) are allowed to issue certificates.

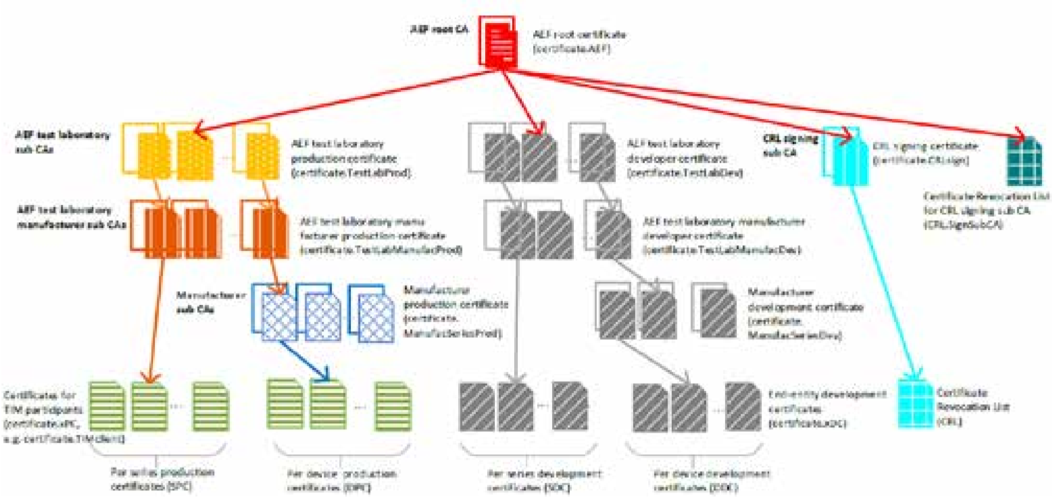

Figure 1 – TIM Certificate hierarchy

The hierarchy concept is depicted in Figure 1. At the very top level the AEF is the owner of the root CA and the root certificate. Both in combination act as a trust anchor for the whole certificate chain. Underneath the root CA four instances are shown (counted from left to right):

- The first (outer left) branch depicts the series production certificate and CA chain.
- The second branch (diagonal stripes) is an equal twin of the first and represents the optional chain for development certificates (a development certificate is utilised by manufacturers when in development or field trial season, but have not yet passed the conformance test [6]).
- The third branch only contains the CRL as an end-entity and the relevant signing CA.
- The forth branch – only as a spare – contains another CRL as a revocation container, designed for the case if a CRL gets compromised and needs to be revoked as well.

The following section refers only to the first (outer left) branch. The AEF allows test labs to generate certificates. This implies technically, that the test labs act as a so called subsidiary (sub-) CA's. Each sub-CA has a certificate containing its identity and its own public key, and is signed by the root certificate.

In order to be able to react on manufacturers' mistakes, the AEF decided to add another sub-CA on the laboratories' level (technically underneath the labs' sub-CA). Revoking this "AEF test laboratory manufacturer sub-CA's" certificate (see Figure 1) implies that ALL certificates of this manufacturer under this laboratory are instantaneously invalid once an updated CRL is considered.

The next level may directly represent the end-entity certificates (bottom layer with horizontal stripes in the leftmost branch – e.g. one certificate for a given SW version). Optionally a manufacturer may decide to work with individual certificates per machine or product. In this case the respective SW version is represented by an intermediate layer, the Manufacturer Sub CA (thin crosslines), while the individual certificates are listed underneath.

3.3. Authentication in the field

The general concept describes that the FwA as well as the LwA are designed to validate the TIM counterpart's integrity. The FwA consists of three phases:

- Phase 1: the certificate chain is exchanged over the ISOBUS. All certificates are to be exchanged to validate the authenticity of all certificates. The first phase guarantees, that both TIM server and TIM client are in possession of an authentic certificate.
- During phase 1 the certificates are also checked against the CRL.
- Phase 2: In this phase a mutual Elliptic Curve Diffie-Hellmann (ECDH) Key Exchange is performed. The ECDH allows for a mutual computation of a shared secret with usage of the received public and the own private key. The secret together with the certificate serial number is to be stored on the device for usage in the LwA start-ups.
- Phase 3: A block Cipher-based Message Authentication Code (CMAC) is used to verify the mutual possession of the shared secret.

The LwA consists of the certificate exchange and the CMAC verification of the common shared secret (stored during phase 2 of the FwA).

3.4. Safety considerations

Reaching a respectively required level of functional safety is defined in various differing standards, such as ISO 25119 or IEC 61508. In order to define a stable foundation for distributed electronical systems, the AEF team "Functional Safety" aligned on a basic set of safety rules valid for ALL TIM systems [3]. Fulfilling the safety rules is a mandatory condition for a TIM component. A manufacturer has to declare his conformance to these AEF definitions when he applies for the AEF conformance test for his TIM product.

4. Infrastructure – AEF managed essential TIM elements

The AEF committed itself to define an open standard for TIM implementations based on ISOBUS with setting up the project team "ISOBUS Automation". The question of "how to verify integrity and to deal with liability?" is close to being answered with AEF Guideline 023 "ISOBUS Automation Principles" [4]. To facilitate the implementation, to reduce the time-to-market, and to deal with common experience of recent ISOBUS function development, the following sections give an overview of infrastructure decisions considered by AEF before TIM is able to enter the market.

4.1. Common authentication stack

A common disadvantage of some ISOBUS implementations – e.g. the Virtual Terminal (VT) implementations – is that there are countless different interpretations and implementations of ISOBUS functions. The introduction of a common Conformance Test as common sense within the industry has improved the situation in recent years, but still the overall costs of the countless developments for the whole industry remains as an unspoken burden. As the TIM authentication is indeed a standardised process and needs to be exactly the same for the whole industry, the AEF decided to order a **common authentication stack** from an external provider. The authentication stack is specified to not depend on specific operating systems (OS's) or hardware platforms, as far as economically justifiable. As AEF does not want to grant liability a specific economical structure was formed:

- AEF holds Intellectual Properties (IPs) on the authentication itself, as defined in e.g. AEF 023 or any upcoming renewal of this definition.
- The 3rd party provider of the authentication stack holds any IPs on the implementation of the security methods (if possible, as the methods are open and known).

- The 3rd party provider grants to follow AEF's definition of the authentication (means that the software requirements specification is defined by AEF).
- Only the OEM is in economical relation to the 3rd party provider – the OEM buys the authentication stack from the provider, but not from AEF.

4.2. AEF Public Key Infrastructure

To enable the TIM product authentication all certificates need to be derived from the same root (Figure 1 – TIM Certificate hierarchy). Therefore the AEF decided to invest in a common infrastructure to get certificates, signatures, and key pairs. This infrastructure is technically called "**Public Key Infrastructure**" (PKI). The interface to the PKI will be integrated in the well-known AEF ISOBUS database. Anyhow the usage of this interface is restricted. The first restriction is an official hosting fee. Secondly, OEMs need to implement specific in-house roles to guarantee conscientious usage of certificates (both production and development intended certificates). Thus e.g. only persons fulfilling a specific role may download a certificate via the AEF database.

Some Ag industry player's security concepts are demanding a communication of in-house IT-servers to the PKI-servers. This requirement has been taken into account both in the certificate hierarchy concept (see Figure 1) and the interface definition of the AEF database enhancements needed for TIM.

4.3. AEF TIM conformance test

As a matter of definition, for TIM the **conformance test** is a mandatory condition. Without successful completion of the AEF conformance test, no certificate will be in place and no open TIM implementation will be available. This implies a major change that the AEF has to deal with: until now the AEF conformance test acts as an instance to assign a seal of quality; for TIM the conformance test is one instance to enable functionality, and needs to act as a trust and liability anchor.

The conformance test concept as of today implies a significant disadvantage for TIM: a test result proving that the test has been passed is only available after the test is performed. This means for TIM that a certificate proving conformity can only be integrated into the TIM software compound – e.g. into the ECUs software payload – after a successful Conformance Test, which may lead to SW version inconsistencies. Anyhow, legal investigations has shown significant criticality once the ECU's payload SW-Version does not match the SW-Version of the certificate. To allow OEMs to face this criticality AEF decided to change the well-known common Conformance Test procedure as follows:

- OEMs have to perform an initial TIM Conformance Test at one of the AEF audited Conformance Test Laboratories. The OEMs shall use an AEF Development Certificate for this test.
- After successful TIM Conformance Test the OEM will be given the allowance to order a production certificate via the AEF database (which provides the interface to the AEF PKI).
- The OEM must now integrate this certificate into the software compound, e.g. into the relevant ECU's payload.
- The OEM has to perform an additional test with the production certificate. To facilitate the logistics for OEMs, AEF is currently working on a concept to enable in-house TIM conformance tests audited by the Test Laboratory which has performed the initial test.

4.4. Validation of Authentication, Certificate structure and Conformance Test cases

The "ISOBUS Automation" project team has formed internal subteams working on the validation of the common authentication stack (Auth.Lib), the Certificate structure and the TIM Conformance Test. Within this subteams representatives of more than 8 leading manufacturers are working on individual integrations and implementations of the common Auth.Lib and the certificates, in order to validate the quality, usability and transferability of the authentication concept and the PKI. To validate interoperability of the implementations, the "ISOBUS Automation" team has been organising special TIM Plugfests, e.g. during the 10th anniversary plugfest meeting in Bologna 2018. The plugfests has shown a solid level of implementation and has been used to improve the AEF023 Guideline [4]. At the time of the editorial deadline of this manuscript the conformance test validation is in process, the oral presentation may be used to show major results of this validation.

4.5. Functional Trials in the field

An open topic now is the scheduling of field tests with TIM functionalities. Until this point the major focus of the "ISOBUS Automation" team has been to work on the definition and technical specification of the authentication as a successor for TIM functions. In the field customers will see the authentication as a mandatory condition for working with TIM systems, but it is the quality of TIM systems that will drive or decline further progress and future perspective of modular self-propelled machinery.

Thus the "ISOBUS Automation" team identified a major need to combine field test power of the whole industry in order to deliver a system architecture that is flexible, scalable and – most important – brand independent to assure higher efficiency in the field.

5. Conclusion and Outlook

The given article shows an overview of the current state of the AEF development towards releasing TIM as an Operator Assistance system; its vision, the systematical technical concept and the infrastructure needed – partially managed and implemented by the AEF.

The technical concept consists of a digital authentication process used for ensuring an acceptable level of liability for the individual manufacturer providing TIM equipment.

The article deals with several non-specific topics and decisions the AEF and the AEF "ISOBUS Automation" team needed to follow in order to facilitate the industry-wide development of such modular self-propelled machinery in the field. Several decisions have already been taken, were and still are leading towards common infrastructure implementations (PKI, Auth.Lib, TIM Conformance Test, common safety goals). Other issues still imply a challenge (TIM Conformance Test validation, functional testing and validation) for a contemporary introduction of TIM products to the market

For the "ISOBUS Automation" team – and the whole AEF – the focus of work for the next months will and need to be concentrating on both the conformance test validation as well as the functional testing.

The implementation and testing of the TIM concept and related infrastructure is in progress by major industry players in the "ISOBUS Automation" team. However, the expectation is that more interested manufacturers join this activity in the upcoming years to deliver an attractive fleet of TIM products to our customers and in parallel share the infrastructure costs between a larger number of players. The overall goal of the group is to reach production level implementation by end of 2019.

References

[1] www.aef-online.org

[2] ISOBUS consists of ISO11783 part 1 to 14 and AEF specific additions formulated in AEF guidelines, which can be obtained under [1]

[3] AEF Functional Safety Guideline: The AEF guideline "AEF 007 FDIG 0.48 ISOBUS – ISOBUS Automation" summarizes the safety aspects of TIM systems. The document can be obtained under [1]

[4] AEF ISOBUS Automation Guideline: The AEF guideline "AEF 023 FDIG 0.01 ISOBUS – ISOBUS Automation Principles" summarizes the AEF security concept and the TIM related processes and methods. The document can be obtained under [1].

[5] VDI LAND.TECHNIK 2013 – "AEF ISOBUS Automation – State of the Discussion"; presented by Dipl.-lng. Florian Ahlers, AgBRAIN GmbH, Osnabrück and Dipl.-Ing. Hans Jürgen Nissen, John Deere GmbH & Co. KG, John Deere Werk Mannheim

[6] VDI LAND.TECHNIK 2014 – "AEF ISOBUS Automation – Status and Progress Report"; presented by Dipl.-Ing. Hans Jürgen Nissen, John Deere GmbH & Co. KG, John Deere Werk Mannheim and Dipl.-lng. Florian Ahlers, AgBRAIN GmbH, Osnabrück

[7] VDI LAND.TECHNIK 2017 – "ISOBUS Automation - On the Road to TIM"; presented by Dr.-Ing. Georg Happich, AGCO Gmbh, Marktoberdorf and Dipl.-Ing. Hans Jürgen Nissen, John Deere GmbH & Co. KG, John Deere Werk Mannheim

Development of TIM Tractor

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Abstract

Farmers aging and serious labor shortage in some parts of the world is already a fact: labor saving and efficiency improvement are a clear challenge for all the actual companies involved in the agricultural world.

Each company is advancing efforts towards the realization of smart agriculture and Kubota came into the European crop market in 2015 presenting the M7001 series with the target to simplify and improve farmers' tasks, but also to develop something able to replace experience and know-how with electronic controls.

A common understanding of these problems between all Agricultural Electronic Foundation (AEF) members led to the creation of Tractor Implement Management (TIM): an Operator Assistance System that establishes a safe common communication protocol for automation between ISOBUS compliant implements and ISOBUS compliant tractors. Since the implement owns the better knowledge of the field processes, the idea is to consider the tractor like a resources provider and the implement like a resources manager.

The connection tractor-implement will constitute a unique system, called *TIM system*, where the implement is controlling some tractor resources, called *TIM Functions*. An *Authentication Protocol*, a process to reach automation and rules for *Closed Control Loop* complete the TIM concept.

There is a perfect synergy between Kubota vision of sustainable agriculture and TIM concept: efficiency improvement, labor saving, progressive automation of farmer's tasks, user-friendly system. The result of this match is a Kubota M7001 TIM tractor, that provides several *TIM Functions*, and a Kubota BVS5160 TIM baler, that manages these *TIM Functions*.

1. Introduction

Tractor Implement Management (TIM) system is the result of some common necessities perceived by all participants of agricultural market: labor shortage, farmers aging, request for more automation in the fields and a better compatibility between all the electro mechanic systems that are already part of the agricultural world.

This Operator Assistance System allows compliant implements and tractors, belonging to different manufacturers, to create a unique system (usually one tractor and one or more implements). In this system, one or more implements can manage at the same time the basic functions of a tractor, called *TIM Functions*.

Each *TIM Function*, like Vehicle Speed, Power Take Off, Hitch, Hydraulic Auxiliary Valves and Auto Guidance, is constituted by several function features called *TIM Function Facilities*: e.g the *TIM Function* Auxiliary Valve can provide the *TIM Functions Facility* "Flux" control and the *TIM Function Facility* "Valve State" control.

A TIM tractor, let's say a *TIM Server*, is a resources provider that, under certain conditions, will allow one or more TIM implements, let's say *TIM Clients,* to manage one or more *TIM Functions* using more or less *TIM Function Facilities*. A *TIM Client* will manage the necessary *TIM Functions* through some messages, called *TIM Command*s, in accordance to some feedbacks received by the tractor and called *TIM Functions Status*.

A *Closed Control Loop* where a *TIM Client* (*Clients*) is controlling the *TIM Functions* and the tractor is performing the *TIM Commands* will be established if all the necessary conditions are satisfied: mutual authentication between all *TIM System* participants, necessary *TIM Functions* availability, operator awareness and right TIM process steps.

The operator will be able at any time to perform an *Override* (specific condition for each TIM Function) taking control of target resource/function under the control of the implement: this action will interrupt the *Closed Control Loop* on the specific *TIM Function*.

The tractor functions or the implement functions not associated with the *TIM System* or associated but not used like TIM features will operate as usual as if *TIM System* didn't exist.

The basic benefit of the *TIM System* is, beyond the clear automation of an already existing process, a better performance (replacing experience and know-how) since implements have the main knowledge about the performed task and may improve variables regulation (like vehicle speed, Rear Power Take Off Shaft Speed, curvature of the wheels).

In addition, the *TIM System* allows different levels of automation for each *TIM Function* and different levels of automation for each task. Different level of automation within the same *TIM Function* can be reached using more or less *TIM Function Facilities* and different level of automation within the same task can be reached using more or less *TIM Functions* to perform the same task.

The above-mentioned flexibility ensures a large diffusion of *TIM System* itself, a compatibility with the biggest range of all the existing TIM tractors and TIM implements and the necessary operator/customer's freedom to decide the desired level of automaton.

In, e.g, a *TIM System* constituted by one TIM tractor connected to one TIM implement, the whole automation level of the *TIM System* is determined by the mixed subset of all tractor available *TIM Functions* and *TIM Functions Facilities* and the TIM implement capacity to command more or less *TIM Functions* using more or less *TIM Functions Facilities* within the same function.

A so powerful and complex system like TIM required several safety goals during development in terms of performances, usage, limits, risk assessment evaluation and reliability of the single parts.

Overall, the reliability theme became a first level topic and this is why the AEF group that worked on the TIM project decided to implement a complete *Authentication Process* between a TIM tractor and one or more TIM implements. A dedicated and developed on demand cyber security library manages special AEF released reliability certificates allowing only certified systems to use the TIM features: this process is called *TIM Authentication* and is the first "handshake" that TIM participants are going to perform once connected together.

Kubota decided to join the TIM challenge providing about all the *TIM Functions* on the TIM compliant M7001 tractor and using a TIM compliant BV5150 round baler. This combination is the perfect representation of TIM concept achieving labor saving and efficiency improvement managing several *TIM Functions* and related *TIM Function Facilities*: Vehicle Speed, Rear Power Take Off, and Auxiliary Valves.

Kubota believes that TIM will become common in a few years since it is an underlying technology of automatic driving and the factory focus about TIM (both tractor and implements) will be on user-friendliness, reducing operator burden, improvement of working accuracy and reducing wastefulness of resources.

Compatibility with other TIM tractors and TIM implements belonging to other manufactures have been and will be a good and training challenge since the TIM will be a norm in a short time.

Several test sessions and AEF TIM Plug-fest took place to develop all the parts of the TIM norm: *Authentication Process*, function handling, *Closed Control Loop*, multi-Client communications, exceptions.

This paper describes Kubota vision of TIM and issues/countermeasures to commercialize *TIM Functions*. Looking at cooperation between tractor manufacturers and future developments are additional targets for this article.

2. Materials and Methods

2.1. ISOBUS automation concept

The main TIM concept is that the tractor, owning the *TIM Functions,* is a resources provider and that the implement/s is/are, under certain circumstances, the direct user/s and controller/s of these resources: we are talking about a *TIM Server* and one or more *TIM Clients*.

Once the automation is reached for one or more *TIM Functions* through a specific process, the whole *TIM System* is in automation with a *Closed Control Loop*: the implement is really controlling some resources of the tractor. In accordance with its internal logic and with the *TIM Functions Status*, that is the functions feedback generated by the tractor, the implement will generate some *TIM Commands* for the selected *TIM Function*s affecting more or less *TIM Function Facilities*.

The tractor will be always the last resources manager with its own logic: this means that it can fully satisfy, partially satisfy or do not satisfy implement requests, interrupt the *Closed Control Loop* or reject the requests.

Since TIM is an Operator Assistance System, the operator presence is fundamental and he can take control of the specific *TIM Function* under the *Closed Control Loop* of a *TIM Client* at any time performing an *Override*.

A *TIM Function* can be controlled by only one *TIM Client* at the same time and, if it is not under the control of a *TIM Client*, it will perform its normal job without any impact on the existing system.

The TIM concept includes several macro phases that go from the initial handshake to the *Closed Control Loop* of the *TIM Functions* to the *Release* phase of the previously mentioned *TIM Functions*. We can resume the *TIM System* phases in the following steps:

1. A handshake phase where TIM participants are authenticating themselves according to a specific *Authentication Process*: they will perform a mutual exchange of some AEF approved certificates through a specific cryptographic authentication library. This step is called *Authentication Process*.
2. An enabling process where the operator clearly enables some parts of the system to operate with TIM.
3. Creation of the *Closed Control Loop* for one or more *TIM Functions* between one or more *TIM Clients* (implements) and the *TIM Server* (tractor).
4. Performing TIM automation with *Closed Control Loop* for some *TIM Functions* between the *TIM Server* (tractor) and one or more *TIM Clients* (Implements). The requests of the implements will be performed by the tractor in different ways according to two main elements:
    a. Internal logic of the tractor (algorithms, settings etc.) that affects the performances, how the tractor is going to perform the requests (reactiveness and so on).
    b. Physical limits of the tractor and environmental limits (max speed, max oil flow etc.) that affect the level of alignment between the commands and reached value.

It's up to the implement logic to parse the feedbacks from the tractor and take proper actions.

5. *Release* of *TIM Functions* by the *TIM Client* that was controlling them.

2.2. TIM System, TIM Functions and TIM Function Facilities

Different TIM participants, at least one *TIM Server* and one or more *TIM Clients*, that talk each other according to some pre-defined rules, constitute a *TIM System*. A *TIM System* may host several *TIM Functions* and the right interaction between all *TIM System* participants and the operator may lead to the automation of these *TIM Functions*.

- To offer one or more *TIM functions* and a related subset of *TIM Function Facilities* is *TIM Server* (let's say tractor) feature.
- To control one or more *TIM Functions* with one or more *TIM Function Facilities* is a *TIM Client* (let's say implement) feature.

The more *TIM Function*s and *TIM Functions Facilities* a *TIM Client* is able to ask and a *TIM Server* is able to provide, the more automation is reached. It's clear that a TIM baler, like the Kubota one, using *TIM Functions* like Vehicle Speed, Rear Power Take Off and Auxiliary Valves, with several *TIM Function Facilities*, is a good match on the road of full automation in the fields.

2.3. Functional and safety aspects

All manufacturers involved in TIM implementation are matching and are going to match the challenge to analyze and evaluate functional and safety aspects of a distributed system constituted by machines belonging to different manufacturers with different internal processes.

To help manufacturer in this new challenge an alignment document between the Safety related ISO25119 norm and the TIM norm has been produced by the AEF group that is working on TIM.

In addition, some limits and common definitions have been set in the first generation of *TIM System* using the "cage approach" to define the borders of the *TIM System*.

2.4. Kubota implementation of TIM System

Kubota decided to manage the TIM challenge with two flagship products of its pool and with one of the most complex couple of TIM participants that can be achieved:

- *TIM Server* - Kubota CVT M7- A big tractor able to provide a lot of *TIM Functions* and *TIM Function Facilities* equipped with a CVT transmission that allows a more fluid and comfortable control of *TIM Speed Function* and a reduction of operator interaction compared to a Power-Shift transmission.
- *TIM Client* - Kubota BVS5160 round baler – An implement that is able to use a lot of *TIM Functions* and *TIM Function Facilities*. One of the most complex *TIM Client* that the *TIM System* allows and, overall, one of the implements that is getting the greatest benefits by the *TIM System* introduction.

This couple, that constitutes a *TIM System*, is going to perform some automatic operations using some *TIM Functions* and associated *TIM Function Facilities:*

TIM Function	TIM Function Facility	Action
Vehicle Speed	Start vehicle motion	To start the vehicle motion when the bale has been released
Vehicle Speed	Vehicle speed while driving in forward direction set by the implement	To drive the tractor in forward direction at a specific speed selected by the baler according to some internal logic
Vehicle Speed	Vehicle speed while driving in forward direction set by operator.	To drive the tractor in forward direction with a speed selected by the operator runtime: the function is still officially under the control of the implement
Rear Power Take Off (Rear PTO)	PTO engagement	To engage the RPTO to start to create the bale collecting grass
Rear Power Take Off (Rear PTO)	PTO disengagement	To disengage the RPTO if not necessary
Rear Power Take Off (Rear PTO)	PTO shaft speed	To tune the speed of the RPTO while collecting the grass and to wrap the bale when it's ready
Auxiliary Valve	Valve state	Necessary control to open/close the baler's gate and to release the bale
Auxiliary Valve	Valve flow	Necessary control to open/close the baler's gate and to release the bale

The functional and risk analysis of the whole *TIM System* has been and is a big match: the *TIM System* rests on already existing heterogeneous systems that must work together and where an additional application layer has been added.

Where the responsibility of the tractor is finishing and the responsibility of the implement is starting? What's happening if an issue or, worse, an accident, is happening during the *Closed Control Loop* of the *TIM System*?

To define the internal architecture of a tractor that is becoming a *TIM Server* and of a baler that is becoming a *TIM Client*, Kubota performed its own standard functional and risk analysis with the addition of a new feature: the functional and risk analysis of the whole *TIM System*. The last step required an additional effort since it's a new approach for agricultural world and several sessions with engineers working on different implements and tractors were required. The TIM couple has been managed also like a unique system during the process to analyze also situations where the borders between the systems are not clear.

The whole process has been developed following the main rules and limits selected by the AEF workgroup and above-mentioned.

2.5. Kubota TIM process description

To reach TIM automation for one or more *TIM Function*, some preliminary steps like the already mentioned *Authentication Process*, a direct activation of the *TIM System* and the creation of the *Closed Control Loop* channel are required. The following set of conditions describes a typical use case of the TIM compliant Kubota tractor and the TIM compliant Kubota baler cooperating like a *TIM System*.

Boundary conditions of the described process for the Kubota *TIM System*:

- The *TIM System* tractor-baler is already authenticated through the apposite process.
- The *TIM System* is already engaged.
- The *Closed Control Loop* for the following *TIM Functions* and some of the related *TIM Functions Facilities* is already active: Vehicle Speed, Rear Power Take, at least one Auxiliary Valve. This means that the implement is controlling the above-mentioned *TIM Functions*.
- The tractor is proceeding at a certain speed different from 0 km/h in forward direction collecting material from the windrow.

Kubota TIM automation description for a baling process with Vehicle Speed, Rear Power Take Off and Valve functions automation:

1. According to some settings, the operator is running along the windrow at a speed selected through the throttle pedal or automatically selected by the implement if different from 0 km/h.
2. The Rear Power Take Off Shaft Speed is fixed by the Implement according to its internal logic.
3. The sensors of the baler detect that there is enough grass in the bale chamber to wrap the bale.
4. The baler reduces the speed below 0.5 km/h and asks the operator to press the brake pedal to stop the tractor.
5. When the tractor is stopped, the baler selects the proper Rear Power Take Off shaft speed to wrap the bale with the net.
6. When the bale is ready, the implement acts the auxiliary valve flux and state to open the gate of the bale chamber and to release the bale.
7. Once the bale has been released, the baler asks for a vehicle speed different from 0 km/h or asks the operator to move the tractor proceeding at the operator's desired speed.
8. The cycle restarts.

2.6. Conformance Test and Authentication phase for TIM participants

The purpose of *TIM AEF Conformance Test* is to guarantee that *TIM System* participants are compliant with common shared safety rules, secure communication and standardized software control. The output of this conformance test will be some digital *AEF Certificates* used during the *Authentication Process*: this configuration generates a strong connection between the Conformance Test compliance and the usage of the TIM System itself.

The purpose of the *Authentication Process* is to allow TIM compliant products to mutually proof their reliability and functional compatibility exchanging the above-mentioned *Certificates* through a dedicated *Cryptographic Library*. The necessity of a *Cryptographic Library* is mandatory to avoid dangerous or fraudulent use of some parts of the System and has been a very big topic during the *TIM System* definition in the proper AEF groups.

This section provides and overview about the *TIM Authentication Process* (2.6.1), *AEF TIM Conformance Test* (2.6.2) and requirements for TIM System and infrastructure (2.6.3).

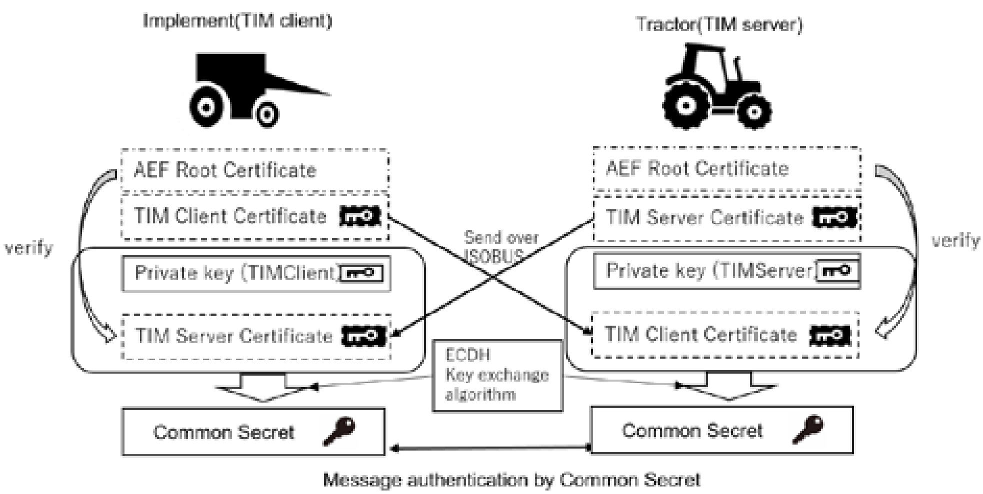
2.6.1. Overview of TIM Authentication Process

The base of *TIM Authentication Structure* and the core of *TIM Authentication Process* is a public key infrastructure (PKI) that sets the roles for AEF digital *Certificates* and public-key encryption management. The *Authentication Process* will take place at each coupling event between the *TIM Server* and each *TIM Client* present in the *TIM System*. This means that actions like a new key cycle of a *TIM System* (one *TIM Server*, one or more *TIM Clients*) or a connection of a new TIM participant to an already existing *TIM System* will trigger a new *Authentication Process*.

Both *TIM Server* (let's say tractor) and *TIM Client* (let's say implement) can generate common secret data owning a private key and counterpart certificate: a key exchange algorithm can extract the common secret without a dedicated data exchange.

Once the *Authentication Process* it's over, *TIM System* can start its functional operations. Several steps constitute the authentication algorithm (we will talk about one tractor and one implement in the example):

1. Tractor and Implement will use AEF Root Certificate, conformance certificates, their own certificate and the private key connected to that certificate.
2. Tractor and Implement mutually exchange their certificates.
3. Tractor and Implement verify the exchanged certificates (counterpart certificates) using the root certificate.
4. Tractor and Implement generate common secret by their private key and counterpart certificate using the already mentioned key exchange algorithm.
5. Tractor and Implement authenticate themselves by common secret key and challenge-response mechanism.



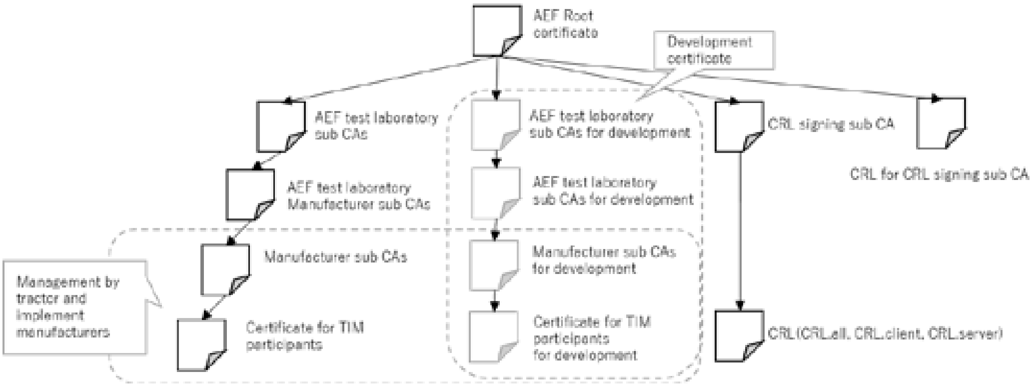
2-1 overview of TIM authentication

2.6.2. Process of AEF TIM conformance

All TIM participants need to pass the *AEF TIM Conformance Test* for TIM functionality since only manufacturers that passed conformance test can get *Manufacture sub CAs* (in figure 2-2) for the target model. TIM participants need to pass through a development certificate to test and tune the system before they are able to successfully pass the *AEF TIM Conformance Test* to get a production certificate.

If a manufacturer needs to test its own device for development or maintenance purposes, it can formally request to AEF a *AEF Test Laboratory Certificate* presenting in the proper locations a signed self-declaration in addition to some software/system information.

Once the system (*TIM Server* or *TIM Client*) is ready for an official test, the manufacturer can require to perform an *AEF Conformance Test* to a *AEF Certified Test Laboratory*. To obtain a *Manufacturer sub CAs*, that is a production certificate necessary to sell the TIM product, the manufacturer needs to pass the conformance test.



2-2 AEF certificate Tree

To perform the Authentication Process, a TIM participant must be equipped with its own private key and the following certificates:

- The AEF root certificate (including the AEF public key only)
- A Testlab certificate (including the Testlab public key only)
- A Testlab manufacturer certificate (including the Testlab manufacturer public key only)
- A manufacturer series certificate (including the manufacturer series public key only)
- A server (client) certificate (including the server ECC public key only)
- A server (client) ECC private key
- Local version of the CRL signing certificate (including the CRL signing public key only)
- Local version of the CRL.SignSubCA
- Local version of the CRL (CRL.all, CRL.server, CRL.client)

2.6.3. Requirement of TIM authentication

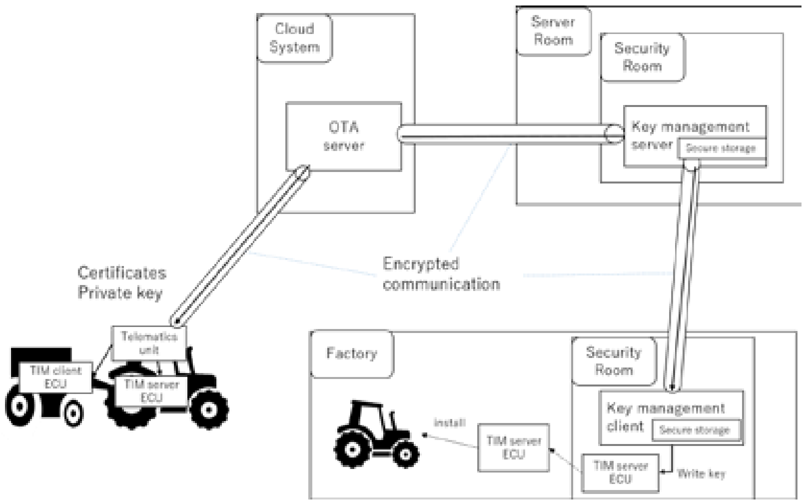
Private Key and common shared secret key are the TIM *Authentication Process* trust anchor and their storage is one of the main TIM System challenges: a tamper resistant area like a HSM (hardware security module in microcomputer) to store them is an important feature. In addition, a good source of not foreseeable random numbers, that is a pseudo random number generator (PRNGs), will avoid security leaks adding additional security to the *Authentication Process*.

Requirement	**Purpose**
Tamper resistant area	To secure storage for private keys and common secret
Pseudo random number generators (PRNGs)	To secure strong encryption

The nature itself of TIM structure and related certificates suggests a regular updating process and, in addition, also a private key update could be required. If a regular or emergency update by OBD port could result not easy, definitely an On-The-Air (OTA) update is a desirable option.

Malicious hackers are one topic that must be faced without doubts: root certificates and private key must be installed in a safe area of TIM participants ECU; cloud system, key pair generator station and End Of Line process for TIM are all elements that must be secured by safe key management system.

Part of the secure Key management system will be also a tamper resistant area in HSM computer where the keys are generated and stored, a secure server room where human activity is restricted and a safe area in the factory where keys and certificates could be stored. A secure path for OTA updates from cloud to *TIM Server* and *TIM Client* ECU will optimize the previous safety precautions.



2-3 system requirement of TIM authentication

3. Results and Discussion

TIM System accelerates the replacing process of experience and know-how with electronic controls and encourages the standardization of a trend that is a fact. This system is a common response of agricultural world to heterogeneous requests like reducing operator fatigue, increasing productiveness, reaching a real cooperation between tractors and implements and increasing the connectivity and integration of all involved systems in the field.

Implementing a *TIM System* has been and will be a big challenge that helped also all the involved manufacturers becoming aware about some themes slightly managed in the agricultural world in the past. We are talking about the concepts of liability, shared reliability, private informatics key storage, common IT structure, real cooperation and compatibility.

Overall, the biggest effort has been required for the common IT structure implementation, the TIM certificates generation and management, their transmission on the CAN Bus, the storage of a private key and its management.

It was something on which all manufacturers had and have to look with a new mind: no more something that it's necessary only to avoid legal problems but like something that will be more and more part of the future of the agricultural world.

The next challenge will be the coexistence of the *TIM System* with new concepts that are coming closer and closer to the agricultural world such as Flashing On The Air, Wi-Fi interconnection regarding agricultural fleets, connected farms, autonomous tractors.

In addition, the adaptation of the market to the new system and the related market strategies adopted by all manufacturers will be very interesting: how the manufacturers will preserve their proprietary autonomous systems? How will they integrate them with TIM? How will they manage *TIM Functions* and *TIM Functions Facilities* in terms of purchasing opportunities for the final client?

4. Conclusions

TIM System is one the most important steps of the agricultural world in these years since it unifies some already ongoing trends in a compatible shared system introducing tractors and implements manufacturers to some themes (like security, reliability, liability) that will be more and more present in the future.

In addition, the word "Safety", in all its meanings and fields (safe communication, safe automation, safe operations) will be another main focus with the new match of "safety for the whole complex system" and not only for the tractor or for the implement.

One of Kubota strongest beliefs is the ease of use of its systems in addition to complete services availability: this means that Kubota will promote the *TIM System* and develop tractors, implements, cloud system and factory procedures for secure, safe and best-performing TIM automation.

References

- F.Ahlers and H.Nissen "AEF ISOBUS Automation – State of the Discussion" VDI LT 2013
- F.Ahlers and H.Nissen "AEF ISOBUS Automation – Status and Progress Report" VDI LT 2014
- H.Nissen "Status of work on TIM and ISOBUS Automation" AKT 2016
- H.Nissen "Status of work on TIM and ISOBUS Automation" VDI LT 2017
- H.Nissen – "AEF IA Presentation TIM Overview Slides, Cyber Security" VDMA 2017
- "AEF 007 DIG 1.03 ISOBUS – ISOBUS Automation" summarizes the safety aspects of TIM systems. The document can be obtained on www.aef-online.org.
- "AEF 023 DIG 0.20 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.

Mundi webservices: a space of new opportunities for agriculture

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Abstract

Mundi Web Services is a digital platform providing better access and use of earth observation data to create and operate innovative apps whatever the market thematic.

The Atos DIAS is called Mundi (www.mundiwebservices.com)

Combining simple access to Copernicus , thematic and in-situ data, cloud and big data technologies, Mundi accelerates the time to market for innovative digital services based on earth observation data. Mundi allows to deliver a service that is distinctive, reliable, and immediately monetizable.

1. Introduction

The European Union Copernicus Programme relies on a family of dedicated Earth Observation missions called the Sentinels. The data acquired from these missions are systematically downlinked and processed to operational user products. Copernicus data and information includes the user products from the Sentinels missions, but also value-added information generated by the Copernicus Services and data and information provided by the Copernicus in-situ component.

The Copernicus DIAS (Data and Information Access Services) consists mainly of virtual systems hosted on a cloud computing environment and providing IT services. This Cloud infrastructure makes available for processing and operations a data offer, which includes Copernicus data and information but may also include other geospatial data (e.g. EO ESA missions, National missions data, etc).

2. Materials and Methods

Led by Atos, the Mundi team is based on a strict European consortium with company widely recognized on their respective specialties.

Mundi consortium ensures access to Copernicus data and information and are responsible for the provision of the DIAS underlying ICT infrastructure and interfaces and offers well-documented and scalable ICT resources to Third-parties.

The Mundi consortium is composed of Atos, T-System, DLR, Thales Alenia Space, GAFag, e-Geos, EOX, Spacemetric and Synergise.

Thanks to its Marketplace, Mundi allows delivering an application that is visible from the global market, distinctive, reliable, and monetizable.

Mundi provides Cloud platform capacities to access a curated Data Collection and a selected Tools Collection.

Data collection:
Mundi offers Copernicus data and information to be used right on the cloud. Of course, it covers Sentinel data, Copernicus Core Services but also Landsat-7, Landsat-8, and many more HR and VHR satellites to come. Data are made available through the standardized OGC interfaces on the Mundi platform.

In addition, other Earth Observation data sets and more thematic data can be used on Mundi to maximize opportunities to quickly and easily develop a distinctive, reliable, and immediately monetizable service.

Tools collection:
Mundi allows to access 2 level of tools:

- A set of free of charge services to reach a first level of Earth Observation Data management,
- Advanced tools provided by different partners for insuring an easier advanced data use.

It's also possible to bring your own tools and softwares on the platform in your dedicated cloud space and benefit from your industrial processes associated with the power of the platform and the proximity of Earth observation data.

Cloud services:
Open Telekom Cloud provided by T-System in Germany bring a secured, robust and performant Cloud infrastructure for European Mundi users.

- Compute with virtual computing servers (Elastic Cloud Server - ECS)
- Storage in block level storage capacities (Elastic Volume Service -EVS) or in Object Storage Service that offer a highly simplified access mechanism and a high level of scalability
- Load balancing for distribute traffic on multiple ECS.
- Big Data functions (Map Reduce Service) offers a range of tools that allows for big data analysis. Run with Hadoop, HBase, Spark, Hue, Loader, Kafka, Storm, Flume and Kerberos.

Support:
Atos and its Mundi consortium can assist Mundi users in a very wide range of support activities, complementing their own skills.
From technical or functional supports to more thematic or business consulting, Mundi team is designed to help Mundi users to reach new opportunities.

3. Results and Discussion

Mundi supports many thematic markets:

- Agriculture
- Urban monitoring
- Services industry (Finance, Insurance, retail…)
- Tourism and transport
- Environment
- …

This, in hosting and enhancing the creation and operations of these many application fields; e.g. Public land reserves follow up for local communities

4. Conclusions

Mundi integrates key elements distributed by its partners, the creation of value-added services for agriculture can rely on robust components and maintained over time.

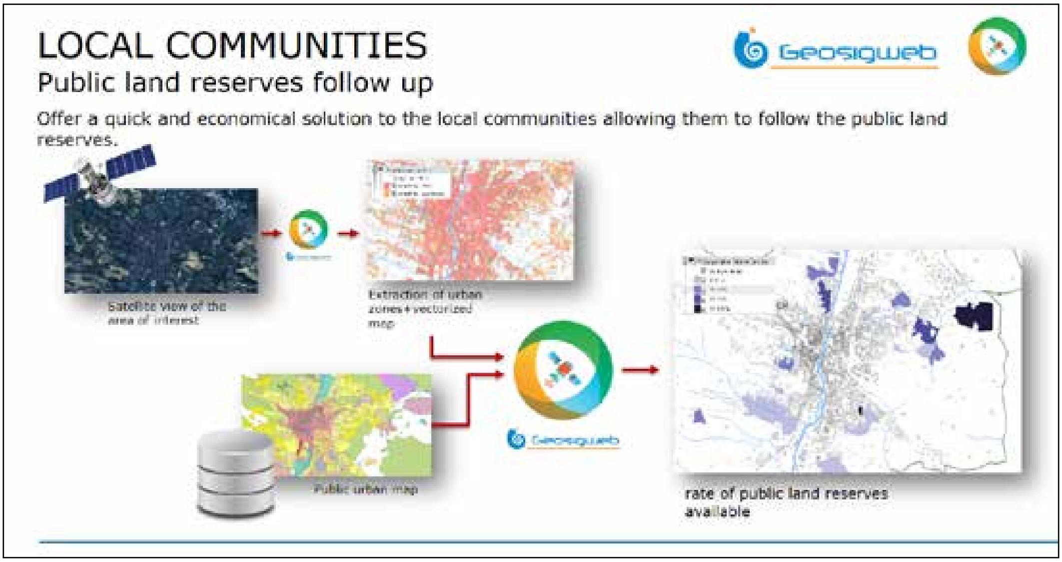
Mundi benefits to results of different research projects carried out by Europe and using the platform to work, for example:

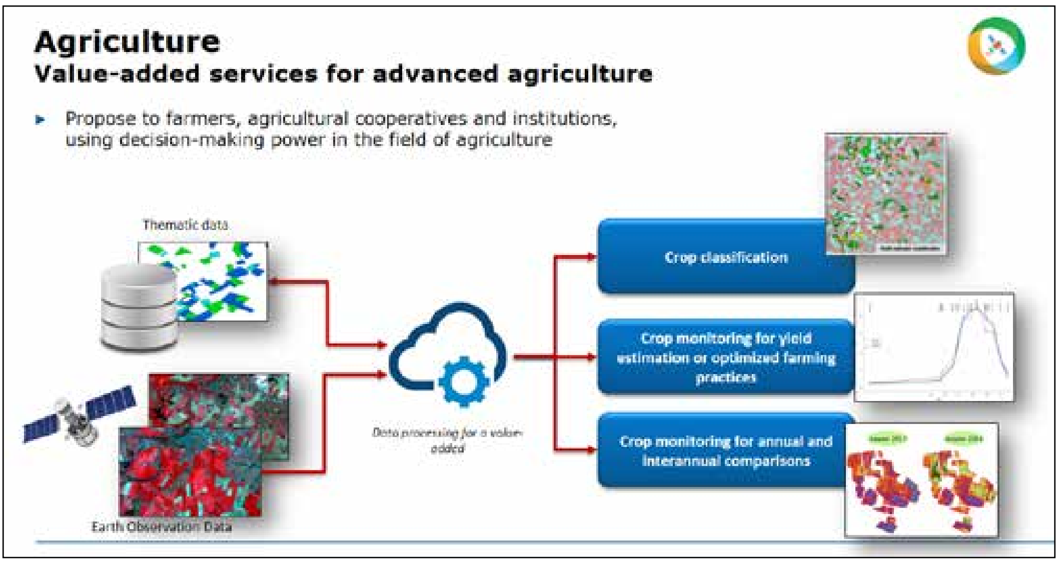
- EUXDAT: http://www.euxdat.eu
- EO4WildLife: http://eo4wildlife.eu

Mundi is already used in various commercial products in different fields of agriculture or regional planning:

Forecast of yields

- Monitoring diseases on the vine
- Monitoring of carbon sequestration at the scale of a territory
- Monitoring the artificialization of soils: http://www.geosigweb.org/Land





Machine Learning in Silage Bale Digitalized Management

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Abstract

Digibale is a cooperative research project of Ministry of Agriculture and Forestry of Finland, Natural Resource Institute Finland and Häme University of Applied Sciences. The project aims to reduce farmers tasks related to silage bales, i.e. harvesting, wrapping and marking, and increase silage bales' values by applying digitalization. One of the project's most significant stages is e-stamping, where silage bales are marked with radio frequency identification tags and wirelessly embedded with relevant data. As the step is automated, the system requires a trigger for the process. This research considered machine vision as the solution to the problem.

The problem was approached by reviewing relevant recommendations and literature. The solution involved training computer models from a set of data to detect different phases in a bale collecting process. Dataset was retrieved from internet and action camera in different farms conditions. As a result, multiple conventional neural networks were generated, and their performances were evaluated by the detection rate to select the most optimal one. In realizing the solution, different Python mathematical toolsets were utilized including OpenCV, numpy, and TensorFlow.

The solution consisted of a trained model for continuous silage bales vision-based detection, integrated to the bales marking system with an action camera as sensory input due to the robust construction against environmental conditions. The marking system is then considered ready for the next stage, where data are visualized on a website for e-commerce implementations. In conclusion, the research is expected to minimize farmer's effort and provide a framework for similar problems in the individual crop identification field.

Keywords: Machine vision, smart agriculture, neural network, individual crop management, real-time object detection.

1. Introduction

Have been existing from the very early stage of mankind, agriculture, though being one of the most integral industry, has not changed comprehensively, when being compared to others. The basic follow of producing victuals includes seeding, growing, harvesting, and storing. While there are remarkable developments in growing flora, most farms still stick to traditional collecting and storing methods. Despite the lack of sufficiently alternative approaches, there are a lot to be done so as to narrow the huge value gap between agriculture's and other branches' products. Together with the trend of Internet of Things (IoT), digitalizing agricultural processes is considered as the most crucial step provided farmers want trade their goods at higher prices.

Silage, mostly used as ruminants' feeds or biofuel feedstock for anaerobic digestions all over the world, is a widely consumed product in Finland's farms. The current situation in silage harvesting branch is that silages are collected in bales in summer and fed ruminants in winter. All the steps from reaping, wrapping, to handling, storing, and selling silage bales are manually done. Normally, a bale is wrapped in nets and colored plastic wraps, due to categorizing purposes and severe environmental conditions. Depending on farmers, information handling can be done by conventional noting methods, meanwhile, bales trading is limited to purchasing acquaintanceships. Even though these daily tasks are not too laborious to act, applying technology is expected to reduce balers' works yet enhance silages' quality and multiply their values.

In attempt of achieving aforementioned goals, Digibale was launched as a cooperative project of Ministry of Agriculture and Forestry of Finland, Natural Resource Institute Finland and Häme University of Applied Sciences at the beginning of 2018. During the first year of the two-year project, an e-stamping system has been developed and produced in order to totally eliminate human work by applying digitalization, with the signature technology being radio frequency identification (RFID). The system is a box consisting of a RFID reader, a microcomputer, multiple environmental sensors and electrical and electronics components. As a feature of RFID technology, all bales are wrapped with nets attaching RFID tags, which, together with RFID reader in the system, help to identify bales individually. After each bale is wrapped, the system will initialize real-time environment values to it, and data will be saved on cloud database. Therefore, later on, farmers can detect individual bale and read their relevant data thanks to RFID tags attached to it. As discussed earlier, the whole step is automatic, which means the system must be able to recognize different stages in a harvesting process. Commonly, reaped silages are rolled into a round bale, which then wrapped in nets in a closed metallic chamber. After that, the bale rolls out from the chamber to plastic wrapping stage. Here, it can be 2D- or 3D-wrapped in several plastic layers, before being dropped to the field. That being said, there are at least two stages needing recognizing by the system. Out of all solutions including magnetic sensors, occupancy sensors, and machine vision, the last one turns out at the most suitable choice as it not only tolerates extreme outdoor conditions but also proposes potentials to further usages. In addition to those, this application cancels tractors' different mechanisms problem when it comes to bringing the prototype into mass-production.

To say "machine vision and machine vision are the new technologies" is an understatement as they have been developed and used in software engineering for a very long time. What prevented them from getting popular as they are now is the speed and power of computers they are ran on. Moreover, when talking about this topic, people tend to think of massive software structures with thousand lines of code. However, with the vigorous changes in information technology in the last decade, machine vision and machine learning are now more approachable than ever. That was why they were not only chosen as solution for the mentioned issue but also expected to solve similar tasks in the field of agriculture.

2. Materials and Methods

Like most of machine learning programs, the solutions included four main steps: data acquisition, model training, model test, and deploy. In conventional software, programmers make rules by writing codes and computers produce data based on those, but in machine learning, especially image detection and classification branches, data is collected from different sources, then their similarities are figured out and become rules, which will be used as standards for later comparation and detection. Therefore, all mentioned steps play equally important roles to the success of a training model. In this project, TensorFlow API (Application programming interface) and training model would be used as tools for training purposes. The API was cloned and extracted from their official Github at https://github.com/tensorflow/models.

Data acquisition is what makes machine learning most distinguishable from other normal programs. Depending on the way data is collected, handled, and trained, it can be divided into four different methods: supervised, unsupervised, semi-supervised and reinforcement. Due to the unpopularity of silages bales leading to the lack of images, supervised learning was considered the most suitable method as it required fewer inputs and its output functions were suited for the aim of image detecting. In this project, data input, a hundred images of silage bales, were retrieved from internet and by action camera mounted on different farms' tractors. The inputs were diverse hence trained model could be utilized in varied farm conditions. Unlike unsupervised learning where input data is redundant, and processor can figure out data's patterns itself, supervised learning needs a set of inputs and corresponding outputs, known as features and labels, implied by programmers. The features were labeled using labelImg software to create annotation XML files. On each image, silage bales, generally known as objects, were marked by rectangular boxes surrounding them. These rectangular were named after the object or what programmers want them to be recognized as. Several different objects' annotations can be made in an image hence a model can be trained to detect many objects at the same time. 60 percent of annotated XML files was sorted as training data, while each half of the rest was categorized as validating and testing data to be used for later evaluation. The files were converted into SVG and then TFRecord format, which stores data as binary strings for training purposes. The advantage of the specific data type was that it required less disk's space and is easier to be copied and read, which made the training faster and more efficient. These steps were done using functions in tf.contrib.data.CsvDataset class provided by TensorFlow.

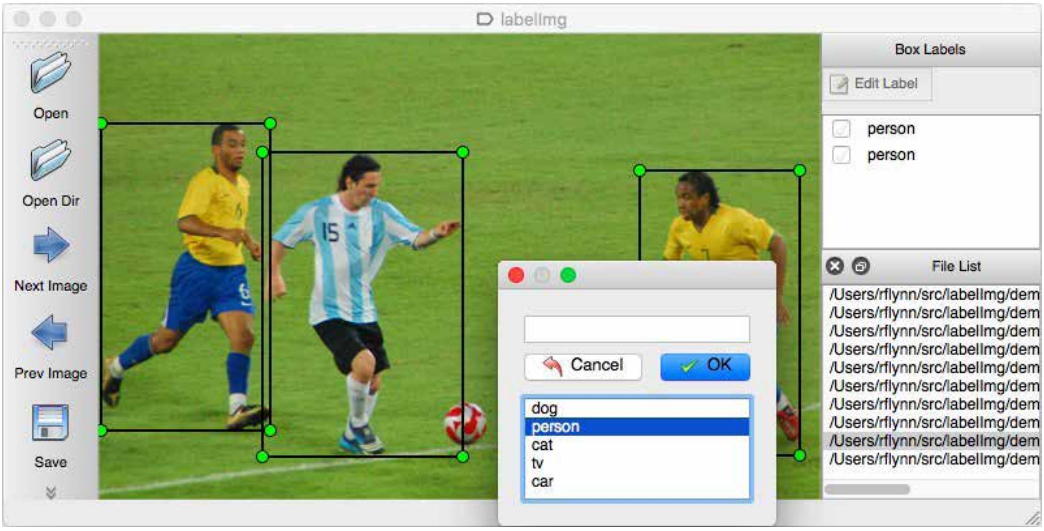


Figure 1. LabelImg object annotation (Tzutalin, 2018)

After being created, TFRecord files were ready to be fed in pipeline for training. However, there was model configuration step to be done before the training starts. Two available options for programmers to choose when it comes to using a model are inheriting a pre-trained model, or to creating a brand new one on theirs owns. The former option is more popular as it is more time-saving and less data-required to learn from a ready-to-use model. TensorFlow has been providing more and more pre-trained models for different usage purposes and hardware configuration. Among all available pre-trained models at https://github.com/tensorflow/models/blob/master/research/object_detection/g3doc/detection_model_zoo.md, ssd_mobilenet_v1_coco was chosen because it had highest detection rate, which was integral in continuous object detection, and relatively good mean average precision (mAP). Once the model being downloaded, put into training directory and extracted, its configuration file was modified to fit the existing data paths and intended memory usage on GPU. In other words, paths to training data folder were added to the file, and batch size was set. Batch is a set of samples fed into a neural network to be trained at the same time, hence batch size is the number of samples in a batch. The bigger the batch size, the more space GPU needed to run the training. For example, in the training, batch size was set at 12, which means groups of twelve silage bales' images were propagated through the neural network one after another, until all images are learnt. In addition to less space requirement, the advantages of using small batch size is that it updates neural network parameters more giving better learning rate, though accuracy on the estimation of gradient being low. Therefore, batch size must be chosen so that the neural network gives reliable outputs with high precision. After images and their TFRecord files and configuration of training model were specified, the training was started by running from directory models/research/object_detection the command "python3 legacy/train.py --logtostderr --train_dir=training/ --pipeline_config_path=training/ssd_mobilenet_v1_pets.config".

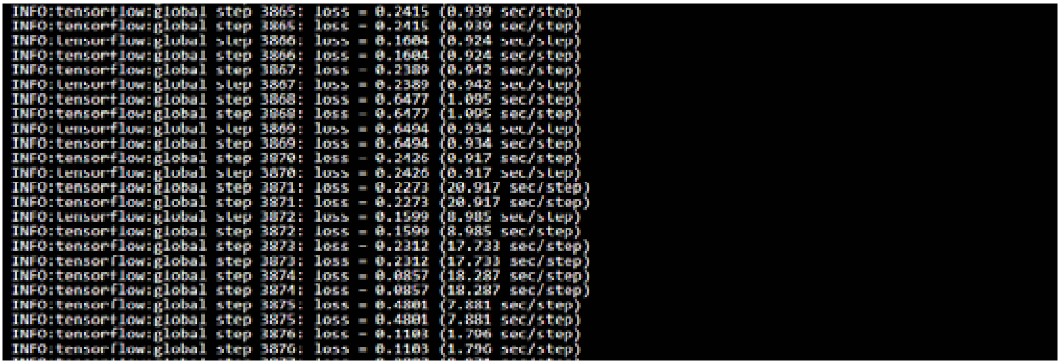


Figure 2. Model training in command terminal

Once the training starts, terminal would appear as showed in figure 2. Depending on the size of training data and machine's power, the step could take from hours to days. During training session, the performance can be viewed by in the same object_detection folder by running TensorBoard command "tensorboard --logdir='training'". By default, the command will run the interface at localhost:6006. The most important variable that should be kept track of is loss, which indicates how good model's predictions are by calculating summation of the errors made for each sample in training datasets. After every step, machine adjust its parameter in the function giving desired results so that it gets as much correct predictions as possible. Therefore, though at first the loss would be great, from 10 to 15, it would decrease rapidly to about 1-2, then gradually toward 0. However, it must be also mentioned that the training should not be let to run for too long as it may cause over-fitting situation. This happens when machine starts remembering the results hence giving incorrect accuracy and loss. Normally, it is acceptable to stop the training when the loss is in the range between 0 and 1.

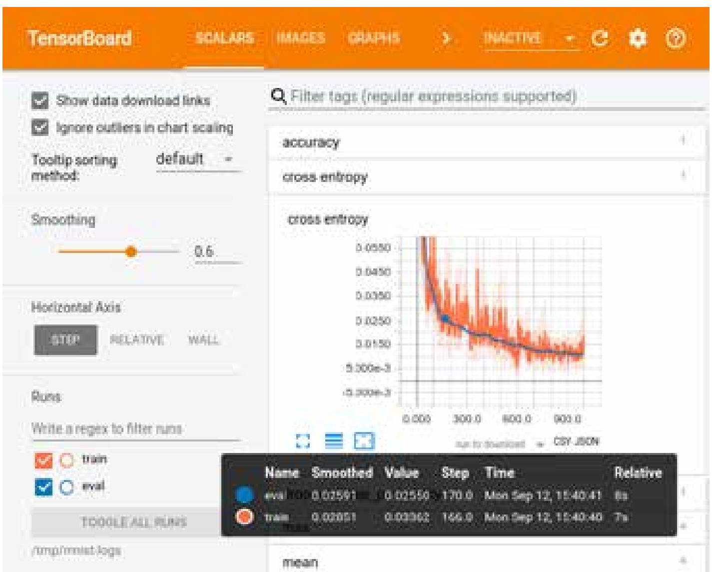


Figure 3. TensorBoard (TensorFlow, 2018).

The training resulted in several checkpoints placed in training folder. These checkpoints saved architecture of a trained model, its weights, configurations, and state of optimizers, allowing programmers to export them as inference graph for ultimate goal, object detection (Chollet, 2015). The conversion was done by using script export_inference_graph.py in training folder after which a new folder was created containing new checkpoint data, new saved_model directory and inference graph, which is then used to detect bales.

3. Results and Discussion

After the inference graph is exported, the model is ready to be used for detection. In order to evaluate its accuracy, object_detection_tutorial.ipynb file was ran on jupyter notebook detecting silage bales in images it had not trained with. Some modifications were required in order to fit the existing script with newly-made inference graph as well as data directory. Figure 4 showed testing results after running the script. It can be seen that all bales were correctly detected, however, a person was also recognized but with lower certainty. Therefore, the problem can be solved either using certainty threshold when an object is found or by re-training the model with bigger input datasets. All in all, the initial goal, which was to automatically detect silage bales, was achieved and the model has been added to main software to detect different stages of wrapping process and start the e-stamping session.

Figure 4. Bales detection testing

Although the accuracy of the detection was relatively high hence the results were reliable, the detecting rate was considerably low compared to requirement that the application was going to be used in continuous detection. The detecting application may require robust machine to be ran on as it required lots of memory space. Another solution for this was to use neural compute sticks, such as Intel Movidius used in Digibale project, as they allow programmers to deploy such deep learning neural networks. The shortcomings of the solutions were that they either require large heavy computer or are expensive. Therefore, the application is limited to companies, farmers, or research projects who have high budgets or want to apply technologies and automation engineering. On the other hand, it was no doubt that machine learning was more approachable than it was thought of and one can easily create their customized learning model following the steps explained above. It was clear, that machine learning in general, object detection in particular can be applied not only in this proven case and other similar harvesting processes, but also in any other branches from any industries.

4. Conclusions

With self-made training and testing datasets, and pre-trained model and API provided by TensorFlow, a silage bale detecting model was developed as an automatic trigger for Digibale's RFID system. The model continuously detects desired object from input flow in the form as images from streaming video recorded by action camera attached to the system. The software outputs by signaling to main data handling application whether a bale is in plastic wrapping process and to start the RFID reading and data collecting procedure. Thanks to the help of the trained model, the whole process was automatic hence reduce farmers' tasks yet increase accuracy in environment measurements as well as silage bales' values.

Being a case study of applying machine learning to comprehensively solve a problem in agriculture and give it potentials for further vision usages, Digibale was expected to create a framework in making object detection so as to automate agriculture's processes and to prove software engineering and machine learning's great application possibilities in agriculture.

References

Chollet, F. (2015). Retrieved from Keras: https://keras.io

TensorFlow. (2018). Retrieved from TensorFlow: https://www.tensorflow.org/guide/summaries_and_tensorboard

Tzutalin. (2018). *LabelImg*. Retrieved from Github: https://github.com/tzutalin/labelImg

Numeric Integrity of Smart Agriculture

Christophe Gossard

Introduction

Identification of gaps on standardization takes place in many organizations and set ups and at various levels. It is important – at European level – to take note of all of these activities and not repeat work that is already done elsewhere but consolidate on actions that have impact on the implementation of policy objectives in the area of digitizing industry and derive from there a set of recommended actions to be included into the EU Rolling Plan on ICT Standardization.

The European legislative background

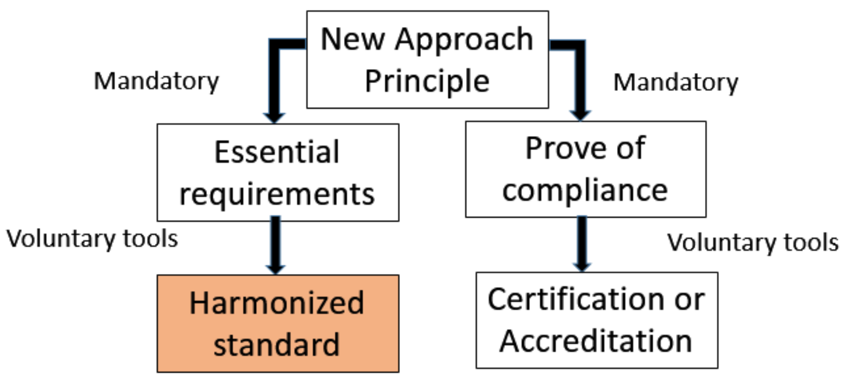
Security and safety are one of the most important criteria for the agriculture equipment manufacturers. In addition to these protection of the end-user, trust and privacy are outermost the information that the farmers want to control in a tight manner.

Existing legislations to apply to the agriculture sector go from GDPR - General Data Protection Regulation, E-Privacy Regulation – Telecommunication, to EU Competition Law, just to mention a few of them. These cross transversal legislative requirements do complexify the development of solutions for the farmers. The complexity and the interfaces required for the seamlessly exchange of data will put the bar so high that the technological challenges won't be fixed only by one supplier from the market.

The agricultural industry is supplying a diverse market and is driven by innovations of numerous manufacturers. The objective of the Agricultural Industry Electronics Foundation (AEF) is the interoperability of different manufacturer's equipment via common standards. This is being facilitated by joint approaches of the industry to technical challenges around electrical systems, electronics and software in agricultural technology and farming.

In many cases, the control of the data generated by the equipment is not transparent and does not allow a good understanding about how the data are mapped and categorized.

The purpose of poster is to explain where we will have the capability to insure the exchange of standardized data based on harmonized standards between different agriculture equipment based APIs and relying on the architecture from various providers used to carry these mapped data.



What are the challenges that the agriculture sector faces?

Compelling multidisciplinary cooperation between different disciplines

We need to have connection on physical world, actuators, sensors, ensuring appropriate level of security, manage all semantics across all IoT layers, make sense of Standard Developing Organization roles, provide experiments for standards, and get some coordination across groups on security and safety.

Increasing social acceptance of agricultural production

We have to build trust in IoT across markets, address the human centric challenges, encourage cross identification common use case and equipment, support the revision of the Machinery Directive considering new technologies, and adapt legislation for safety and security.

Technical possibilities must be aligned with human needs and heterogeneous process requirements

We should have a bottom up approach for the sector providing solutions for missing standards in relation with GDPR / e-Privacy, rank and provide categorization of devices - machine vs personal data, have some ownership control, drive the debate for the coordination with policy <-> standards, and maximize reuse across verticals.

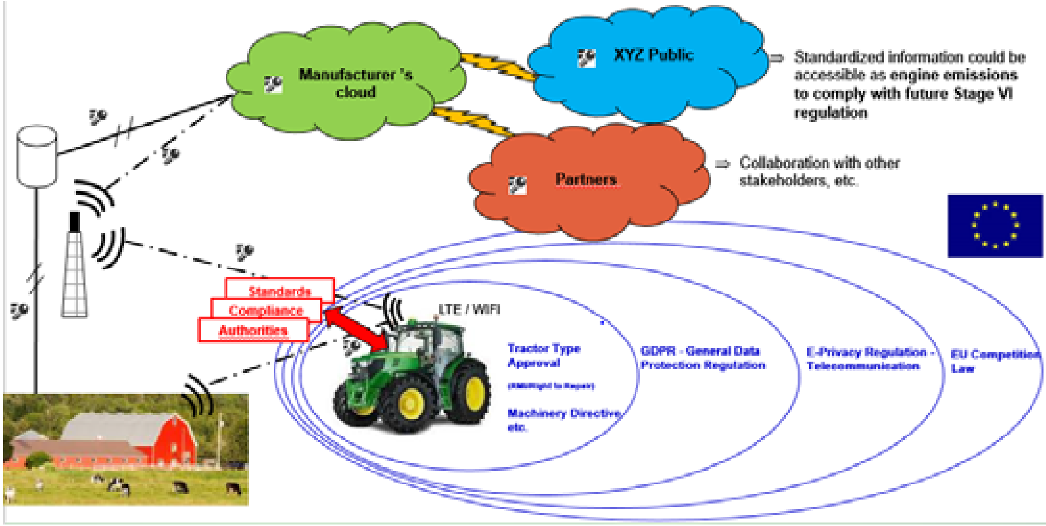
What should be the architecture to be used?

Before answering this interrogation, we need to ask ourselves the following questions:

- Is an agriculture equipment like a Smart Phone or a connected device?
- Has the machinery fulfilled its obligations under the future Machinery Regulation with all the connected devices?
- Has the manufacturer identified the relevant and applicable Essential Health and Safety Requirements related to the standard applicable to the machinery?
- What will be the technical file to create for this connected environment?
- Has the machinery provided a design that meets the level of safety envisioned by the EHSRs?
- Has the design taken into consideration harmonized EN or CEN CENELEC or ETSI standards?
- Does the machinery have quality controls in place to assure that the produced product meets the safety related design and performance requirements?

⇨ The overall answer is not an easy one, however one option could drastically simplify the solutions to be developed in a near future: virtualization of agriculture equipment.

Virtualization of our equipment



Standardize smart agriculture data

The demonstration from the industry to enable machine-to-machine communication is one of the hurdles that each agriculture manufacturer has to face today. As I said, this should include vehicle security and functional safety features going through the cloud or directly to the machine.

The lack of unique specifications between all the "things" such that all things can "speak" the same language is the gap to fill. If you don't integrate the existing architectures from each sector, this will be very difficult to accept these intermediary definitions, and transversal communication between sectors will remain very difficult.

Regulation or Directives under New Approach are good tools if you know how to feed them with the right standards. Mandatory requirements with a mix of legislative tools and standards could help our industry to leverage what has been developed so far under the current transversal legislation (Machinery Directive, EMC, RED etc.)

Making available smart agriculture data through standardized APIs

Standardized API enabling integration of existing environment to update information from many different sources where we don't want only to Identify appropriate ontologies & data publishing platforms, but also integrate all these requirements and implement them on some hardware, but where the privacy of the farmer is fully protected.

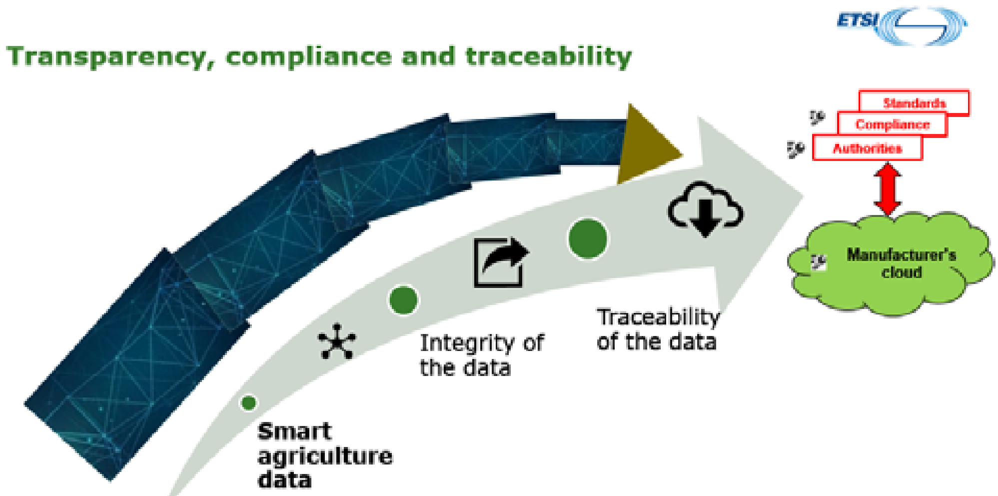
Solution to foresee in the future

Agriculture is producing a lot of data for decades. The digitizing of the agriculture market makes agriculture even richer generating different type of data:

Operational, compliance/personal, security, machine data

The value of the data depends on the integration and the correlation with other data.

- ⇨ Do we have exchange of data and interoperability between all stakeholders?
- ⇨ Do we have data categorization covered by Standard Body Organizations?



Categorisation is vital: without operational data the agriculture eco-system won't work…

The success of the agriculture eco-system will go through the integration of existing scheme, and its extension through improved interoperability. API cloud based standardization could facilitate the dissemination of the existing standards used in agriculture through proprietary and open platforms.

Conclusion

The IoT environment in agriculture will play a key role to address the needs for food of our growing population in a sustainable way. We are already in the middle of the digitalization of Agricultural machinery. Safety and security have to be properly addressed. Privacy for M2M / M2C / C2C mapping through standardization is required. More and more players provide services and offer big data based prescriptions. Within which framework do we define the rules against potential litigation? This solution could save to our industry hundreds of millions and where the farmer will identify some added value for the equipment purchased. Smart Agriculture can only be successful with cloud-based seamless data exchange and partnering of the companies in the value chain.

Some challenges to address in order to target the second generation of agricultural robots

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Abstract

Beyond some scientific and technological challenges, this presentation will underline several other criteria to consider in order to give the key for a real market development of agricultural robots in close relationship with the operational needs and the constraints of farmer end-users.

Keywords: .Agricultural robotic, challenges, market access conditions, end users

1. Introduction

Digital farming will favour the increase of the productivity whilst in the same time the sustainable development of agriculture. In one of its synthesis document (CEMA, 2017) the European Agricultural Machinery Industry Association clearly defines the terms of "Digital Farming & Agriculture X.0". The Agriculture 3.0 was in link with the 1990-2000 timing decade with early adopters of GPS guidance assistance systems, yield mapping on combine harvesters and first telematics technology used to monitor vehicle fleets. The 2000-2020 period corresponding to Agriculture 4.0 boosted the Precision Agriculture, thanks to the evolution of several technologies in terms for example of i/ some cheap sensors and actuators, ii/ low cost micro-processors, iii/ high bandwidth cellular communication. The next Agricultural 5.0 (with full expression from 2020 year) will be devoted on cloud and Big Data analytics. Autonomous decision systems given by Artificial Intelligence and **unmaned operations given by robotic systems** will be also resolutely parts of Agriculture 5.0.

Agricultural Robots are announced to play a key role in agriculture domain. Today effectively, farmer end users put more attention and interest to robotic solutions. If in livestock production area, robotic market already exists, robotic market for plant production is still in their early stages of development ("Research prototypes" level or in the best case "Early commercial" level). So one main question is: "What are challenges to address in order to favor "Market Penetration" of agricultural robots"?

2. Still a lot scientific and technologic issues to solve

Agricultural plant production presents a lot of complex and uncertainty environments. The Figure 1 below illustrates some specific bricks to reinforce in order to reach real operational agricultural robots.

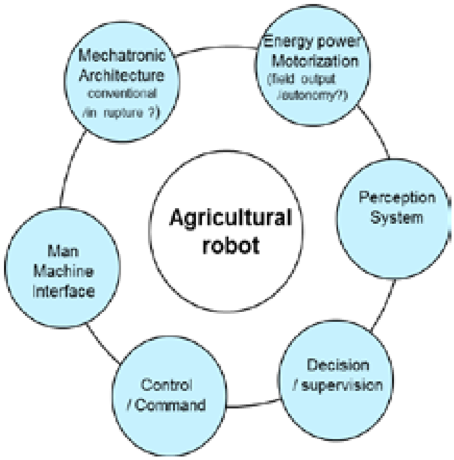


Figure 1: Robotic bricks

Some efforts in term of perception (ex: sensors fusion), decision (ex: AI) and control/command systems must be carried out by complementary actors (manufactures, components suppliers, integrators, researchers…). As example we can mention the case of early commercial sales for robotic weeding solutions. Currently, these last ones are moving at low speed on flat and well-structured open fields. High performances are absolutely necessary to evolve in more harsh conditions (presence of slope terrains, sliding disturbances, complex environments, high speed…).

Robotic offers also huge possibilities to reinvent agricultural machines in term of mechatronic architectures, energy power motorization, cooperation of several small, medium (or big!!) smart machines working together under the supervision of one remote human operator…A lot of scientific and technologic developments still must be done in order to increase the performances of all the bricks involved in the whole robotic systems.

Today we assist to an explosion of agricultural robot solutions coming from various part of the world. Presented results show in general a very good functioning of the solutions relayed directly by their own developers or / and by public or professional Medias (ex: video supports). These results which give the impression that "all is perfect and soon available" are generating growing interest among farmers and their representatives. Nevertheless, achieving the interest of End users which are the farmers does not mean triggering the final purchase of the robotic solutions by these farmers. In the next chapter, some criteria (list not exhausted) must be taking into consideration in order to facilitate the acceptation by the end farmers of robotic solutions.

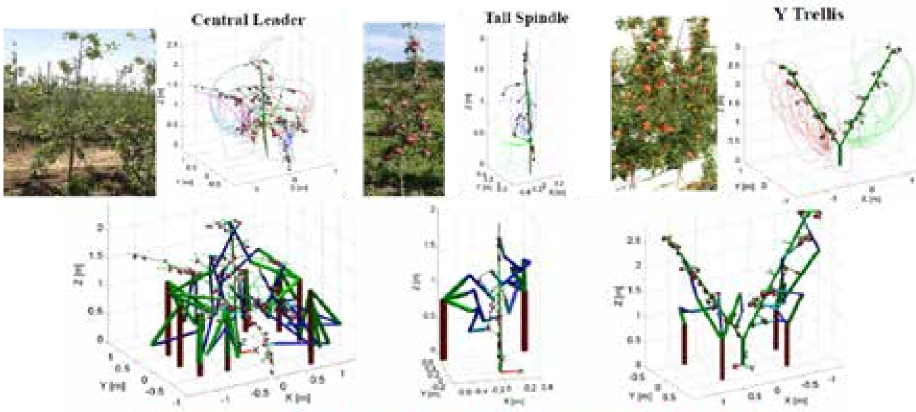
3. Some other important criteria to consider for the dissemination of agricultural robots

The Figure 2 introduces a second constellation of satellites (in yellow colour) about criteria to take into account in order to satisfy the needs of End Users and thus to give some keys for a real market development of the agricultural robots.

Figure 2: Other criteria to consider from End-User position

- **"Economic Adoption Cost"** ***criterion***

Never the final Customer (with the exception of exception!!) buys a machine for its high technology, but for its ability to provide added value in terms of Return On Investment. One possibility to optimize the ROI is to optimize the "Robot - Agro System" couple. As illustration, in the Figure 3, the author (Degani, 2015) compares by simulation the cost of different robot architectures (composed of 3 or 4 Degree Of Freedom) for picking fruits in three tree configurations ("Central leader", "Tall Spindle", "Y-Teillis" pruning modes). Resolutely the "Tall Spindle" training system with more compact and wall spatial disposition of the fruits on the tree can use the robot with lowest cost function.



	Central Leader	Tall Spindle	Y-Trellis
		Cost	
3DOF	88.8	36.5	56.3
4DOF	65.5	27	47.4

Figure 3: Example of the "Robot – Agro System "optimization

So affordable cost robots could be more easily achieved by simultaneously adaptation of morphology of plants. Robot Technology and Agronomy communities are thus called to work together.

- **"Robustness" and "Output performances"** ***criteria***

Robustness and out-put performances of robotic solutions are also essential for the End-users. Staying always in the Fruit picking robots domain, a lot of developments show poor yield out-put with long execution cycle time (several seconds) to detect the fruit, launch the arm to fetch the fruit, collect the fruit and arrange it in the conditioning box before to restart a new cycle. Under the respect of previous criterion ("Robot - Agro System" optimization), we advance the hypothesis that "simple architecture robotic machine" gives additional asset to improve robustness and output performances. An example of "simple robotic machine" is the automatic apple picker developed by FFRobotics (GoodFruitGrower, 2017) with two main elementary linear mechanic devices to reach fruits in the vegetation wall.

- **"Easy to use"** ***criterion***

Demonstrations of agricultural robots are always showed in the field. In fact, "agricultural robotics doesn't start in the field, **but inside the yard of the farm!!**" .That means that End-users will be attentive to all the phases of the mission of the robot: Preparation, Execution, and Finalization, and not only during the execution work in the field. The phases of preparation and finalization of the mission integrate a lot of logistical operations, for example with the connexion of implements on the robotic platforms. Thus, one asked question is about the execution facility of manoeuvers for implement linking operation from remote screen tablets? In the case of deployment of several robots (swarm robots), the End users will be concern by accentuated logistical issues with a lot of fuel tank to fill-up each morning, or batteries to charge each morning and other time during the day!!. So for the development of agricultural robot market, it is capital that developers bring suited solutions for all the phases of the mission in terms of Usability / Easy to use of the solutions in order to obtain complete satisfaction from End-users.

- **“Respect of environment”** ***criterion***

As introduce in chapter 2, Robotic offers huge possibilities to reinvent agriculture machinery with for example cooperation of small or medium size robots working together (Blackmore, 2008; Berducat, 2007). Thanks to robotic technologies, this approach gives new alternatives to the single way evolution of agricultural machinery proposed during the last century: “always bigger, always powerful…but always heavier!!”. The opportunity to suppress the compaction of soil deep layers (30 cm to 1 m depth) by suppression of big machines paths is a real benefit for sustainable agriculture. In the case of small robots (working or not in cooperation), one question nevertheless must be put on the table: “With a footprint on 90% of the surface area (due to small track, repeated paths) what about superficial compaction generated by these machines in certain working conditions (type of soil, moisture)” ?

- **“Safety”** ***criteria***

The rise of robotic in general and agricultural robotic in particular is depending of safety guarantees which will be given by the manufactures. The mobility increasing of robots in their working environment in autonomous modes requires a special attention on safety associated devices. Safety devices for agricultural robots don’t be limited to detection of obstacles (static or dynamic, positive or negative, known or unknown). The preservation of the robot integrity needs other security modules (hard and soft). For example, taking into consideration the presence of slope terrains and/or tanks or hoppers embedded on the mobile robotic platform that can fill-up or empties during the work execution, it is necessary to have safety devices able to anticipate dynamic instability or roll-over risks (Denis, 2016). Physical or virtual geo-fences are also an obligation in open field areas in order to guarantee that agricultural robots will stay in their dedicated work areas.

- **“Integration in FMIS”** ***criterion***

Concerning agricultural robots in plant production and open fields, we are just at the beginning of the history!!. Currently, agricultural sites welcome only one or two robots in the same place under the close supervision of a human operator at proximity. For the real boom of the robotic in agriculture (in particular for big farms), it is absolutely necessary to go past the level of the lonely machine in its field. Robots must be full integrate in the Farm Management System (FMS) able to plan, control and supervise all the fleet of robots working at the same time in several field areas of the farm.

Farm Management Systems (Digital Farming tools) exist today to share information in real time about exchange of spatio-temporal data in the frame of Precision Agriculture. These tools must progress and be adapted to the arrival of agricultural robots (which is not the case today). To facilitate this evolution, agricultural robot community must take benefit of developments done in industry sectors. The figure 4 (Pugliesi D, 2014) presents the five functional levels of a manufacturing control operation in industry sector. The two low levels standards (Level 0 and Level 1) correspond to levels embedded on the physical machine. Upper levels (2, 3 and 4) will respectively permit to supervise, control and schedule all the robots to the right stage has to be digging.

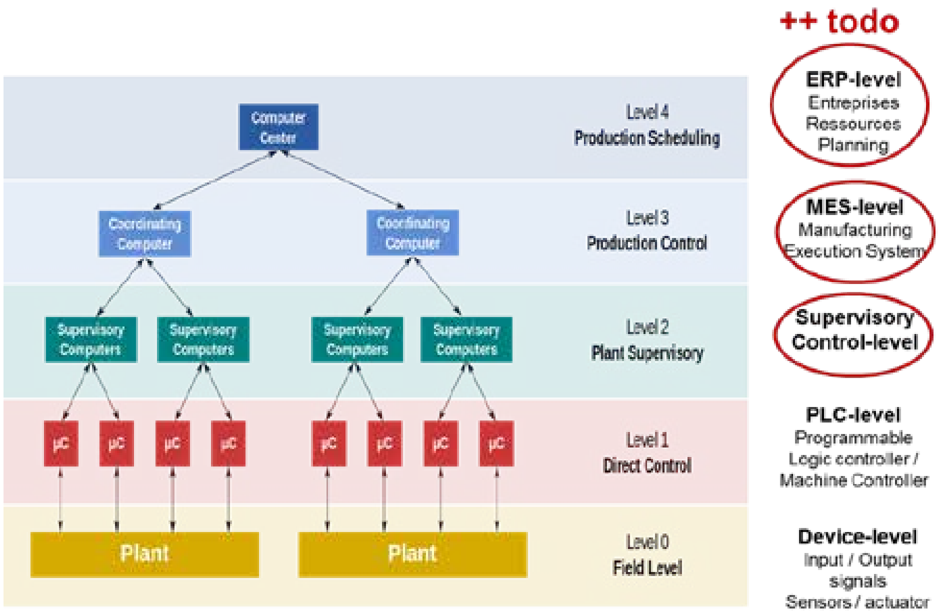


Figure 4: Integration of agricultural robots in FMS

- **“Education Training” and “Society acceptance” *criteria***

The introduction of robotic solutions in farms requires some precautions. Manufactures must take care to propose adapted training to their customers in order to educate them to these new advanced technologies. No saving can’t be done in this domain, if the agricultural robotic community wants to success. In the same manner, transparent exchanges between all the actors of the Value Chain (researchers, manufactures, distributors, farmers) must be develop toward civil Society in order to explain and demystify the role of robotic in agriculture.

Conclusion

The aim of this paper was to underline huge challenges to solve for the development of agricultural robots. Challenges concern a lot of scientific and technology issues in order to reach performant robotic offers with appropriate associated solutions in terms of safety functions and target cost. To convince customers, developers must also take care to consider all the phases of the mission of the robots (and not only functioning inside the field). Logistical aspects in the farmyard, between farm yard and fields must be also proposed to end users to offer complete operational solutions. To increase the maturity level of robotic solutions for agriculture, it is also necessary to break up the current limiting approach, consisting to use robots as lone units. Tomorrow mobile robotic platform(s) must be fully integrated in the whole Farming Management System, one more, not only during mission execution inside the field, but also during the mission preparation from the farm yard (linkage of implements, full of energy…).

Note

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References

Berducat M., 2007, Evolution of agricultural machinery: the third way, 7th European Conference on Precision Agriculture, Wageningen, NL, p363-369

Blackmore B.S., 2008, A specification for an autonomous crop production mechanization system, University of Thessaly, Greece, ICPA, 9th Denver, July 2008, 16p

CEMA. 2017. Digital Farming: What does it really mean? http://www.cema-agri.org/page/digital-farming-what-does-it-really-mean

Degani, P., 2015, BARD foundation workshop, Volcani Center, July 12th-14th, Israel

Denis D., 2016, Online adaptive observer for rollover avoidance of reconfigurable agricultural vehicles, Computers and Electronics in Agriculture 126, 32-43

GoodFruitGrower, 2017, https://www.youtube.com/watch?v=UaL3UxUclKY&t=22s

Pugliesi D., 2014, https://commons.wikimedia.org/w/index.php?curid=31527335

Development of the AgriRobo Tractor

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Abstract

With the aging of society, the number of retired farmers is increasing in Japan. On the other hand, business-minded farmers and agricultural corporations are increasing. As agricultural lands are consolidated by these farmers, the scale of agricultural farms is expanding. Due to the expansion, reductions in production costs are required. As smart agriculture utilizing ICT (Information and Communication Technology) is being promoted as the next generation of agriculture, Kubota has been developing smart agricultural technology using GNSS (Global Navigation Satellite System) to support efficiency and labor saving for farmers. In 2017, Kubota developed the AgriRobo tractor. This enables automatic operation of an autonomous monitored tractor and cooperative work with a manned tractor monitoring the autonomous tractor.

A tractor is capable of conducting various types of work by using various implements; however, the major processes in Japan are rotary tilling and the puddling of rice paddies. Therefore the development of the AgriRobo tractor was focused on efficiency improvements in tilling and puddling. Determining the shape of the field and position of the tractor in operation allows the AgriRobo tractor to create a highly efficient work route. Kubota advanced the autonomous development by targeting the three following points: [1] automate the tractor work processes and reduce wasted travel with high precision in order to increase efficiency and save labor in the farming process; [2] realize further efficiency improvements and labor savings by implementing coordinated work between two tractors under automatic operation; and [3] ensure safety in operating multiple automated tractors simultaneously.

Keywords: Smart-agriculture, Autonomous, Control, GNSS, Detection System

1. Introduction

The number of people moving out of farming in Japan is increasing in association with the aging of the population. Meanwhile, the number of business-minded farmers (known as NINAITE) is increasing, and the organization and incorporation of agricultural business is advancing. As farmland has become more concentrated under these professional farmers, the cultivated acreage per agricultural business organization has increased. To continue efficient and stable farm management, improvements in productivity and profitability are necessary, and greater efficiency and labor-saving is demanded from agricultural machinery.

While smart agriculture utilizing ICT, the next-generation agriculture, was being promoted, Kubota developed the AgriRobo Tractor, which is capable of unmanned, automatic operation utilizing GNSS, in order to realize higher efficiency, greater precision and further labor savings.

2. Concept and goals of the development

2.1. Concept of the development

While a tractor is capable of conducting various types of work by replacing the implement, its major processes in Japan are rotary tilling and the puddling of rice paddies. Efficiency improvements in tilling and puddling, which corresponds to most of its operational period, are demanded.

The general flow of rotary adjacent tilling work starts with determining the width of the field headland based on the tiller width and the start position for work based on the shape of the field. The tractor is moved to the work start position, and tilling is started by lowering the implement. During the tilling work, the tractor is operated along the target route while being subjected to loads and vibrations in the field, where conditions such as the unevenness of rice stubble the crawler trails of combine harvesters, and soil softness vary. When work is done on the other side of the field, the tiller is raised to make a small turn, then lowered to match the cultivated land and field headland so that no untilled area remains after turning. Then the tractor is operated again in accordance with the target route. These processes are repeated thereafter.

To enable efficient work, it is necessary to measure the shape of the field and position of the tractor in operation, set up a highly efficient work route suited to the width of the implement and shape of the field, and operate along the target route within the field, where conditions keep changing.

AgriRobo accomplishes this by targeting the three following points : [1] automate the tractor work processes and reduce wasted travel with high precision in order to increase efficiency and save labor in the farming process without depending on the skills or experience of the operator; [2] realize further efficiency improvements and labor savings by implementing coordinated work between two tractors under automatic operation; and [3] ensure safety in operating these automatically operated tractors.

2.2. Outline of the Agrirobo tractor

2.2.1. Outline of the automatic operation system

An outline of the automatic operation system is shown below (Fig. 1).

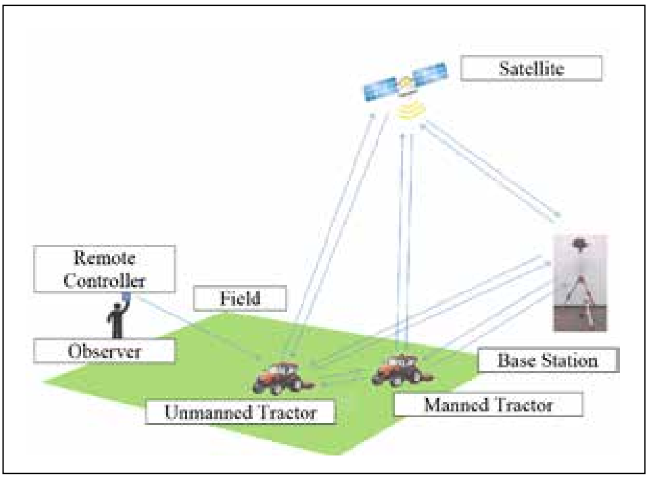

Fig. 1 Schematic Diagram of the Automatic Operation System

[1] The tractor communicates with the RTK-GNSS (Real Time Kinematic-GNSS) base station (hereafter referred to as the “base station”) and the satellite and measures the position information for itself and the field.

[2] The tractor communicates constantly with the base station and satellite during automatic operation and updates the position information to calculate positions in the field precisely and conduct work, turning, straight advances and stopping automatically.

[3] The starting, pausing, and stopping of automatic operation is determined by the monitor as necessary, with instructions given from a remote controller that communicates with the unmanned machine.

[4] In cases of coordinated work, in addition to the above communication, the area around the unmanned machine is monitored, and position information and work information on both units are shared by communication between the unmanned and manned machines.

2.2.2. The work area of an autonomous tractor

We set the work area within a field where automatic operation is enabled to the innermost part comprised of the adjacent tilling section and field headland tilling at the center of the field. A paddy sluice and intake valve for the pumping and drainage of water often project into rice paddies from the edge, and many field edge ridges are made of concrete. Considering the possibility of the tractor or its implement coming into contact or colliding with them, the field headland and periphery of the field were removed from the automated work area. The same work area was set up for two-unit coordinated work. The work sequence is comprised of a leading unmanned, automated tractor tilling alternate passes, and the manned, automated tractor tilling the in- between areas. By allowing the unmanned tractor to go first, it can be more easily monitored by the observer riding on the manned tractor (Fig. 2).

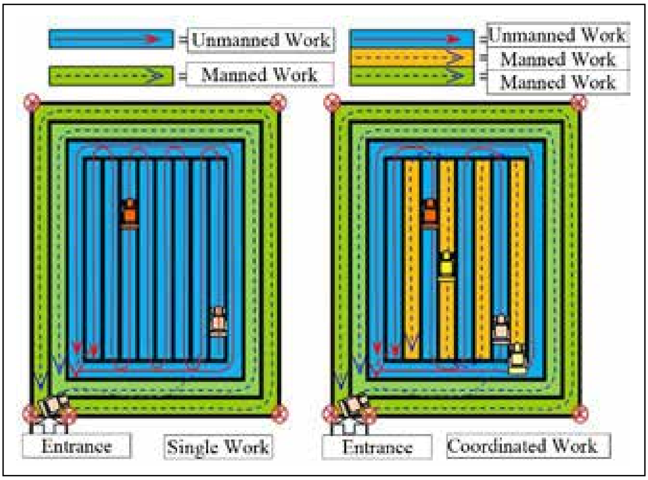

Fig. 2 Autonomous Tractor Work Area

2.2.3. AgriRobo Tractor systems

The major devices and systems that were incorporated in order to realize automatic operation of the AgriRobo Tractor include the RTK-GNSS system , a terminal monitor , an electronic control and steering system, an automatic driving control system, a safety monitoring system, cameras and other sensors , a communication system and a remote control communication device. The RTK-GNSS system provides high-precision position information, so that the terminal monitor can register position information in the field and generate work routes, to aid in field work condition setting and display of information. The terminal monitor also uses information obtained from sensors and devices to create planned routes, which are executed by the automatic driving control system. The safety monitoring system detects proximity to the tractor of other vehicles, persons, or objects, using cameras and other sensors. It utilizes the communication system to share information between vehicles and with the observer via the remote control. The observer has the ability to start, pause or stop work via the remote control.

3. Technical challenges to be solved

Several technical challenges described in this section had to be overcome and are addressed in section 4.

3.1. Automatic driving challenges

3.1.1. High driving precision

Agricultural field work requires higher position precision than on-road automobiles and it takes more time to eliminate deviations in driving since they move at lower speeds and under larger workloads. Furthermore, deviation from the target position may occur instantly due to slipping or unevenness on the ground. Our challenge was to newly establish a control technology that realizes high driving precision while handling these various factors.

3.1.2. Stable automatic turning

One of the important items in automatic driving control is turning control. This technology is for rice paddies, and assuming domestic fields, we wanted the central part of fields to be maximized while the field headland part is minimized. Therefore, our challenge was to implement turning control within the narrow field headland area without the tractor protruding from the field or entering the already tilled area.

3.1.3. Efficient route generation for coordinated work

To implement work in the center of a field under automatic operation, a driving route must be generated. Since this technology will enable independent work with one vehicle and coordinated work between two vehicles (one unmanned operated automatically, the other operated automatically or manually with the monitor riding), our challenge was to generate work routes ensuring that the work completion point is near the field entrance/exit so that the machine(s) can move out of the field without going over the tilled area after work completion.

Also, with work routes for two-unit coordinated work, which can improve work efficiency, we had to generate work routes ensuring that the work completion point was near the entrance/exit so that the preceding vehicle would never obstruct the following vehicle whatever the shape of the field.

3.2. RTK-GNSS unit challenges

3.2.1. RTK-GNSS unit cost reduction

The RTK-GNSS, a core technology of AgriRobo, is based on the RTK-GNSS for land surveying and is extremely expensive among commercial products. They are also comprised of multiple devices (a GNSS antenna, receiver, radio equipment and IMU, etc.), making it difficult to transfer a unit between different agricultural machines and to tune the unit, so it is a burden for users.

3.2.2. Position and azimuth angle detection

Automatic steering systems, which have become more popular in recent years, are capable of automatic driving only in straight lines (using GNSS position information only). However, automatic driving including various work patterns including turning requires high-precision and high-rate position and azimuth angle detection.

3.3. Ensuring safety in unmanned operation

The guidelines for automatic operation by the Ministry of Agriculture, Forestry and Fisheries1) stipulate that an observer should monitor the tractor from nearby when implementing automatic operation. However, in practice, it is difficult for a person to keep monitoring visually until all processes are completed, and a system to detect obstacles in proximity of the tractor and automatically stop the tractor before collision occurs is necessary as a support function for the observer. In addition, an international standard on the automatic operation of agricultural machinery (ISO18497)2) is expected to be issued, so we needed to conform to this standard.

The standard stipulates the use of a test obstacle (Fig. 3) for a system to detect obstacles, and it requires that the system detects this model and stops automatically before a collision occurs during automatic operation.

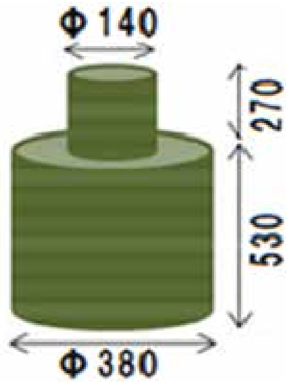

Fig. 3 Test Obstacle (Unit millimeter)

4. Developed technology

4.1. Driving control, autonomous turning control, and generation of coordinated work route

4.1.1. Development of high-precision driving control

Setting “driving toward the target azimuth (minimum azimuth deviation)” and “minimum positional deviation from the target route” as two types of control targets, we incorporated a control algorithm to determine steering output based on synthesis of the two targets. This allowed us to realize good driving properties without a sense of meandering, regardless of the field conditions. In addition, the AgriRobo Tractor not only keeps driving on a certain route, but also conducts a series of work processes while switching between various operation sequences. These include guiding itself to the operation start point, automatic turning, and movement to the work start point on the target route in order to re-engage “automatic operation” of the tiller. To realize this, high adaptability was required for the driving control algorithm.

For example, while both positional deviation and azimuth deviation are relatively stable along a certain target route, a sudden large positional deviation occurs immediately after a switch in operation sequence, such as switching from a turning operation to straight line travel. This results in excessive steering output and low convergence with the target route, if the control remains the same. We therefore developed a variable gain algorithm (Fig. 4) to increase azimuth gain as the vehicle comes closer to the target route, so that the approach angle gradually becomes smaller. This allows optimal control at any time in accordance with the state of the machine body (Fig. 5). We enabled high-precision driving at all times regardless of field conditions with the development of the above technologies.

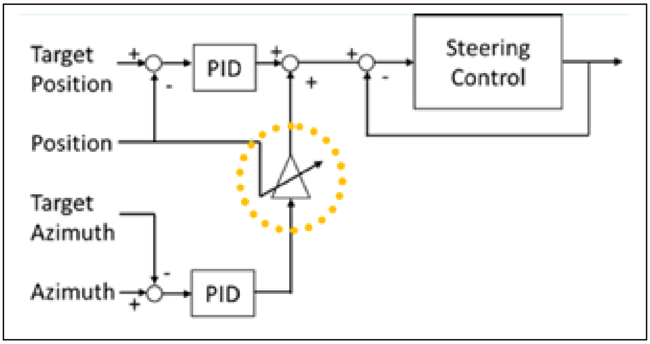

Fig. 4 Configuration of the Controller

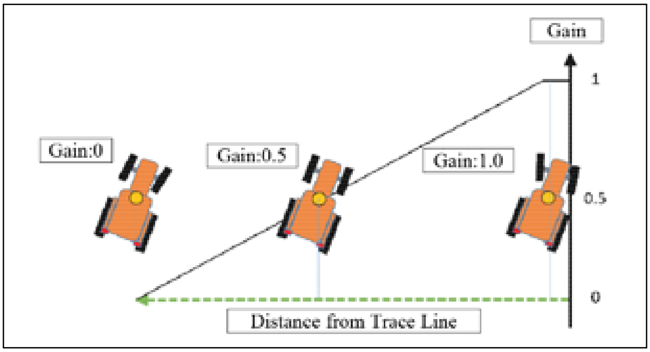

Fig. 5 Distance from Trace Line vs Gain

4.1.2. Solution for automatic turning control

Information on the travel path is obtained from the guidance application in advance of the next pass through the field. For example, the start position, line azimuth and positional relationship with the vehicle for the next work path can be calculated when the tractor reaches the end of the previous pass (end of the work path in the central part of the field). While the virtual turning route is generated based on this positional relationship and the turning operation is executed along that route, the tractor may protrude from the field, depending on the azimuth of the traveling line to the ridge. In this case, the turning route is recalculated so that the tractor can turn within the minimum possible space (Fig. 6).

In addition, a retry control allows deceleration when the turning route deviation exceeds a certain level during a turning operation. The retry control will then generate a new turning route to further improve turning precision. During turning, the control system considers safety by detecting if the tractor is stuck or the wheels are slipping, based on a comparison of assumed vehicle speed obtained from axle rotation with actual vehicle speed obtained from the GNSS. An inclination of the vehicle based on IMU information and protrusion from the field based on GNSS position information are considered as well. If the system determines the tractor is outside certain operating boundaries, it will stop the movement of the tractor.

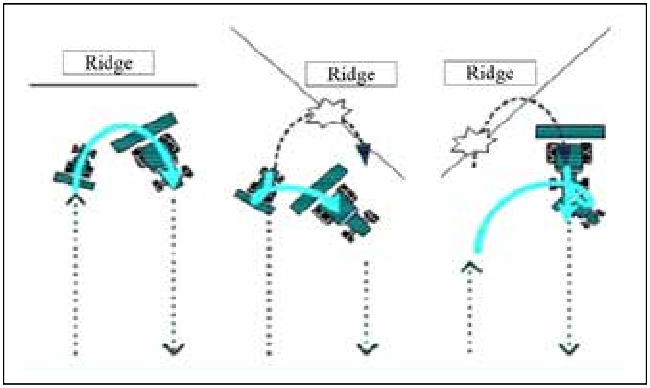

Fig. 6 Turning Route

4.1.3. Solution for coordinated work route generation

If the total number of lines in the work route in the center of the field is even, the work line closest to the entrance/exit is set as the work line for the leading vehicle and the direction of the work line is determined so that the end of the line near the entrance/exit is the ending point for the work line. This is then used as a reference to determine the work vehicle, direction of work, and work start position for other lines (Fig. 7).

If the total number of lines in the work route at the center of the field is odd, the two work lines closest to the entrance/exit are set as the work lines for the preceding vehicle, and then the work vehicle, direction of work and work start position for other lines are determined (Fig. 8).

Considering possible contact between the preceding and following vehicles when they pass by each other, the work completion position of the following vehicle will be opposite to the entrance/exit in this case. However, this will not be a problem as the monitor will be on the manned machine, which is the following vehicle, and it moves on to field headland area to work on the outermost periphery under manual operation after the completion of automatic operation.

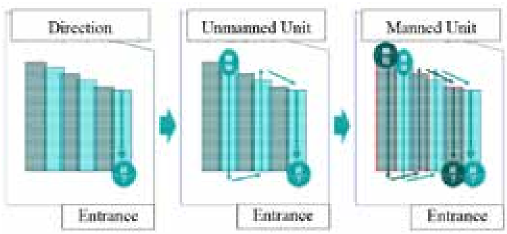

Fig. 7 Generation of Work Line (Even Number)

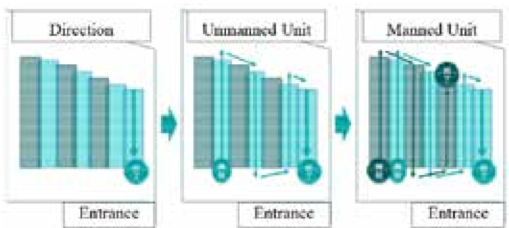

Fig. 8 Generation of Work Line (Odd Number)

4.2. The optimal RTK-GNSS unit for automatic driving of agricultural machinery

4.2.1. An integrated and low-cost RTK-GNSS unit

We developed an integrated RTK-GNSS unit integrating all of the component devices (Fig. 9) on our own. We realized a high-performance, low-price RTK- GNSS unit by adopting inexpensive devices, developing our own GNSS antenna and developing precision improvement software (hybrid navigation described below that combines IMU and GNSS). Incorporating the components as an integrated unit not only enables simple transfer between agricultural machines, it also makes it possible to install the IMU near the GNSS antenna and execute more accurate position and azimuth operation.

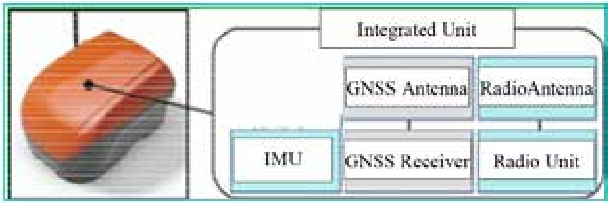

Fig. 9 Developed RTK-GNSS Unit

4.2.2. Position and azimuth angle detection method

To develop a navigation sensor capable of high-rate output, which enables high-precision farm work in fields with uneven ground, we carry out unique optimized calculations in accordance with driving conditions using a hybrid navigation system. The system utilizes the advantages of GNSS and IMU as the base and combines information from the main body (vehicle speed and steering angle of the machine, and driving conditions for the machine generated from map information). By doing so, we addressed high-rate output and high-precision position (3 cm or less) and azimuth angle (1 degree or less) detection (Fig. 10) under various work patterns, including both turning and straight line travel, completing the optimal navigation system for the automatic driving of agricultural machinery.

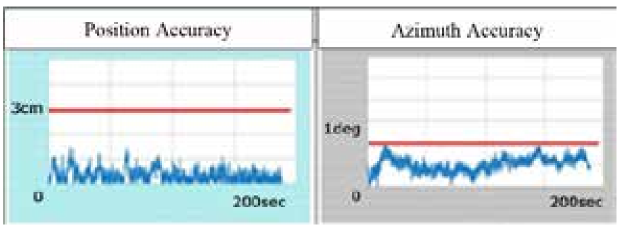

Fig. 10 Result of Performance Evaluation

4.3. An object detection system

4.3.1. The area of detection

A tractor has a "complex" external vehicle shape, with front wheels placed outside the hood and an implement wider than the cabin. The test obstacle in ISO18497 is low at 800 mm so we needed to combine multiple sensors in order to detect this in the proximity of the tractor.

To stop before colliding with an obstacle detected during automatic operation, we mounted laser scanners on both sides and the back of the vehicle. The laser scanners we selected were capable of scanning one plane in a wide angle and were thus suited to detecting distant obstacles. Meanwhile, there were blind spots under the scanning planes of the scanners close to the tractor. We assigned ultrasonic sonar to detect obstacles of low height. While the ultrasonic sonar has a short detection distance, it is capable of detecting nearby objects and is used in object detection in proximity of the tractor before starting automatic operation.

We installed each of the sensors with consideration of their characteristics as discussed above. Their detection functions are all enabled before starting and during automatic operation, with their detection capacities utilized in a complementary manner.

Obstacle monitoring in proximity of the AgriRobo tractor is thus accomplished with three laser scanners and eight ultrasonic sonars in the arrangement as shown in Fig. 11.

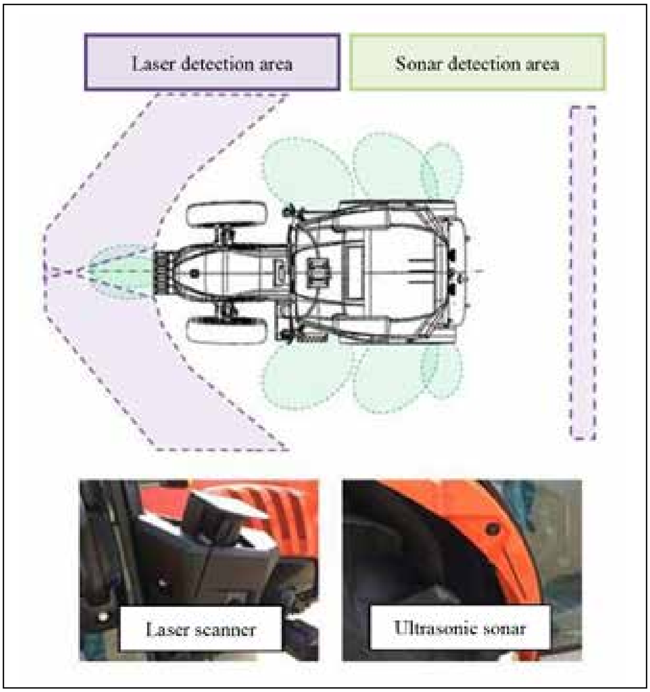

Fig. 11 Object Detection System

4.3.2. Adapting to the actual field

While the mounted laser scanners and ultrasonic sonars can detect that there is an object in proximity, they cannot identify what this object is. There are many things in a tractor's work environment that may be falsely detected as obstacles, such as weeds, stubble left after harvesting, and mud adhering to the tire. False detection of obstacles deteriorates availability of the automated operation and may ruin the original purpose of improved efficiency through automation. Repeated evaluations in various different fields provided data for adjustments to avoid the false detection of obstacles and aided in development of a detection algorithm.

For the laser scanners, we tuned the minimum size value for objects to be detected as obstacles, and the detection count until an object is judged to be an obstacle, in particular to minimize the false detection of weeds inside the field. For the ultrasonic sonar, uneven ground created some false detection alarms. A reduction in false alarms was realized by establishing a weighting system on the distance detected by the sensor and using various object parameters to estimate how much the detected item resembled a true obstacle.

For the edge of the field (ridge), where obstacles are more likely to be present, we extended the detection area in front of the laser scanner in the turning direction to check for obstacles in the turning path before commencing the turning operation.

5. Conclusion

We developed the autonomous AgriRobo Tractor under the concepts of greater efficiency, higher precision, and labor savings. By realizing automatic operation and coordinated work, we expect that it will contribute greatly to achieving the efficient farm management demanded by the market.

In the future, we intend to improve versatility and expand the technology for other Kubota tractors based on the evaluations and demands of customers. This work will be done in coordination with the Kubota Smart Agri-System and will lead to complete automation, which is the next step.

References

1. Ministry of Agriculture, Forestry and Fisheries: Guidelines on Ensuring Safety in Relation to the Automatic Traveling of Agricultural Machinery (Notice of the director of Agricultural Production Bureau, the Ministry of Agriculture, Forestry and Fisheries, 28 Production No.2152, dated March 31, 2017)
2. ISO/FDIS 18497 : Agricultural machinery and tractors -- Safety of highly automated agricultural machines (draft in process)

Can the hydraulic trailer brake system meet new and future market requirements and new regulations?

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1. Introduction

Hydraulic trailer brake systems on agricultural vehicles are widely used in many European countries. They share the entire European market with the air brake systems, known from the truck sector, to approximately equal parts. In contrast to 2-line pneumatic, the hydraulic trailer brake has always been used as a single line brake system. This very simple and popular system holds almost the entire market share of existing vehicles in some important agricultural countries like France, Spain, Italy, etc. In some other countries, such as Germany, national regulations have required a 2-line brake system since years for the vehicle classes concerned. This is the reason why the hydraulic brake has not established itself there.

With the new Tractor mother regulation (TMR), EU-VO 167/2013 and EU-DVO2015/68, the European Union has now brought into force a new regulation (since 1.1.16) which lays a new pan-European foundation for braking systems on agricultural machines. The following main reasons are pursued:

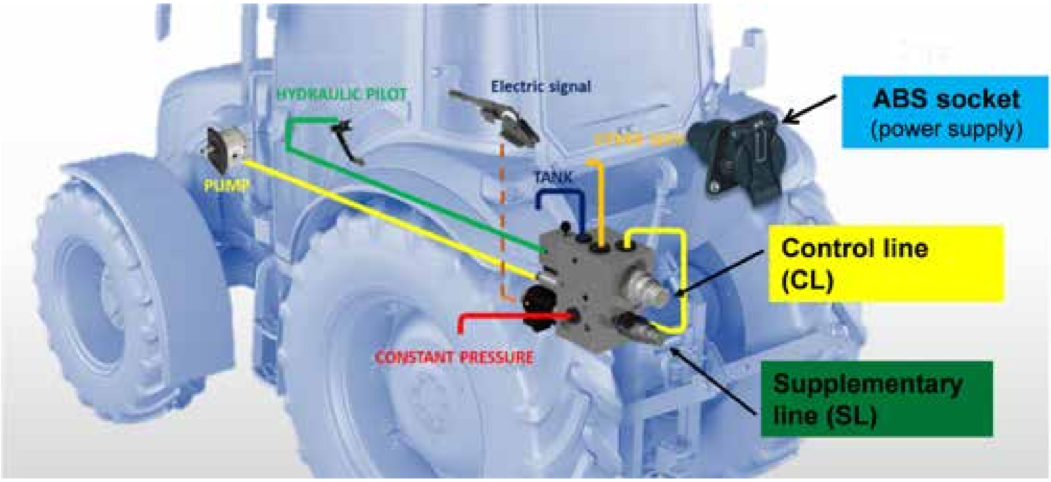
- Improvement of the safety of agricultural and forestry vehicles in road traffic. All requirements for brake systems are documented in detail.
- Harmonisation and implementation of the regulations for type approvals at European level for the relevant vehicle classes.
- The safety requirements for pneumatic or hydraulic braking systems are the same.

The new EU regulation gives the market the freedom to choose between hydraulic and pneumatic systems. The main reason for an individual system decision lies doubtless in the continuity and interchangeability of the individual existing vehicle fleet with new machines.

What technical changes does the EU-DVO2015/68 require of braking systems of new vehicles?

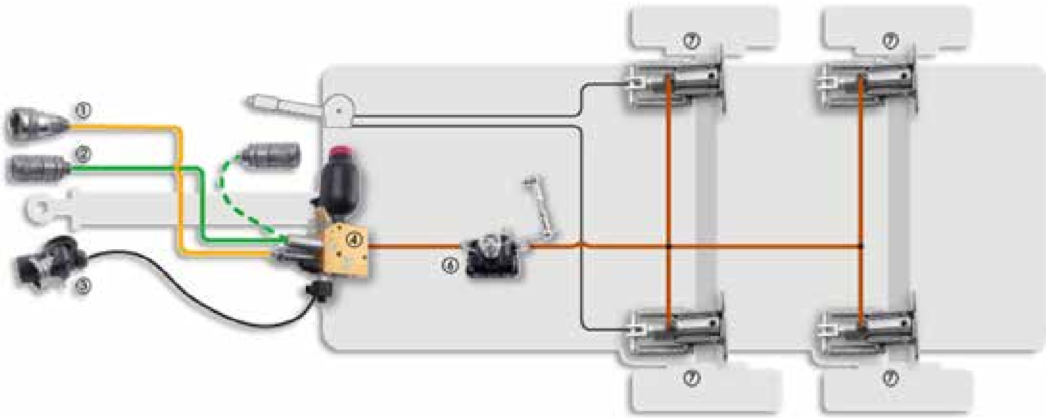
- A service brake, a parking brake and an auxiliary brake are required.
- A 2-line brake system is required.
- A trailer must have load-dependent brake force control.
- The minimum decelerations are defined for all vehicles.
- Vehicles with a permissible maximum speed >30km/h must have a brake performance according to the compatibility band (diagram 2 & 3, EU-DVO2015/68) for empty and loaded conditions (comparable to EC-R13)
- A fixed minimum response and threshold time is requested
- Additional requirements such as: various safety specifications, documentation, brake calculation, test procedures, simulators, etc.

The new hydraulic dual line trailer brake => Installation of the tractor components:



Example of the minimum equipment of a towing vehicle of category Ta

The new hydraulic dual line trailer brake => Installation of the trailer components (systm H2L):



Example for the minimum equipment of a tandem trailer class R3a

Legend:

1. control line couplings (CL)
2. supplementary cable couplings (SL)
3. ABS plug ISO7638-2 (monitoring and power supply)
4. NBV16 dual line emergency brake valve with accumulator
5. mechanical parking brake control
6. ALB-H16 automatic, load-dependent brake force regulator
7. brake cylinder

Description of the main components on the trailer side:

NBV16 - Emergency brake valve, dual line with integrated switchover to single line operation, auxiliary and breakaway brake, accumulator discharge device and accumulator monitoring with immobiliser. Conformity of the hydraulic dual line brake system with EU-DVO2015/68.

ALB-H16 - Automatic, proportional, hydraulic brake force regulator for controlling the brake force of brake cylinders as a function of the load condition of a vehicle. Compatible with the following vehicle classes: S2/R3/R4

RVS16 - The relay valve enables fast bridging of the idle stroke of the brake cylinders of hydraulic trailer brakes, independent of the towing vehicle. The valve is required, for example, for 4 or more brake cylinders with Ø 30mm or for pressure transmission to a second trailer. Thus, the preset threshold time limit can be reached in any situation.

2. Test materials and methods

A group of well-known manufacturer representatives (vehicles and axles), as well as TÜV-Nord (Technical Service for Brake Systems according to EU VO167/2013) have now carried out joint driving and braking tests with this system on the premises of the Dynamic Test Center DTC in Vauffelin (CH) in spring 2018 with the support of the Bern University of Applied Sciences (BFH) in order to test its practical suitability.

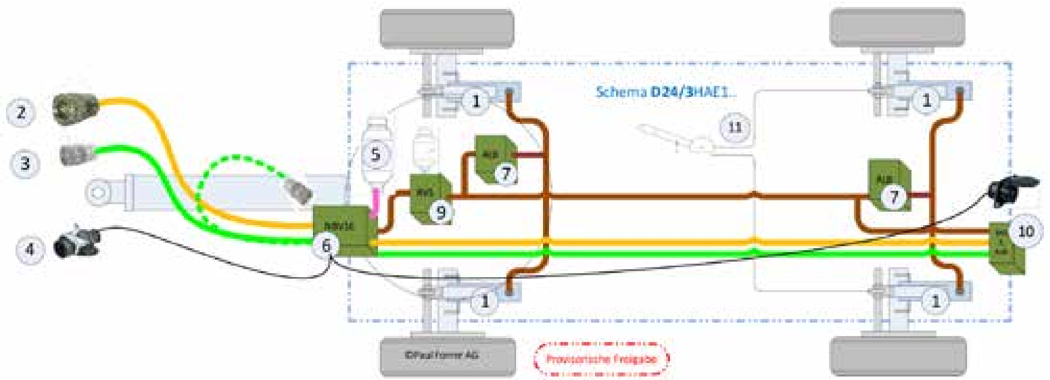
Fliegl Agrartechnik GmbH provided two 18-tonne turntable trailers for these tests, which were loaded with their permissible total weight for the test runs. The axles were first checked and run in by the German axle manufacturer BPW, as is usually done for type approval tests.

In the driving tests, the known behaviour of agricultural trailer trains (tractor with one or two trailers) with 2-line air brakes was used as a basis for comparison / benchmark. In extensive test drives, measurements were taken in various driving situations to check the conformity, functionality and braking behaviour of the system.

Test vehicles:

- Tractor: NH T7.270 (TMR) 200kW - Weight 8.95to - v max 40km/h -
- 2 trailers: Fliegl DK180-88 - 2-axle tipper - weight loaded: 18to / empty: 4.5to

Trailer brake scheme:



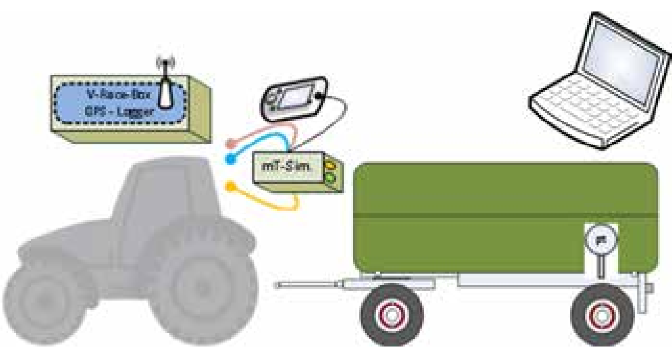
Legend:

1. Brake cylinder with return spring
2. Control line with coupling sleeve
3. Supplementary line with coupling sleeve
4. Electric plug connection in accordance with ISO 7639-2 (ABS 12V)
5. Hydraulic accumulator
6. Dual line emergency brake valve
7. Automatic, proportional, hydraulic brake pressure regulator
8. Relay valve with accumulator
9. Dual line coupling connection for second trailer
10. Park brake lever

3. Tests and results

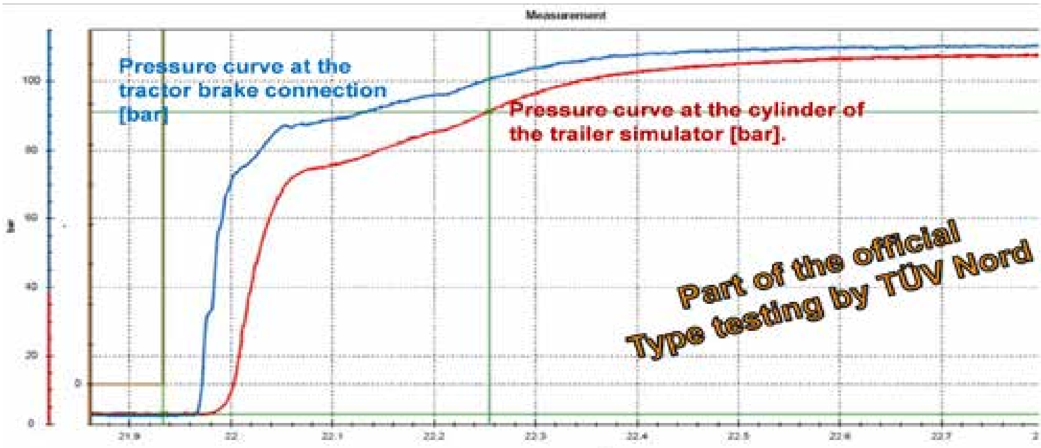
Tests and test methods performed

A) Tests & results of reaction time measurements



Threshold time measurements on the trailer, measurement results:

- CL Flow and pressure from the towing vehicle simulator
- 0.32 sec @ 75% of the reference brake pressure measured on the furthest axle.

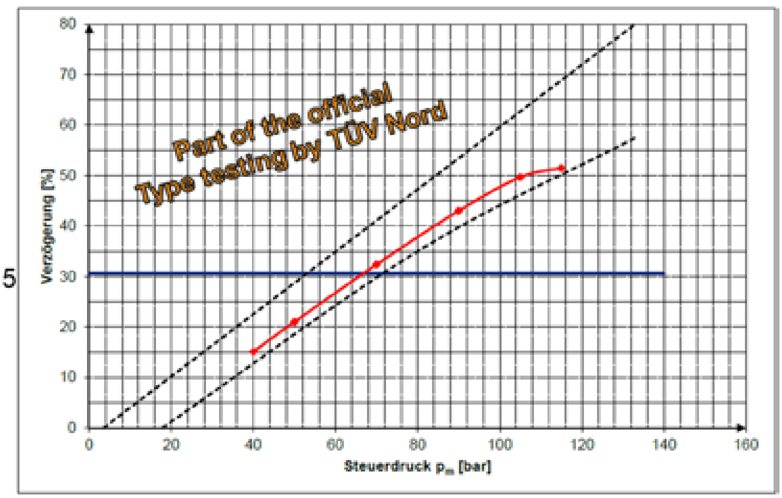


B) Trailer braking performance tests & results

Measurement results of the deceleration measurement on the loaden trailer

- according to EU DVO2015/68 - Pressure from T-Simulator
- six measurements from 40 to 115 bar pm
- Reference measurement z = 5.1m/s² @ 115bar

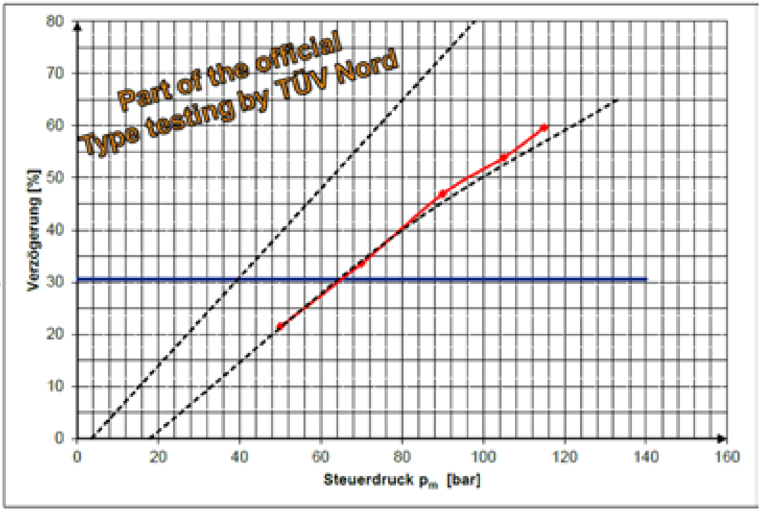
- Simulator braking
- Type-0 test
- Loaded trailers:
- Braking at pm 40/50/70/90/105/115 bar



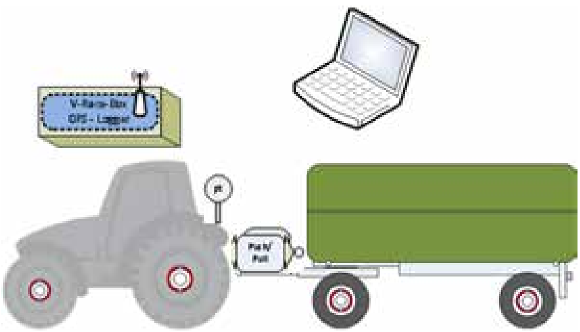
Measurement results of the deceleration measurement on the unloaden trailer

- according to EU-DVO2015/68 - Pressure from T-Simulator
- five measurements from 40 to 115 bar pm
- Reference measurement z = 6.1m/s² @ 115bar

- Simulator braking
- Type-0 test
- trailer empty:
- braking at pm 50/70/90/105/115bar

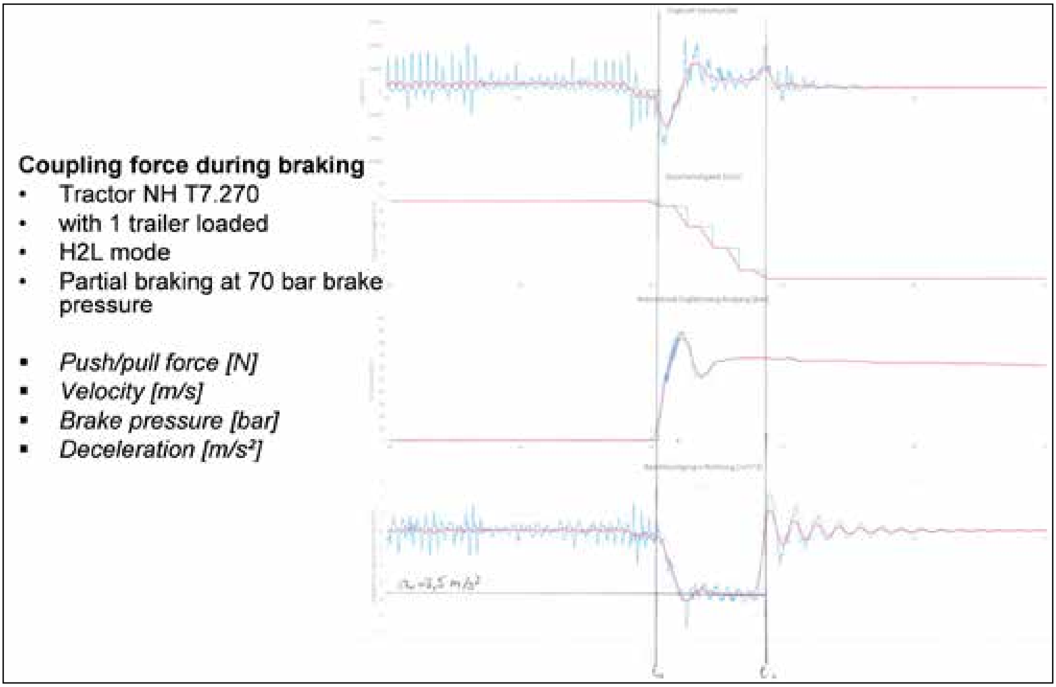


C) Tests & results of the coupling forces / train tuning

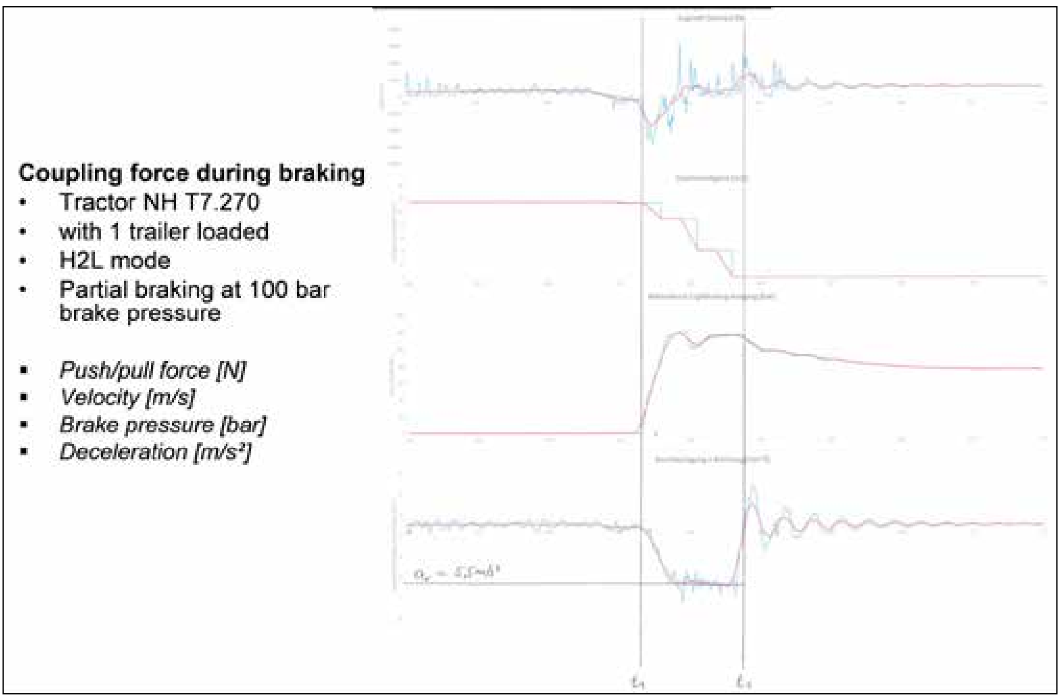


Testing the coupling forces between tractor and trailer during braking

- Coupling force Measurement results with loaded trailer
- Measurement results at pm 70bar:



- Measurement results at pm 100bar :



The results achieved are a very good testimony to the hydraulic brake system H2L of Paul Forrer AG:

- The tests carried out by TÜV-Nord in accordance with EU-DVO2015/68 have been fulfilled and were concluded positively.
- The driving and braking tests with the 2-line hydraulic braking system H2L, with one and two trailers in the train, showed balanced braking and driving behaviour. This applies both to the loaded condition and to the unloaded condition of the trailers.
- The measured decelerations of the individual vehicles in the train were judged to be absolutely uniform.
- With regard to the response and release behaviour of the trailer brakes, no noticeable deviations could be observed from trailers of the same type equipped with compressed air brakes.
- All the technical specifications were met or even exceeded in the test vehicles without any retention.

Following these successful tests, European manufacturers are now carrying out homologations and type tests on various trailers and equipment with hydraulic brakes. Due to the approaching deadlines, a practical dual line hydraulic solution with the higher safety level requirements can now be offered to the market.

References

Thanks to all the participants and the willing support that made these tests possible.

The Involved Members and Test Participants:

- University of Applied Sciences Bern (BFH)- Test Recording / Monitoring / Test Management
- DTC Dynamic Test Center - Test Site and Infrastructure
- TüV-Nord-Mobillity - Test equipment and test devices
- Paul Forrer AG – Tractor- and Trailer Simulators

Test supporters / Participants and co-sponsors:

- Paul-Forrer / Fliegl Agratechnik / CNH-Center-Switzerland
- University of Applied Sciences Bern (BFH) / TüV-Nord / TüV-Süd / VDMA / DTC-Vauffelin
- Various well-known trailers and axle manufacturers from the DACH region

Novel technological framework for digitalizing silage bale life cycle management

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Abstract

The revolution of digitalization has gained interest across all commercial sectors, also in variable applications of agriculture. This paper present demand-based framework of silage bale lifecycle management, and justification of technology solution selections for practical implementation. All the steps from crop harvesting, until the end use is analyzed in farmer's point of view. Information needed for knowledge-based management is gathered and technology selections are initiated in application environment and by value added measuring parameters. Research methodology is based on qualitative summary and analysis over farmers' requirements and daily work practices, combined with literature review and background knowledge on latest technological solutions. Farmers require mittens in hand-working principle, inclusion of quality and location information, and extremely low costs in bale level. Continuously changing temperature and humidity level, dust, vibration and dirt causes challenges to technology selection. In addition, life cycle management in all seasons including tolerability over ice, frost, snow and rain causes challenges to modern technology solutions. The outcome of this research introduces a framework and technology specification of Digibale system, which enables unique bale identification, collecting microclimate information, bale related quality and location data, and enabling data visualization and analysis for further silage production and feeding planning.

Keywords: Silage bale, Digitalization, Digibale, Technological framework, Life cycle management

1. Introduction

Digitalization in farming sector has gained interest and further lead to many pilots and tests. Nevertheless, commercial applications and are still rare, and farmers tend to utilize manual methods without any system level corp management system. This paper aims to this lack: authors present a demand-based framework for silage bale life cycle management, and justification of technology solution selections.

Currently, in Finnish farming context, silage bales are conserved from fall until up to springtime. They are wrapped with bale net and multiple plastic layers. The bales are stored in stacks on the edge of field or near cowshed without any special tag identification (Penttilä, K. 2018). In many cases spray paint is used for bale marking, which often suffer from elapsing, precluding unique tracking, bringing farmers back to manual and population based rough bookkeeping (Penttilä, K. 2018). This causes financial loses as

1) Crop may be used in unideal order,

2) Inefficient logistical arrangements, and

3) Unused bales turning to waste.

Aside of visible bookkeeping, the quality of individual bales is a key parameter influencing on the prioritization of the use of individual bales and further bales' life cycle management (Penttilä, K. 2018). The crop quality is determined by soil composition, grass plant species, fertilizer amount, period of growth, harvesting time and weather conditions (Borreani, G. et all 2018, Crook, T. et all 2016). Based on these parameters, farmers are able to aim high quality silage. Significant factor affecting quality of silage is digestibility, which is predicted by using heat summation (The Natural Resource Center of Finland 2018). Other valuable parameters measured during the harvesting process are dry matter, harvested yield, microclimate and weather forecast (McDonald, P. et all 1991). Combined with unique bale identification and location information, and measuring of crop quality in real-time, enables powerful and systematic methodology to enhance viability. The beneficiaries achieved by digitalization are clear, and to overcome the state of art challenges, this paper presents technological framework and implementation solution to manage silage bales' life cycle from field to cowshed.

1.1. Silage bale life cycle

Silage bale life cycle consists of four phases, which can be differentiated by user needs and technological solutions (Growing opportunities Center 2008). The remainder of this subsection describes these stages, and concludes related technical requirements.

1) Baling process
   Silage bale baling process consists of silage mowing, harvesting, and rolling and wrapping to bales. In Finnish context, the mowing is typically a separate action, where the silage is purely cut and left at its growing location. After mowing, harvesting, rolling and wrapping is conducted by baler machine. The process is automated in a way that the frames just need to set the start point and end point by respectively laying down and up the harvester pick up. To maintain similar automation level, the technological solution to be developed shall operate in automated and invisible manner. (Growing opportunities Center 2008, Penttilä, K. 2018)

2) Bale logistics
   Bale logistics include silage bale transportation from a field to a cow house or a storage, bale handling with forklifts, and possible logistics related to commercial actions. In each transportation step, the physical location of the bales is changed, and the prevailing location shall be updated to database. This requires both bale identification and location information. Commercial actions include trading tool for farmers, such as a web store, which contains the relevant bale specific data and location information. Possible trading actions must enable data transfer between seller and buyer. (Penttilä, K. 2018)

3) Bale management at a cow house
   Bale management at a cow house requires up to date information on silage bales' location and their quality. Therefore, multiple identification points, also manual identification equipment are needed to continuously collect the needed location information to enable optimal feeding and guaranteeing the availability of most optimal silage. (Penttilä, K. 2018)

4) Ending bales' life cycle
   Last step in silage bales' life cycle is marking the bale "used". This step is needed as a general withdrawal of a bale does not allow data analytics for future planning. Data collected from used bales is stored for analytical purposes, enabling farmers to make decisions based on factual information, not just based on experience and feelings. Once a bale is marked as used, it is automatically removed to history file, where analytics picks up relevant data for further processing. (Penttilä, K. 2018)

1.2. Digibale concept

Digibale concept, developed in HAMK Bio research unit, in collaboration with relevant research experts, is a concept enabling digitalized life cycle management of silage bales (Digibale project 2018). It consists of multiple functions, namely: unique bale identification, collecting microclimate information, analyzing bale related data, managing bale storages, visualization of bale related data both in single bale and crop level, and selling and buying silage bales from a web store. The project is divided to four work packages (WP1 – WP4), which are presented in Fig. 1 and described shortly in the following (Digibale project 2018):

Fig.1. Schema of Digibale concept (Digibale project 2018)

WP1: Background data collection, benchmarking and foundations:

- to collect information about the life cycle management of bales' life cycle
- seek information on which parameters are important for the target audience
- hardware and network connections: microclimate measurements, radio frequency identification (RFID) reader and transponders, location information, database connection, supply in baler machine
- field acceptance testing

WP 2: Building database and compatibility

- develop the unique marking of bales
- collect and export the status and location data to the database
- field testing with baler machine

WP3: Collection and use of data

- collect, analyze and combine binary identification, location and measurement data from internal and external data sources
- user interfaces for different purposes

WP 4: Business and Service Design

- Web store
- own data for farmers
- big data for researchers

This paper focuses on technology reasoning and specification conducted in WP1 and WP2.

1.3. The basis of Digibale system

Even though farmers typically use manual bookkeeping on harvested silage crop, they have gained understanding and expertise concerning their fields' and crops' quality, and harvesting periods. Most of this knowledge is feel-based, and based on actions on previous years. The Digibale -project brings out the factual parameters, introduces justified methods to measure them, and finally, concludes how farmers may benefit the proven data on their crop (Digibale project 2018).

The fundamentals of this research is gained from discussions with farmer representatives in Digibale project innovation group. By combining practical experience with literature review (Borreani, G. et all 2018, Crook, T. et all 2016, Fukagawa, S. et all 2017, , McDonald P. et all 1991), the conclusion of system requirement is as follows:

- Weatherproof system
- Tolerance over vibration, dirt, moisture, and rodents
- Unique bale identification
- Information on bale harvesting location
- Information on temperature and humidity of harvested silage (Crook, T. et all 2016)
- Information on digestibility and dry matter content to enable optimal feeding, planning, and bale weight to enable the calculation of the yield per location and hectare (Borreani, G. et all 2018, Fukagawa, S. et all 2017)
- Fully automated system: need to operate by mittens in hands –principle
- Own, separate operating system, only power from tractor
- Fast installation
- Possibility to integrate already existing farming management systems

2. Materials and Methods

The technological framework and technology specification of Digibale system solution is reasoned by farmer's current operations and need based evaluation of each operation phase in silage bale life cycle management. Research work is based on literature reviews (Borreani, G. et all 2018, Crook, T. et all 2016, Fukagawa, S. et all 2017, Kuhn VBP2265 baler specification 2018., McDonald P. et all 1991), discussions and meeting memos with Digibale project's innovation group members (Digibale project 2018, Penttilä, K. 2018), and background knowledge on relevant technology (ETSI Technologies and Glusters: RFID 2018, Finkenzeller K. 2003, Penttilä, K. 2018, Sachdeva, P. 2014, Sobota, R. et all 2013). System specification is based on technological experience on commonly known technologies, and their suitability on diverse environments and applications.

2.1. Silage bale harvesting principle in Finnish context

Silage bales are conserved from typically three harvested summer corps, over winter and up to until springtime. Typical harvesting timeframes are first in the beginning of June, second at the end of July and third at the end of September. The timing varies slightly depending on the weather conditions of the growing season. The best feed effect is obtained from the first crop when the digestibility (D-value) of the silage is high (McDonald P. et all 1991). A warm period during the harvest of the first crop increases the dry matter content, but at the same time the digestibility decreases rapidly (Borreani, G. et all 2018). The optimal harvesting period is about one week. In general, the D-value of the second crop decreases more slowly than of the first crop (The Natural Resource Center of Finland 2018). The challenge with harvesting of the third crop is often the autumn wetness and low fiber content of the silage. The amount of the fiber can be controlled by mixing the third crop with previous crops, if this is possible on the farm. In Finnish context, The Natural Resource Center offers D-value predictions based on the heat sum that facilitates the determination of silage harvesting time (The Natural Resource Center of Finland 2018).

After mowing, silage is harvested by baler machine, and further wrapped with bale net and multiple plastic wrapping layers. The bales are stored in stacks on the edge of a field or near a cowshed. Bales are often marked with spray paint to identify harvesting year and crop. Combined with manual bookkeeping, easily elapsing bale markings do not offer reliable bale identification method. Furthermore, bales are subjected to variable weather conditions, such as rain, snow and frost, and repeating freezing and thawing. In addition, ultraviolet radiation caused by sun, and rodents and birds may cause damage to bale wrapping, which may either ruin the fermentation process or later during the storage season, devastates the existing microclimate in the bale. Silage bale conservation is based on lactic acid fermentation, with pH around four and dry matter variation between 20% and 45% (McDonald P. et all 1991, Growing opportunities Center 2008). This condition will stay constant only if the microclimate is isolated from surrounding environment. Therefore unbroken wrapping plays a crucial role in the quality of the silage (Growing opportunities Center 2008). After baling process, the bales are handled with pallet forklifts so that the bales' axis is oriented vertically. Bale handling is somewhat rough, and manual treatment is avoided. In this research, the bale size varies between 1300 mm and 1600 mm in diameter.

2.2. Description of sequences in baling process

The understanding of baler specific baling process is a key factor to enable the collection of location data of each bale, during the baling process. As baler may handle two bales at once, understanding the sequences, and how to combine location information to each bale, becomes important.

Baling process consists of two different sequences: baling of first bale, and baling of mid and last bales. The remainder of this subsection details sequences for Kuhn VBP2265 baler (Growing opportunities Center 2008, Kuhn VBP2265 baler specification 2018).

2.2.1. First bale

The baling process starts when the farmer turns the tractor power on. Simultaneously the silage pick-up starts to rotate. Once the pick-up is laid down, the start location of the first bale harvesting is detected. Detection is based on the triggering of the limit switch aside of the pick-up, and combining the information with GPS location data. Once the chamber of the baling machine is full, the bale is ready and the baler stops. This is detected by the embedded software, and again GPS information is stored. Once the bale is wrapped, it is dropped on field. The dropping location is detected by adding a secondary limit switch to wrapping machine, and according to triggering point, the third GPS location is stored. (Kuhn VBP2265 baler specification 2018)

2.2.2. Mid and last bale

Baling the mid and the last bale, i.e. all bales from the second to the last, starts when the baler starts to move again after dropping the first bale from the chamber. The GPS location information is detected and handled by embedded software. The end of the bale harvesting is detected similarly as in the first bale case, and also the drop location is detected in similar manner by using limit switch and GPS. (Kuhn VBP2265 baler specification 2018)

2.3. Technological requirements for Digibale system solution in a baler

This section introduces the requirements for technological solutions, which can be utilized in baler to achieve Digibale system solution. Requirements are concluded based on user expectations, application environment demands and baling process sequences.

2.3.1. Embedded system

Identification and quality parameter's measurement system, and location information system shall be controlled by an efficient embedded system. In addition, initial data processing shall be conducted, and relevant output information is sent to cloud service system. Raspberry Pi is chosen to conduct these actions, as it offers sufficient performance and connection possibilities for the Digibale application (Sobota, R. et all 2013, Sachdeva, P. and Katchii, S. 2014). Operating power is acquired from the tractor, but otherwise fully independent operation capability is enabled.

2.3.2. Identification technologies

According to innovation group discussions, three major requirements for identification technology were acknowledged:

- Low costs: single identifier should not cost more than 50 Euro cents
- Sufficient durability over winter season and against rodents and birds: identifiers should be placed inside bales, forcing non-visual, electrical identifier
- Farmers require mittens in hand –operation: identification procedure shall be automated

Passive RFID technology were chosen to implement identification technology in Digibale system. It offers sufficient identification distance, requirement of nonvisible identifier, weather tolerability and low costs (ETSI Technologies and Glusters 2018, Finkenzeller K., 2003, Keskilammi M. et all 2003, Sydänheimo L. et all 2008). Suitability of passive RFID to silage bale identification has been previously tested and verified by authors (Penttilä, K. et all 2018).

2.3.3. Location technology

Location information is required from multiple steps during baling process. Specifically and according to farmers needs, three different location marks from baling of each bale shall be detected by the combination of GPS and state sensors operating according to baling process sequence. The needed locations include the start and the end locations of harvesting process of each bale, and the drop location of each bale. The drop location presents the last seen location until the bale is collected, and location is updated accordingly. With these location points, farmer is able to combine silage in each bale to certain area in the field, and also follow the up to date location of each bale in field and in cow house.

Technology solution for location information was decided to keep separate from the tractor's or baler's navigation system. This requirement was initiated in order to avoid any possible errors and system management faults and challenges in machine warranties.

2.3.4. Silage quality quantification

In pilot system, silage quality is determined by measuring continuously multiple parameters from the silage harvested. Quantities to be measured were determined according to the requirement of how silage quality is determined and future production planning is conducted (McDonald P. et all 1991). Based on literature review (McDonald P. et all 1991) and farmers' experience following parameters were chosen and measuring quantities:

- Temperature
- Humidity
- Weight
- Digestibility
- Dry matter

Quality sensors must fulfill the requirements of challenging environment with high humidity, temperature and dirt level, and tolerability of vibrations, shocks, wetness and freezing. Minimum of IP44-classified components or integration in such a field box is therefore mandatory.

2.3.5. Communication to cloud service system

The embedded identification system and measurement system shall include wireless link to cloud service, where the application software handles data visualization. Data is updated with short time frames, so relatively fast link is preferred. In addition, short-range links are not favored, since the system should be able to operate also in fields.

2.3.6. Cloud service

A cloud service was chosen to manage the user interface and visualization of bales and their measured and identified parameters. The selection of cloud service system was made according to developer's preference, and application itself do not require the use of any specific solution.

2.4. Equipment selection for Digibale system solution

The proposed equipment selection is not absolute, and one should notice that the choices are not unique, but based on authors' experience; as attractive and potential options for piloting and performance verification. Reasoning is based on:

- Component's' tolerability against challenging environmental conditions in the application
- Components' usability, availability, easy workability and simplicity
- Components' low costs

Table 1 introduces the pros and cons of the chosen technologies for Digibale system solution.

Table 1. Technology selections

Subsystem	*Technology*	*Pros.*	*Cons.*
Embedded system	Raspberry Pi	Easy to use, commonly known, efficient	Requires IP classified field box
Identification technology	Passive RFID	Low cost, can be integrated inside bale wrapping, do not suffer from environmental wearing	Reader costs
Location system	GPS and state sensors	Generally approved and known technology, state sensors enable multiple locations per bale	Requirement of monitoring bale process sequences, and ability to handle information of two bales at once
Silage quality sensors	temperature, humidity, digestibility, dry matter, weight	Added value on crop quality to farmer. Temperature and humidity sensors have low cost	Digestibility, dry matter, and weight sensors are relatively expensive, but have strong additional value
Wireless link	3G/4G	Low cost, well known technology, easy to integrate	Wireless technology has always a small risk of blind spots, though the network coverage is very high in Finnish context

Fig. 2 presents a schematic diagram on chosen technologies, and the communication links between them. All components marked with pink color are integrated as one application system in baler machine, and communicate wirelessly with passive RFID transponders i.e. tags (marked in green), and with cloud application (marked in yellow).

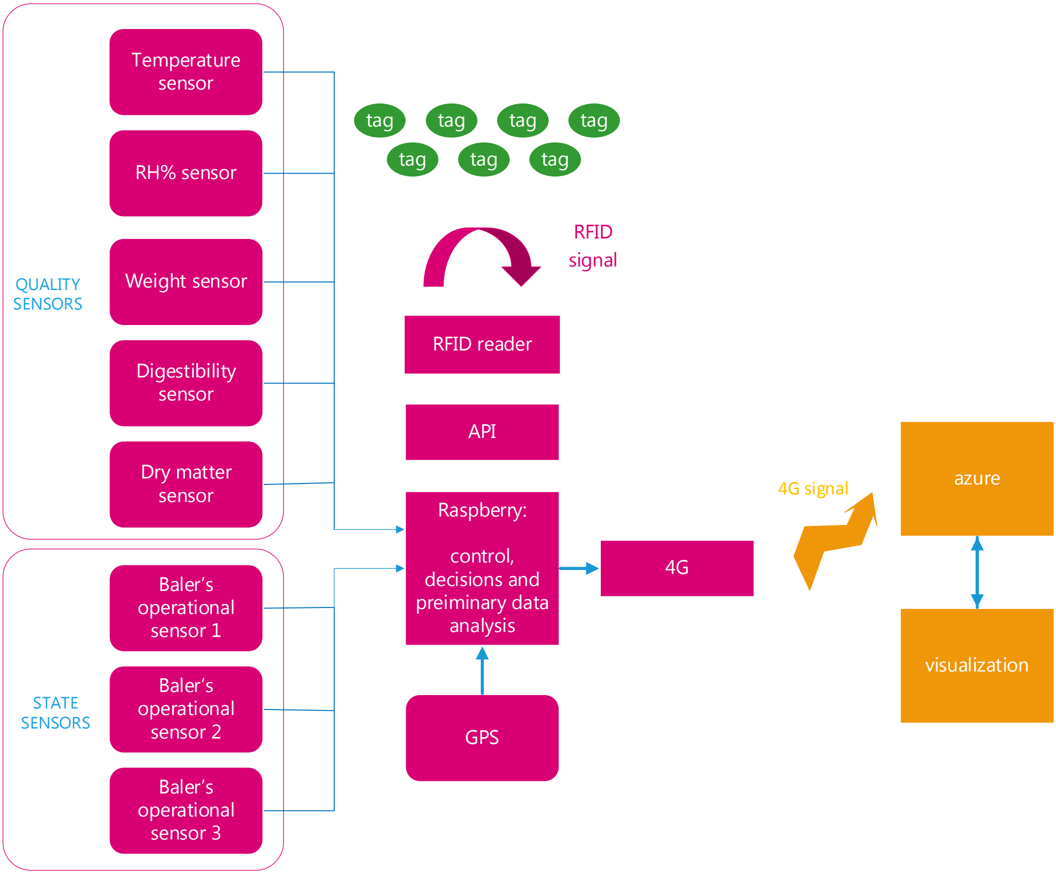

Fig. 2. Schematic diagram on chosen technologies and their connections

2.5. Pilot

Presented framework was piloted in a field lab, in real farm and with baler in actual use. Fig. 3 introduces system implementation in practice: left side presents identification, location and quality sensing systems integrated to embedded control system, and further sealed with IP44 classified field box to achieve a real utilization conditions and corresponding verification results. The right side presents ready-made bale with unique identifier, waiting for bale wrapping.

Fig. 3. Practical implementation

3. Results and Discussion

The introduced system specification was verified with pilot system arrangement, in a real field lab with a member of the Digibale project innovation group. Baling process operated in a regular manner, where the farmer run the baler machine in a conventional way. No extra actions were required from him, while the Digibale system identified all baled silage bales, measured the quality data and location information. Totally 151 silage bales were successfully identified, and location and quality data were collected and combined to bales' unique identifier information in the embedded system. Development of the weight, the digestibility and the dry matter sensors and their integration is still ongoing and the verification shall wait until next harvesting season. However, technical arrangement for the integration already exists.

The specified and piloted system will have significant impact to the production planning of silage bales, planning of cattle feeding and the management, logistics and trading of silage bales. In Finnish context, farmers have shown genuine interest and willingness to either participate or follow up the research program developing Digibale concept. Presented technological framework enables extensive sampling and development work for silage bale management on next harvesting season. Already conducted pilot enables weather condition testing and analysis over winter season. Fig. 4 introduces RFID transponder in a silage bale and identification procedure with handheld reader, verified in October, just before winter season. This preliminary verification gave 100% identification performance after two-month storage period. With the quality sensors being currently under study, the crop quality analysis can be launched in full.

Fig. 4. RIFD transponder in bale (left) and identification of the transponder (right)

4. Conclusions

This paper presented technological framework for silage bales' life cycle management in digitalized manner. The research work done in this paper detailed and analyzed the baling process, its technical sequences and needed solutions for identifying, collecting location information and quality information from the process. In addition, silage bales' life cycle from mowing until feeding were evaluated from technical point of view, and reasoning for the quality quantities were justified in order to optimize the identified quality factors for silage.

The beneficiaries achieved by digitalizing silage bale life cycle are clear, and introduced Digibale project has gained interest along Finnish farming sector and agricultural business. Next steps in the research program include full verification of quality measurements and analytics, durability evaluation over winter season, and population testing in multiple field lab sites.

Acknowledgements

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References

Borreani, G., Tabacco, E., Schmidt R., Holmes B., Muck R. (2018) Silage review: Factors affecting dry matter and quality losses in silages. Elsevier Journal of Dairy Science. Vol 101, Issue 5. pp 3952-3979

Crook, T., Stewart, B., Sims, M., Weiss, C., Coffey, K., Beck, P. (2016). The Effects of Moisture at Baling and Wrapping Delay on Storage Characteristics of Annual Ryegrass Round Bale Silage. *Journal of Animal Science*, Vol. 95, Issue 1. Pages 13. https://doi.org/10.2527/ssasas2017.026

The Natural Resource Center of Finland (2018). Digestibility value predictions based on heat sum. Available at: www.karpe.com/darvoennuste Assessed: 10.12.2018.

Digibale project (2018). Digibale – Efficiency in life cycle control of forage bales. Luke, Natural Resources Institute Finland. Available at: https://www.luke.fi/en/projects/digipaali/ Assessed May 21, 2018

ETSI Technologies and Glusters: RFID (2018). Available at: http://www.etsi.org/technologies-clusters/technologies/radio/rfid. Accessed: May 18, 2018

Finkenzeller K. (2003). *RFID handbook 2nd ed*. John Wiley & Sons Inc. West Sussex, UK 427p.

Fukagawa, S., Kataoka, K., Ishii, Y. (2017). Round-Bale Silage Harvesting and Processing Effects on Overwintering Ability, Dry Matter Yield, Fermentation Quality, and Palatability of Dwarf Napiergrass. Agronomy 2017,7(1), p.10. doi:10.3390/agronomy7010010

Keskilammi M, Sydänheimo L, Kivikoski M. (2003). Radio frequency technology for automated manufacturing and logistics control. Part 1: passive RFID systems and the effects of antenna parameters on operational distance. International Journal on Advanced Manufacturing Technology 21 (10–11):769–774

Kuhn VBP2265 baler specification (2018). Available at: https://www.svtechnika.lt/uploads/Kuhn_VB-VBP.pdf Assessed 10.10.2018.

McDonald P., Henderson A.R., Heron S.J.E. (1991). *The Biochemistry of Silage.* Second Edition. Chalcombe Publications, Aberystwyth. p.340.

Penttilä, K. (2018). Meeting memorandums with Digibale project innovation group members. Multiple meetings in 2018.

Penttilä, K., Suokannas, A., Pölönen, I. (2018). Performance Evaluation of Passive Radio Frequency Identificaton in Silage Bale Application. Agricultural Engineerging, AgEng conference July 8-12 2018 Wageningen, the Netherlands

Sachdeva, P., Katchii, S. (2014). A Review Paper on Raspberry Pi. International Journal of Current Engineering and Technology. Vol. 4, No.6. E-ISSN 2277 – 4106, P-ISSN 2347 – 5161. Available at: http://inpressco.com/category/ijcet Assessed: 10.12.2018

Growing opportunities Center (2008). Silage Production. Available at: https://www.gov.mb.ca/agriculture/crops/production/forages/pubs/baled_silage_production.pdf Assessed: 10.10.2018.

Sobota, R., Ŝl, R., Balda, P., Schlegel, M. (2013). Raspberry Pi and Arduino boards in control education. IFAC Proceedings Vol. 46, Issue 17.Pages 7-12. https://doi.org/10.3182/20130828-3-UK-2039.00003

Sydänheimo L., Nummela J., Ukkonen L., McVay J., Hoorfar A., Kivikoski M. 2008. Characterization of Passive UHF RFID Tag Performance. IEE *Antennas and Propagation Magazine, vol.* 50, pp. 207-212, 2008, ISSN 1045-9243.

Pneumatic distribution of straw from within a Straw blower impeller to the ground, a predicting tool

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Abstract

Straw blowers are machines that carry out straw pneumatic distribution to troughs. They considerably cut down time spent travelling between fodder stocks and troughs. The performance criteria of such a "feeder" are measured by feeding or bedding quality in terms of the regularity and cleanness. Therefore an accurate straw distribution predicting tool is useful to guaranty distribution quality.

The straw blower system ensures the circulation and distribution of a two-phase mixture consisting of air and strands of straw. The technical challenge is to be able to predict the flow of this mixture to an acceptable level of precision, by implementing acceptable computational power.

In this context we developed and present an Eulerian-Lagrangian (i.e. CFD-DEM) numerical tool using the open-source OpenFOAM toolbox. The solver includes the effect of the straw volume fraction on the air and is suitable for dense particle flow simulation. It uses existing functionality for particle clouds and their collisions which take into account straw-straw interactions (i.e. "4 –way coupling" interactions).

Keywords: Computational fluid dynamics, CFD, DEM, predicting tool, straw blower, numerical simulation, feeder, trough

1. INTRODUCTION

Straw blowers are machines equipped with mechanical elements intended to detach straw bales and to project straw on the stabling area of the farm animals (see Figure 1).

The operating principle is as follows:

1. Straw bales, usually in a cylindrical form, are introduced into a trailer;

2. They are pushed by a conveyor towards one or two feed rotors which detach the straw from the bales;

3. Downstream, a Turbine create the flow of air which drive the strands of straw towards the distribution chute;

4. Finally, an air jet and blown straw is oriented by the chute and the jet orient the straw over the distribution area.

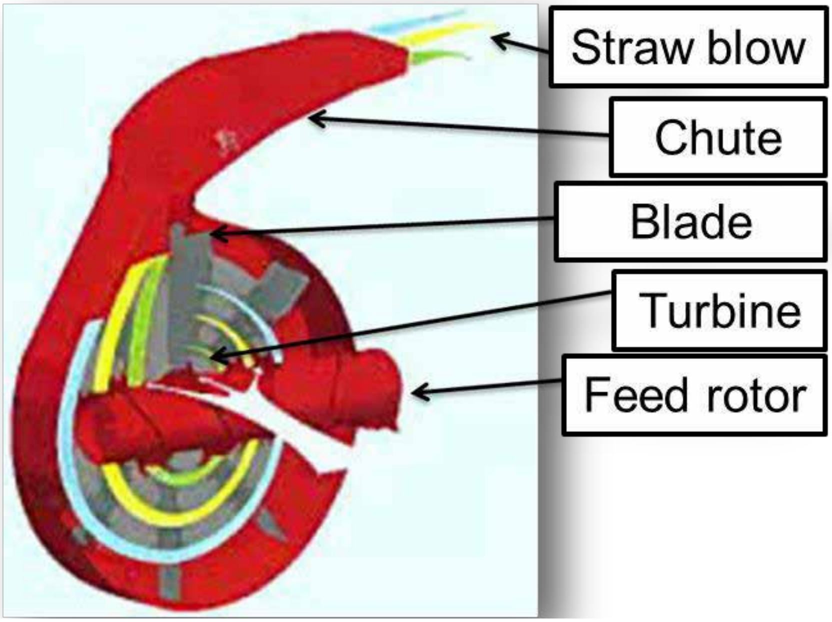

Figure 1: Basic components of the Straw blower [1]

The turbine wheel is fitted with eight bolted-on blades. The straw spread over the entire surface of the turbine after the feed rotor to be blown in identical quantities over the entire depth of the bedding area.

After the feed rotor, the system must ensure the circulation and distribution of a two-phase mixture of air and strands of straw. The technical challenge is to be able to simulate numerically the flow of this mixture to an acceptable level of precision, by implementing acceptable computer resources.

2. MODELING STRATEGIE

The development of a tool for predicting pneumatic distribution of straw from the turbine to the jet requires taking into account the highest level of interaction, i.e. “Four-Way coupling”. In other words, both the influence of the straw on the flow and the interaction phenomena between strands of straw (collisions) must be taken into account.

The calculation approach selected for the air-straw mixture is the (Computational Fluid Dynamics) CFD - DPM/DEM (Discrete Particle Modeling / Discrete Element Method). This approach, also called Eulerian-Lagrangian approach, treat the fluid phase as a continuum while the dispersed phase is treated as particles modeled individually or in packs. In this case, the continuity and motion conservation equations are solved for the continuous phase, while the dispersed phase is solved by the Discrete Element Method (DEM) for the individual particles.

A set of experimental measurement has been carried out using Particle image velocimetry (PIV) and High speed camera (HSC) acquisition on the straw blower machine with and without straw. Air velocity profiles and straw velocity distribution are used to calibrate the numerical model, thus ensuring accuracy and details of the predicting tool to unprecedented levels.

3. DRAG COEFFICIENT OF STRAW

The particles that concern us are strands of straw. They are characterized by a cylindrical shape with high aspect ratio and possibly deformable. The driving dynamics of these particles in the air is governed mainly by the value of the drag coefficient. Depending on the orientation of the strand with respect to the direction of the flow, it is possible to obtain different straw orientations, and therefore very different drag coefficient values. The usual method used to determine the drag coefficient of a particle is to measure the velocity of an ascending air jet that keeps the particle in equilibrium. This 'terminal velocity' is also called the speed limit of the object falling into stagnant air [2]. The equilibrium relation between the drag force exerted by the air and the weight of the object makes it possible to obtain the relation between the terminal velocity and the drag coefficient. This experiment allows us to estimate the drag coefficient against the length of the straw strand (see Figure 2).

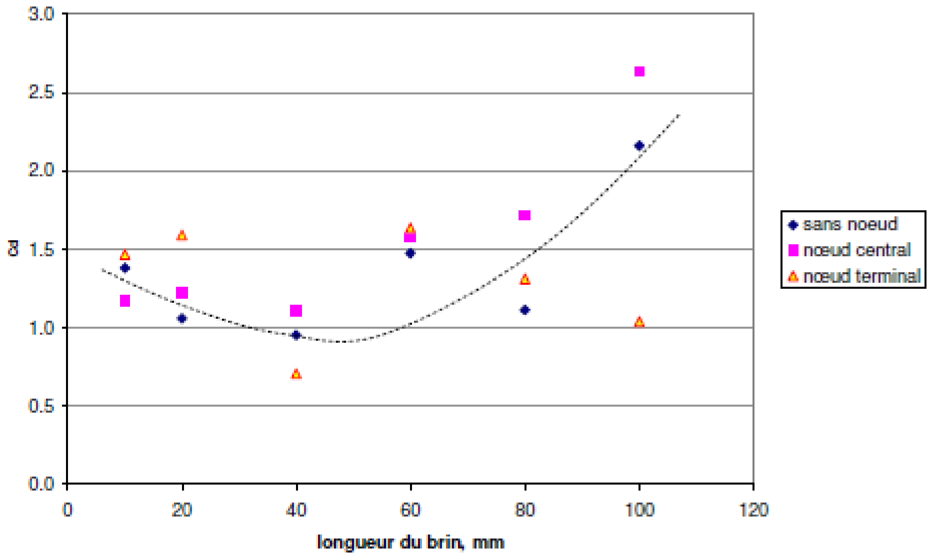

Figure 2 : Drag coefficient Cd vs the length of the straw strand in mm [5]

4. SOFTWARE

The study is carried out with OpenFOAM (Open Field Operation And Manipulation) [3] a multi-physics simulation toolkit mainly focused on solving the equations of fluid mechanics. It has been distributed since 2004 under the GNU / GPL open source license by the British company OpenCFD Ltd. Its development, in C ++, was initiated by "Imperial College London". It consists mainly of a software library in free C ++ language, and various tools, in the form of libraries and applications, to perform resolutions. It comes with numerous solvers covering a wide range of fields such as combustion, compressible, incompressible, multiphasic, particulate flows, with chemical reactions, heat transfers ... Different turbulence models (RANS, LES ...) are also present. Solvers used in this study are PIMPLEFOAM and MPPICFOAM of OpenFOAM 4.1.

5. CFD MODEL VS AIR MEASUREMENT

Detailed comparison of AIR velocity profiles in the chute, show that numerical simulation results (see example in Figure 3) are in agreement with measurements (see example in Figure 4).

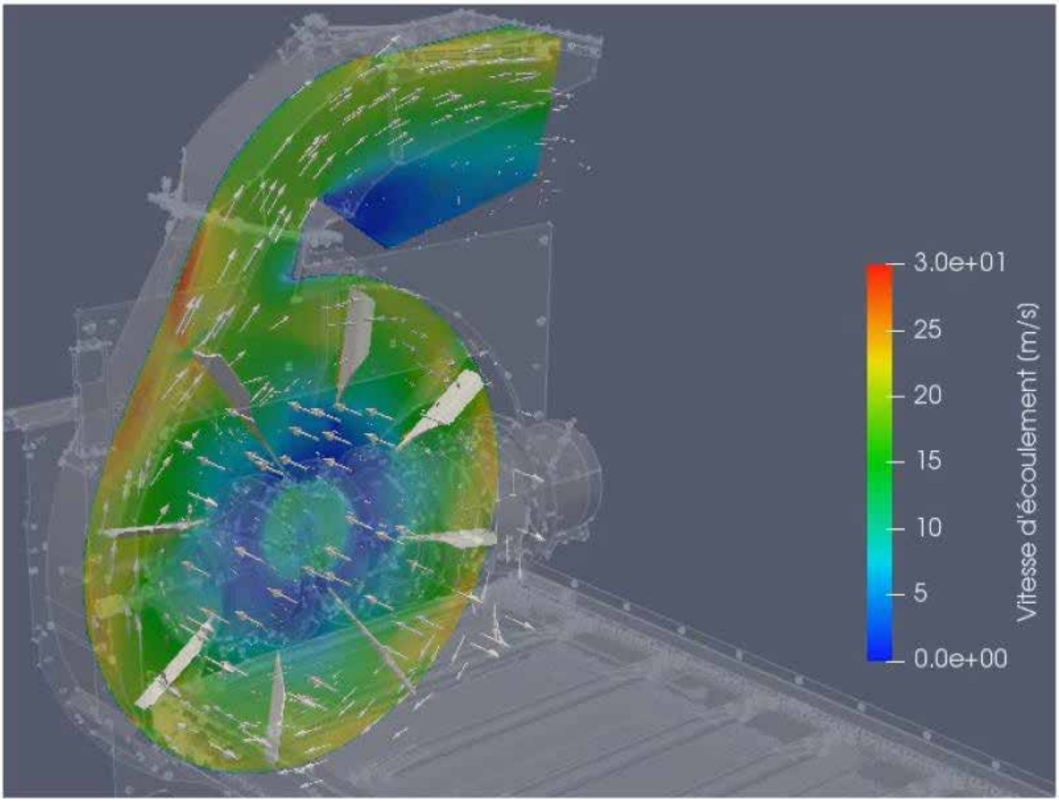

Figure 3 : Snapshot of the transient numerical simulation with AIR

Velocity at the chute outlet is of the order of 20 m/s at turbine rotation speed of 270 rpm and 40 m/s at 540 rpm both in the measurement results and in the results of numerical simulations.

Finally, the comparisons of turbulent intensities show that the "Spalart-Allmaras" turbulence model, the simplest and fastest model available for CFD calculations, is sufficient to capture qualitatively and quantitatively the turbulence phenomena in the chute.

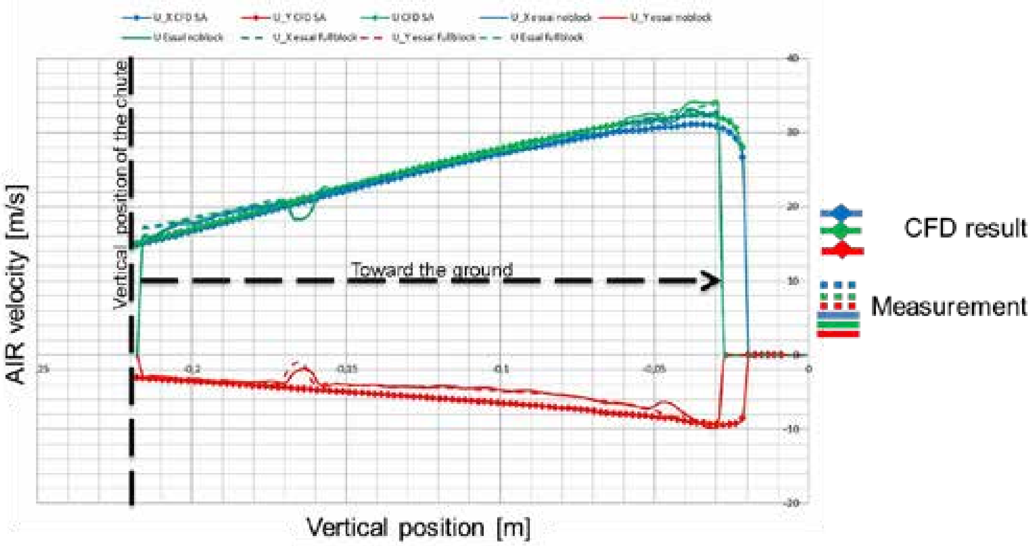

Figure 4 : Comparison of velocity profiles from measurements vs CFD results in the chute

6. STRAW MOTION IN AIR

The equation of motion needs to take into account all the relevant forces acting on the straw, in order of importance:

1. drag forces; → > 80% of the total force
2. gravitational force;
3. lift;
4. pressure force.

} < 20% of the total force

These forces available in OpenFOAM are implemented in the following routines:

1 *NonSphereDragForce*: Drag model for non-spherical particles;
Derived from the Haider and Levenspiel correlation [4] which introduces a form factor defined as the ratio of the surface of a sphere having the same volume as the particle and the real surface of the particle.
This drag coefficient law is compared in Figure 5 with other available laws and measurements of Figure 2.

2 *GravityForc*e: gravity;

3 *SaffmanMeiLiftForce*: Saffman-Mei lift model;

4 *PressureGradientForce*: pressure gradient force.

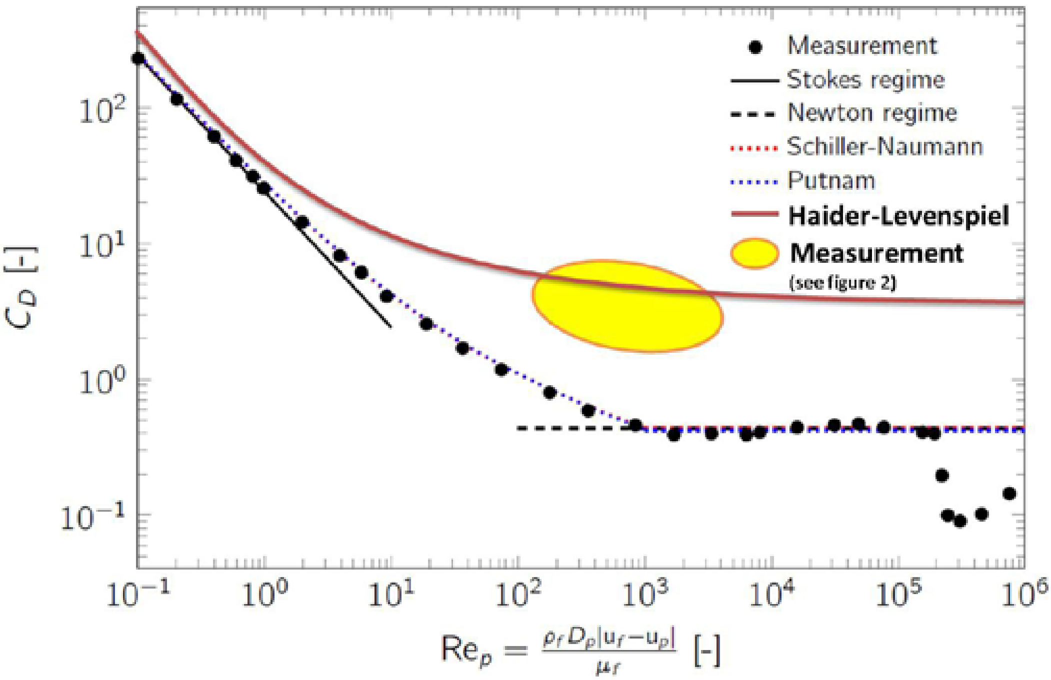

Figure 5 : Drag coefficient versus Reynolds number of particles, comparison of measurements (from Figure 2) with Schiller-Naumann (1935), Putnam (1961) and Haider-Levenspiel (1989)

7. CFD/DEM MODEL VS STRAW MOTION MEASUREMENT

In order to compare the different experimental conditions, all velocity values are normalized with respect to the mean flow velocity of the straw *Uref*. This value depends on the speed of rotation of the turbine, and results from the observation of the average velocity for different series of tests carried out under the same experimental conditions.

The values of the reference velocities are listed in Table 1.

Rotational Speed [*rpm*]	U_{ref} [m/s]
270	8
540	14
620	17

Table 1 : Reference velocities used in the following plots

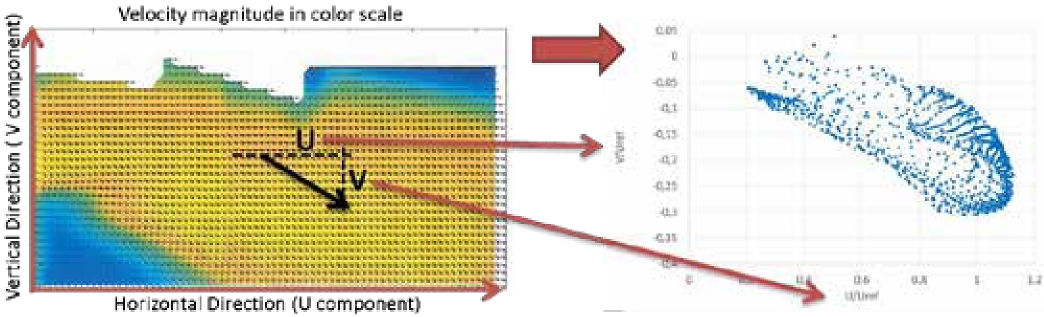

Figure 6 : Velocity field of the straw with color magnitudes as well as velocity glyph (left panel). Velocity dispersion in horizontal vs vertical components (right panel).

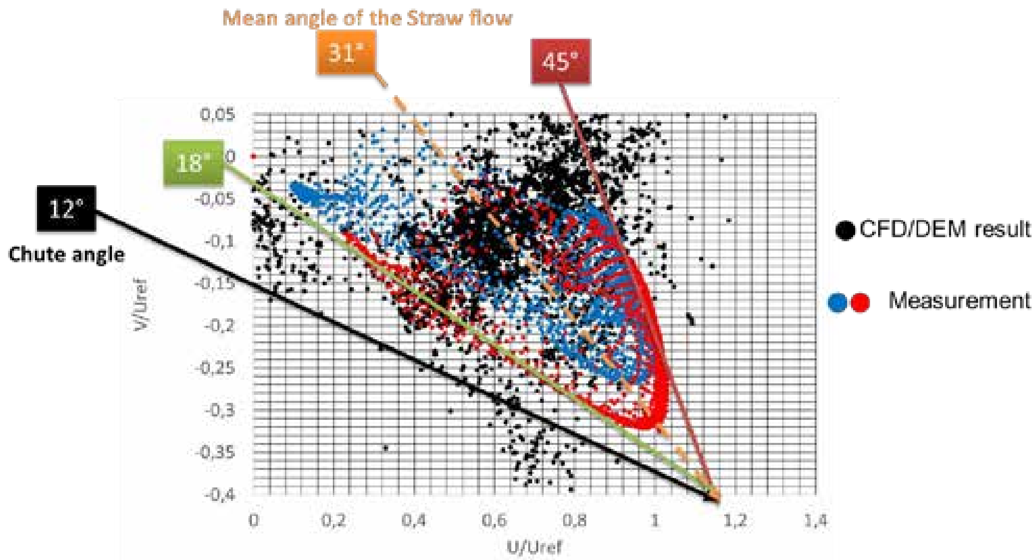

Figure 7: Velocity dispersion in horizontal vs vertical components with highlights of flow angles at the chute outlet.

Comparison of straw velocity dispersion plot (see Figure 7) shows that the numerical simulation results are in agreement with the test results. Figure 7 shows that the average magnitude of the straw velocity is of the same order of magnitude in measurements and in numerical simulations.

It is important to note that average magnitudes of the straw velocity (listed in Table 1) are nearly three times lower than the velocity magnitudes resulting from measurements & calculations in AIR only (without straw) (see Figure 3, Figure 4). It can be concluded that the straw has a significant effect on the air flow. It is not sufficient to perform AIR only calculations to predict straw spray and straw distribution on the ground.

Figure 7 show the velocity dispersions of the experimental measurements (blue and red dots), which show a characteristic "V" shape with an average exit angle of 31° with respect to the horizontal plane (to the ground). This characteristic "V" shape indicates that the straw flow at the outlet of the chute is divided into two main streams, one oriented at 18°, the other at 45°. The angle formed by the chute with respect to the horizontal plane is 12°. The jet oriented at 18° is the jet controlled by the angle of the chute. The 45° jet is a jet condemned to go less far and can represent a significant loss.

The dispersion of the numerical simulation results (black dots in Figure 7) reproduces only slightly this characteristic “V”-shape. The average angle of the jet of straw from the numerical simulation is nevertheless equivalent to the average angle of the jet of straw resulting from the test results, that is to say approximately 30°.

This indicates that the choice of collision modeling in the MPPICFOAM solver (“MP-PIC” collision technique) is able to reproduce the average jet angle of the straw, but it is probably necessary to use a non-statistical collision technique to reproduce the characteristic “V”-shape.

8. OUTLOOK

At this stage, this study shows that the numerical simulation tool used is appropriate and effective for predicting the overall pneumatic conveying of straw from within the turbine, through the chute.

This tool allows optimizing the turbine and the chute to obtain a concentrated single jet, perfectly oriented by the chute.

In addition, this tool can be used to estimate the mechanical load of straw on mechanical parts such as the turbine (see Figure 8), and can be extended to predict the distribution of straw on the ground as shown in Figure 9.

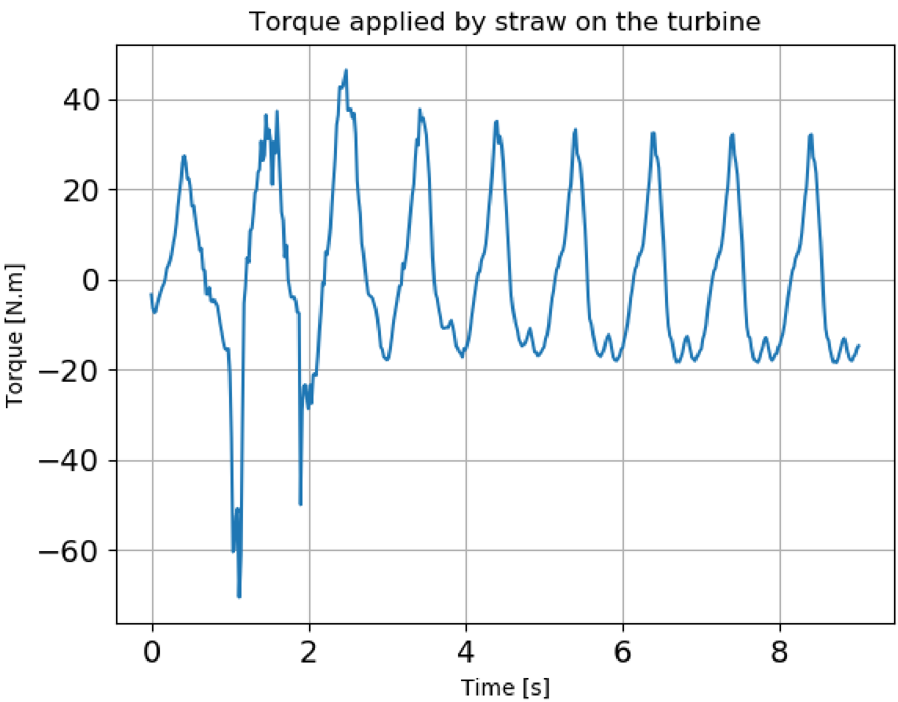

Figure 8 : Torque applied by the straw on the Turbine from the numerical simulation

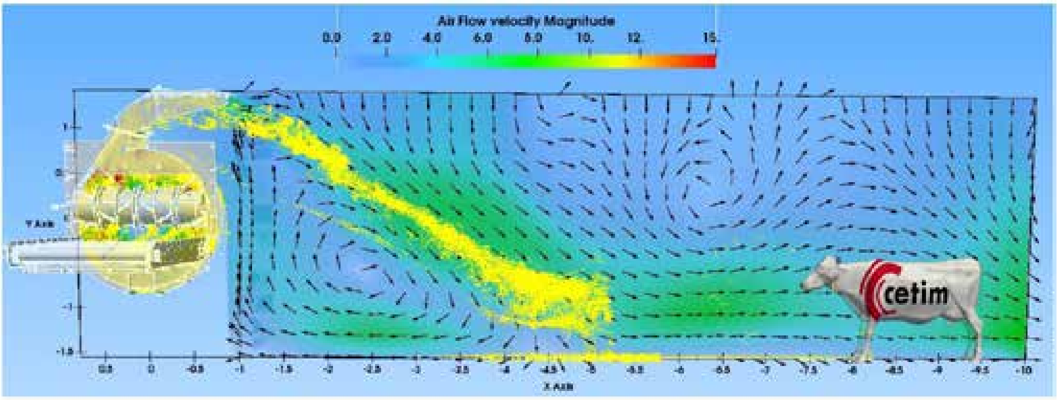

Figure 9 : Snapshot of the straw feeder predicting tool

This project allows modeling of the complete path of straw from upstream part, the turbine, to the ground. The general modeling strategy of the product “Straw” can be easily applicable to other materials.

Acknowledgement

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Références

[1] Documentation KUHN, « Althor-Athenor 4560-5070m-6070 ».

[2] M .H. Khoshtaghaza, R. Mehdizabeh, « Aerodynamic properties of Weat Kernel and Straw Material », Tarbiat Modares University, Iran

[3] OpenCFD Ltd, « OpenFoam, The Open Source CFD Toolbox », http://www.openfoam.com/

[4] “Drag coefficient and terminal velocity of spherical and nonspherical particles”, A. Haider and O. Levenspiel, Powder Technology, Volume 58, Issue 1, May 1989, Pages 63-70

The design and development of three planters (Marks 1, 2 and 3) to plant daffodil bulbs under agricultural upland grassland and a harvester to collect the above ground biomass

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Abstract

The number of people suffering from dementia is considerable and growing at a significant rate. Alzheimer's disease accounts for between 50 and 75% of these cases. Galantamine is a pharmaceutical compound that has been an approved treatment for Alzheimer's disease since 1998. Galantamine can be synthesised chemically but it is a difficult and expensive process. Producing galantamine from the alkeloid galanthamine extracted from daffodils is more cost effective, but supplies are limited.

Research has suggested that the environmental challenges associated with upland areas trigger a higher concentration of galanthamine in daffodils compared to daffodils grown under lowland conditions. A 4.5 year UK Agri-Tech Catalyst Industrial Research project is investigating daffodil-derived galanthamine production by integrating daffodil growing into permanent upland sheep pasture. The aim is to increase the economic sustainability of hill farming by providing farmers with a high value supplementary daffodil crop while maintaining a traditional farming system.

Machinery is readily available for lowland daffodil production for the cut flower market and for the production of bulbs. Soils are typically deep, fertile and free draining. However, the UK uplands are characterised by low temperatures; exposure to wind; high rainfall; winter snow and frosts; thin impoverished stony soils; a shortage of major nutrients and steep slopes. As part of the research project Harper Adams University agricultural engineers have developed machines for planting daffodil bulbs and harvesting the above ground daffodil biomass in these arduous upland grassland pastures. The planter uses belts to meter and deliver bulbs from the storage hopper to two drop chutes positioned above the purpose built ground opening winged tines. The harvester removes and collects the above ground biomass which is then transferred to sealed containers before being processed.

Keywords: Galanthamine, Galantamine, Daffodil, Upland Pasture, Planting, Harvesting.

1. Introduction

The number of people suffering from dementia is considerable and growing at a significant rate. In 2017, there were estimated to be 50 million dementia sufferers worldwide (Alzeimers Disease International, 2018) and 4.6 million new cases are diagnosed each year. Alzheimer's Disease (AD) accounts for between 50 and 75% of these cases. The U.S. Food and Drug Administration, the UK Medicines and Healthcare Products Regulatory Agency and The European Medicines Agency has approved galantamine as an AD treatment since 1998. Galantamine can be synthesised chemically but it is a difficult and expensive process (Trost and Toste, 2000; Marco-Contelles et al, 2006). Producing galantamine from galanthamine extracted from plants, for example, daffodils (*Narcissus sp*) (Torras-Claveria et al, 2013) is more cost effective, but supplies are limited. The annual global consumption of galantamine is currently constrained to 3-4 t yr^{-1} by existing production levels, but published figures predict the potential global market could be nearer 40 t yr^{-1}. Independent reports project the competitive active pharmaceutical ingredient price for galantamine drugs will remain between £15,000 - £18,000 kg^{-1} in the medium term.

Previous research has suggested that the environmental challenges associated with upland areas (low temperatures; exposure to wind; high rainfall; winter snow and frosts; thin impoverished stony soils; a shortage of major nutrients and steep slopes) trigger a higher yield of galanthamine in daffodils (bulbs and above ground bio-mass) that are grown there when compared to those grown in normal lowland conditions (Department for Environment Food & Ruarl Affairs, 2006). Daffodils grown for galanthamine production, therefore, could offer a novel, high-value crop for upland farmers that will provide an important new income stream, increasing their economic resilience.

Currently, daffodil-derived galanthamine production using normal bulb/flower growing systems requires annual mouldboard ploughing of the soil (with the associated release of greenhouse gases and soil erosion) and strict herbicide regimes to control weeds (with associated impacts on biodiversity). A 4.5 year UK Agri-Tech Catalyst Industrial Research project (commenced March 2015) is investigating daffodil-derived galanthamine production by integrating daffodil growing into improved permanent upland sheep pasture. The aim is to increase both the production of galanthamine and the economic sustainability of hill farming by providing farmers with a high value supplementary daffodil crop while maintaining a traditional farming system. This paper describes the equipment that has been developed for planting daffodil bulbs and harvesting the above ground daffodil biomass in these arduous upland grassland environments.

2. Materials and Methods

2.1. Prime mover

A range of vehicles, including compact agricultural tractors, *all-terrain vehicles* (ATVs) and off road utility vehicles, as well as self-propelled tracked vehicles, were evaluated as potential prime movers for both the planting and harvesting operations. Because the production of the daffodils is designed to be integrated within existing pastureland and the required tractive forces needed to pull the planter, a 55 kW tractor was chosen to pull both the planter and harvester.

2.2. Planter

The aim of the planter was to plant commercially available daffodil bulbs (sizes 10/12, 12/14, 14/16 and 16+) under sloping permanent pasture at rates of 4 to 10 t ha^{-1}. Upland soils are typically shallow and stony with the subsoil containing large stones / rocks (Soil Survey of England and Wales, 1984a; Soil Survey of England and Wales, 1984b). Ideally, daffodil bulbs should be planted 150 mm deep and, in cold climates, the bulbs should be covered by at least 75 mm of soil to protect them from frost.

2.2.1. Row spacing

As it is not known how long daffodils will remain productive under these harsh conditions when they are harvested each year with limited opportunity to regenerate the below ground biomass, it was decided to plant the bulbs in two rows 800 mm apart. This will allow, if necessary, daffodils to be planted in between existing rows by moving the tractor / planter combination over by “half a wheel-track width”.

2.2.2. Metering mechanism

Typically, metering mechanisms on bulb / tuber planters consist of either flat belts or cup mechanisms (Bell, 2016). For simplicity, a belt mechanism was chosen but, unlike machines used on flat / slightly undulating ground, a cleated belt (Figure 1) was used to provide traction for the bulbs and provide consistent feed rates when going up and down hill. To give a controllable, wide range of planting densities, a tractor driven hydraulic motor was used to drive the metering mechanism and provide planting rates of up to 10 t ha^{-1}.

(a) Two row planter cleated belts.

(b) Close up of a cleated belt.

Figure 1. Planter cleated belt.

2.2.3. Depth control

Depth control was via wheels at both the front and rear of the planter. The rear wheels also acted as press wheels to consolidate the loosened sward to give good soil / bulb contact.

2.2.4. Ground opening device

Upland soils are generally shallow (75 to 150 mm) and have low shear strengths. To minimise the damage to the existing grass sward, a heavy duty plain disc (Figure 2) was used to make a vertical cut through the sward. To minimise draft forces (Godwin and Spoor, 1974) and to allow the sward to remain intact whilst being lifted and then allowed to fall back in its original position once the bulbs had been planted, an opener with a low rake angle was required (Payne and Tanner, 1959). Experiments by Cooper (2015) evaluated a range of commercially available tines. A specially designed furrow opener (Figure 3) was manufactured with the aim of peeling back the sward cut by the leading disc, gently lifting it intact whilst the bulbs were planted before allowing the sward to fall back into place so covering the bulbs.

Figure 2. Planter tine and disc unit.

Figure 3. Soil opener.

2.2.5. Frame

Because of the undulating ground profile, local depressions and mounds, and rocks close to the soil surface, an articulating frame was manufactured for the Mk2 two row planter to enable independent movement of the front and rear halves of the planter so improving the depth control.

2.3. Harvesting machinery

The aim of the harvester is to harvest the above ground daffodil bio-mass and grass leaving "stubble" of between 80 and 100mm and deliver the product into water tight boxes sealed with a lid to prevent external contamination from vermin, birds and weather. These boxes are then transported off site where the material is processed and the galanthamine extracted, before further processing to extract the galantamine.

Typically, above ground bio-mass of agricultural or horticultural products is harvested either by cutting or flailing. A range of commercially available equipment, for example, baby leaf salad harvesters and amenity flail grass collectors were considered as base units. Both of these techniques were evaluated on daffodils in 2016. In order to eliminate the need for additional processing of the harvested bio-mass at the galanthamine extraction phase and reduce transportation costs, flailing was chosen as the preferred method. In 2017, a commercially available flail harvester with a working width of 1.3m was purchased. This enabled two rows of daffodils to be harvested at the same time. Modifications in 2017 and 2018 included changes to the cutting height mechanism (range 0 to 350 mm), modifying the rear castor wheels and the addition of a hopper discharge mechanism.

3. Results and Discussion

The Mk1 and Mk2 planters and harvester have been used to establish and harvest a total of 16 ha of experimental plots at the Aberystwyth University Upland Research Centre, Pwllpeiran, Wales (52.3553° N, 3.8006° W). The project plots are in permanent pasture that ranges from 250 to 430 m above sea level with slopes of up to 27 degrees. The soil is a clay loam with an average cohesion of 22.5 kN m^{-2} and angle of internal shearing resistance of 9.5^{o} and an average stone content of 45% (Cooper, 2015).

3.1. Planting

The first-year planting (2015) was completed using a single row (Mk1) version of the final machine (Mk2) (Figure 4) using a ground wheel drive and a V-belt driven metering mechanism. A total of 6 ha of plots were planted with size 10/12 and 12/14 bulbs at a rate of 4 t ha^{-1} and rows spaced at 800 mm apart. For the second year, planting rates of up to 10 t ha^{-1} were required with bulbs sizes ranging from 12/14 up to 16+ and the ground wheel V-belt drive system was replaced with a tractor driven hydraulic motor. An additional 10 ha of project trial plots were planted in the second year using the two-row planter as shown in Figure 4.

Figure 4. Mk2 planter at Aberystwyth University Upland Research Centre.

The articulated frame performed well and enabled good planting depth control over the undulating ground profile.

The metering mechanism resulted in the bulbs being randomly orientated between "apex up" and "apex down". Additional plots and small scale plot experiments in 2016 and 2017 showed that bulbs planted "apex down" emerged up to 2 weeks later than those planted "apex up" leading to inconsistencies in growth stage at harvest. This suggests it may be worthwhile designing a metering mechanism that will plant all the bulbs "apex up". However, the effects on plant growth in subsequent years is comparatively minimal.

3.2. Harvesting

To maximise the amount of daffodil bio-mass whilst minimising the amount of grass and soil contamination, the flail height was set to give an average cut height of 100 mm. Cutting daffodils just as they are about / have started to flower (Figure 5) is contrary to normal growing advice which is to leave the foliage to wilt and die back for at least six weeks after flowering before removing it to allow the bulb time to recover ready for flowering the following year (*Royal Horticultural Society, 2018)*.

Figure 5. 2018 harvest at AU Upland Research Centre.

It is not known at this stage if flailing the bio-mass, rather than cutting it with a reciprocating knife, has any effect on making the plants susceptible to viral and bacterial diseases.

3.3. Future work

Future work may include modifying the planter to plant the bulbs “apex” up. Additionally, the harvester may require further modifications to adjust the cut height automatically depending on the ground profile and provide a system for lifting lodged crop that has fallen outside the standard cut width. Harper Adams is also designing and manufacturing a trailed planting machine (Mk3), based on the Mk2 two row planter, but with the bulbs delivered towards the tractor.

4. Conclusions

A planter to establish two rows of daffodils bulbs at 800 mm spacing in permanent upland pasture has been manufactured and a flail harvester has been modified to collect the above ground biomass ready for processing to extract galanthamine

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References

Journal articles:

Godwin, R. J. and Spoor, G. Soil Failure with Narrow Tines. Journal of Agricultural Engineering Research, Vol 22, No 3, p 213-228, 1977.

Marco-Contelles J., Carreiras, M.D., Rodríguez, C., Villarroya, M., and Garcia, A.G. Synthesis and pharmacology of galantamine. *Chemical Reviews* **106**, 116-133, 2006.

Payne, P.C. and Tanner, D.W. The relationship between rake angle and the performance of simple cultivation implements. *J. Agric. Eng. Res.* 4(4), 312-325, 1959.

Torras-Claveria, L.,Berkov, S.,Codina, C.,Viladomat, F., and Bastida, J. Daffodils as potential crops of galanthamine. Assessment of more than 100 ornamental varieties for their alkaloid content and acetylcholinesterase inhibitory activity. *Industrial Crops and Products*. (44). 237-244. 2013.

Trost, B.M. and Toste, F.D. Enantioselective total synthesis of (-)-galanthamine. *Journal of the American Chemical Society* **122**, 1262-1263, 2000.

Books:

Bell, B., 2016. Farm Machinery, 6th edition. Sheffield: Old Pond.

Soil Survey of England and Wales, 1984a. Soils and their use in Northern England. Harpenden: Soil Survey of England and Wales.

Soil Survey of England and Wales, 1984b. Soils and their use in Wales. Harpenden: Soil Survey of England and Wales.

Technical reports:

Department for Environment Food & Ruarl Affairs, 2006. Sustainable production of the natural product galanthamine. Defra project code NF0612. Institute of Grassland and Environmenatl Research, Plas Gogerddan, Aberstwyth SY23 3EB

Theses and dissertations:

Cooper, M., 2015. An investigation into the terramechanics of a prototype daffodil bulb planter. CREST Report (unpublished). Harper Adams University, Newport, Shropshire, UK.

Internet resources:

Alzeimers Disease International, 2018. Dementia Statistics. https://www.alz.co.uk/research/statistics Accessed May 30, 2018

Royal Horticultural Society, 2018. Daffodils. https://www.rhs.org.uk/advice/profile?PID=91 Accessed June 1, 2018.

GridCON[1]
Development and test of an all-electric, cable powered, autonomous mobile agricultural machine

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Abstract

Since more than one decade John Deere has been carrying out research and advanced engineering on integrated concepts for sustainable energy production and consumption on farms including electromobility concepts for mobile agricultural machinery. On the SIMA fair 2017 in Paris, John Deere presented the so called SESAM tractor – the first all battery electric tractor fully operational for all type of tractor applications in arable farming. With the new and visionary GridCON tractor concept John Deere sets a new milestone on the pathway towards electromobility of off-road working machines. As a battery free and cable powered autonomous machine, the new GridCON tractor overcomes some drawbacks of the SESAM tractor - amongst these especially the insufficient installable battery capacity. GridCON represents the next visionary generation of all electric off-road machines. Compared to conventional tractors, GridCON provides doubled power density and operational performance at reduced costs. The grid, large batteries at field border or generators can be used as main power sources.

Background

According to a publication of FAO (Food and Agriculture Organization of the United Nations) globally agriculture is responsible for 24% of all greenhouse gas emissions (see FAO: Greenhouse Gas Emissions from Agriculture, Forestry and Other Land Use. FAO-document I6340En/1/10.16, Link: http://www.fao.org/3/a-i6340e.pdf seen on Jan. 15th, 2019). At the same time, agriculture is one of the primary economic sectors suffering consequences from climate change. Thus, mitigation of climate change must be one of the top challenges of agricultural engineering of today and in future.

Agriculture provides a great potential to be a key driving force for development, production and application of renewable energy, because it is the only productive sector within our EU society which at the same time not only consumes, but also produces large amounts of energy. Farms partially are energy producers and, if not, at least indirectly contribute to renewable energy production since they provide land and biomass as fundamental resource for energy production. Types of renewable energy resources and carriers from rural areas are heterogeneously diversified into resources bound to electricity (such as wind power and photovoltaic systems) and thermochemical resources (such as liquid, gaseous and solid fuels). Electric energy is expected to be a future key energy form because most stationary energy production plants are by their nature coupled to electric energy production. Wind energy and PV installations are dramatically increasing and already lead to electric grid bottlenecks in some areas. This is typically the case in rural areas with weak electric grids where agriculture is predominant. Hence, more local use of renewable electricity in such areas, e.g. with electric vehicles, can reduce the need for quick and strong grid extensions and improve the overall economy of enhanced renewable energy use.

1 The project GRIDCON was funded by the German Ministry for Economics and Energy on the basis of a decision of the German Bundestag. Project partners: John Deere GmbH & Co. KG, Technical University Kaiserslautern, B.A.U.M.Consult. Funding project no. 01ME14004A

John Deere's SESAM approach

Figure 1: Vision of the SESAM farm

John Deere has been working on a vision for a farm operation concept which is with regard to its energy balance at least energy-neutral or can also be described as energy-autonomous farming (what does explicitly not refer to energy autarky). We call our vision SESAM (Sustainable Energy Supply for Agricultural Machinery). The main idea is to secure highest efficiency and profitability for farms in future.

At the SIMA 2013 John Deere presented the Multifuel Tractor as a visionary concept for agriculture which was awarded with a gold medal. Based on a fuel detection sensor the engine could adapt automatically to different types of fuel. Besides diesel these were especially different types of pure plant oil and biodiesel. This way, farmers could access regionally or even on farm produced energy (fuel) for powering mobile machinery and they could choose the economically best fuel at any time. It was JD's first step towards *S*ustainable *E*nergy *S*upply for *A*gricultural *M*achinery – abbreviated the SESAM vision.

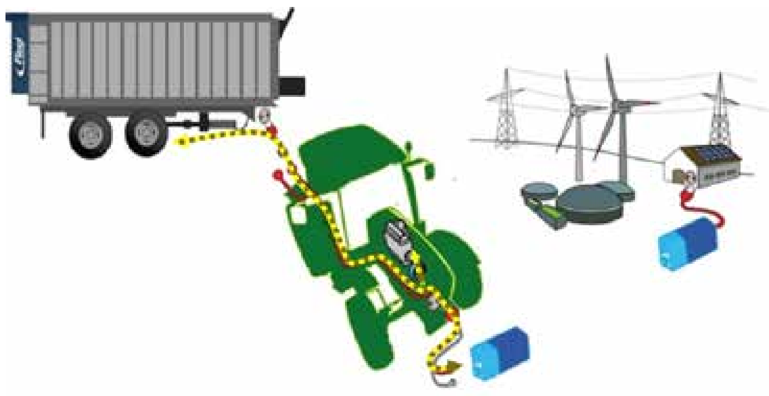

Figure 2: The BatteryBoost concept of a grid plug-in hybrid tractor with a battery change system

The next step two years later was JD's BatteryBoost system:
a grid-plug hybrid tractor with a battery exchange concept. BatteryBoost was awarded as outstanding innovation with Citation in 2015 and in 2017 the functional prototype of a fully battery electric tractor – the SESAM tractor concept – was again winning a Citation award for JD. While the

SESAM tractor showed extremely high energy efficiency and of course gives access to (renewable) electric energy sources, it lacks enough onboard energy storage capacity and cost efficiency due to today still high prices for battery cells. While battery prices will likely go down in the next couple of years the problem of poor energy storage capacity cannot be solved with having batteries onboard for applications demanding high power such as soil tillage, harvest etc. Even when batteries would have half the weight and volume of today, on tractor implementable energy storage could by far not suffice a full day of operation. Thus, in the follow-up project GridCON new goals were formulated and achieved. These were:

- permanent power supply,
- doubled power density, and
- doubled productivity.

The result was a completely new concept for a mobile working machine called GRIDCON which is fully electric, permanently cable powered, and in-field autonomously operational. The GRIDCON-tractor is a visionary functional prototype and a further milestone in the far-sighting SESAM vision.

Figure 3: The SESAM Tractor

The GridCON set up

Inspired by historic ideas of cable powered tractors as for example shown in figure 4, John Deere decided to investigate opportunities for permanent powering of the SESAM tractor via cable. While the balloon concept shown in figure 4 seems not to be applicable the idea to have a semi-mobile transformer station as a connection point between the electric power grid and tractor was interesting.

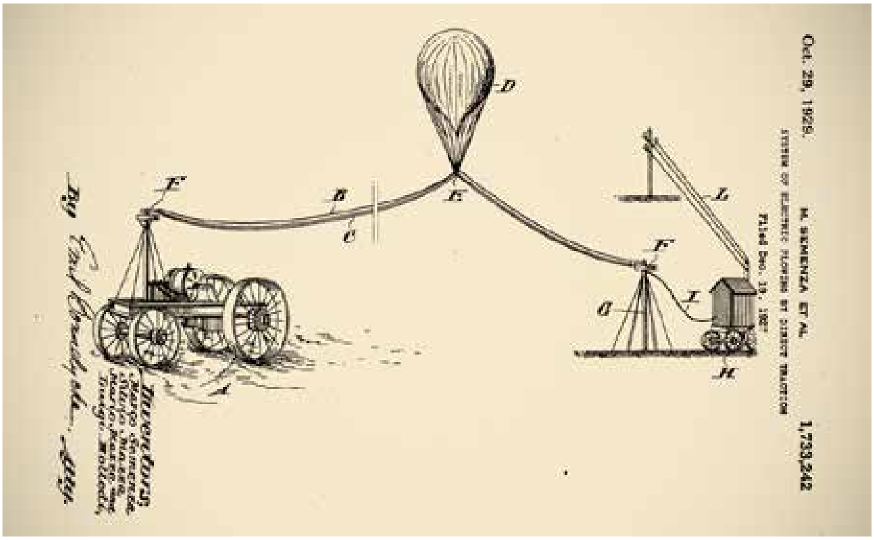

Figure 4: M. Semenza et al.: System of Electric Plowing by Direct Traction, Pat.Nr. 241243, 1929

Additionally, replacing the ballon for variation of distance between mobile machine and transformer a cable drum on the tractor was identified as basic concept. This again was inspired by systems well known from slurry distribution on larger fields where a slurry buffer storage is placed at the field border and the slurry distributing tractor tractors carries a hose reel unwinding and winding up the slurry hose lane by lane.

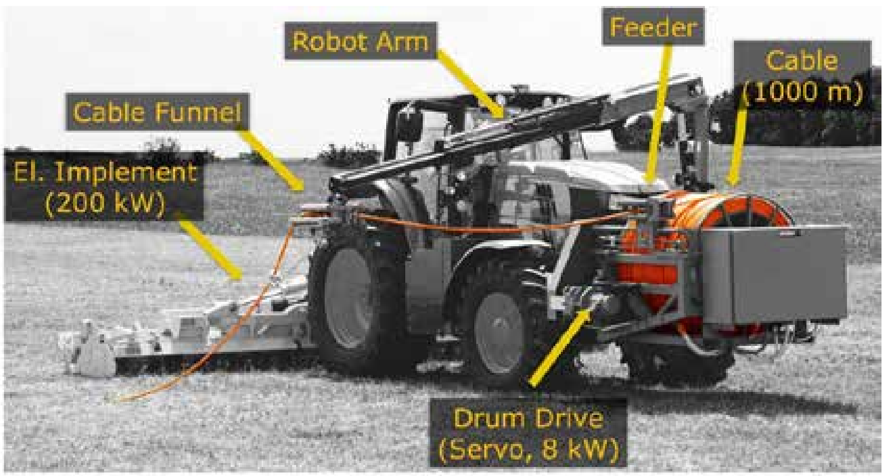

Figure 5: SESAM tractor as development platform for GridCON

The result of the design adaptation of this ideas in the first step was a modified SESAM tractor carry a cable drum in the front as shown in figure 5. The winding and unwinding of the cable and the placement of the cable to the ground is controlled by a robot mechanism. Practical tests showed quickly that the steering of this system can no longer be managed by a human driver. Thus, during research and development it was decided to change a follow-up design to a driverless machine. The protoype is shown in figure 6.

Figure 6: GridCON tractor

The GRIDCON concept currently is based on 2.5 kV (AC at 3.6 kHz) connection via cable from field border to machine allowing for 300 kW permanent power transfer. The cable drum carried by the machine is designed for 1000 m range (cable length). The concept is scalable so that cable length and power could be extended. Onboard, the machine is using a 700 VDC bus for electric power distribution. Electric power can be used by implements ("electric power off-boarding"). For this additional cooling infrastructure is provided by the base machine.

For special manoeuvres (e.g. for going to field border when starting work) a tractor operator (the "driver") can manage the machine with a remote control. Afterwards at in-field operation, the vehicle follows fully autonomously pre-planned paths with operation speed of up to 20 km/h. After starting ride for field work, the unwinding cable is guided by a robot arm and laid down besides the machine. A minimal longitudinal force needed for cable handling (50 to 200 N) is kept up by the control system of the machine. In addition, cable handing is completely vibration- and friction-free. When reaching headland, the machine turns automatically around the end of the lying cable and while returning on the next track the cable is being recollected to the drum without overlapping. When reaching the field border there will be another turn to the next track and this process is repeated for the whole field.

There are two servo drives on the cable drum – one for spinning the drum and maintaining the necessary cable tension and one for cable feeding during winding and unwinding. For steering a servo-driven hydraulic pump actuates a steering cylinder. For braking a failsafe system locks the rear wheels when the emergency-stop is pushed.

A central onboard industrial automation system changes the GRIDON vehicle into a machine tool on wheels: The automation system is based on an Intel Core i7-CPU and controls all actuators on the vehicle in real-time at a cycle time of one millisecond. All the controls like cable handling, autonomous driving, communication, transmission control and steering are model based designed in Simulink and run on the central computer as isolated modules. The connection to the physical layer is done using the industrial real-time communication system EtherCAT.

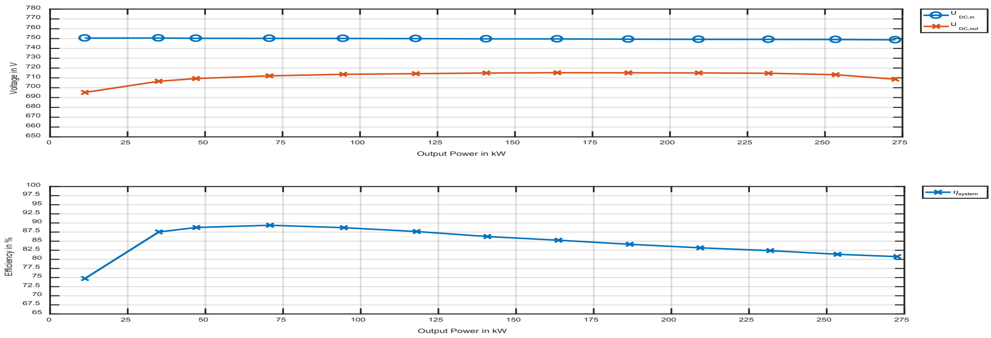

Figure 7: Total power transmission efficiency from grid connection point to drive train

The power line is designed for achieving highest efficiency between 40 kW and 100 kW. For high power applications efficiency still stays at 80 % and higher. We are optimizing the system for even better efficiency in near future. The GRIDCON tractor uses the same permanent electric drive technology (permanently excited synchronous machines) as its predecessor (SESAM-Tractor). Thus, the total efficiency of the drive train can be assumed to be in the dimension of up to 85%. The total weight of the functional prototype of the GRIDCON is about 8.5 t (empty, but including cable drum and robot arm) and thus has about the same weight as a 6195R conventional John Deere tractor (195 hp rated power) but at the GRIDCON with doubled power and emission (exhaust gas and noise) free. In a series design, further weight reduction of at least 1t would be achievable.

The GridCON tractor concept shows a pathway towards all electric machines. Increased power density allows for doubling machine performance at half of the costs per hp of a comparable conventional machine. Autonomous driving allows for further significant reduction of operational costs for driver as well as due to 24 h per day uptime. The concept enables direct grid connection but also other power supply concepts such as mobile generators or large batteries at the field border as soon as battery prices will drop. GridCON enables electromobility for mobile farm machines based on renewable energy.

Simulation model development for advanced powertrains in agricultural tractors

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Abstract

The powertrains of agricultural tractors are developing rapidly and are becoming more complicated. The modern continuously variable transmissions provide smooth and clutchless gear shifting in a wide driving speed range. The development of advance powertrains require dedicated tools in order to evaluate and compare different technologies. This research presents an approach to model and simulate different powertrains in agricultural tractors. The approach is based on numerical simulation and the Autonomie vehicle simulation software is used as the development platform. Powertrain models were developed for a conventional, parallel hybrid electric, and series hybrid electric tractors. These models were simulated on specific test cycles in order to evaluate their operating performance and to verify correct operation of the powertrains and individual components. According to the simulation results, the chosen simulation environment is well suitable for the modelling of agricultural tractors. The results show that the speed and hybrid system controls are well adapted for the operation of hybrid tractors. The dual-clutch transmission model shows also good performance in the conventional and parallel hybrid powertrains.

Keywords: Agricultural tractor, advanced powertrain, model development, simulation.

1. Introduction

The powertrains of agricultural tractors have been developed in a fast pace during the last decade. Most of the modern tractors have some type of a power-shift transmission that allows effective use of the engine in different tillage operations in the field. The engine speed can be controlled effectively for better fuel economy and higher performance due to the continuously variable transmission (CVT) systems. Most of the power-shift transmissions use hydraulic pumps and motors for continuous power delivery from engine to the wheels [1]. By using hydrodynamic or hydro-mechanical systems for the transmission, the power and torque can be delivered smoothly to the driven wheels but the overall efficiency is lower in comparison to mechanical transmissions. Recently electric powertrain systems have been developed increasingly in automotive industry, also for heavy vehicles and non-road mobile machinery (NRMM) [2]. Electrical systems are under great interest because of the high efficiency over wide operation range, good controllability, and elimination of idling losses [3]. However, lot more research and development needs to be carried out for finding the best solutions for advanced powertrains with electrical systems [2].

Due to the more stringent emission regulation and demand for more energy efficient mobile machinery, advanced and alternative powertrain and transmission technologies have been developed increasingly [3], [4], [5]. Among construction machinery, hydraulic and electric systems have been proposed for powertrain hybridization [4]. Hydraulic systems are well suitable for construction machinery because there are usually many auxiliary systems that can be efficiently operated by hydraulic power such as booms and buckets [5], [6]. Hydraulic hybrid powertrains are based on storing energy into a hydraulic accumulator that provides additional power, better control for engine and regeneration of braking energy from driving wheels or other systems. The same advantages can be obtained with hybrid electric powertrains when an electrochemical batteries are used as energy storages, electric generators for producing electrical power and electric motors for tractive force and powering other systems [2]. In heavy vehicles and NRMM, the primary energy and power source is often a diesel engine for hybrid electric powertrains. Diesel engines can be replaced by fuel cell systems that are mature technology although their costs are currently too high for being economically competitive in mobile machinery [7], [8]. Presently, hybrid electric powertrains are still rather uncommon but recent years the related technology have gained certain maturity that many manufacturers are developing advanced powertrain solutions and new products are introduced all the time [9], [10]. Full electric powertrains are increasingly common in passenger vehicles but because the energy capacity requirement in mobile machinery and agricultural tractor for uninterrupted daily work is quite high in relation to the energy capacity of the modern lithium-ion batteries, much more technological development is needed [11].

In agricultural tractors, the powertrain development has been heavily focused on the transmission and basically all the manufacturers can offer some type of a continuously variable transmission. Most of these transmissions rely on using hydraulic and mechanical power path from engine to the driving axles. By dividing the traditional mechanical power path, different types of stepless speed control can be developed and tractor work performance is enhanced especially in high power tillage operation. These CVT systems can be rather simple with a single planetary gear set and a hydraulic system or much more complicated with multiple planetary gears and clutches. The advantages of CVTs are indisputable even though their development costs can be high and overall efficiency lower than traditional mechanical transmissions. The energy efficiency can be also optimized for a certain extent because the engine speed can be more freely adjusted but it is often a compromise with the tractor performance.

In this research, simulation models of three different agricultural tractors are developed in the Autonomie software. The following tractor powertrains were developed: a conventional diesel engine with a dual-clutch transmission (DTC), parallel hybrid electric powertrain with a DTC, and a series hybrid electric powertrain with a 3-speed gearbox. The primary use of the models is to predict the tractor and transmission performance in different tillage operations. This research focuses on the model development, evaluation of the powertrain performance, and operational verification of the models. Four different test cycles were generated for the evaluation purposes.

2. Materials and Methods

2.1. Simulation model development

The simulation models of a conventional and hybrid electric tractors were developed in the Autonomie vehicle simulation software. The tool has been developed by the Argonne National Laboratory in the United States and is described as "*an open architecture to support the rapid integration and analysis of powertrain/propulsion systems and technologies*" [12]. The software have been continuously developed since it was released and provides model libraries for different powertrain components as well as component initialization data for heavy vehicles. The practical interface and powertrain modeling offers a convenient way to investigate and compare different powertrain architectures and configurations. Figure 1 presents the developed powertrain models in the Autonomie software: the conventional tractor powertrain with a dual clutch transmission, the pre-transmission parallel hybrid powertrain, and series hybrid powertrain. The tractor models were built up based on their generic predefined architectures existing in the Autonomie library. The chassis model was modified to be able to simulate the influence of external load such as implements. This was done by creating a time-dependent load force in the chassis block. The pre-transmission parallel hybrid system includes high voltage battery, electric motor, torque coupler and electric auxiliary devices. The electric traction motor is connected via a torque coupler to the input of the dual- clutch gearbox. The series hybrid powertrain includes an engine-generator (gen-set) as a primary energy source and a high voltage battery as the secondary energy source. An electric motor with a 3-speed gearbox delivers the power to the wheels.

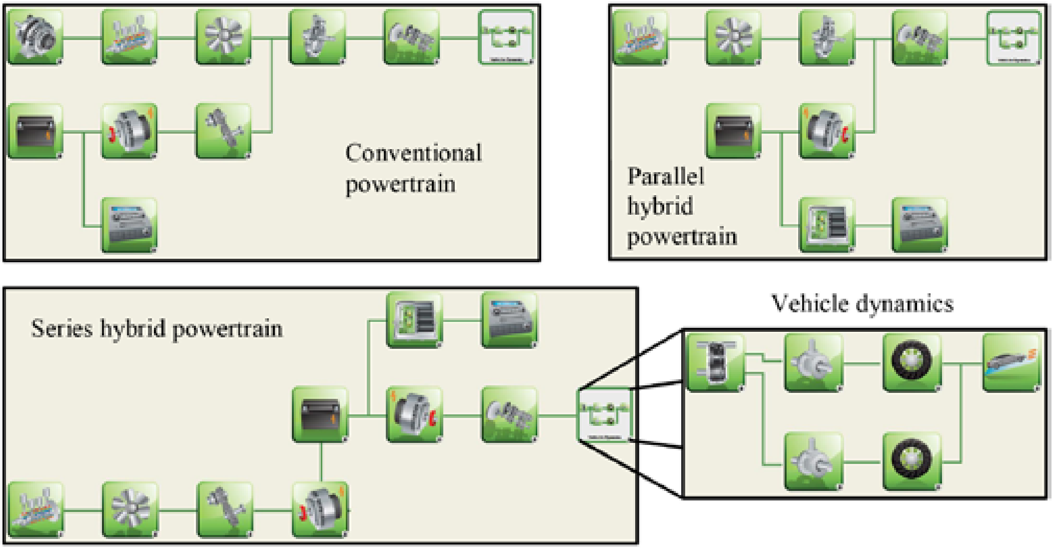

Figure 1: Developed powertrain layouts for agricultural tractors in the Autonomie.

2.2. Model parameters

The simulation models were parameterized based on a typical agricultural tractor in the engine power range of over 200 kW. The Autonomie libraries provide component initialization data for a wide range of components used in light and heavy duty vehicles. There are no specific data available for off-road vehicles, however most of the tractor powertrain components are similar to the components used in heavy vehicles so that the most of the component data could be found from the software library. Table 1 presents the general technical specifications of the tractor models and Table 2 the specifications of the hybrid electric powertrains. The power consumption of the auxiliary devices such as engine fan, air conditioning, and power steering was modeled as individual component consumption. The energy consumption of these components was dependent on the engine speed. The auxiliary devices were not electrified for the hybrid electric tractors.

Table 1. General technical specifications of tractor models.

Component	Description
Diesel engine	maximum power 225 kW, maximum torque 924 Nm
Transmission	8-speed dual clutch transmission (DCT) with 3 ranges
Rear axle	bevel set ratio of 3.28:1 and planetary gear ratio of 6:1
Fron axle	bevel set ratio of 2.48:1 and planetary gear ratio of 6:1
Tires	front: 540/65R30, rear: 650/65R42
Weights	kerb weight: 8600 kg, payload: 3900 kg

Table 2. Specifications of the hybrid electric transmissions.

Component	Parallel hybrid	Series hybrid
Diesel engine	maximum power 175 kW, maximum torque 719 Nm	
Generator	---	power 150 kW, max torque 478 Nm, gear ratio of 1.67:1
Transmission	8-speed (DCT) with 2 ranges	3-speed gearbox
Battery configuration	Saft 6 Ah cell, 2 packs in parallel, 180 cells in series in a pack, 648 V, 7.8 kWh	
Electric motor	max power 100 kW, max torque 542 Nm, max speed 4400 rpm	max power 225 kW, max torque 611 Nm, max speed 8000 rpm

2.3. Simulation parameters

The tractor models were simulated in dedicated test cycles for the verification of correct functioning of the powertrain and for analyzing the performance. Figure 2 illustrates the four different test cycles that have following characteristics:

A. Target speed of 6 km/h with an increasing load force by steps of 10 kN until 60 kN and back to zero,

B. Varying target speed by steps of 2 km/h until 12 km/h and back to standstill with a constant load force of 20 kN,

C. Varying target speed by steps of 2 km/h until 12 km/h and back to standstill with a varying load force,

D. Target speed of 8 km/h with a varying load force, average force of 20 kN and amplitude of 30 kN.

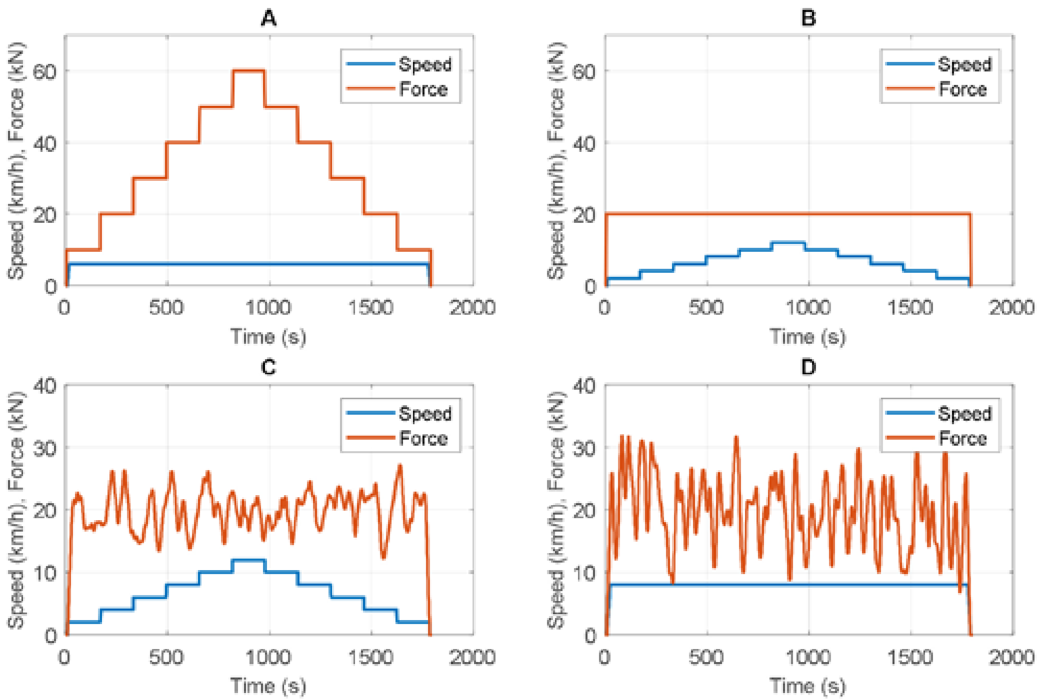

Figure 2: Generated test cycles for the evaluation of tractor simulation models.

3. Results and Discussion

The simulation results were thoroughly analyzed in order to evaluate the performance of the different tractor powertrains in the developed test cycles. Even though the Autonomie provides automatic post-processing and analyzing tools, it was easier and more effective to use separately developed Matlab scripts because the software is more focused on post-processing of on-road vehicle results.

3.1. Speed control

The speed control of tractor models was evaluated based on the test cycles A to C. All the tractor models have the same driver model. The hybrid electric powertrains have a separate control system that provides controls for the power generation based on a predefined control algorithm. The Figure 3 presents the results of the speed control for the three tractor models in the test cycle C. Overall, it can be noticed that the hybrid powertrains allow more precise vehicle speed control especially at the low driving speeds. The variation in the load force influences significantly on the speed control of the conventional tractor at low driving speeds. These results show that the gear shifting of the hybrid tractors could be improved. For the parallel hybrid tractor, there is a momentary decrease in driving speed when increasing the target speed from 6 km/h to 8 km/h around t = 500s. For the series hybrid tractor, the shifting speed should be faster since the driving speed drops dramatically when shifting from 1st to 2nd gear around t = 650s as seen in the Figure 3.

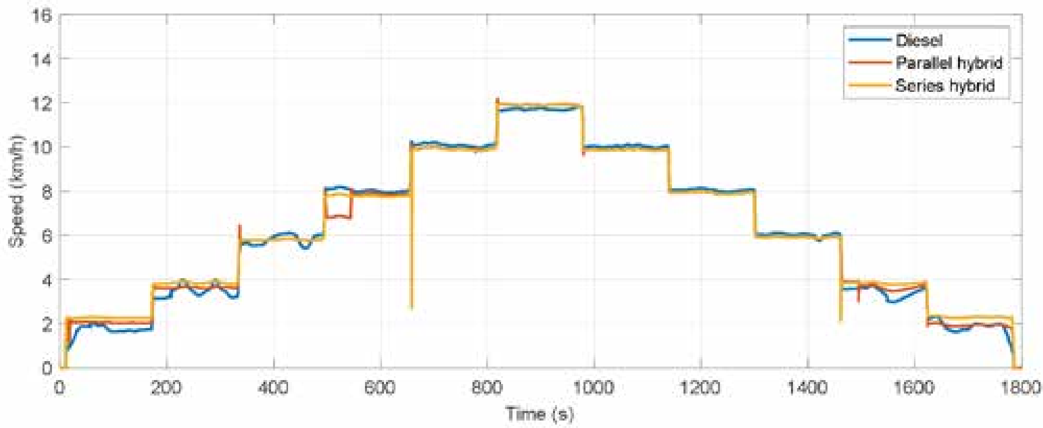

Figure 3: Tractor speed on test cycle C.

3.2. DCT gear shifting

The conventional and parallel hybrid tractor models are using a dual-clutch transmission model that is included in the Autonomie library. The transmission model was originally developed and validated for a passenger car but it is considered to be suitable also for heavy vehicles [13]. The gear ratios were defined based on the commercial data of tractors having a DCT. The test cycle B provided results for analyzing the gear shifting operation of DCT because the load force was constant. Figure 4 presents the speed signals of the engine and gearbox for a single and double gear shift. The single gear shift happens when shifting from 7th gear to 8th gear (target speed change from 6 km/h to 8 km/h) and the double gear shift happens when shifting from 5th to 7th gear (target speed change from 4 km/h to 6 km/h). The figure shows the shifting operation and how the gearbox axle speeds change during shifting. In the lower figures, the tractor driving speed and gear number is presented. Based on these results, the gear shifting happens very smoothly that indicates a robust shifting control. The results were very similar also in the test cycle C with varying load force.

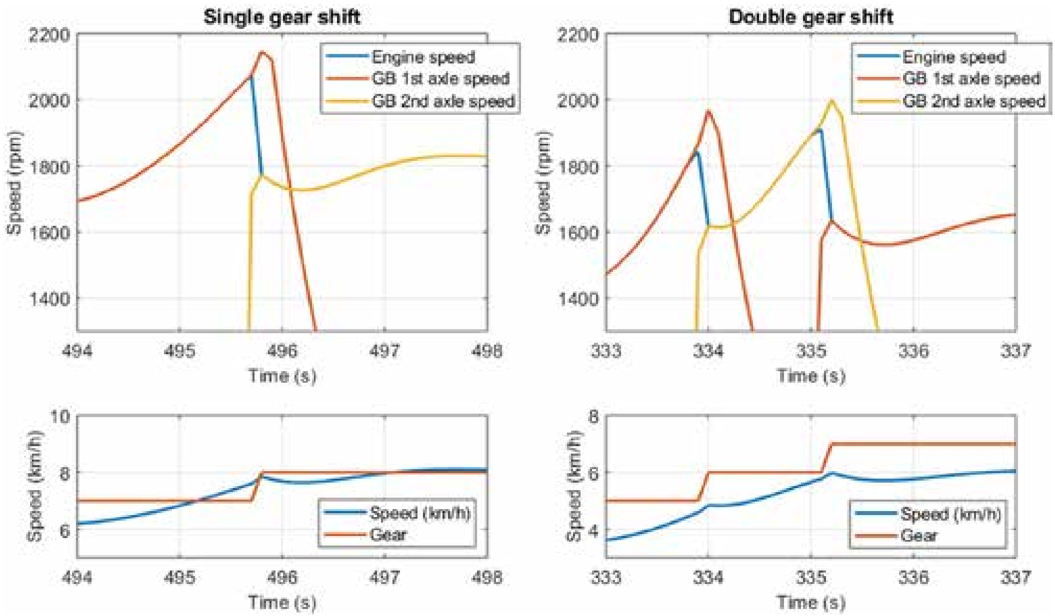

Figure 4: DCT gear shifting example in test cycle B for the conventional tractor.

3.3. Engine operation

The Figure 5 shows the diesel engine operation points for all tractor models in the test cycle C. These results show some advantages of powertrain hybridization. Firstly, the diesel engine can be downsized because the energy storage can provide additional power when needed. Secondly, the engine operation point can be adjusted in terms of torque for the parallel hybrid and in terms of speed and torque for the series hybrid. Without hybridization, the best efficiency area of the diesel engine can be reached only with a high torque demand. The hybridization allows the engine to operate more often in the highest efficiency area, and for series hybrid, it is possible to operate the engine along the Optimal Operating Line (OOL) as seen in Figure 5.

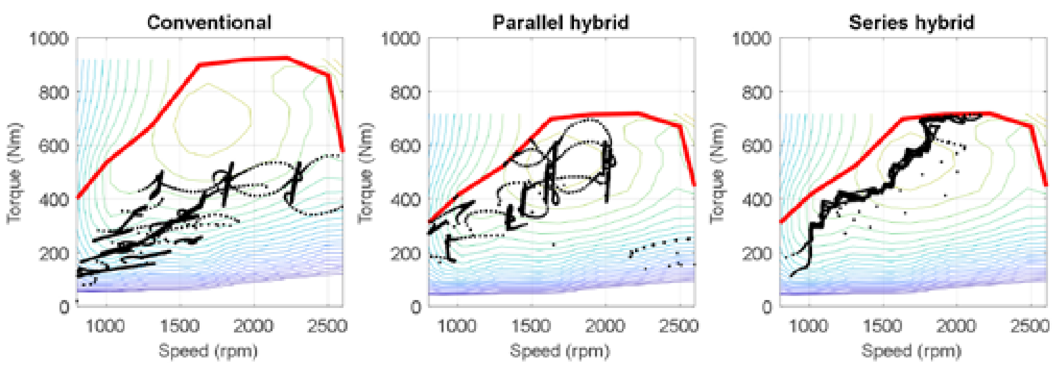

Figure 5: Diesel engine operation points in the test cycle C.

3.4. Hybrid system operation

The benefit of powertrain hybridization in vehicles in general depends on the vehicle type and usage patterns. In passenger vehicles, the average required power is low comparing to the maximum power capacity of a typical vehicle. This is often because of the high rated top speed that requires the high output power from the engine. On-road vehicles are influenced by the fluctuating speed patterns, which requires frequent decelerations and provides a significant amount of braking energy to be recovered by the electric motor. These benefits can reduce energy consumption significantly for on-road vehicles depending on the driving patterns and conditions. For mobile machinery and agricultural tractors, these important benefits of powertrain hybridization does not actually provide significant energy savings. For agricultural tractors, the energy consumption can be reduced by eliminating idling losses, electrifying auxiliary devices, and optimizing the hybrid system operation. Figure 6 presents the engine and battery power, and the battery state-of-charge (SOC) of the series hybrid tractor in the test cycle A. The battery energy is used when the power demand is very high, and then later on, the battery is charged when the power demand is lower. The hybrid system operates in charge-sustaining mode as shown by the battery SOC.

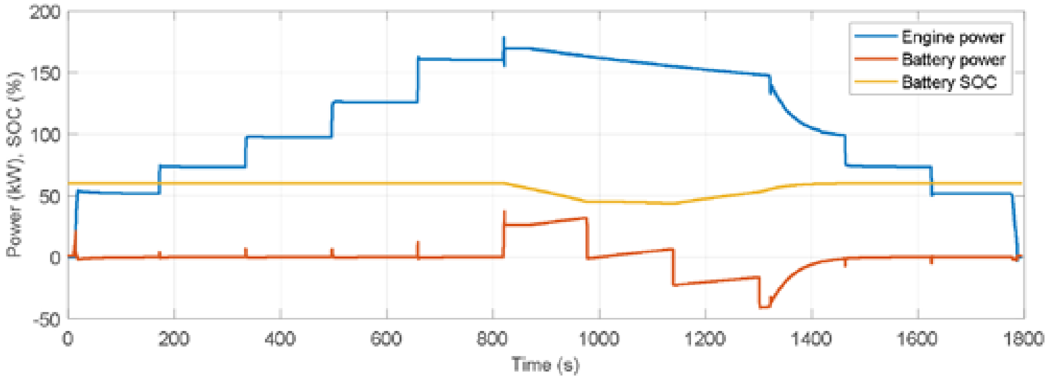

Figure 6: Engine and battery power of the series hybrid tractor in the test cycle A.

3.5. Energy losses

Because the focus of the presented research was on the model development and operational validation, the energy consumption and losses were only briefly analyzed. The energy balances of the simulation models were verified and they were found correct. Because the energy consumption of agricultural tractors heavily depends on their operation, it would need either measured data or data corresponding to real operating conditions for reliable evaluation of the energy consumption. Therefore, the obtained simulation results were not used to analyze the energy consumption of the developed tractor models. Only the distribution of losses was calculated for each tractor model. The energy losses were calculated for five distinct component groups by including the following components or elements:

- Energy sources: engine, gen-set, and battery
- Auxiliary components: engine fan, air conditioning, and power steering, etc.
- Transmission: clutch, gearbox, transfer case, final drive
- Tires: wheels and tires
- Work: energy required by the work done e.g. load force of an implement

Figure 7 shows the distribution of losses in the test cycle D. There were some differences in the distribution of losses between the tractor models. The parallel hybrid has the lowest share of losses in producing energy (Engine/Battery) and the series hybrid has the highest share of transmission losses. The latter is because of the multiple energy conversions in the powertrain.

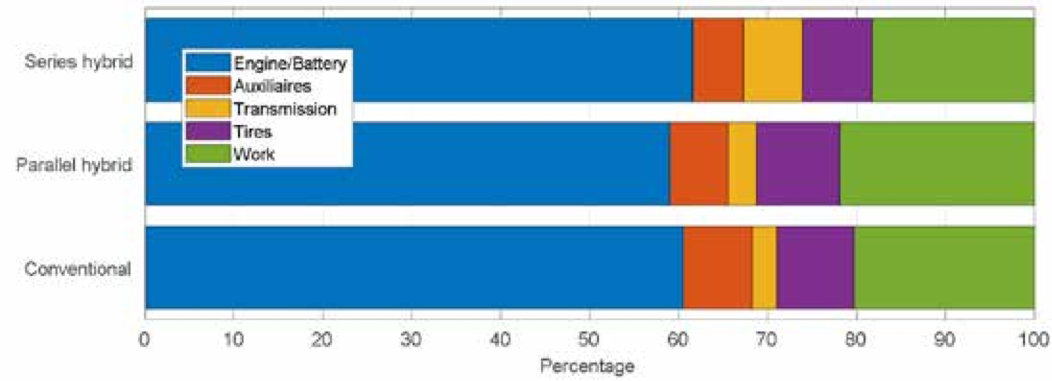

Figure 7: Distribution of energy losses.

4. Conclusions

This research presents an approach for modeling advanced powertrains in agricultural tractors. A numerical simulation environment using Matlab/Simulink was selected as the model development platform. Three different powertrain configurations were modeled: a conventional diesel engine with dual-clutch transmission (DTC), parallel hybrid electric powertrain with DTC, and a series hybrid electric powertrain with a 3-speed transmission. The vehicle simulation software, Autonomie was presented and based on the research results the simulation environment is suitable also for off-road vehicle modeling. Four different test cycles were developed for evaluating model performance and for verifying the operational functioning of the models. According to the research results, the tractor models showed good performance in terms of speed control in various conditions. In some occasions, the gear shifting control could be enhanced especially for the hybrid tractor models. The engine operation results illustrated the correct operation of each model, for example, the hybrid system control was working as planned.

The simulation results showed that numerical simulation can be a powerful tool in development and comparison of different vehicle technologies. For more accurate evaluation of the energy consumption and tractive performance of agricultural tractors, much more model development needs to be done. First, a tire-soil interaction model is required for the accurate estimation of load force and tire slip in different soil conditions. Second, the time-based simulation should be changed to distance-based simulation. This would not impact on the powertrain development but would create more realistic simulation environment. Third, real-world measurement data is required for model validation especially for the energy consumption.

References

[1] Y. Xia and D. Sun, "Characteristic analysis on a new hydro-mechanical continuously variable transmission system," *Mechanism and Machine Theory,* vol. 126, no. 1, pp. 457-467, 2018.

[2] A. Lajunen, Improving the Energy Efficiency and Operating Performance of Heavy Vehicles by Powertrain Electrification, Espoo: Doctoral Dissertation, Aalto University, 2014, p. 92.

[3] A. Lajunen, P. Sainio, L. Laurila, J. Pippuri-Mäkeläinen and K. Tammi, "Overview of Powertrain Electrification and Future Scenarios for Non-Road Mobile Machinery," *Energies,* vol. 11, no. 5, p. 1184, 2018.

[4] J. Wang, Z. Yang, S. Liu, Q. Zhang and Y. Han, "A comprehensive overview of hybrid construction machinery," *Advances in Mechanical Engineering,* vol. 8, no. 3, pp. 1-15, 2016.

[5] X. He and Y. Jiang, "Review of hybrid electric systems for construction machinery," *Automation in Construction,* vol. 92, no. 1, pp. 286-296, 2018.

[6] P. Casoli, L. Riccò, F. Campanini and A. Bedotti, "Hydraulic Hybrid Excavator—Mathematical Model Validation and Energy Analysis," *Energies,* vol. 9, no. 12, p. 1002, 2016.

[7] M. Liukkonen, A. Lajunen and J. Suomela, "Feasibility study of fuel cell-hybrid powertrains in non-road mobile machineries,"

[8] Automation in Construction, vol. 35, no. 1, pp. 296-305, 2013.

[9] A. Lajunen, "Energy Efficiency of Conventional, Hybrid Electric, and Fuel Cell Hybrid Powertrains in Heavy Machinery," *SAE technical paper 2015-01-2829,* pp. 1-8, 2015.

[10] O. Hegazy, R. Barrero, P. Van den Bossche, M. El Baghdadi, J. Smekens, J. Van Mierlo, W. Vriens and B. Bogaerts, "Modeling, analysis and feasibility study of new drivetrain architectures for off-highway vehicles," *Energy,* vol. 109, no. 1, pp. 1056-1074, 2016.

[11] S. Florentsev, D. Izosimov, L. Makarov, S. Baida and A. Belousov, "Complete Traction Electric Equipment Sets of Electro- Mechanical Drive Trains for Tractors," in *IEEE Region 8 International Conference on Computational Technologies in Electrical and Electronics Engineering (SIBIRCON)*, Listvyanka, Russia, 2010.

[12] G. P. Moreda, M. A. Muñoz-García and P. Barreiro, "High voltage electrification of tractor and agricultural machinery – A review," *Energy Conversion and Management,* vol. 115, no. 1, pp. 117-131, 2016.

[13] R. Vijayagopal and A. Rousseau, "System Analysis of Multiple Expert Tools," *SAE Technical Paper 2011-01-0754,* pp. 1-11, 2011.

[14] N. Kim, H. Lohse-Busch and A. Rousseau, "Development of a model of the dual clutch transmission in autonomie and validation with dynamometer test data," *International Journal of Automotive Technology,* vol. 15, no. 2, pp. 263-271, 2014.

Environmental impact assessment of tractors equipped with different devices for reducing the exhaust gases emissions

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Abstract

The concern about the environmental impacts arising from agriculture is quickly growing and alternative production solutions able to reduce this impact are fundamental. Concerning mechanization, machinery and their technological progress also play a role, mostly in relation to fuel consumption and exhaust gases emissions. Both fuel use efficiency and the more stringent emission limits to exhaust gases are the key points. Two of the most applied solutions to reduce such emissions are the Exhaust Gas Recirculation (EGR) and the Selective Catalytic Reduction (SCR), together with Diesel Particulate Filter (DPF). They all involve beneficial effects, but also some critical issues (i.e. increase in specific fuel consumption with EGR, consumption of a urea solution with SCR). Up to now, however, only few studies assessed the environmental consequences of these solutions.

Therefore, in this study, the Life Cycle Assessment (LCA) approach was applied to evaluate the environmental impact of ploughing conducted with three similar tractors equipped with different devices for pollutants control: an EGR-equipped tractor, a SCR-equipped tractor and a third tractor without technology for pollutants emission control. The specific aim was to highlight whether the SCR keeps being an effective solution to pollutants emissions although urea solution is consumed together with fuel.

Results show that the SCR-equipped tractor reduces considerably the impacts affected by pollutants emissions and slightly those affected by fuel consumption. However, it shows a less positive result on the impact categories affected by the urea solution consumption and by the presence of a heavier tractor.

Keywords: Agricultural tractors, pollutants emissions, EGR, SCR, environmental impact

1. Introduction

There has been a recent and marked growth of interest in the quantification of the environmental impact of agricultural productions. As a matter of fact, it is widely known that agriculture contributes to both benefits and side effects on air, soil and water resources (IPCC, 2006).

Among others, agricultural mechanization is related to a substantial share of these negative effects, mostly because of fuel consumption, exhaust gases emissions and the consumption of mineral and fossil resources for the construction and maintenance of machinery (Boone et al., 2016; Lee et al., 2016). Furthermore, there exist several machinery options among which to choose for performing the same operation, every of which can be characterized by different mass and tractor's engine power request. Such variables reflect on the environmental sustainability of the field operation under study (Lovarelli and Bacenetti, 2017b). In addition, the geographical, pedo-climatic, temporal and managerial specificities are much relevant in the evaluation of the environmental benefits or impacts of agricultural machinery both when considering the collectable data (Janulevičius et al., 2017; Perozzi et al., 2016) and the quantification of the environmental impacts (Bacenetti et al., 2018).

Finally, when studying the environmental outcomes related to agricultural mechanization, a very important role is played by fuel consumption and exhaust gases emissions, for which the analysis of the solutions for reducing pollutants emissions results fundamental. In particular, among the most adopted solutions there are the Exhaust Gas Recirculation (EGR), the Selective Catalytic Reduction (SCR), the Diesel Particulate Filter (DPF) and the Diesel Oxidation Catalyst (DOC). They all show both benefits and drawbacks: they contribute to reduce pollutant emissions released during engine combustion, but they can also involve higher specific fuel consumption (i.e. EGR), higher fuel consumption (i.e. DPF) or the consumption of a urea solution (i.e. SCR).

In order to take into account all these different issues on the environmental point of view, standardized and holistic methods are fundamental to be used to make complete analyses and avoid omitting important interrelations and environmental effects. To this aim, the most frequently adopted and recognized tool for environmental analyses is the Life Cycle Assessment (LCA) (ISO 14040 series, 2006). LCA can be used on a wide range of products and sectors, and for agricultural productions its application is very promising. Although lately LCA is widespreading, up to now, only few studies assessed the environmental consequences of agricultural machinery solutions, and even less when using agricultural tractors equipped with different devices for the reduction of exhaust gases emissions. Reasonably, this lack is mostly due to the difficulties in collecting site and time dependent inventory data and in the wide variability of machines, tractors and technologies that characterize agricultural machinery.

Having seen that LCA is a promising tool for analyses of the environmental sustainability, in this study it is used to quantify the environmental impact of ploughing carried out with tractors equipped with different devices for reducing pollutants emissions and for responding to the restrictions defined by EU legislation (97/68/EC, 2010/22/EU, 2010/26/EU). The importance of these outcomes is related to the widespread presence of outdated tractors that affect both the effective environmental analyses about agricultural productions as well as the effective impact of legislation on agricultural mechanization.

Thus, the achieved outcomes can be useful for:

- LCA practitioners involved in the evaluation of agricultural systems;
- manufacturers and operators of the agricultural machinery sector (implements and tractors) to understand how the environmental performances of their machines can be evaluated without using generic data and achieving effective results on everyday activities;
- policymakers to get information about the sustainability of different field operations and to develop modular subsidies and legislation.

2. Materials and Methods

2.1. Life Cycle Assessment

The analysis was performed using the LCA method to quantify the environmental impacts of ploughing operations using two very similar tractor models that represent the most recent technologically advanced tractor models to date and one outdated tractor without equipment for abating pollutants.

As mentioned, LCA is a standardized method adopted worldwide to quantify the potential environmental impacts of processes by considering their whole life cycle. Using LCA brings to avoid omitting important environmental effects. This method consists of four phases:

1. Specification of the goal of the study, selection of the functional unit and descriptions of the system and system boundary;

2. Life cycle inventory (LCI) data collection, which quantifies the flow of materials and energy from the system and the environment;
3. Life cycle impact assessment (LCIA), where inventory data are converted to numeric indicators of environmental impact by means of specific characterization factors;
4. Interpretation of the results and identification of the process hotspots and mitigation strategies.

2.2. Goal and scope

LCA was adopted to evaluate whether the reduction in pollutant emissions and the increase in fuel efficiency achieved with the recent tractor model equipped with Selective Catalytic Reduction (SCR) offsets the environmental impacts related to the urea solution production and consumption by comparing this solution with the tractor equipped with Exhaust Gas Recirculation (EGR) or with the oldest and outdated tractor without emission reduction devices.

2.3. Functional Unit and system boundary

According to the ISO standard 14040, the Functional Unit (FU) is the “reference unit that defines what quantity of the product’s function is achieved to cause the environmental impacts identified”. In this study, the FU is “the ploughing of 1 ha of plain field” to analyze the ploughing of a comparable unit.

The system boundary includes all inputs and outputs associated with ploughing. Inputs include mass and energy to complete the process: production and use of fuel, lubricant and urea solution (only for the SCR-equipped tractor), manufacture of tractors, their implementation, maintenance and disposal. Outputs include: emissions into the environment, among which into soil and water (e.g., for ire abrasion) and into air (for exhaust gas emissions due to fuel combustion). The ploughing is studied by simulating the operation with a PTO dynamometer and evaluating engine variables (speed, torque, brake specific fuel consumption) and effective field capacity, thus providing a detailed sustainability evaluation. Moreover, working time was split into tasks of effective work in field, turning at headlands, farm preparations and travelling between farm and field, as shown in Fig.1.

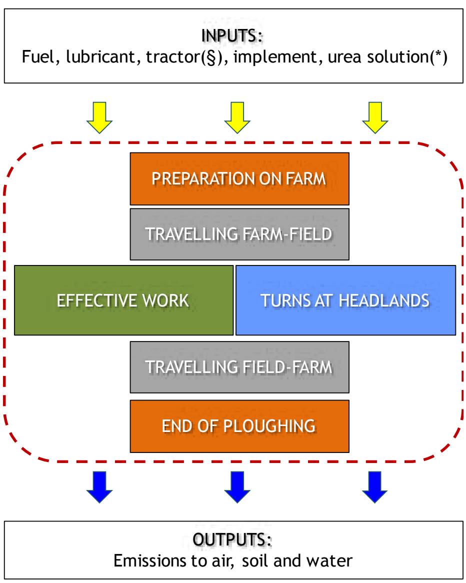

Fig. 1. System boundary for the ploughing process. (§) Three tractors are studied. (*) Only the SCR-equipped tractor is considered for urea solution.

2.4. Life Cycle Inventory (LCI)

A 4-furrow reversible moldboard plough working at a 35-cm depth on a medium texture-clay soil was considered.

With regard to the tractor, the following three tractors were taken into account:

1) tractor A, engine power 179 kW, minimum specific fuel consumption 213 g kWh^{-1}, emission Stage 3A, equipped with EGR (Exhaust Gas Recirculation). The EGR consists of a valve that allows recirculating part of the exhaust gases as intake air in the engine, involving a lowered oxygen content per unit volume of intake air and that intake air has already high temperatures, hence NO_x formation is lowered,
2) tractor B, engine power 191 kW, minimum specific fuel consumption 196 g kWh^{-1}, emission Stage 3B, equipped with SCR (Selective Catalytic Reduction) in which a urea solution is used at 3.4% volume of the fuel consumed. In the SCR, a 32.5% solution of urea is injected into the hot exhaust gas stream, water evaporates and the urea thermally decomposes to form ammonia and isocyanic acid; the NO_x are catalytically reduced by the ammonia into water and nitrogen,
3) tractor C, engine power 135 kW, minimum specific fuel consumption 235 g kWh^{-1}, previous to emission Stage limits, therefore no equipment for pollutants reduction is included. Moreover, at that time more powerful tractors were not available on the market, therefore was selected this less powerful tractor in respect to A and B.

Tractor A and tractor B have only slightly different engine power ratings (179 kW and 191 kW, respectively). The difference is mainly related to the engine setting and to the technologies adopted for emissions control. In fact, Tractor B is considered as the more recent version of tractor A, introduced to comply with the European Directive on emission limits, but designed to maintain the same performance features.

The consumption of fuel (and of urea solution on tractor B) were measured for all three tractors, while pollutants emissions were quantified referring to the emission limits of the emission Stage of belonging (EU Directive 97/68/EC, 2010/22/EU and 2010/26/EU) and to Schäffeler and Keller (2008). This allows taking into account the features of the single tasks of ploughing (i.e. effective fieldwork, turnings at headlands and travelling) (Lovarelli et al., 2018). It is assumed that the emission limits are met during all working conditions, even while working at partial engine loads.

Information needed for calculating inventory data for each tractor included engine power, power absorbed during ploughing (that depends on the work variables of type of plough, working speed and soil texture), emission limits per emission Stage, and correction factors due to the engine load (Schäffeler and Keller, 2008). Turning at headlands was evaluated with a fishtail manoeuvre. For the urea solution used in the SCR device in Tractor B, the consumption of liquid urea and demineralized and decarbonized water were taken into account, as well as the specific energy consumption of electricity (at 0.07 kWh kg^{-1}) and natural gas (at 1.71 MJ kg^{-1}) (Bacenetti et al., 2017).

Background data for the raw materials extraction (e.g., fossil fuels and minerals), manufacture (e.g., tractors and implements), use, maintenance and final disposal of the machinery and for the buildings housing the machinery were retrieved from the Ecoinvent Database v. 3.5 (Moreno Ruiz et al., 2018).

Regarding the available technologies, the EGR brings the conversion of nitrogen oxides (NOx) during the combustion in the engine to less than 90%. However, the main disadvantage of EGR is an increase in fuel consumption (4-10%) (Volvo, 2010) mainly due to the filter regeneration for the high soot production. In this study, +5% in fuel consumption was considered for this reason. NO_x can also be removed by the SCR, which adopts ammonia (NH_3) as reducing agent in an aqueous solution containing 32.5% urea. With this after-treatment system, urea injected is converted to NH_3 through thermolysis and hydrolysis. Respect to EGR, the advantages of SCR regard a higher specific power output, improved engine life and lower fuel consumption due to an increase in fuel efficiency (4-5%; Maiboom et al., 2009; Volvo, 2010). Nevertheless, urea solution is consumed, for a total of 1.08 dm^3 h^{-1} (3.4% vol.).

Conversely, tractors still present on the market that were produced more than about 20 years ago are characterized by no device for pollutant emissions control, because no emission limits for agricultural tractors were present. Pollutants released during fuel combustion were very high in quantitative terms and dangerous for human health. However, although such tractors are outdated, they are still common on some Italian farms. The tractor selected in this study allows performing the same ploughing of tractors A and B, but since its engine power is lower, to perform the same operation of tractors A and B, ploughing with tractor C is carried out at 4.3 km h^{-1} instead of 6.0 km h^{-1} as for tractors A and B. This difference affects the total working time and, consequently, the annual use of tractor C for ploughing and the annual use of the plough.

In particular, the annual working time of 500 h was used for the tractors. At the theoretical end of their lifespans (i.e. after 12 y) (Lazzari & Mazzetto, 2016), each tractor worked 6000 h, which is about the half of the average value available in literature. However, this value is also in accordance with the effective use and lifespan of machinery operated by Italian farmers (Bietresato et al., 2015). The effective field capacity for tractors A and B was 0.68 ha h^{-1}, composed by effective work (61.2%), turns at the headlands (with the fishtail turn manoeuvre; 25.6%), farm preparation (including plough coupling and uncoupling, diesel tank filling, etc.; 6.1%, travelling between farm and field (considering an average one-way distance of 1 km at 15 km h^{-1}; 6.8%). For tractor C, the effective field capacity was 0.55 ha h^{-1}. Engine features were assumed for the test bench by taking into account this temporal distinction. The engine load ranged between 80–85% during ploughing, 20–35% during turning at headlands and 20–40% during travelling, while the tractor idling during farm preparations.

The mass of machinery (tractor and plough) represents the mass depleted during the field operation, so that the amount of materials consumed during the lifespan of both tractor and plough is considered. This brings to quantify the environmental impact of the machinery production, maintenance and disposal at the end of lifespan. Table 2 and Table 3 report the main inventory data used.

Table 2. Inventory data for the ploughings.

Variables		**Unit**	**Tractor A, Stage 3A with EGR**	**Tractor B, Stage 3B with SCR**	**Tractor C, with no emission control**
Fuel consumption		kg ha-1	40.3	38.4	39.4
Urea solution consumption		dm3 h-1	--	1.08	--
Mass of tractor		Kg	7200	8140	6665
Mass of plough		Kg	1280	1280	1280
Working time per year	Tractor	h y-1	500	500	500
	Plough	h y-1	130	130	160(*)
Consumed mass	Tractor	kg ha-1	1.53	1.74	1.01
	Plough	kg ha-1	1.04	1.04	1.16

Note: (*) because the engine power is lower and the pedo-climatic characteristics are the same the working speed must be lower, therefore working time is higher.

Table 3. Exhaust gas emissions during ploughing operations.

Exhaust gas	Unit	Tractor A, Stage 3A with EGR	Tractor B, Stage 3B with SCR	Tractor C, with no emission control
CO_2	kg ha^{-1}	126.9	121.0	123.0
CO	g ha^{-1}	349.1	166.1	314.4
NO_x	g ha^1	947.2	94.3	1555
PM	g ha^{-1}	69.7	5.5	208
HC	g ha^{-1}	66.8	48.2	77.3

3. Environmental impact assessment (LCIA)

The following 12 environmental impact categories were used (ILCD, 2012): Climate Change (CC, kg CO2 eq), Ozone Depletion (OD, kg CFC-11 eq), Human toxicity, non-cancer effects (HTnoc, CTUh), Human toxicity, cancer effects (HTc, CTUh), Particulate Matter Formation (PM, kg PM2.5 eq), Photochemical Oxidant Formation (POF, kg NMVOC eq), Acidification (TA, molc H+ eq), Terrestrial eutrophication (TE, molc N eq), Freshwater eutrophication (FE, kg P eq), Marine eutrophication (ME, kg N eq·10), Freshwater ecotoxicity (FEx, CTUe), Mineral, fossil and renewable resources depletion (MFRD, kg Sb eq).

The ILCD 2011 Midpoint method was released by the European Commission, Joint Research Centre in 2012. It supports the correct use of the characterization factors for impact assessment as recommended in the ILCD guidance document “Recommendations for Life Cycle Impact Assessment in the European context - based on existing environmental impact assessment models and factors? (EC-JRC, 2011).

4. Results and Discussion

The environmental results of the ploughing operation are reported in Table 5. For all the evaluated environmental impact categories, the ploughing carried out using the tractor without emission control strategy (tractor C) has the worst environmental performance. On the opposite, not univocal results are obtained when the operation is performed with tractors A and B, and this is mostly due to the specific engine and operative characteristics of every tractor.

Ploughing with Tractor B shows the lowest environmental impacts on all the evaluated impact categories, except for those affected by tractor’s mass and materials wear. This means that the use of the urea solution for the SCR system does not affect negatively any impact category; instead, the benefits that arise from the abatement of pollutants and from the reduced fuel consumption are higher than the impact of the urea solution consumption. In addition, the biggest reduction in environmental load can be highlighted for the categories affected by NO_x and NMVOC emissions (i.e. TA, ME, POF, PM), with reductions ranging between –59% and –73% with respect to the results for tractor A. Considering the categories of CC, OD and FD, the impact reduction is restrained (–3% for each impact category) and is completely related to the reduction in fuel consumption in tractor B. However, the environmental impact of tractor B is worse than tractor A for FE and MD (+9% and +7% for FE and MD, respectively) because of the production of the tractor (tractor B has a higher mass than tractor A, in part due of the pollutant abatement device) and of the consumption of the urea solution. For FE, the impact is mostly related to the mining activities for minerals extraction, while for MD, the impact is mostly due to the metals used during the manufacturing.

Table 5. Absolute environmental impacts for the 3 studied ploughing operations.

Impact category	Unit	Tractor A Stage 3A	Tractor B Stage 3B	Tractor C - no emission control
CC	kg CO_2 eq	162.69	158.37	162.99
OD	kg CFC-11 eq · 10^{-5}	2.64	2.55	2.64
HTnoc	CTUh · 10^{-5}	4.96	5.09	14.80
HTc	CTUh · 10^{-6}	3.72	3.95	4.61
PM	kg PM2.5 eq	0.0677	0.0411	0.1266
POF	kg NMVOC eq	1.2145	0.3623	1.8572
TA	molc H+ eq	1.0604	0.4354	1.5441
TE	molc N eq	4.4619	0.8445	7.0982
FE	kg P eq	0.0130	0.0142	0.0165
ME	kg N eq	0.4082	0.0774	0.6493
FEx	CTUe	349.67	380.06	487.77
MFRD	kg Sb eq	0.0133	0.0150	0.0174

Figure 2 shows the relative comparison of the environmental impact of the three ploughing operations.

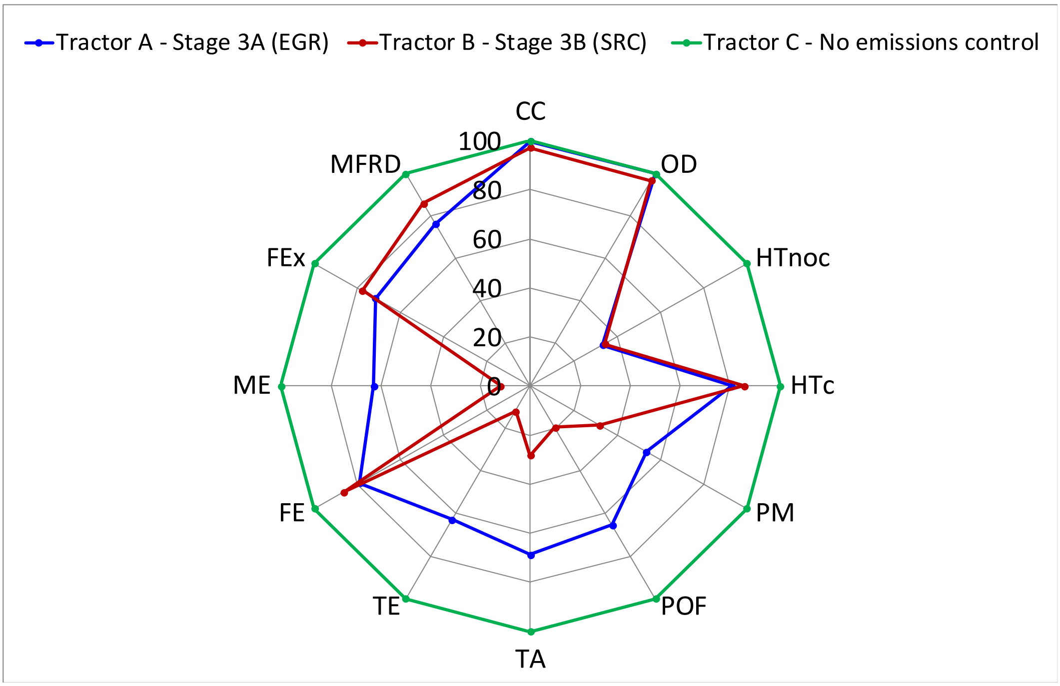

Fig. 2. Comparison among the ploughing operations performed with the three tractors A, B and C.

Tractor C reports the highest environmental impact on all impact categories, especially on those affected by pollutants emissions. On CC and OD, the environmental outcomes are very close to each other for tractor A and C, due to the fuel consumption. Tractor B shows the best environmental behavior on 7 of the 12 evaluated impact categories, especially on those affected by the pollutants emissions; respect to tractor C, the impact reduction for PM, POF, TA, TE and ME ranges between

68% and 88% for tractor B. On HTnoc, HTc, FE, FEx and MFRD, tractor B results worse than tractor A because of the more complex SCR system respect to the EGR (tractor A) one; this implies that mass of tractor B is higher than the other tractors. Still, tractor C keeps behaving the worst on these categories as a consequence of the higher working time per ha that affects the consumption of tractor and plough.

5. Conclusions

The LCA approach is used to compare the environmental impacts of ploughing conducted with three tractor models equipped with different devices to reduce pollutant emissions (EGR and SCR) or without devices for emissions reduction (i.e. old and outdated tractor, still frequently present on farms). Although the SCR involves production costs and materials for its manufacturing such as tanks, nozzle, sensors, electronics, etc. as well as for the production of the urea solution, it also involves higher fuel efficiency and less pollutant emissions with respect to the EGR. With the EGR, it can be observed a low increase in production costs but also a less beneficial environmental effect, since fuel combustion efficiency is reduced as a consequence of the partial re-introduction of unclean intake air. Although the EGR participates in the reduction of pollutant emissions much more than the previous Stage 2 tractors, SCR brings to a much more evident reduction in the environmental impact.

The quantification of the environmental load of the tractors that belong to different emissive stages permits to quantify effectively the benefits of modern technologies, and allows policymakers and stakeholders to make decisions on possible incentives and/or measures to support the introduction of newer machinery on agricultural farms. Moreover, knowing the age of the tractor fleet improves knowledge of the effective pollutant emissions and their role in the environmental impact evaluations of agricultural processes, differently from what can occur selecting average fleet data on machinery retrieved from databases.

These outcomes can be useful also when evaluating the effect of the devices on the field operation, and decide whether and to what extent different devices should be introduced to respect emission limits.

References

Bacenetti, J., Lovarelli, D., Facchinetti, D., Pessina, D. (2018). An environmental comparison of techniques to reduce pollutants emissions related to agricultural tractors. Biosystems Engineering. 171, 30-40.

Bacenetti, J., Lovarelli, D., Pessina, D. (2017*)*. Life cycle assessment and environmental evaluation of agricultural mechanisation: potentiality, unsolved issues and possible interactions. Associazione Italiana Ingegneria Agraria, Bari, Italy, 5-7th July 2017.

Bietresato, M., Calcante, A., Mazzetto, F. (2015). A neural network approach for indirectly estimating farm tractors engine performances. Fuel. 143, 144–154.

Boone, L., Van linden, V., De Meester, S., Vandecasteele, B., Muylle, H., Roldán-Ruiz, I., Nemecek, T., Dewulf, J. (2016). Environmental life cycle assessment of grain maize production: An analysis of factors causing variability. Science of Total Environment. 553, 551–564.

EC-JRC - European Commission, Joint Research Centre, Institute for Environment and Sustainability. Characterisation factors of the ILCD Recommended Life Cycle Impact Assessment methods. Database and Supporting Information. First edition. February 2012. EUR 25167. Luxembourg. Publications Office of the European Union; 2012.

European Directive 97/68/EC. On emissions from non-road mobile machinery. In: Official Journal of the European Communities 1998. L 59: 1.

International Reference Life Cycle Data System (ILCD) Handbook- Recommendations for Life Cycle Impact Assessment in the European context, 2011. EUR 24571 EN. Luxemburg. Publications Office of the EU.

IPCC, Agriculture, Forestry and Other Land Use (2006). In: Eggleston et al., IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme.

ISO 14040 series, 2006. Environmental management – Life Cycle Assessment – Requirements and guidelines. International Organization for Standardization.

Janulevičius, A., Juostas, A., Čipliene, A. (2017). Nitrogen-oxide emissions from diesel-engine farm tractors during real-life cycles and their correlation with the not-to-exceed operating zones. Biosystems Engineering. 161, 93-105.

Lazzari, M., Mazzetto, F., 2016. Meccanica e meccanizzazione dei processi produttivi agricoli. REDA Ed.

Lee, J.W., Kim, J.S., Kim, K.U. (2016). Computer simulations to maximise fuel efficiency and work performance of agricultural tractors in rotovating and ploughing operations. Biosystems Engineering. 142, 1–11.

Lovarelli, D., Bacenetti, J. (2017b). Seedbed preparation for arable crops: environmental impact of alternative mechanical solutions. Soil Tillage & Research. 174, 156-168.

Lovarelli, D., Fiala, M., Larsson, G. (2018). Fuel consumption and exhaust emissions during on-field tractor activity: A possible improving strategy for the environmental load of agricultural mechanisation. Computers and Electronics in Agriculture. 151, 238-248.

Maiboom A., Tauzia X., Shah S. R., Hétet. J.-F. (2009). Experimental study of an LP EGR system on an automotive diesel engine, compared to HP EGR with respect to PM and NOX emissions and specific fuel consumption, Tech. rep., SAE Technical Paper.

Moreno Ruiz E., Valsasina L., Brunner, F., Symeonidis A., FitzGerald D., Treyer, K., Bourgault G., Wernet G., (2018). Documentation of changes implemented in ecoinvent database v3.5. Ecoinvent, Zürich, Switzerland.

Perozzi, D., Mattetti, M., Molari, G., Sereni, E. (2016). Methodology to analyse farm tractor idling time. Biosystems Engineering. 148, 81-89.

Sabelhaus, D., Röben, F., Meyer zu Helligen, L.P., Schulze Lammers, P. (2013). Using continuous-curvature paths to generate feasible headland turn manoeuvres. Biosystems Engineering. 116, 399-409.

Schäffeler, U., Keller, M. (2008). Non-road fuel consumption and pollutant emissions. Study for the period from 1980 to 2020. p. 171. Bern.

Volvo (2010). SCR and fuel efficiency, Tech. rep. http://www.volvotrucks.com/SiteCollectionDocuments/VTNA_Tree/ILF/Products/2010/09-VTM097_FW_SS.pdf

Measurement of Ammonia Emission in Practical Dairy Farm Environment

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Abstract

Ammonia emission measurement in practical farm environment needs to meet several contradictory requirements. The instrumentation has to be accurate enough yet economical and easy to use. Most of new dairy production buildings are loose-housing type which sets special requirements to positioning of the sensors in 3D. Measurement locations have to be carefully selected so that they represent the flow patterns inside and out of the building. Sensors have to have suitable dynamic behavior and sampling needs to be dense if rapid changes in concentrations due to e.g. the effect of changing daily routines are to be detected.

A practical instrumentation for Ammonia emission measurement was designed and tested in one-week sessions in six different Finnish dairy barns during all four seasons. The positioning of sensors in 3D was tested. The sampling rate was set high to detect the dynamics of emission.

Results show how the instrumentation affects the obtained results. It was concluded that the instrumentation was feasible. It was economical yet accurate enough for the calculation of farm-level Ammonia emission. Further studies are, however, needed to refine the measurement procedure.

Keywords: Ammonia, Emission, Measurement, Dairy, Practice

1. Introduction

Ammonia emissions from dairy barns depend on several variable factors, most importantly on indoor temperature, ventilation, manure composition (type, nitrogen content and pH), manure handling method used, and the quality and quantity of litter (Groot Koerkamp et al. 2001, Gustafsson et al. 2005, Starmans et al. 2007, Maasikmets et al. 2015). National Finnish emission model, however, has been developed on the basis of international guidelines that have been developed for more or less different climatic and technological environments as compared to Finnish conditions. To compensate the difference, correcting coefficients have been used (Grönroos et al. 2009). In order to check and improve the reliability of these calculations, a sufficient number of domestic emission measurements is needed (Hellstedt et al. 2018).

Accurate assessment of national gaseous emissions needs measurements from different practical situations. The measurements need to be done in a proper way so that the results would represent the actual situations accurately enough. On top of this, the environment inside barns sets strict requirements for the measurement electronics, especially as regards to tolerance against low temperature and high relative humidity (Haapala 2003).

In order to be able to detect changes in emission level, the measurements need to be continuously recording. The resolution and detection rate need to be adjusted to detect the emission accurately enough both in level and time. The sensors need to be positioned so that their results represent the flows inside the building. Finally, the instrumentation needs to be easy to use and economical so that it can be widely used on farm level. (Hellstedt & Haapala 2018)

2. Materials and Methods

Measurements of Ammonia emissions were conducted in Finland in insulated and uninsulated stationary and loose-housing barns with different manure management and littering systems. The instrumentation was done with an economical setup enabling accurate measurements in both space and time. Usability of the results and instrumentation were assessed. (Hellstedt et al. 2018)

The measurements were done in 24 one-week sessions, i.e. six barns were measured during all the four seasons. Continuously measuring Dräger PAC 7000 Ammonia sensors with a range of 0 to 300 ppm and a resolution of 1 ppm were used. The Dräger sensors are originally designed to act as personal protection devices in hazardous environments. They were chosen for barn environment because of their ruggedness, adequate accuracy and relatively low price. (Hellstedt & Haapala 2018, Fig. 1.)

The positioning of sensors is critical since airflow patterns depend on barn layout (Teye 2008, Ngwabie et al. 2009). In this study, sensors were installed in three elevations (0.1, 1.0 and 2.5 meters) according to the method used by Teye (2008). There were 9 to 12 Ammonia sensors altogether in the barns, depending on the size of the barn. Airflow was measured with a hot-wire anemometer to position the sensors in representative locations. (Hellstedt & Haapala 2018, Fig. 2.)

Fig. 1. The Ammonia sensors together with CO_2, temperature and RH gauges (left) were placed inside the barns in three elevations (0.1, 1.0 and 2.5 meters) (center) and three to four locations, depending on the size of the barn. If accessible to the cows, the instruments were protected by rugged steel casings (right). (Hellstedt & Haapala 2018)

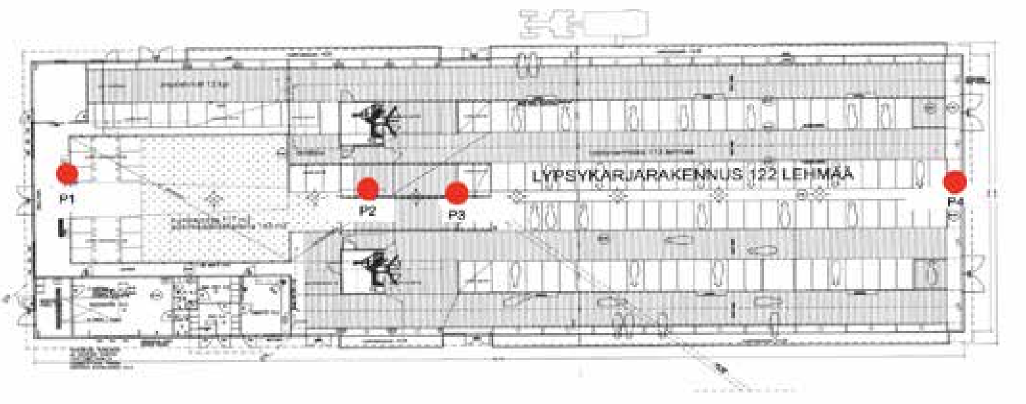

Fig. 2. An example of the positioning of sensors in a loose-housing barn with two milking robots and 122 cows. In each position there are three Ammonia, CO_2, temperature and RH sensors in three elevations (Hellstedt & Haapala 2018).

The detection rate was set high, every 2 minutes, in order to be able to detect the dynamics of the emission. The ventilation rate in the barns was derived out of the measured CO_2 balance. The Ammonia emission was then calculated based on the Ammonia concentrations and the ventilation rate (Teye & Hautala 2007, Eq. 1 and 2)

Production of gas x depends on concentration difference and ventilation:

$$P_x = q_{V_x} \left(C_{g_x} - C_{out_x}\right)$$

where q_{V_x} *is ventilation (m³/h)*

C_{g_x} *is concentration of the gas inside the building (ppm)*

C_{out_x} *is concentration of the gas in inlet air (ppm)*

Eq. 1.

Emission in g/h/m² is calculated by ventilation and concentration difference:

$$j_{CO_2} = \frac{q_{V_{CO_2}} \rho_{NH_3} \left(C_{g_{NH_3}} - C_{out_{NH_3}}\right) \times 10^{-6}}{A}$$

where

ρ_{NH_3} is density of Ammonia (g/m³)

A is area of manure-covered areas (m²)

Eq. 2.

3. Results and Discussion

According to the emission measurement results the barns had significant differences in Ammonia emissions both during the seasons and between the farms as well. In loose-housing barns the level was mostly under 5 g/cow/day whereas in stationary barns it was less, under 3.5 g/cow/day. The emission level for loose-housing barns was considerably lower than the figures that had been previously measured and used in national calculations (Teye 2008, Grönroos et al. 2009). For stationary barns the situation was opposite so that somewhat higher levels of Ammonia emission were found. Loose-housing, however, is the dominant housing system in future in Finland, and stationary barns are not built anymore.

There were several peaks in Ammonia emission during the day. When closer analyzed and compared to the log file kept by the farmer, the peaks occur when the manure is handled or the animals are active. The daily routines cause animal movement and agitation of manure-covered surfaces which enable higher concentrations of Ammonia inside the barn. (Hellstedt et al. 2017, Fig. 3.)

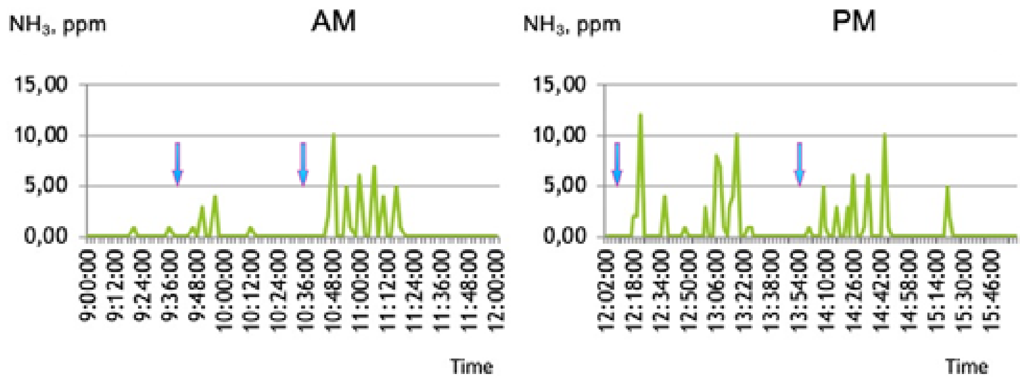

Fig. 3. Ammonia emission during morning and afternoon. The dense detection rate (every 2 minutes) reveals fluctuations in emission. The fluctuations happen as people enter the barn to make the daily management routines (marked with arrows) that cause increased animal movement or agitation of manure-covered surfaces. (Hellstedt et al. 2017)

As there were several sensor locations in the barns, local disturbances causing increased Ammonia level could be detected. In one of the loose-housing barns, the manure removal system was accidentally left on for a longer period. The sensors detected the rise of Ammonia level near the source and how the turbulent airflow mixed the caused higher concentration inside the barn. If there had not been several measurement locations, the reason for elevated Ammonia concentration had not been detected. (Hellstedt et al. 2017, Fig. 4)

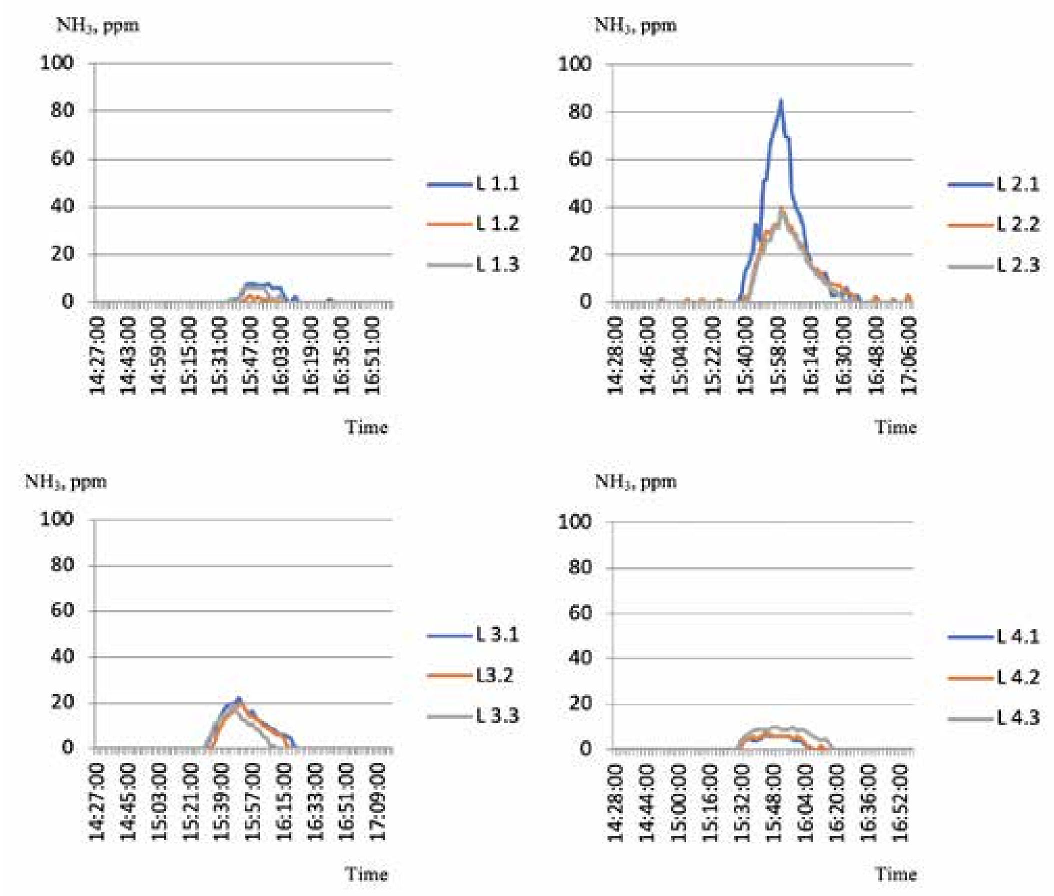

Fig 4. Effect of manure agitation. Manure removal system was accidentally left on for a prolonged period near the point nr 2. The nearby sensors (L2.1 to L2.3.) measured a highly increased Ammonia level specially at ground level (0.1 m). Sensors at positions 1, 3 and 4, further from the source, detected lower levels that had been equalized by the turbulet airflow. (Hellstedt et al. 2017)

4. Conclusions

The measured data suggest that Ammonia emission level in current Finnish barns is significantly lower than projected in the previous modelling. In future, loose housing is dominant and better technologies are utilized so that Ammonia emission per cow will be further diminishing.

Besides the type of barn (layout, milking, feeding, and manure removal systems) the Ammonia emission seems to be greatly affected by management operations. Same type of barn can be managed in different ways, causing considerably different levels of emission. The daily management causes changes in ventilation, temperature and relative humidity, but also in cow activity which has an effect on manure agitation and resulting emission.

The results concerning the implementation point out the importance of understanding the local circumstances and the ability to make the measurement design accordingly. The measurement principle utilized enables a more precise analysis of the differences of barns.

Instrument positioning needs to be adjusted to the barn layout both in 2D and 3D. The continuous measurement principle with dense detection rate and relevant instrument locations allow the researchers to find daily and momentous fluctuations in emission rate caused by the individual management practices on the farms and disturbances in them. These might explain the large variation in emission measurements that have been done before with inadequate instrumentation, i.e. using random sensor locations or unsuitable detection rates.

The price-quality ratio of instrumentation limits the practical usability of measurement methods. Research and inspection have different requirements from those of farm level usage. If emissions need to be measured continuously for practical purposes such as farm management, it is important to create optimized methods for farm level usage.

Further studies are needed to further improve the validity of measurements, to assess the effect of management practices and to assess the effect of manure storage.

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References

Groot Koerkamp, P.W.G., Metz, J.H.M., Uenk, G.H., Phillips, V. R., Holden, M.R., Sneath, R.W., Short, J.L., White, R.P., Hartung, J., Seedorf, J., Schroder, M., Linkert, K.H., Pedersen, S., Taka, H., Johnsen, J.O. & Wathes, C.M. 1998. Concentrations and emissions of ammonia in livestock buildings in Northern Europe. Journal of Agricultural Engineering Research, 70: 79–95.

Grönroos, J., Mattila, P, Regina, K., Nousiainen, J., Perälä, P., Saarinen, K. & Mikkola-Pusa, J. 2009. Development of the ammonia emission inventory in Finland. Revised model for agriculture. The Finnish Environment 8/2009. 60 p.

Haapala, H. 2003. Operation of electronic identification devices in northern winter climate. In: Cox, S. (ed.) Precision Livestock Farming. Wageningen Academic publishers. p. 59-66.

Hellstedt, M., Luostarinen, S., Regina, K., Särkijärvi,. S., Gröroos, J. & Haapala, H. 2017. In Finnish: Lypsykarjanavetoiden ammoniakkipäästöjen nykytaso ja vähentämismenetelmät. [The current level of Ammonia emissions and available reduction methods in dairy barns]. Luonnonvara- ja biotalouden tutkimus 53/2017. Luonnonvarakeskus (Luke), Helsinki 2017. 64 p.

Hellstedt, M. & Haapala. H. 2018. Continuous on-farm measurement of Ammonia emissions in dairy barns. CIGR-AgEng 2018 Conference. Antalya, Turkey.

Hellstedt, M., Luostarinen, S., Grönroos, J. & Haapala, H. 2018. Ammonia emissions from dairy barns in Finland. AgEng2018. Int. Conference of Agricultural Engineering. 8-12 July. Wageningen, Holland.

Maasikmets, M., Teinemaa, E., Kaasik, A. & Kimmel, V. 2015. Measurement and analysis of ammonia, hydrogen sulphide and odour emissions from the cattle farming in Estonia. Biosystems engineering 139: 48–59.

Ngwabie, N.M., K.H. Jeppsson, S. Nimmermark, C. Swensson, and G. Gustafsson. 2009. Multi-location measurements of greenhouse gases and emission rates of methane and ammonia from a naturally-ventilated barn for dairy cows. Biosystems Eng. 103:68–77. doi:10.1016/j.biosystemseng.2009.02.004

Teye, F. 2008. Microclimate and gas emissions in dairy buildings: Instrumentation, theory and measurements. Academic dissertation. Department of Agrotechnology University of Helsinki Finland. https://helda.helsinki.fi/handle/10138/20762.

Teye, F. & Hautala, M. 2007. Measuring ventilation rates in dairy buildings. International Journal of Ventilation 6: 247–256.

Viticulture sprayers' classification according to deposition efficiency and homogeneity.

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Abstract

The French national action plan EcoPhyto 2 aims at reducing the total amount of pesticides used in France by 50% between 2006 and 2025. The strong interest of spray application techniques improvement in viticulture in order to comply with the plan EcoPhyto objectives has been demonstrated. Indeed, the assessment of several spray application techniques showed that the best ones could achieve five times more deposition on the canopy than the worst one using the same quantity of product per unit ground area.

In order to assess the spray application techniques performances, IFV and IRSTEA developed the EvaSprayViti test bed which is a standardized artificial vine vegetation able to mimic three growth stages (early, medium and full). A total of 116 tests with 20 different sprayers were carried out on this test bed at the 3 different growth stages. Based on these results a classification of sprayers according to dose rate reduction potential is proposed.

Tests on EvaSprayViti bed provided two indicators values: average normalized deposition ($ng.dm^{-2}$ for $1g.ha^{-1}$) and coefficient of variation of deposition. In order to build a classification for sprayers taking into account both average normalized deposition and its coefficient of variation, an aggregated indicator named "normalized corrected deposition" has been proposed.

Then, three thresholds of "normalized corrected deposition" have been defined allowing to get a four classes classification of spray application techniques according to this criterion.

The spray application techniques classification obtained shows that promoting the use of the most efficient sprayers would allow to make a large improvement in terms of pesticides reduction compared to the current situation.

Keywords: Viticulture sprayer, efficiency, spray deposition, test bed, classification.

1. Introduction

The French national action plan "EcoPhyto 2" aims at reducing the total amount of pesticides used in France by 50% between 2006 and 2025. Improvement of spray application techniques in viticulture has been identified as an important lever in order to comply with the plan EcoPhyto objectives in the short and medium term. Indeed, measures of surface spray deposition achieved by several spray application techniques highlighted that the best techniques could achieve five times more deposition than the worst ones (Verges et al, 2017, 2018). These spray deposition measurements also showed that the majority of spray application techniques currently implemented are far from the most performant in terms of deposition optimization. Then, when standard spray application techniques are used, using more performant spray application techniques in terms of deposition would allow to use a reduced dose of pesticides whereas the spray deposition amount and the crop protection efficiency remain constant.

These preliminary works showed that improvement of spray application techniques in terms of deposition optimization could be achieved by two ways. The first way is the improvement of ongoing sprayers' settings. The second one is the renewal of the sprayer's fleet towards more performing machines. In order to formulate accurate advice to viticulture farmers concerning sprayers' settings improvement and sprayers' fleet renewal, an important amount of spray deposition measures was needed.

Then, in order to assess the spray application techniques performances at different growth stages of grape vines in repeatable conditions, IFV and IRSTEA developed the EvaSprayViti test bed which is a standardized artificial vine vegetation able to mimic three growth stages (early, medium and full). This tool allowed to measure spray deposition profiles in standardized conditions. Then, all the spray application techniques tested could be reliably compared on this criterion and an important amount of reference acquisition could be achieved.

A total of 116 tests with 20 different sprayers were carried out on this test bed at the 3 different growth stages. For each spray application technique assessed, tests on EvaSprayViti bed provided two indicators values: average normalized deposition ($ng.dm^{-2}$ for $1g.ha^{-1}$) and coefficient of variation of deposition. Based on these results, advice for sprayers' settings improvement have been formulated and a classification of sprayers according to dose rate reduction potential has been proposed.

In order to build a classification for sprayers taking into account both average normalized deposition and its coefficient of variation, an aggregated indicator named "normalized corrected deposition" has been proposed. Then, three thresholds of "normalized corrected deposition" have been defined allowing to get a four classes classification of spray application techniques according to this criterion. For the sprayers dedicated to the large vineyard (over 2 m between rows), the first threshold has been set at the average level of "normalized corrected deposition" provided by pneumatic arch sprayers which are the most common sprayers used in French large vineyards. Therefore, this first threshold has been set at the reference level, representing the most common level of spray quality got in the vineyard. Then, the second and the third threshold have been set relatively to the first one in order to identify spray application techniques representing an improvement from the reference level. The relative position of a sprayer to the three thresholds reveals its ability to keep or not an equivalent level of deposition to the reference level when considering a dose rate reduction.

The spray application techniques classification obtained shows that promoting the use of the most efficient sprayers proposed by the manufacturers, would allow to make a large improvement in terms of pesticides reduction compared to the current situation. It appears that the configuration of the sprayer is a major factor determining deposition and that sprayer's technology (air assisted or pneumatic) has a secondary influence on spray deposition. This classification process will be presented to the various French institutions concerned in order to use the knowledge produced to concur with the objectives of plan EcoPhyto.

2. Materials and Methods

The assessment of viticulture sprayer's performances was carried out using EvaSprayViti test bed. This test bed consists in an artificial vineyard allowing to make measurements of spray deposition profiles according to the ISO 22522 standards (Codis et al, 2013, 2015). The test bed EvaSprayViti is a structure, composed by four 10 meters long rows of two different types: collection rows and edge rows (Figure 1). Collection rows are composed of artificial PVC leaves. Collection rows are dedicated to capture and assess spray deposit on the canopy. Edge rows are composed of porous nets. Edge rows aim at intercept the air flow of the tested sprayers comparably at a real vine and limit side effects. The artificial vegetation has been designed with an adjustable height and width in order to be able to characterize the performance of sprayers at three distinct growth stages: early stage, medium and full growth stage.

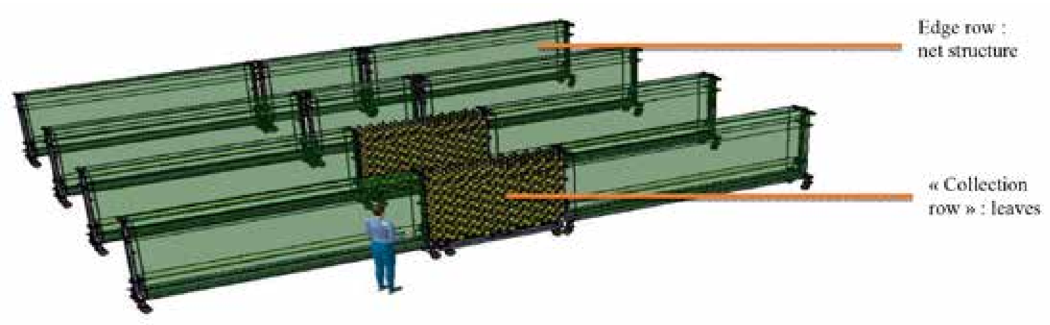


Figure 1. EvaSprayViti at full growth stage configuration.

In this study the distance between the rows was set at 2.5 meters. The test bed characteristics have been chosen to mimic three different growth stage. The table 1 below indicates the characteristics of the three growth stage in terms of leaf area index (LAI) and number of leaves over the 2 meters of length of the collection row. The figure 2 below is a schematic representation of the collection row at the three growth stages used in this study.

Table 1. Characteristics of the vegetation simulated by the three possible "growth stages" of the collection rows:

Growth stage	Early	Medium	Full
Leaf Area Index (ha/ha)	0,24	0,88	1,68
Number of leaves	120	440	840
Heigh of the canopy (m)	0,6	1,1	1,4
Width of the canopy (cm)	30	60	70

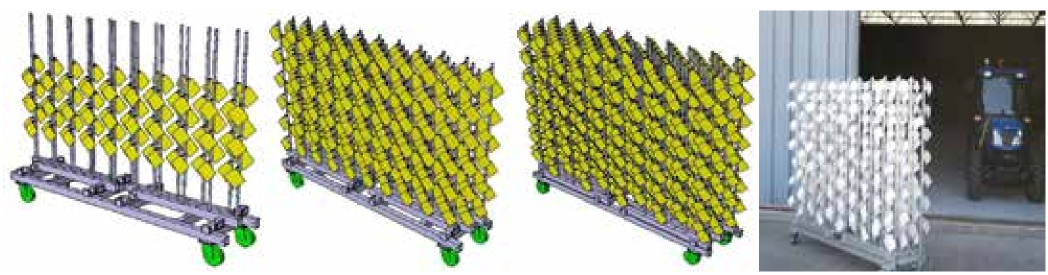


Figure 2. Characteristics of the "collection row" at different growth stages. From left to right: early, medium and full growth stage. Photograph at the collection row at full growth stage.

Before the test bed construction, the use of PVC collectors for spray deposition measurement has been evaluated. Spray deposition amount on the tested PVC collectors and on real vine leaves have been compared for several spray application techniques in terms of droplet size and air velocity. The use of this PVC material has been validated. Then the same material was used for the artificial leaves of the EvaSprayViti test bed.

Spray deposition profiles measured on EvaSprayViti test bed and on real vines equipped with collectors were compared. First it showed that the same shapes of spray deposition profile were measured for the two methods. Secondly it showed that the performance of the different spray application techniques assessed were classified in the same way whatever the method of deposition measure used.

The reproducibility of the measure of spray deposition on EvaSprayViti test bed has been assessed. Whatever the spray application used, the coefficient of variation of 5 replicates of average deposition measurement was less than 5%.

Tartrazine (E102) was used as tracer. For each test, a water solution of tartrazine was sprayed over the test bed. For each spray application technique assessed, a sample of the sprayed solution was taken. After spraying over the EvaSparyViti test bed, a time of latency was left until the liquid deposition dried. Then, all the leaves, loaded with dried deposition of tartrazine were collected in boxes. Each box of collect received the artificial leaves of a precise compartment of vegetation. The artificial canopy of the test bed was segmented into compartments. At early growth stage the number of compartments was 4 (4 depths). At medium growth stage, the number of compartments was 12 (4 depths and 3 heights). At full growth stage, the number of compartments was 9 (3 depths and 3 heights).

The measure of the amount of tartrazine collected by the leaves disposed in each box of analysis was carried out in three steps. A known amount of distilled water has been introduced in each box. Each box has been agitated. The absorbance of at 427 nm (wave length) of the water of each box has been measured. The absorbance at 427 nm of 3 different known dilutions of the sample of solution sprayed has been measured.

Then, the quantity of normalized deposit per unit of leaf area for one gram of tracer sprayed per hectare (unit: ng/dm2 for 1g/ha) has been calculated for each compartment of artificial canopy. Two indicators of spray application quality were calculated. The first indicator is the average quantity of deposit per unit of leaf area for one gram of tracer sprayed per hectare (unit: ng/dm^2 for 1g/ha) calculated for the whole vegetation. The second indicator is the coefficient of variation of deposits measured in each compartment of vegetation expressed in percent of the average deposit.

In order to build a classification for sprayers taking into account both average normalized deposition and its coefficient of variation, an aggregated indicator has been proposed. Named "normalized corrected deposition" this indicator is defined by: normalized corrected deposition = normalized average deposition – standard deviation.

Then, a first threshold of performance considered as a reference level (RL) has been defined. It corresponds to the average performance of pneumatic arch sprayers which are the most common sprayers used in vineyards (70% of the fleet) when they are used in compliance with manufacturer's recommendations (a path every two rows). Afterwards, compared to this reference level (RL), two other classification thresholds have been defined by RL/0.7 for the second one and RL/0.5 for the third one.

The three classification thresholds defined previously allow getting a four classes classification of spray application techniques. The relative position of a sprayer to the three thresholds reveals its ability to keep or not an equivalent level of deposition to the reference level when considering a dose rate reduction. For example, a spray application technique that reaches the second threshold (RL/0.7) when used with a dose rate of only 70% of full dose rate will provide the same level of corrected deposition that the reference technique used with the full dose rate.

20 sprayers dedicated to the large vineyard have been assessed. Most types of sprayers on the French market are represented in the sample of sprayers assessed (table 2).

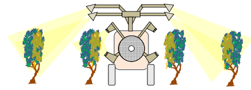
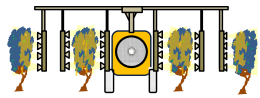
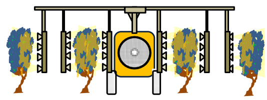
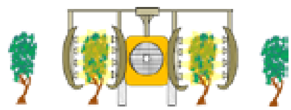
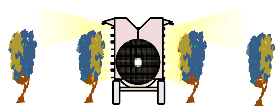
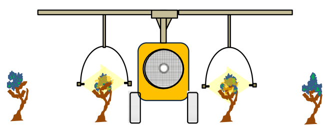
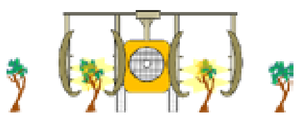
Tested sprayer	Diagram	Number of tested sprayers
Pneumatic arch sprayer (new generation), run every 2, 3 or 4 rows.		3
Pneumatic arch sprayer (old generation), run every 2, 3 or 4 rows.		1
Side by side pneumatic sprayer.		3
Side by side air assisted sprayer. Set with different kind of nozzles.		3
Schielded air assisted sprayer. Set with different kind of nozzles.		3
Airblast sprayer.		5
Early growth stage hoop sprayer.		1
Shielded sprayer without air assistance. Set with different kind of nozzles.		1

Table 2: Description of the sample of sprayers assessed.

Considering the fact that spray quality offered by a given sprayer also highly depends on the settings implemented, reference settings had to be defined for each kind of sprayer (Vergès et al. 2015). For any parameter likely to be set, the definition of reference settings has been carried out taking into account two factors: the range of variation currently run into the field and the manufacturer recommendations. Then, for each assessed sprayer, a measure of performance was carried out for every defined reference setting. Reference settings that have been used for each kind of sprayer are inscribed in the table 3 below.

	Forward speed	Volume rate	Spatial arrangement of spray outlets
Pneumatic Arch Sprayer	Between 4.5 and 5.5 $km.h^{-1}$	Between 50 and 100 $l.ha^{-1}$ at early growth stage. Between 100 and 180 $l.ha^{-1}$ at medium and full growth stage.	Vegetation targeting set with "rusty iron plate".
Airblast sprayers	Between 6 and 7 $km.h^{-1}$	Between 50 and 100 $l.ha^{-1}$ at early growth stage. Between 100 and 180 $l.ha^{-1}$ at medium and full growth stage.	Adaptation of the number of opened nozzles to the vegetation height with "rusty iron plate".
Side by side pneumatic and air assisted sprayers	Between 4.5 and 5.5 $km.h^{-1}$	Between 50 and 100 $l.ha^{-1}$ at early growth stage. Between 100 and 180 $l.ha^{-1}$ at medium and full growth stage.	Adaptation of the number of opened nozzles (or outlets) to the vegetation height with "rusty iron plate".
Shielded sprayers	Between 4.5 and 5.5 $km.h^{-1}$	Between 50 and 100 $l.ha^{-1}$ at early growth stage. Between 100 and 180 $l.ha^{-1}$ at medium and full growth stage.	Adaptation of the number of opened nozzles to the vegetation height with "rusty iron plate".

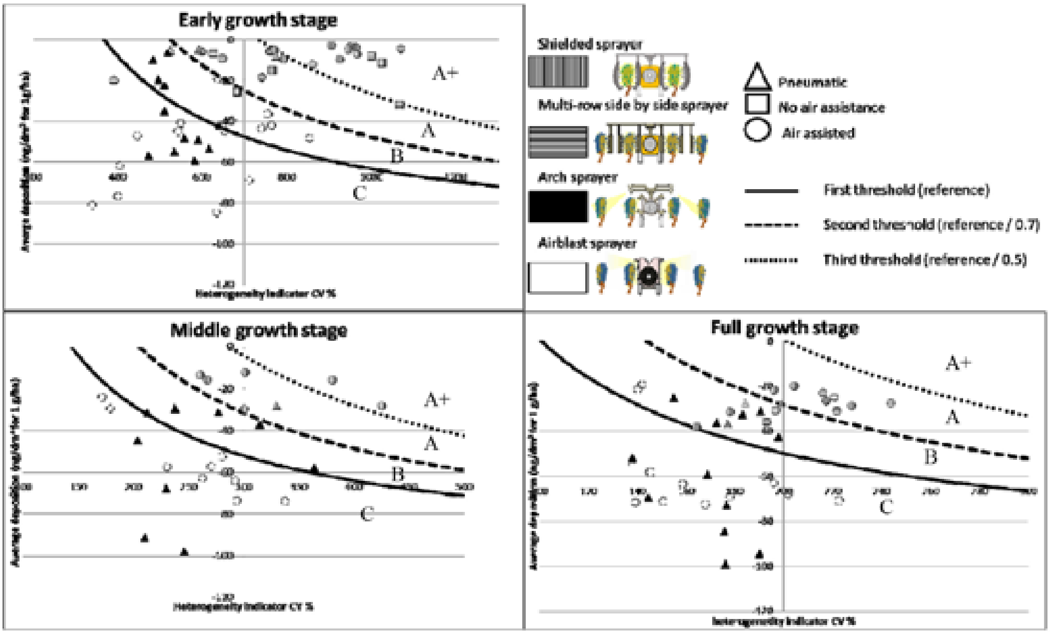
Table 3: Reference settings for each kind of sprayers.

3. Results and Discussion

Results of sprayers performance assessment measured on the test bed EvaSprayViti are represented in the figure 3 below. For each growth stage, the spray application technique performances are represented by a point which coordinates are the two indicators of spray quality (average deposition; coefficient of variation). A spray application technique is defined as a couple (sprayer model; setting).

The three classification thresholds defined previously are represented by the curves plotted in these three graphics. The equation of the curves has been calculated using the definition of the corrected deposition and the definition of the classification thresholds. The letters inscribed between the classification thresholds indicate the classification grade attributed to the points located in the delimited zone.

The shape of the points indicates the technology of spraying: pneumatic (without nozzle), air assisted or without air assistance. The filling of the points indicates the sprayer conformation.



This synthetic representation enables to get a global view of vineyard sprayers' performance range. Whatever the growth stage and the technology (pneumatic, air assisted or not), multi-row side by side sprayers and shielded sprayers appear to be the typology offering the best spray quality according to both criteria, average amount of deposits and homogeneity of deposits (representative points located on the top right of the figures). It appears that pneumatic arch sprayers and airblast sprayers are offering very variables quality of spray depending on the commercial model, the applied settings and practices. It appears that the configuration of the sprayer is a major factor determining deposition and that sprayer's technology (air assisted or pneumatic) has a secondary influence on spray deposition.

Considering the fact that arch sprayers represent the majority of the ongoing fleet of sprayers in the French vineyard and that their average performance is represented by the first threshold, this work shows that promoting the use of the most efficient sprayers would allow to make a large improvement in terms of spray quality. Then this improvement could be used by farmers to make pesticides dose rate reduction while maintaining crop protection efficiency, in line with the national action plan EcoPhyto objectives.

4. Conclusions

This classification of vineyard sprayers is currently used in the project "LabelPulve". This project aims at create a labeling system for the sprayers. Each viticulture sprayer is likely to receive a label grade (A+,A, B, C) depending on his performance in terms of deposition for each of the three growth stage. The label grade depends on the relative position of the sprayer's performance and the classification thresholds. The construction of the label rules is currently in progress in collaboration with sprayers manufacturers and French ministry of agriculture.

Two different ways to get the label "LabelPulve" will be offered to sprayers' manufacturers. The first way consists in measuring the performance of the candidate sprayer on the EvaSprayViti test bed and attribute the label according to the relative position of the measured performance and classification thresholds. The second way consists in asking for a label grade "a priori" according to the sprayer characteristics. A table of the grades attributed “a priori” has been proposed. For each kind of sprayer, the grade attributed “a priori” is the minimal grade noted on the sprayers of the same kind already tested.

The purpose of this work is to build a tool that aims at orientate the fleet of viticulture sprayers renewal towards more performing machines. This work will be presented to the different stakeholders: farmers, advisers, administrators. In the future, this label could be used by French authorities to orientate public policies of sprayers fleet renewal.

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References

Codis S., Bonicel JF., Diouloufet G., Douzals JP., Hébrard O., Montegano P., Ruelle B., Ribeyrolles X., Vergès A., 2013, EvaSprayViti: a new tool for sprayer’s agro-environmental performance assessment, Suprofruit 2013 pp. 23-25.

Codis, S, Vergès, A, Ruelle, B, Hebrard , O, Magnier, J, Montégano, P, Ribeyrolles, X, (2015). EvaSprayViti : Une vigne artificielle pour l’optimisation agro-environnementale de la pulvérisation en viticulture. Innovations Agronomiques 46 (2015), 27-37.

Vergès A., Codis S., Bonicel JF., Diouloufet G., Douzals JP., Magnier J., Montegano P., Ribeyrolles X., Ruelle B. Sprayers’ classification according to their performance in terms of spray deposition quality, Suprofruit 2015 pp. 64-65.

Vergès A., Codis S., Bonicel JF., Diouloufet G., Douzals JP., Magnier J., Montegano P., Ribeyrolles X., Ruelle B., Carra M., Delpuech X., Savajols B. Sprayer classification in viticulture according to their performance in terms of deposition and dose rate reduction potential, Suprofruit 2017

Verges A., Codis S., Ruelle B., Bonicel, JF., Bastidon, D., Ribeyrolles X. Montegano P., Carra M., Delpuech X. (2018) Labellisation des pulvérisateurs viticoles selon leurs performances agro-environnementales - AFPP - colloque sur les techniques d’application de produits de protection des plantes - Lyon – 13 et 14 mars 2018

Efficiency Assessment of H3O® Smartomizer

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Abstract

The new generation of pesticide application sprayers developed by Pulverizadores Fede adjusts airflow and spray volume rate to the characteristics of the canopy and the target of the treatment. The aim of this work was to assess the efficiency of this new generation in citrus crop. Field trials were carried out to compare the new H_3O® S3.0 Sprayer with a Fede Futur 1000L 2005 as reference. Each trial consisted of spraying a tracer (brilliant sulfoflavine) in two central paths of the orchard. Results showed that the H_3O® sprayer was a highly efficient airblast sprayer. It reduced the power consumption by 55 %, the noise contamination by 15 dBA, and the potential sedimenting drift by 48 %, always with respect to the bottom line reference sprayer. The mean coverage in the canopy was around 50 % with both sprayers, showing a similar spray distribution.

Key words: Airblast sprayer, precision agriculture, noise, power consumption, spray distribution, drift.

1. Introduction

One of the most common methods of protecting high growing 3D crops against pests and diseases is the use of *Plant Protection Products* (PPP). Pesticide applications are usually carried out using airblast sprayers, also known as atomizers. They deliver the spray in a radial way and are assisted by turbulent air currents generated by fans on the sprayer. However, during pesticides applications several associated problems can occur. Large quantities of spray volume and airflow are fairly common today without properly adjusting the amount of product to the actual needs and specific conditions of the application (vegetation to be treated, pest to be controlled, pesticide used and machinery). This practice normally entails an excessive release of products that remain in the food and pollute the environment, with the consequent pesticide risk for fauna, flora and humans (Gil&Sinfort, 2005; Derksen *et al.*, 2007; Cunha *et al.*, 2012; Garcerá *et al.*, 2017), and also increases crop production costs. Moreover, the fans of airblast sprayers produce noise contamination, that can affect people both physically and psychologically (Durgut and Celen, 2004). Fans are also responsible for high gasoil consumption that increases the cost of the treatment.

With the EU Horizon 2020 project *Healthy crop, Healthy environment, Healthy finances through Optimization* (H_3O®), Pulverizadores Fede has developed a completely new generation of sprayers that adjust airflow and recommend spray volume in accordance with the characteristics of the canopy and the treatment (pest and crop).

The aim of the presented study was to assess the efficiency of this new generation of H_3O® sprayers, in citrus crop with emphasis on *power consumption*, *canopy spray distribution*, *noise contamination*, and *drift losses*.

1.1. H_3O® Smartomizer Hardware

The most notable physical features of the H_3O® S3.0 sprayer (Figure 1) are, on the one hand, the aileron in the top of the nozzle channels that allows the adjustment of the spray profile to the canopy profile, and on the other hand, the fan, which can be adjusted mechanically both in the angle of the blades and the aperture of the air output channel. Moreover, this intelligent Cloud connected atomizer is fitted with a *Global Position System* (GPS) as well as temperature and relative humidity sensors. Especially, intelligence and Cloud connectivity make it the first of a completely new generation of sprayers that have been named Smartomizers.

During the spray application, working pressure is automatically adjusted depending on the real-time measured advance speed to change the water flow in order to obtain the recommended spray volume. Regarding the recommended air flow, prior to the application, the fan system is automatically adjusted by changing the angle of the fan blades (20º / 25º / 30º / 35º) and the aperture of the air output channel (110 mm / 130 mm / 150 mm). During the mixing of the products, the system measures ambient temperature and relative humidity to determine if the conditions are appropriate for the intended spraying application.

Figure 1. H_3O® S3.0 Smartomizer (Source: Garcerá et al. 2018 © 2018 The Association of Applied Biologists).

1.2. Specialty Crops Platform – Connectivity

The spraying accounts for 30% of costs in the special crop production and has a direct impact on quality and harvest selling price. With current state of the art, approximately 80% of treatment failure is a consequence of the incorrect use of the airblast. In this sense, the H_3O® technology is presented as the solution to the application error problem thanks to its proactive error avoidances system in the tractor's cab and its Cloud connectivity to a tailor made precision agronomic management platform (Specialty Crops Platform: www.specialtycropsplatform.com). The result is an intelligent and connected airblast known as Smartomizer. The H_3O® S3.0 Smartomizer works with custom made software, installed on a tablet that interacts with the Smartomizer wirelessly via a Wi-Fi connection. The software recommends a spray application volume and an airflow rate depending on the characteristics of the orchard (*Tree Row Volume* (TRV), tree and row spacing, hedgerow *vs.* isolated trees configuration), and the characteristics of the treatment (internal *vs.* external). Based on the recommendations of the software, the user selects the nozzles to get the recommended spray application volume at a selected advance speed and with a working pressure between 8 and 15 bar.

During spraying application, the tablet mounted in the tractor's cab allows real-time control of spraying parameters such as pressure, and forward velocity. It also displays proactive warning messages, should application parameters differ from the intended. After the spraying application, the GPS and Internet/Cloud connection allow treatment analysis from the back office, and spraying data is securely stored in a Cloud database to allow for full treatment traceability.

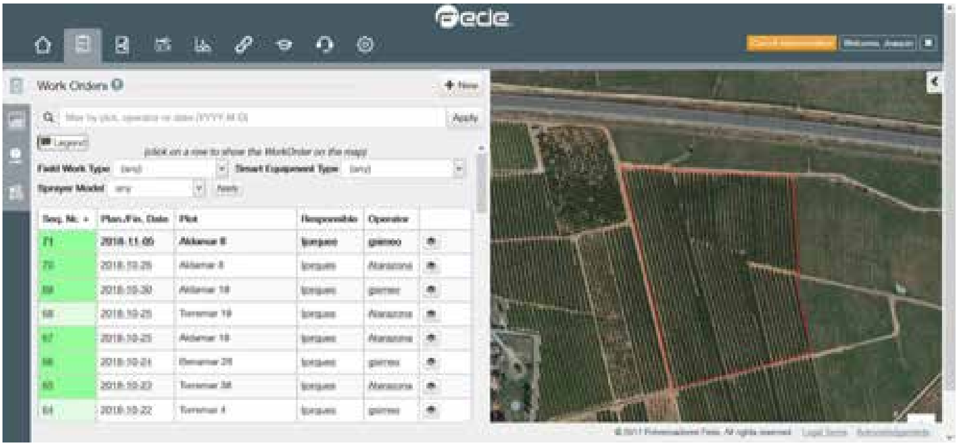

Figure 2. Specialty Crops Platform registered work orders.

The Specialty Crops Platform offers a complete range on functionalities based on the connectivity of the $H_3O^{®}$ Smartomizer. This agronomic management tool entails the total control and precision of the treatments carried out in the specialty crops fields:

- **Registration of the plantation/field, tractors and Smartomizers in the Specialty Crops Platform**: The plantations are perfectly delimited in the platform, and can be viewed in its entirety with the satellite map. Likewise, the tractors and Smartomizers that will work in the plantation are registered and the work calendars for the realization of treatments are programmed (Figure 2).

- **Configuration of the treatment work order in the platform**: With these data registered in the platform, the system - which has integrated the agronomic formulas - suggests to the technician/agronomist the dose and volume of air according to the TRV for the realization of an optimal treatment. The technician/agronomist supervises the values to adjust them if necessary depending on the needs of the crops at the time of the application. Thus, the technician/agronomist completes the work order, specifying the parameters of the treatment, identifying the plot, spray equipment and tractor. The Smartomizer is connected to the Internet, that is, it allows direct connection between the technicians/agronomists and the equipment operators.

- **Sending of the treatment work order to the $H_3O^{®}$ Smartomizer**: The technician/agronomist directly sends the work orders with the exact parameters for the application of the treatment to the air blast. The work order arrives at the *tablet* associated with the air blast and notifies the operator. Once the work order has been downloaded, the Smartomizer self-regulates to carry out the treatment following the parameters established by the technician// agronomist.

- **Proactivity**: In case that during the spraying work any of the parameters is not correct, the operator will receive notifications in real time to correct what is necessary: speed, *revolutions per minute* (RPM), agitation, pressure (Figure 3).

Figure 3. Treatment display screen and proactive system (not adequate air volume).

- **Real-time treatment visualization system on the tractor**: During the realization of the treatment, the operator visualizes in the *tablet* whether there are treatment errors.

- **Visualization of the treatment carried out with precise and detailed data**: Once the treatment is finished, the technician/agronomist can view it in detail on the Cloud platform. The seamless connection between Smartomizer, operator, and technician offers an unprecedented advance: All treatment parameters (Volume of plant protection products applied, RPM of the power take off, advance speed, pressure and agitation) are recorded and stored in the cloud once the treatment is finished. In this way, technicians can analyze the data to verify that treatments have been made as ordered and make decisions that help improve the quality of future treatments. In addition, the geo-location of the work area with date and time can be controlled and the treatment indicator offers very graphic and quick information to interpret (Figure 4).

Figure 4. Indicator of treatment, dose (volume of product) applied.

- **Correction of the treatment if necessary**: The technician can configure a new partial treatment order to perform a new treatment in the areas that are necessary with an adjustment of the parameters.
- **Field notebook and real traceability**: All the data recorded during the treatments are stored in an orderly manner on the platform to provide a field notebook with total precision. This field notebook entails real traceability since it represents the reflection of the exact data recorded during the treatments, which represents an important improvement of agri-food safety standards.

2. Materials and Methods

2.1. Efficiency Evaluation in a Citrus Orchard

2.1.1. Experimental orchard

A commercial 19-years-old 'Clemenules' mandarin (*C. reticulata, Blanco*) orchard (39°26'30.06"N 0°33'12.05"W) with a tree and row spacing of 6.3x2.8 m was used for the field trials. Row direction was North-South. Average tree size was: 2.75 m in height, 3.20 m in diameter along the row, and 4.41 m in diameter across the row (calculated from ten randomly selected trees), which gives a mean canopy volume of 20.32 m^3/tree (considering citrus canopy as an ellipsoid). The tree rows were configured as hedgerows.

2.1.2. Treatments and applications description

Two treatments were compared: (1) *Standard treatment* (ST) following the indications of the orchard technician, applied with a reference sprayer (Fede Futur 1000L 2005), and (2) *Adjusted treatment* (H3OT) following the recommendations of the H_3O® software, applied with the H3O® S3.0 Smartomizer. Applications were repeated three times with each sprayer, alternating each one of them. Both sprayers were fitted with standard, disc and core conic nozzles (model 1553, Hardi International A/S, Nørre Alslev, Denmark), with black core (hollow cone). Both treatments were set up to emulate a treatment against California red scale (*Aonidiella aurantii*, Maskell). This means that the treatment should cover the whole canopy, internal and external. The spray parameters used for ST and H3OT are shown in

Table 1 and

Table 2, respectively. Since recommendations in the tablet related to the airflow rate for the H3OT are indicated through the blades angle and the aperture of the air output channel, real airflow rate and air speed were measured.

Table 1. Spray parameter for the Standard Treatment (ST)
(Source: Garcerá et al. 2018 © 2018 The Association of Applied Biologists)

Spray volume (l/ha)		Advance speed (km/h)	Water flow (l/min)	Working pressure (bar)	Air flow (m^3/h)
Theoretical	Real				
3700	3820	1.59	63.77	10	92859

Table 2. Spray parameters for the H3O® treatment
(Source: Garcerá et al. 2018 © 2018 The Association of Applied Biologists)

Spray volume (l/ha)		Air				Mean advance speed (km/h)	Mean water flow (L/min)	Mean working pressure (bar)
		Theoretical		Measurements				
Theoretical	Real	Blades angle	Air output channel aperture	Flow (m^3/h)	Speed (m/s)			
3520	3465	25°	150 mm (minimum output speed)	66336	26.18	1.59	57.84	10

Based on the spray volume used for each treatment, flow rate was manually adjusted by selecting nozzle disc sizes, taking into account that working pressure would be 10 bar. Afterwards, the nozzles were manually orientated.

Spray solution consisted of a mixture of water and the fluorescent tracer *Brilliant Sulphoflavine* (BSF) (Biovalley, Marne La Vallee, France), at a concentration of 1 g/L. Each application consisted of applying the mixture in two central paths of the orchard, along 50 m, with both sides of the sprayer opened. During each application, meteorological conditions were taken from the Godelleta weather station (39º25'14.7"N 0º40'38.3"W, 270 m altitude) belonging to the Valencian Irrigation Technology Service (STR) network (Table 3).

Table 3. Meteorological conditions during the applications mean values (Source: Garcerá et al. 2018 © 2018 The Association of Applied Biologists).

TREATMENT_ REPLICATE	Predominant wind direction*	Average wind speed (m/s)	Average temperature (°C)	Average relative humidity (%)
ST_1	SW	2.34	11.3	49.67
ST_2	SW	2.62	16.78	57.69
ST_3	SW	2.98	16.77	58.93
H3OT_1	SW	2.69	13.3	44.45
H3OT_2	W	3.01	13.3	69.54
H3OT_3	SW	3.07	18.13	55.46

*Row direction was North-South

2.1.3. Efficiency assessments

The following parameters were measured to assess the efficiency of the $H_3O^{®}$ Smartomizer.

1. *Power consumption* (W): it was determined by measuring the tractor's Power Take-Off (PTO) revolutions (rev per min) and torque (Nm) with a torque sensor (model TM-215, MAGTROL Inc., USA) during the spray applications. Once in the laboratory, W was calculated with the Equation 1.

$$Power\ (W) = \frac{Torque\ (Nm) \times PTO\ speed\ (rev\ per\ min)}{9555 \times 1000}$$

Equation 1

2. *Noise contamination* (dBA): it was determined by measuring A-weighted sound pressure level (dBA) with a sonometer (model SLM-1352A, ISO-TECH, UK) directed towards the application area with a frequency of 1 Hz, located at 100 m distance from the application area and at 1.5 m height from the ground. Sonometer was set in fast mode and fitted with a protective hood. Once in the laboratory, the A-weighted equivalent sound pre ssure level (LAeq) was calculated with Equation 2.

$$L_{Aeq}\ (T) = 10 \log \frac{1}{T} \sum_{i=1}^{T} 10^{L_i/10} \times t_i$$

Equation 2

where L_i is the A-weighted sound pressure level (dBA) taken in the second t_i, and considering the whole measuring time coincident with the application, $T(\Sigma t_i)$.

3. *Canopy spray distribution* was assessed by means of *percentage of coverage on leaves* (%), estimated with Water Sensitive Papers (WSP). WSP were placed in 18 quadrants (three heights, two depths and three widths) (Figure 5) of the half canopy in three randomly selected trees of the central row. Inside each quadrant, two WSP were stapled onto the upper side of two random leaves and two onto the underside of other two leaves.

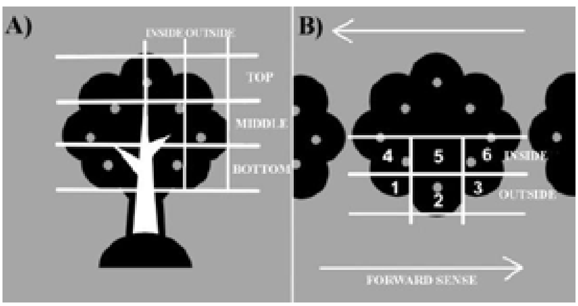

Figure 5. A) Side view of a citrus tree. Distribution of Water Sensitive Papers (WSP) in height. B) Top view of a citrus tree. Distribution of WSP at each height (Source: Garcerá et al. 2018 © 2018 The Association of Applied Biologists).

Once in the laboratory, the WSPs were digitized and analysed with a custom made software programme. For each image, the programme calculated the percentage of the total surface covered by the impacted droplets (coverage, %). Mean coverage at two depths at each height for the upper side and the underside of leaves, respectively, was calculated.

4. *Potential drift losses* were assessed by estimating:

4.1. *Potential sedimenting drift* was assessed by pieces of blotting papers (ANOIA S.A., Barcelona, Spain) located at ground level in three adjacent paths at each side of the two central paths.

4.2. *Potential airborne drift* was measured with nylon threads (Model Star. Golden Fish fishing lines. Efectos Navales OCAÑA S.L., Pontevedra, Spain) with 2 mm of diameter and 9.0 m long, located in the next adjacent path at each side of the two central paths. After the application, the threads were cut into 1 m length sections.

Once in the laboratory, The amount of spray deposited per unit surface of collector (μl/cm^2) was quantified by fluorometry (fluorometer model Cary Eclipse. Varian Instruments, California, USA).

3. Results and Discussion

3.1. Efficiency Evaluation in a Citrus Orchard

Power consumption and *noise contamination* were much lower with H3OT than with ST, with a percentage of reduction of 55.45% of power consumption and 15.20 dBA less than the reference sprayer. (Table). .

Spray distribution in the canopy was similar with both sprayers, regardless height and depth and the side of the leaves. Mean coverage was also similar for both treatments (Table).

Table 4. Mean values of power consumption (W), noise contamination (dBA), and coverage (%) for each treatment (Source: Garcerá et al. 2018 © 2018 The Association of Applied Biologists).

Variable	ST	H3OT
Mean power consumption (W)	36946.43	16458.22
Noise contamination (dBA)	68.34	53.14
Mean coverage (%)	52.8	53.5

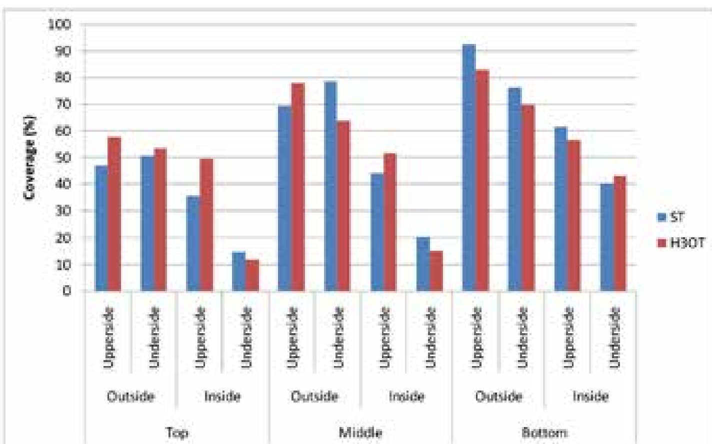

Figure 6. Percentage of coverage in different parts of the canopy depending on the treatment (Source: Garcerá et al. 2018 © 2018 The Association of Applied Biologists).

Potential sedimenting drift was lower for H3OT in almost all the paths. As expected, it decreased as the distance to the sprayed paths increased in both treatments (Figure 7). If deposits on the central paths (paths 1 and path -1 Figure 7), on which the sprayer advance, are not taken into account, the ground received almost 48% less deposits with H3OT.

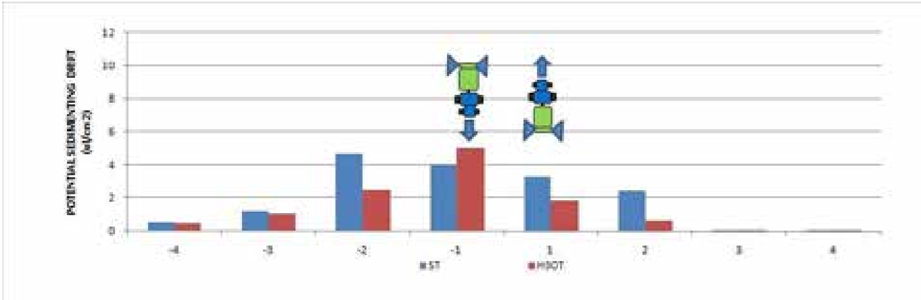

Figure 7. Potential sedimenting drift (µl/cm2) in the ground of each path of the experimental site depending on the treatment
(Source: Garcerá et al. 2018 © 2018 The Association of Applied Biologists).

Potential airborne drift profile was similar for both treatments. The high height of the trees with respect to the sprayers and the small distance between the sprayer and the vegetation might have confined the spray between the trees and this could explain the small differences between treatments for heights up to 7 m. Furthermore, in both treatments the upper zones received much larger deposits than the lower zones, and the thread at 1 m height received higher deposit than the following ones. This reflected the size and shape of the trees, because the dense vegetation of citrus constitutes a great resistance to the spray movement driven by the air flow generated by the fan, and droplets rose over the trees and passed under them.

Nevertheless, H3OT potential airborne drift decreased with height after reaching a maximum value at 6 m, but it did not decrease for ST, which could indicate that with ST the spray cloud showed a more vertical movement due to the lack of deflector in the reference sprayer.

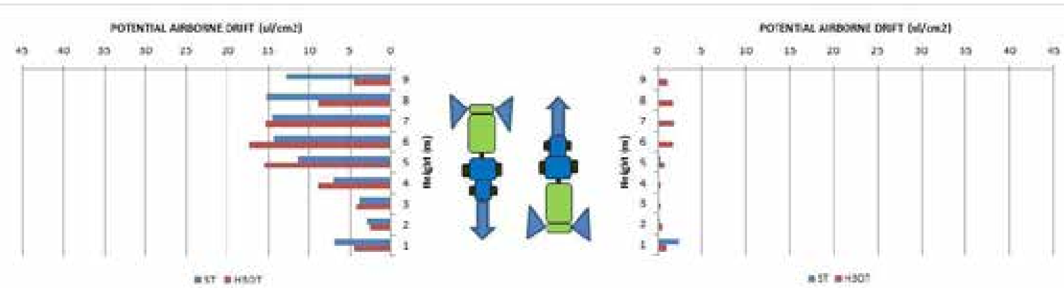

Figure 8. Potential airborne drift (µl/cm^2) profile at each side of the central paths depending on the treatment
(Source: Garcerá et al. 2018 © 2018 The Association of Applied Biologists).

4. Conclusions

It can be summarized that the $H_3O^{®}$ Smartomizer reduced the power consumption by 55 %, the noise contamination by 15 dBA, and the potential sedimenting drift by 48 %, always with respect to the bottom line reference sprayer. The potential airborne drift was not reduced. The mean coverage in the canopy was around 50 % with both sprayers, showing a similar distribution in the canopy.

In conclusion, with $H_3O^{®}$ a commercial highly efficient airblast sprayer was designed, good for resource-efficient eco-innovative food production as well as for food producers' competitiveness. Intelligence and Internet/Cloud connectivity make it the first of a completely new generation of sprayers called Smartomizers.

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References

Cunha JP, Chueca P, Garcerá C, Moltó E. 2012. Risk assessment of pesticide spray drift from citrus applications with airblast sprayers in Spain. *Crop Protection* **42**, 116-123.

Derksen, R.C., Zhu, H., Fox, R.D., Brazee, R.D., Krause, C.R. 2007. Coverage and drift produced by air induction and conventional hydraulic nozzles used for orchard applications. *Transactions of the ASABE* **50 (5)**, 1493–1501.

Durgut, M. R., & Celen, I. H. 2004. Noise levels of various agricultural machineries. Pakistan

Journal of Biological Sciences, 7(6), 895-901.

FAOSTAT (Food and Agriculture Organization of the United Nations. Statistic Division) 2017. Food and agriculture data. Updated August 14 2017. [Available at: http://www.fao.org/faostat/en/#home. Accessed 23/08/2017].

Garcerá, C., Moltó, E., Chueca, P. 2017. Spray pesticide applications in Mediterranean citrus orchards: Canopy deposition and off-target losses. *Science of the Total Environment* **599–600**, 1344–1362.

Garcerá, C., Berger, L. T., Chueca, P. 2018. Efficiency assessment of H3O Smartomizer in citrus. *Aspects of Applied Biology* **137**, International Advances in Pesticide Application, pp.93-100.

Gil Y, Sinfort C. 2005. Emission of pesticides to the air during sprayer application: a bibliographic review. *Atmospheric Environment* 39: 5183-5193.

Herbicide site specific spraying: use of simulations to study the impact of section width

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Abstract

Site specific spraying is one way to reduce the amount of herbicide required to control weeds. The impact of boom section width was investigated by using simulated weed infestation maps with various weed coverage rates. Herbicide applications were simulated combining these virtual maps with various boom sections widths and various theoretical spray patterns. The objective was to quantify the herbicide reduction possibilities and potential under-application areas. Simulation derived results are analyzed using three indicators: i) the ratio between herbicide amount in the case of a targeted application and the amount deposited in the case of a full application, ii) the proportion of weed coverage on which the application rate is higher than 85% of the rated dosage, iii) the proportion of the weed surface on which the deposited application rate is lower than 50% of the rated dosage.

Keywords: sprayer, site specific weed management, boom section control, spray pattern.

1. Introduction

Reducing herbicide use is still challenging to maintain crop yields and harvest quality. In the case of chemical control, one way for herbicide saving consists of site specific weed management (Timmermann, Gerhards et al. 2003, Weis, Gutjahr et al. 2008) by triggering spraying only where weeds lie. Selective spot herbicide application technologies have been developed for decades (Stafford and Miller 1993, Lee, Slaughter et al. 1999, Gerhards and Oebel 2006, Nordmeyer 2006, Gutjahr, Sokefeld et al. 2012). Therefore, various control units enable sprayers to switch on or off boom sections or individual nozzles to locally spray herbicide only onto weed clusters or individual weed plants. Moreover, detection systems have been developed to detect weeds using real time sensors or provide a weed infestation map before herbicide application. Although some technologies have been available for several decades, their adoption rate by farmers is still extremely low. One brake is the cost of the required technologies, and uncertainty regarding the return on investment. On the one hand, technology costs increase when the width of the independent application sections decreases, especially from a boom section of half dozen nozzles to individual nozzles. On the other hand, reducing the width of independent controlled sections improves the spatial resolution of the application. Thus, it is expected that the effective sprayed surface becomes closer to the weed coverage surface, involving a reduction of the herbicide amount required on the field (with respect to full application). Assessing this relationship in fields would require tedious, costly or unrealistic experiments. Consequently, to overcome the limits of practical experiments, studies were carried out using virtual experiments based on numerical simulations. Recently, Franco, Pedersen et al. (2017) have addressed the problem of selecting the appropriate precision spraying technology for weed management. They performed simulations on two small virtual spraying areas infested with many scattered circular patches or few significant circular patches respectively. In their simulations, the spray pattern of the smaller independent boom section was a rectangular shape of 1 m in width. Findings showed that the potential gains not only depend on spraying resolution, but also on the density and the distribution of weed patches.

At the present time, there is still a lack of knowledge concerning the interaction of parameters that affect herbicide savings. Moreover, no study has addressed the potential problem of herbicide rate variations on the sprayed surfaces in the case of targeted spraying. The objective of the present work is to investigate the influence of spray deposit patterns, section widths, weed infestation rates and weed spatial distributions on herbicide reduction, as well as on under- application area increase. The study is based on virtual experiments resulting from numerical simulations.

2. Materials and Methods

In this work, targeted herbicide applications were simulated combining virtual weed infestation maps and virtual sprayer parameters. Simulations were implemented with Matlab® software.

2.1. Modelling infestation map

In this work, virtual infestation maps were built to simulate the location of weed patches in arable fields. They simulate the maps that could be provided by weed detection and localization devices mounted on various platforms (satellite, aerial, or terrestrial vehicle) and used on crops or bare soil.

2.1.1. Weed map derived from spatial process generation

For decades, numerous works have addressed the problem of describing the spatial distribution of weeds in arable crops (Rew and Cousens 2001, Kristensen, Olsen et al. 2006, Longchamps, Panneton et al. 2016), investigated weed dispersal process (Wallinga, Kropff et al. 2002, Barroso, Navarrete et al. 2006) and suggested models to predict weed development (Brix and Chadœuf 2002). Nevertheless, at the present time, the choice of a model to simulate a realistic spatial distribution of weeds is still very difficult because of the multispecies weed variability in fields. Various spatial processes used to simulate weed distribution are based on a Cox process (Cox 1955) which is a non-homogeneous Poisson process with a random intensity function. Assuming that the statistical distribution is such that weeds grow in patch elongated lengthwise in the direction of cultivation as traditionally observed (Longchamps, Panneton et al. 2016), a Cox process was used to simulate the weed patches based on 2D-Gaussian distributions. This spatial point process was used to simulate a virtual weed map from which a weed density map is derived as depicted in Figure 1. This area is of 24 m in width and 200 m in length. The weed density is from 0 to 40 plants/m^2. The spatial resolution of the infestation map was 0.025 m/pix.

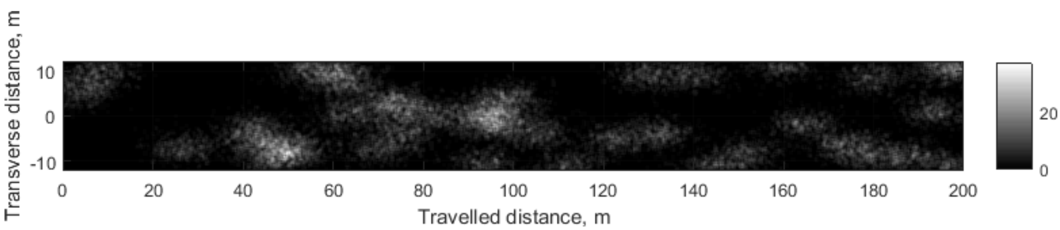

Figure 1. Virtual weed density map.

The map of weed patches, on which application was required, was deduced from the weed density map by assuming that the herbicide was applied only on the area where the weed density is above an “application decision threshold”. In this example the threshold was set arbitrary at 10 plants/m^2. Figure 2 presents the binary application map resulting from the use of this threshold on the weed density map depicted in Figure 1. The size and the shape of the application areas result from the weed density, the spatial weed distribution and value of the application decision threshold.

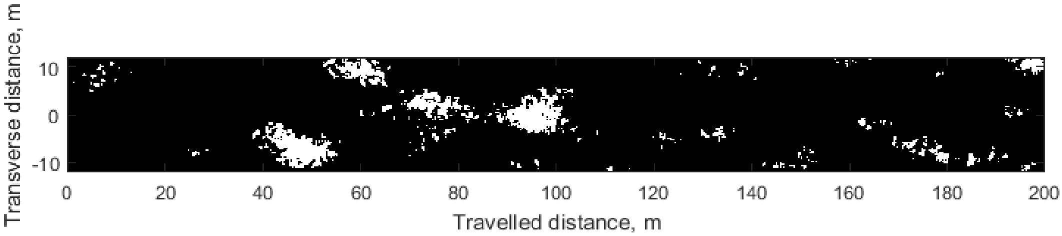

Figure 2. Binary map of weed patches on which herbicide application is required (white: herbicide required; black: no application required).

In order to put the emphasis on the impact of weed patch size and coverage rate on herbicide application, a second and simpler weed map generation was also implemented.

2.1.2. Elliptical weed patch generation

To simplify the creation process of map of weed patches and their analysis, binary weed infestation maps have been simulated by placing full elliptical patches at random on virtual field bands. These bands were of 24 m in width, 20 000 m in length, and computed with a spatial resolution of 0.025×0.025 m/pix (*i.e.* pixels of 6.25 cm²). These correspond to a sprayer pass with a working width of 24 m. The length of the band was chosen long enough so that the assessment indicators computed in the study reached stabilized values. Weed patches were modelled with ellipse surfaces defined by their width (w_e) and length (l_e). Assuming that weed patches were elongated in the cultivation direction (*i.e.* seed dispersal due to natural processes, combine harvesting and tillage processes), the ellipses were oriented so that their major axes were in the direction of the band lengths (*i.e.* aligned with the travel direction of the virtual sprayer). A set of virtual field bands were computed for various weed coverage rates set at 5, 10, 20, 30, 40 and 50% of the total area; various ellipse lengths of 0.5, 1, 4, 8, 16 and 32 m; and various minor axis to major axis ratio of ellipses of 0.2, 0.5 and 1 (ellipses correspond to circles when the ratio is 1). Thus a set of weed patch maps were simulated representing various infestation rates and aggregation degrees. Figure 3 shows two examples of virtual weed infestation maps presenting the same global coverage rate but obtained for two different patch sizes.

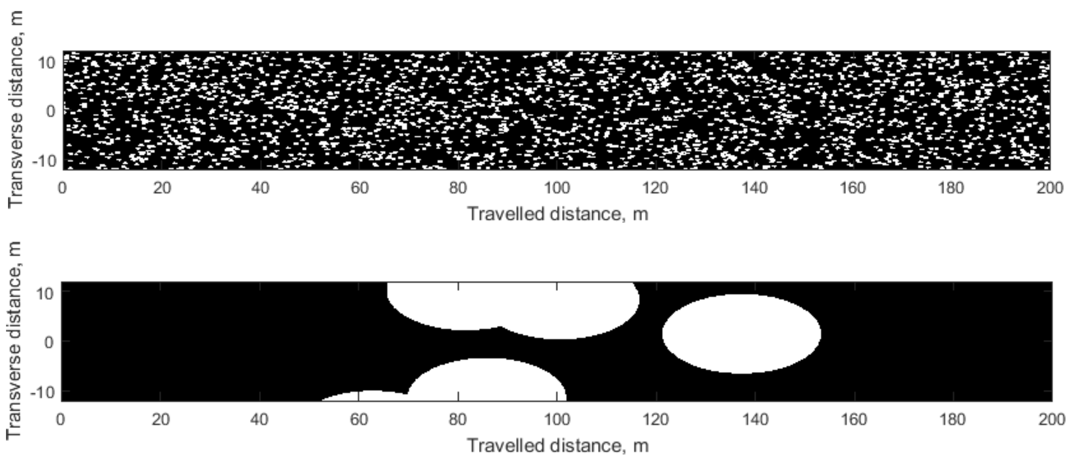

Figure 3. Example of areas extracted from weed maps simulated for small ellipse (l_e = 1 m, w_e = 0.2 m) patches (upper row) and large ellipse (l_e = 32 m, w_e = 16 m) patches (bottom row) with a coverage rate of 20 %.

2.2. Modelling site specific spraying

A simple spray application simulator was developed considering a virtual boom equipped with nozzles spaced every 0.5 m. The spray boom was divided in independently controlled sections including a proportional number of nozzles to the section width (constant nozzle spacing). Simulations were implemented with sections of 1, 2, 4, 6, 12, 24 and 48 nozzles. For the virtual application of herbicide, each section was switched on only when weeds were present under the "weed detection width" of the considered section. For example, in the case of nozzles controlled independently, the "weed detection width" was of 0.5 m centered under each nozzle as depicted in figure 4. More generally, since nozzles were spaced every 0.5 m, the weed detection width of a section composed of N_N nozzles was $N_N \times 0.5$ m. Concerning the spatial distribution of the spray deposit, the spraying simulator was designed to take into account the overlapping between adjacent nozzles or adjacent sections. Regarding the system reaction time of the virtual system, an instantaneous application was assumed, without any time lag of the control valve inducing or any smoothed herbicide rate transition in the travelled direction.

Regarding the transverse direction (*i.e.* orthogonal to the virtual travelled direction), three different theoretical spray patterns were simulated: i) a rectangular pattern with a spraying width of 0.5 m (corresponding to a perfect even spray nozzle distribution), ii) a "narrow" triangular pattern with a spraying width of 1 m (corresponding to a flat fan spray of a reduced top angle nozzle of 80° to 90°) and iii) a "large" triangular pattern with a spraying width of 1.5 m (corresponding to a flat fan spray of a nozzle top angle of 110° to 120°). For each spray pattern, the virtual flow rate was set such that the mean value of the application rate after spray overlapping was 1 in arbitrary units (abbreviated AU in this paper), as depicted in figure 5. Consequently, in the case of triangular patterns, the application rate on the centerline of a single nozzle was 1 AU for the "narrow" triangular pattern and 0.66 AU for "large" triangular pattern. The shape of each of the three spray patterns and the associated flow rate ensured that the herbicide amount applied by each nozzle (computed as the integral of the transverse application rate) was the same in the three cases.

Carrying out simulations, herbicide application maps were obtained with the same spatial resolution as the input infestation maps (*i.e.* 0.025 × 0.025 m/pix). The application was at the rated dosage when the value of the application map pixels was 1 AU.

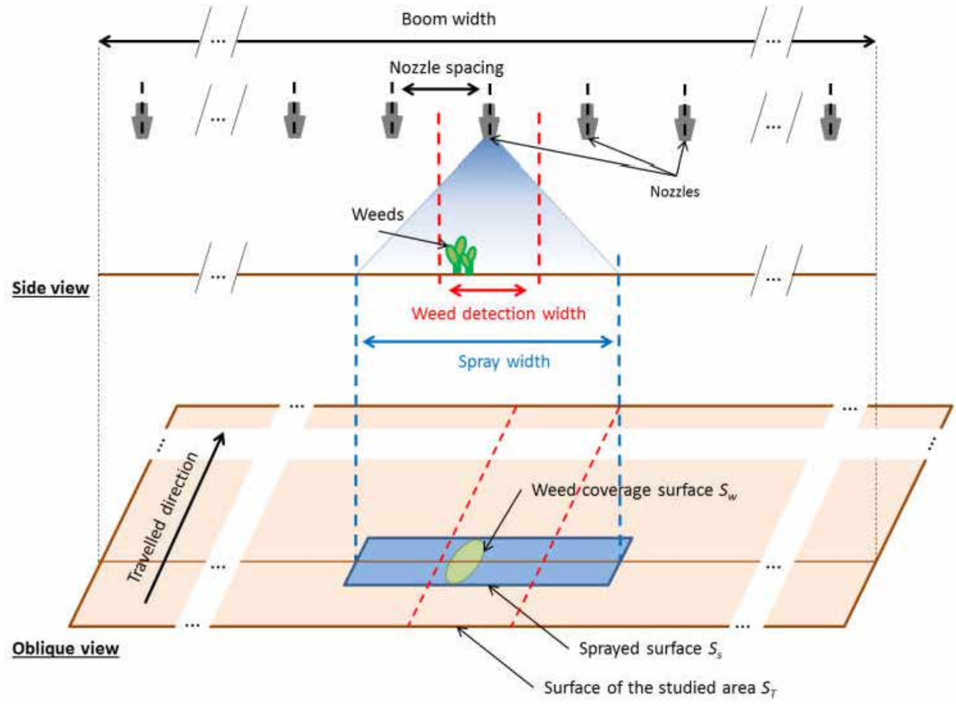

Figure 4. Weed detection width and spray width in the case of nozzles controlled individually.

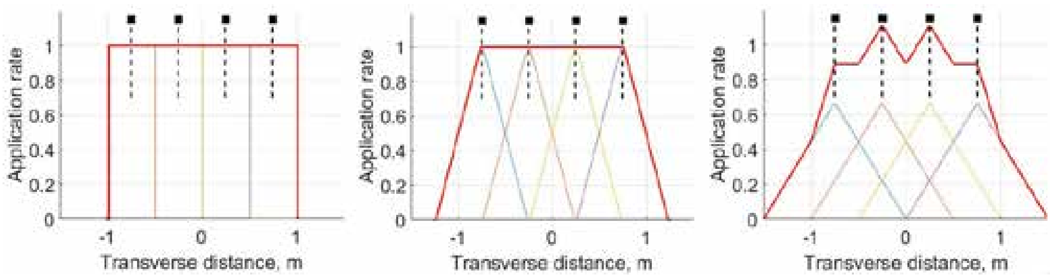

Figure 5. Transverse application rates (in arbitrary units) for single nozzles and after overlapping (bold) for a section of 4 nozzles with rectangular pattern of 0.5 m in width (left), triangular pattern of 1 m in width (middle) and triangular pattern of 1.5 m in width (right). Black squares and dashed lines correspond to the nozzles and their vertical axes.

2.3. Spraying indicators

Some indicators are required to assess the reduction of herbicide use and the application efficacy. These indicators have been computed on the area corresponding to the virtual sprayer pass (whose working width was 24 m). The parameters used in this study were defined as follows:

- S_T is the surface of the studied area, corresponding to the central pass of the sprayer (figure 4),
- S_W is the weed coverage surface (figure 4),
- S_S is the sprayed surface (surface subjected to real herbicide deposit) (figure 4),
- $S_{W>\alpha\%}$ is the weed surface on which the application rate is higher than α% of the rated dosage,

- $S_{S<\beta\%}$ is the sprayed surface on which the application rate is lower than β% of the rated dosage,
- Q_S is the amount of herbicide used in the case of a targeted application (this is applied on the surface S_S),
- Q_T is the amount of herbicide required in the case of a uniform application at the rated dosage on the entire studied area (of surface S_T).

These parameters have been used to compute the following indicators: the sprayed surface ratio S_S/S_T, the sprayed amount ratio Q_S/Q_T, the proportion of weed patch surface on which the application rate is higher than α % of the rated dosage $S_{W>\alpha\,\%}/S_W$ and the proportion of sprayed surface receiving less than β % of the rated dosage $S_{S<\beta\,\%}/S_S$.

In this paper, the thresholds α and β were arbitrary set at 85% and 50% to provide simple indicators related to the proportion of weed surface receiving an application rate considered high enough to be lethal and, on the other hand, the proportion of sprayed surface receiving sub lethal dosage and thus presenting conditions that may contribute to potential development of herbicide resistance.

3. Results and Discussion

3.1. Impact of section widths and nozzle spray patterns for a constant infestation rate

The impact of section widths and spray patterns on herbicide reduction was first assessed using the weed patch map presented in figure 2 and derived from spatial point process presented in section 2.1.1. This virtual map includes a collection of patches of various sizes covering 6 % of the total area. Figure 6a and 6b show the evolution of the sprayed surface ratio (S_S/S_T) and the sprayed amount ratio (Q_S/Q_T) as a function of the section width (expressed in nozzle number). The values obtained for the three spray patterns are superimposed on the graphs. Regarding the results obtained for the three transverse spray patterns, some differences appear in the sprayed surface ratio which is logically higher when the spray width of the spray pattern is larger. Nevertheless, figure 6b shows that the values obtained for the sprayed amount ratio (Q_S/Q_T) are not affected by the spray patterns used in the simulations. This is due to the shapes of nozzle spray patterns and application rate settings chosen in this study. These ensure that the amount applied by each type of nozzle (computed as the integral of the spray pattern) is the same and the mean value of the application rate obtained after overlapping is also the same for the three patterns.

Thus, whatever the spray pattern, figure 6b illustrates how the section width affects the amount of herbicide required to control weeds. In this example, the sprayed amount ratio (Q_S/Q_T) increases with the section width from approximately 11 % in the case of individually controlled nozzles to 76 % in the case of full boom width. Because of the patch distribution, the sprayed surface ratio (S_S/S_T) as well as the sprayed amount ratio (Q_S/Q_T) is lower than 100 % including when the full boom is used since the whole boom is switched off when no weed patch is present under the sprayer boom.

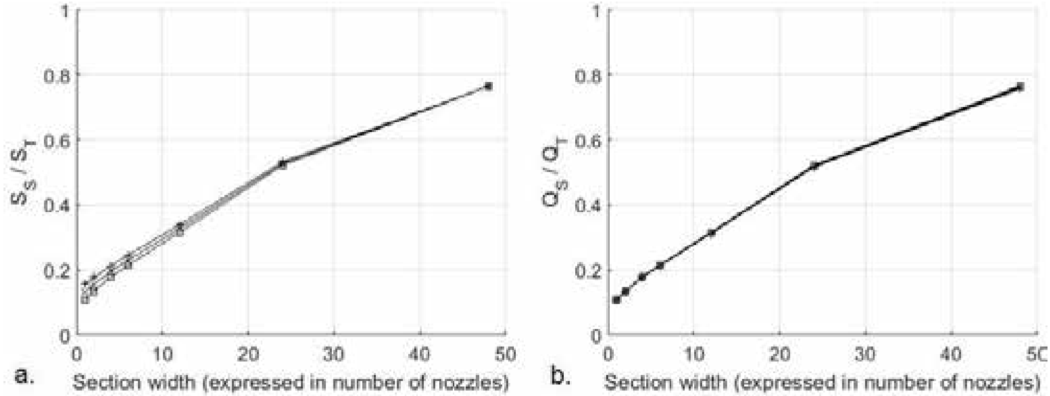

Figure 6. Sprayed surface ratio (a) and sprayed amount ratio (b) with respect to the section width (expressed in nozzle number); for three spray patterns: rectangle of 0.5 m in width □, triangle of 1 m in width × and triangle of 1.5 m in width +.

The above results demonstrated that the shapes of the transverse spray patterns ensure to obtain the same herbicide amount use for a given weed infestation map and a given section width. Thus, avoiding any bias due to any herbicide reduction difference, it is interesting to investigate how the transverse spray pattern could affect the application rate with respect to the rated dosage, through the localization and quantification of over/under dosages. In the case of a pure rectangular shape, the theoretical application rate is obviously the same on the entire sprayed surface whatever the number of adjacent nozzles that are switched on simultaneously. This would be the case of a perfect even flat nozzle. In the case of triangular spray patterns representing most of conventional flat fan nozzles, Figure 7 helps in addressing the effect of the section width on the application rate. Two surface ratios were computed: the proportion of weed patch surface on which the application rate is higher than 85% of the rated dosage ($S_{W>85\%}/S_W$) and the proportion of sprayed surface receiving less than half the rated dosage ($S_{S<50\%}/S_S$). Results show that the ratio $S_{W>85\%}/S_W$ obtained for the whole virtual weed infested area increases with the section width, although the ratio values are close to 100 % for all the section width. Actually, in the worst case the ratio equals 94 % when nozzles with a large triangular spray pattern (*i.e.* 1.5 m) are controlled individually. Concerning the ratio $S_{S<50\%}/S_S$, results show that the value decreases with the width of boom section and the width of the nozzle spray pattern. It also appears that a significant proportion of sprayed surface can receive less than half the rated dosage, since the value of $S_{S<50\%}/S_S$ reaches 35 % when nozzles with a large triangular spray pattern (*i.e.* 1.5 m) are controlled individually.

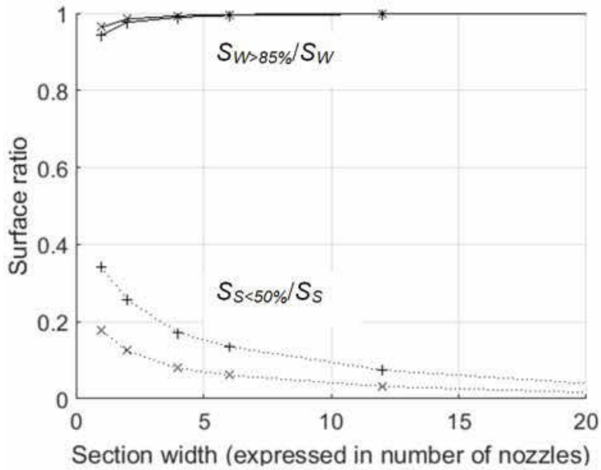

Figure 7. Sprayed surface ratio $S_{W>85\%}/S_W$ (continuous line) and $S_{S<50\%}/S_S$ (dashed line) for triangular spray pattern of 1 m (×) and 1.5 m (+) width.

These results show that switching on or off spray boom sections according to the presence or absence of weed patches can strongly reduce the amount of herbicide required to control weeds lying in pre-identified patches. Simultaneously, when the section width decreases, the proportion of the sprayed area exposed to under-application rate could be significant (up to 35% in the case presented in figure 7). Nevertheless, the value of the ratios presented in this section results from global surface or amount computed for the entire studied area in which patch sizes are locally variable. Consequently global values do not reproduce the variability that could locally occur in the field concerning the different ratio and cannot be analyzed in this first section relating to the patch size and coverage rate. The impact of patch size and coverage rate is studied in the next section.

3.2. Impact of patch size and coverage rate

In order to study how patch size and coverage rate affect the ratios Q_S/Q_T, $S_{S<50\%}/S_S$ and $S_{W>85\%}/S_W$, spraying simulations have been carried out using simplified infestation maps (see section 2.1.2) in which weed are assumed to lie on elliptical patches of constant size.

First, the impact of the patch shape on the sprayed amount ratio Q_S/Q_T has been observed through simulation results. For constant values of weed coverage rate, section width and spray pattern, simulations showed that sprayed amount ratio Q_S/Q_T only depended on the width of the patches regardless of their lengths in the travelled direction. Figure 8 illustrates this result. The figure presents the values of the ratio Q_S/Q_T computed for elliptical patch of $w_e = r$ in width and $l_e = 2\times r$ in length as a function of the values computed for circular patch of radius r in the same conditions (same coverage rate, section width, and spray pattern). This can be explained by: i) the number of switched-on sections that were only depending on the width of the patches and ii) by the fact that the cumulated surface of patches is constant for an infestation rate. Thus, the simulations confirm the intuition that the most important feature of weed patch shapes is the width of patches in the direction orthogonal to the spraying direction. Nevertheless, in this work, elliptical shapes were only elongated in the virtual spraying direction. So, additional simulations are required to extend the conclusions concerning the impact of the patch shapes (for a constant coverage rate) on herbicide reduction potential.

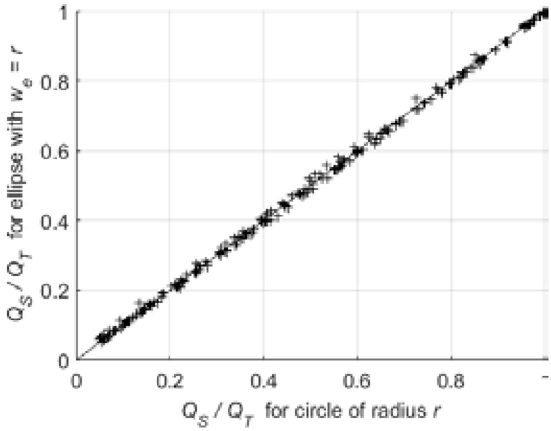

Figure 8. Comparison of the value of the sprayed amount ratio Q_S/Q_T when it is computed for elliptical patch of $w_e = r$ in width and $l_e = 2 \times r$ in length and when computed for circular patch of radius r.

Figures 9 depict the evolution of the sprayed amount ratio (Q_S/Q_T) as a function of the boom section width (as in figure 7) and figure 10 presents this evolution as a function of the weed coverage. The evolution of the sprayed amount ratio is the same whatever the spray pattern (*i.e.* rectangle of 0.5 m in width, triangle of 1 m in width, triangle of 1.5 m in width), as already observed in figure 6b. Figures 9 and 10 also compare the sprayed amount ratio Q_S/Q_T for two different patch sizes. Clearly, the ratio Q_S/Q_T increases with the section width or the weed coverage rate. Furthermore, considering the same global coverage rate, the reduction of herbicide use is more important in the case of large patches than in the case of small patches.

Figure 9 and 10 also demonstrate that the patch size directly affects the sensitivity of the herbicide reduction to the section width and the coverage rate. In a more refined way, in the case of small patches ($l_e = 1$ m, $w_e = 0.2$ m), with low weed coverage (5%), the required amount of herbicide is very sensitive to the spray section width and the infestation rate: the amount is only 20% with 1-nozzle sections, 50% with 4-nozzle sections and almost 90% with 12-nozzle sections. Moreover, regarding the effect of the infestation rate, the amount of herbicide approximately rises to 60% and 95% for 1 and 4-nozzle sections respectively when the coverage rate reaches 20%. In the case of large patches ($l_e = 32$ m, $w_e = 16$ m), the reduction of herbicide use is more important no matter the spray section width and the infestation rate: considering large patches, the sprayed amount ratio is less sensitive to the spray section width and the infestation rate. In this case, the difference observed in the ratio Q_S/Q_T between the use of narrow section widths or large section widths is highly reduced. For example, when the weed coverage rate is 10%, the sprayed amount ratio Q_S/Q_T is 10% with 1-nozzle sections, 15% with 12-nozzle sections and less than 20% with 24-nozzle sections. Additionally, the range of change in the ratio Q_S/Q_T decreases with the patch widths. For example, when the weed coverage rate reaches 50%, the ratio Q_S/Q_T is approximately 52 % with 1-nozzle sections, 63 % with 12-nozzle sections and 75 % with 24-nozzle sections.

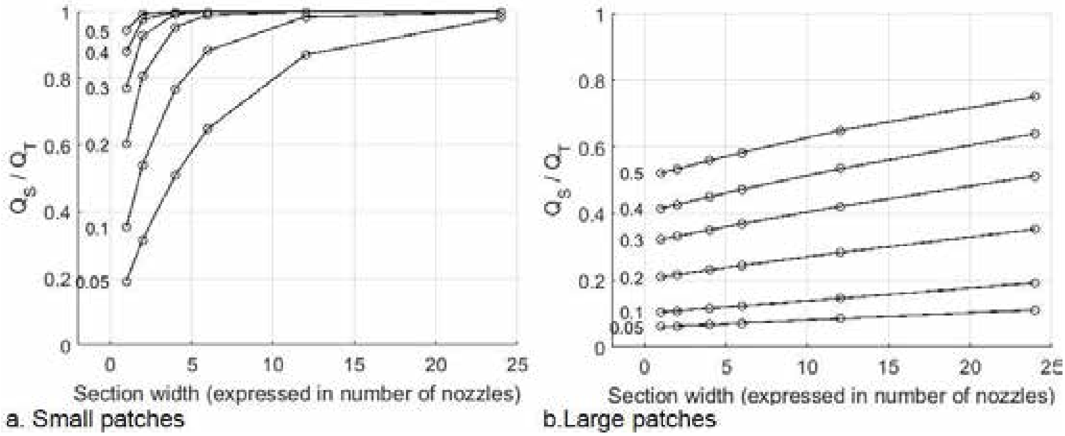

Figure 9. Sprayed amount ratio with respect to section width (expressed in number of nozzles) for (a) small ellipse patches (l_e = 1 m, w_e = 0.2 m) and (b) large ellipse patches (l_e = 32 m, w_e = 16 m). The coverage rate is indicated next to the curves.

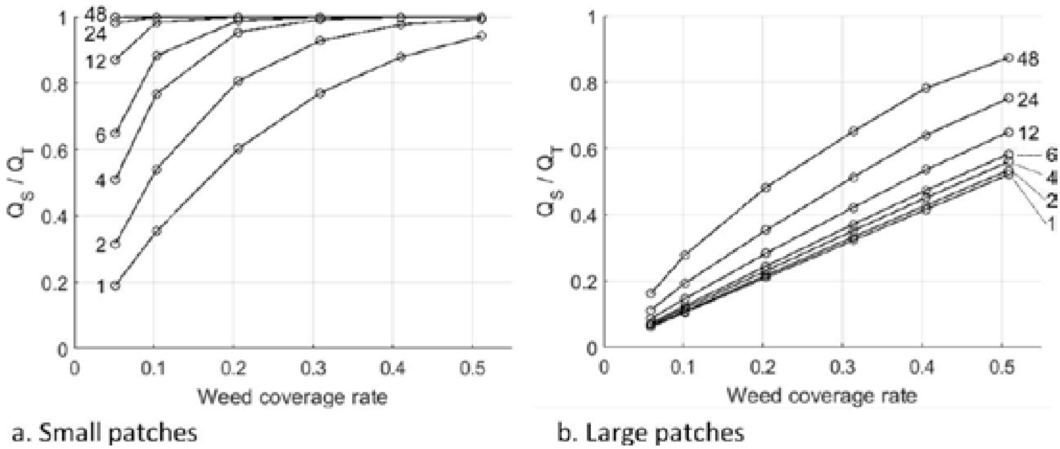

Figure 10. Sprayed amount ratio with respect to weed coverage rate for (a) small ellipse patches (l_e = 1 m, w_e = 0.2 m) and (b) large ellipse patches (l_e = 32 m, w_e = 16 m). The section width (expressed in number of nozzles) is indicated next to the curves.

In the case of small patches, figure 11 depicts the influence of spray pattern on the application rate regarding the proportion of weed patch surface on which the application rate is higher than 85% of the rated dosage ($S_{W>85\%}/S_W$) and the proportion of sprayed surface receiving less than half the rated dosage ($S_{S<50\%}/S_S$). In section 3.1 it was established that the ratio $S_{W>85\%}/S_W$ increases with the section width. This first finding is verified in the figure 11. The other finding ofsection 3.1 which is also confirmed is the fact that the large triangular spray pattern (*i.e.* 1.5 m in width) causes the worst- case ratio values (under dosing). Actually, in the case of a triangular spray pattern, which is more representative of conventional flat-fan nozzles, the sprayed area is necessary wider than the one obtained with a theoretical rectangular pattern and the application rate is lower than the rated dosage in the case of limited or no overlapping (see figure 5). For example, in the case of small patches (l_e = 1 m, w_e = 0.2 m), a significant proportion of weed surface can receive an insufficient rate to ensure weed control (figure 11) while a significant proportion of sprayed surface presents a low application rate that can yield to resistance condition development. For example, with large triangular spray pattern (*i.e.* 1.5 m), the proportion of weed surface on which the application rate is higher than 85% of the rated dosage ($S_{W>85\%}/S_W$) can drop under 50% when nozzles are controlled individually. Considering the same spraying situation, the proportion of sprayed surface receiving less than half the rated dosage ($S_{S<50\%}/S_S$) reaches a significant level of 60%. This could be avoided by increasing the application rate when independent nozzles or narrow sections are activated or by widening the spray section on both side of the weed detection width. However, both of these solutions would increase the herbicide amount required for the application. It is then recommended to use even spray nozzles when no overlapping from other nozzles may occur.

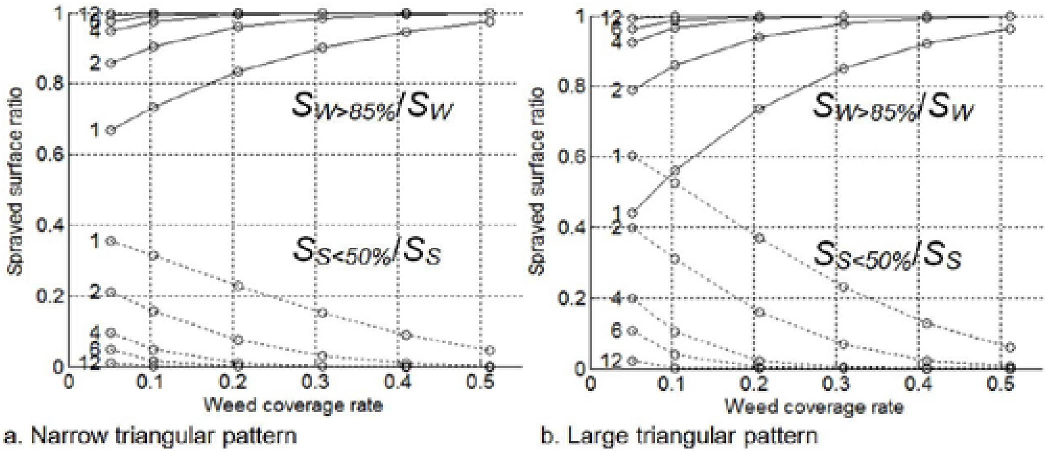

Figure 11. Analysis of the sprayed surface with respect to the weed coverage rate, in the case of small patches (l_e = 1 m, w_e = 0.2 m) and triangular spray patterns with a spray width of 1 m (left) and 1.5 m (right): $S_{W>85\%}/S_W$ (continuous line), $S_{S<50\%}/S_S$ (dashed line). The section width (expressed in number of nozzles) is indicated on the left of the curves.

Taking into account the results presented previously, some recommendations can be made regarding the optimal adjustment of boom sections relative to a given weed infestation map. The optimal section width is directly related to the spatial distribution of weeds and especially to their aggregation degree. Boom sections with a low number of nozzles are required to reduce herbicide use in the case of very small patches. However, a significant reduction can be obtained with moderate section width in the case of large patches. Moreover, the bigger the weed patch is the most efficient is the spray application (reducing over/under application). In the case of small section widths, when the number of nozzle per section is less than 4, the results show that the use of even nozzles is recommended or at least low angle flat fan to limit underdosing areas. When the number of nozzle per section is greater than 4, the impact of the type of nozzle becomes neglictible.

3.3. Limits and future work

At the present time, the results have mainly been analyzed from a qualitative point of view. The mathematical relationships between the performance indicators and the influencing parameters (*i.e.* section widths, weed coverage rate, patch size) are still in progress and not reported here.

Regarding the virtual infestation maps, the modelling could be improved to extend the conclusions concerning the impact of the patch shapes. Simulations could also be carried out on infestation map directly derived from spatial point processes. However, these refinements will require consideration of additional parameters and make more difficult the expression of the indicators as functions of the different input parameters.

In this study the longitudinal rate transitions (*i.e.* in the travelled direction), due to non-instantaneous on-off switching of sprayer sections were not taken into account. Moreover infestation maps were assumed to provide the exact location of weeds present in the field. Taking into account rate transitions and potential weed positioning errors should increase the chemical amount ratio Q_S/Q_T presented in this study. This should also leads to decrease the weed surface correctly controlled and increase the surface exposed to sub-lethal rate especially in the case of narrow spray sections or individual nozzle control. Furthermore, the spray patterns used in this work were limited to three theoretical shapes. However, the spraying simulator has been designed to use any theoretical or experimental transverse spray pattern.

The use of experimental spray pattern is of particular interest to deepen the study of the impact of the spray pattern on potential over or under applications, due to the lack or excess of overlapping when individually controlled nozzles or independent narrow width sections are used. Thus, future works are expected to take into account experimental spray pattern, longitudinal rate transition, and application margin around the target.

In the case of individual nozzle or narrow boom sections width (*e.g.* 2 or 3 nozzles) to apply herbicide on small weed patches, technical solutions could be assessed to reduce the surfaces exposed to under or over dosage. This includes the use of PWM control nozzles where nozzle output can be adjusted according to the duty cycle and may compensate the lake or the excess of overlapping. In the case of boom section with 2 or 3 nozzles, asymmetric fans (off-center nozzles) could also be combined to optimise the resulting spray pattern. The use of the virtual sprayer is of particular interest to investigate these possibilities.

4. Conclusions

Spraying simulations using virtual weed infested maps appears as a relevant way to study factors that affect herbicide savings in site specific weed control. The study demonstrates that the herbicide reduction achieved by the width reduction of independent application sections is highly affected by the infestation rate and the weed spatial distribution (*i.e.* patch sizes). Thus, the use of narrow application sections (*i.e.* 1 to 4 nozzles) can be relevant in the case of small patches randomly distributed, but moderate width sections also appear as a good choice when weeds are aggregated in larger patches. In the case of narrow boom sections equipped with triangular spray pattern nozzles, used to apply herbicide on small patches, the study demonstrates that the surface exposed to sub-lethal rate can reach a significant proportion of the total sprayed surface. This could be regarded as a potential risk of weed-control failure or herbicide-resistance development.

These first results show the interest of the spraying simulator to study the influence of the parameters and pave the way for the development of further simulator versions to assess more deeply new site specific spraying technology.

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References

Barroso, J., L. Navarrete, M. J. Sanchez Del Arco, C. Fernandez-Quintanilla, P. J. W. Lutman, N. H. Perry and R. I. hull (2006). “Dispersal of Avena fatua and Avena sterilis patches by natural dissemination, soil tillage and combine harvesters.” Weed Research **46**(2): 118-128.

Brix, A. and J. Chadœuf (2002). “Spatio-temporal Modelling of Weeds by Shot-noise G Cox processes.” Biometrical Journal **44**(1): 83-99.

Cox, D. R. (1955). “Some Statistical Methods Connected with Series of Events.” Journal of the Royal Statistical Society.

Series B (Methodological) **17**(2): 129-164.

Franco, C., S. M. Pedersen, H. Papaharalampos and J. E. Ørum (2017). “The value of precision for image-based decision support in weed management.” Precision Agriculture **18**(3): 366-382.

Gerhards, R. and H. Oebel (2006). “Practical experiences with a system for site-specific weed control in arable crops using real-time image analysis and GPS-controlled patch spraying.” Weed Research **46**(3): 185-193.

Gutjahr, C., M. Sokefeld and R. Gerhards (2012). “Evaluation of two patch spraying systems in winter wheat and maize.” Weed Research **52**(6): 510-519.

Kristensen, L., J. Olsen, J. Weiner, H. W. Griepentrog and M. Nørremark (2006). “Describing the spatial pattern of crop plants with special reference to crop–weed competition studies.” Field Crops Research **96**(2): 207-215.

Lee, W. S., D. Slaughter and D. Giles (1999). “Robotic weed control system for tomatoes.” Precision Agriculture **1**(1): 95-113.

Longchamps, L., B. Panneton, R. Reich, M.-J. Simard and G. D. Leroux (2016). “Spatial Pattern of Weeds Based on Multispecies Infestation Maps Created by Imagery.” Weed Science **64**(3): 474-485.

Nordmeyer, H. (2006). “Patchy weed distribution and site-specific weed control in winter cereals.” Precision Agriculture **7**(3): 219-231.

Rew, L. and R. Cousens (2001). “Spatial distribution of weeds in arable crops: are current sampling and analytical methods appropriate?” Weed Research **41**(1): 1-18.

Stafford, J. and P. Miller (1993). “Spatially selective application of herbicide to cereal crops.” Computers and Electronics in Agriculture **9**(3): 217-229.

Timmermann, C., R. Gerhards and W. Kühbauch (2003). “The Economic Impact of Site-Specific Weed Control.” Precision Agriculture **4**(3): 249-260.

Wallinga, J., M. J. Kropff and L. J. Rew (2002). “Patterns of spread of annual weeds.” Basic and Applied Ecology **3**(1): 31-38.

Weis, M., C. Gutjahr, V. R. Ayala, R. Gerhards, C. Ritter and F. Schölderle (2008). “Precision farming for weed management: techniques.” Gesunde Pflanzen **60**(4): 171-181.

Evolutions of Agricultural Tire technologies
Their impact on Tractive Efficiency and soil compaction

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Abstract

Continuous improvement has been made in agricultural tire technologies to allow more powerful vehicle to transmit high traction effort while lowering the impact on soil compaction. The latest step of this improvement is the association of a Central Tire Inflation System and a dedicated tire that changes its shape with pressure change to adapt its performances for road or field usage

Keywords: Traction, Tire, soil compaction, central tire inflation system

1. Introduction

Modernization of agriculture has led to a continuous increase of the size of farms in the past decades. To be able to manage those farms, bigger implements were needed requiring higher pulling force from the tractor. As there is an optimal ratio between the pulling force and the weight of the tractor, usually around 40%[1], this situation implied the usage of always heavier tractors.

Consequently, this increase in vehicle weight has a major impact on the risk of soil compaction. This is identified as one of the reasons of the slowing increase of agricultural yield in the last years[2]

To face this challenge, the improvement of the tire soil interaction is a major lever

2. Evolutions of tire technologies

The major steps historical steps in agricultural tire technology were

2.1. The transition, from bias to radial structure:

in the radial tires, there is a clear separation of the functions of the tread and the sidewall leading to a stability of the contact patch and an homogeneous distribution of stresses in the contact patch. The radial technology was introduced on tractor tires as early as 1970, this technology is well spread in Europe but still corresponds to a minority of tractor tires in the rest of the world.

2.2. The evolution of aspect ratios of the tires.

The aspect ratio of a tire is defined by the height of the sidewall as a percentage of the tire width. For example, for a given tire diameter (1850 mm) and rim diameter (38''), it can be increased by an increase of the tire width. There has been, for example an evolution from 520/85 R38 to 580/70R38 then 650/65 R38 leading to an increase of the tread width in contact with the soil and a reduction of the pressure needed to carry a given load. For this range of tire, the needed pressure to carry 3800 kg at 40 km/h being respectively 1,6 - 1,4 and 1,2 bar[3]

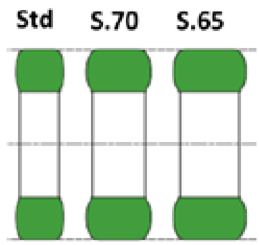


Fig. 1: Tire aspect ratio for given diameter Series 85 (standard) – 70 and 65

2.3. The evolution from standard to 'IF' and 'VF' tires.

For a given tire dimension the IF tires can carry an additional 20% load at the same pressure. The gain is 40 % with VF tires (fig 2). This gain can also be used to generate a reduction of pressure needed for a given load. For example : a standard 650/65 R42 can carry 4250 kg at 1,6 bars while a VF 650/65 R42 can carry 6000 kg and only need 1 bar for the same 4250 kg. [4] This reduction of pressure bringing a gain in the size of the contact patch and in the stress in the agricultural soil.

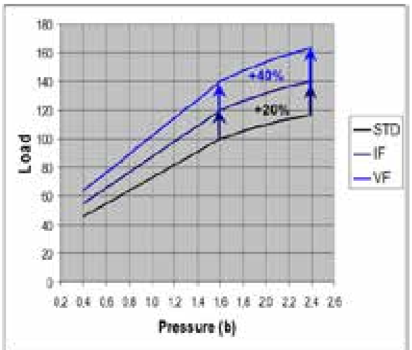


Fig. 2: Pressure/load capacities of standard, IF and VF tires

2.4. The usage of Central Tire Inflation Systems (CTIS).

A CTIS is a system installed on the vehicle which, through a system of compressor and rotary union can manage in real time the inflation pressure during operations. With this system, it is possible to differentiate the inflation pressure that is use in the various usages of the tractor and, in particular, to use always in the field the lowest possible pressure (higher pressures being needed in road usage due to the higher speed of operation). For example, a 710/70 R42 carrying 5600 kg has to be inflated at 1,6 bar to stand a 65 km/h usage, this pressure can be reduced to 1 bar when operating at less than 10 km/h on the field[3].

2.5. adaptative tire

The latest of these technical evolutions is the EvoBib Technology: an 'adaptive tire' that is able to change its shape when changing from road to field usage.

This technology differentiates from previous art by the fact that the tire presents 2 completely different shapes depending of its usage. The activation of the change of shape is obtained by change of pressure through, for example, the usage of a Central Tire Inflation System.

The first shape is designed to optimize the tire for road or hard soil usage. Compared to the 'classical V lug' agricultural tire, the width of the tread in contact with the ground is narrower and present a higher 'rubber vs. void' ratio, with a 'quasi-continuous' tread profile at the centre. It is reached when high pressure level (over 2/3 of the nominal tire pressure) is activated through CTIS

Fig. 3: Tire shape and contact patch in 'Road' configuration

The second shape is designed to optimize the tyre for field, or soft soil usage. In this case, the contact patch is much wider than in a classical tyre. The 'shoulder' part of the tread, is specifically designed with a low 'rubber vs. void' ratio. This shape is obtained when low pressure level is activated.

Fig. 4: Tire shape and contact patch in 'Field' configuration

It is well known that the key benefit of the radial technology is to allow, through a functional separation of the 'tread' and 'sidewall' zones of the tyre, a robust and homogeneous contact patch. However, this radial structure used to structurally 'fix' the width of the contact patch independently from the load and pressure applied. The key challenge to design the EvoBib was then to keep, in both shapes, a homogeneous repartition of stress in the contact patch.

This result was obtained by the combination of an innovative tread profile and of a carcass and belt structure in which the rigidities are scaled in such a way that the 'shoulder' of the tire s like a sidewall at high pressure and like a tread at low pressure.

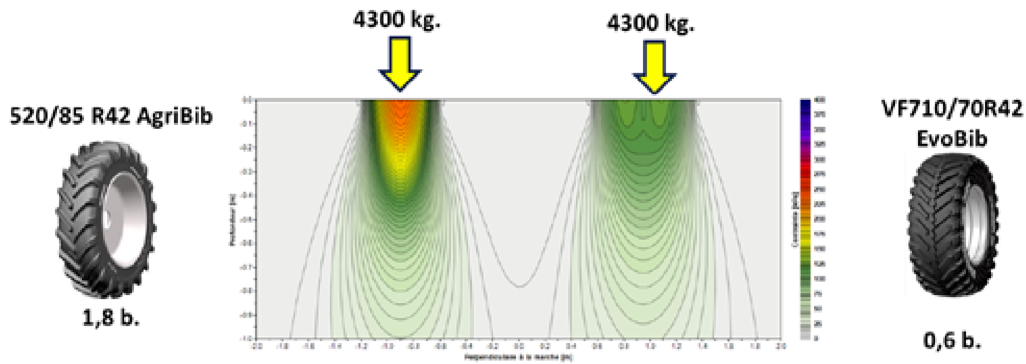
3. Results and Discussion

3.1. Performances obtained (1): Impact on soil stresses and crop yield

The impact of these evolutions on the soil stresses were evaluated with the ‘Terranimo®’ model[5]. This model evaluates the bulb of soil stress distribution as a function of the load, the tire, the pressure and the soil characteristics.

The effect of increasing footprint by the use of wider tire brings a significant reduction of pressure level in the soil (ex. 10% less pressure stress at 30 cm. depth with the same rim and tire diameter when switching from 650/65 R38 instead of 520/85 R38 to 650/65 R38). But, for a similar gain in contact patch surface, the effect of pressure decrease on soil compaction is significantly bigger (approx. 20% reduction in soil stress at same depth by switching from standard to VF tires)

The addition of all the technologies can bring a gain of over 50% is contact patch surface for a given load and 35% stress deep in the soil as describes in the table here below



Contact patch surface (m²)	0,37	0,58	+ 56 %
Max pressure in contact patch (kPa)	236	125	-47 %
Max pressure at 30 cm depth (kPa)	157	102	-35 %

Fig. 5: ‘Terranimo®’ simulation of tire technologies on soil stress for a given load

Those gains were experimentally confirmed on field testing in collaboration with Agroscope and the Universities of Aarhus and Bern[6]

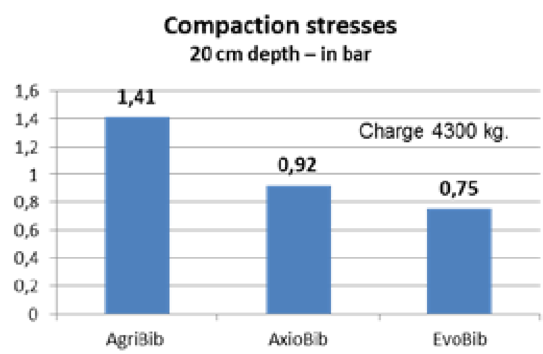


Fig. 6: ‘Bölling Probes’ measurement of soil stress for a given load[6]

The positive impact of these evolutions on the global crop yield has been studied and showed on specific studies conducted at Harper Adams (UK) and University of Illinois (USA) significant improvements in crop yields on corn and wheat with up to 4% gains.7

3.2. Performances obtained (2): Impact on tractive efficiency and on tractor engineering

Traction Force : the increased width in soft soil, associated with a lower sinkage of the tire in the soil due to the bigger footprint brings a higher capacity of the tire to transmit high tractive efforts.

This performance can be measured in a test were 2 tractors are linked by a drawbar in which the stress is measured. The front tractor tries to accelerate while the second maintain the speed constant. Simultaneously, the stress in the drawbar and the slip ratio of the tires of the front tractor are measured. After analyze, we build 'slip/traction curves' showing the ability of a set of tire to generate a traction effort at a given slip ratio

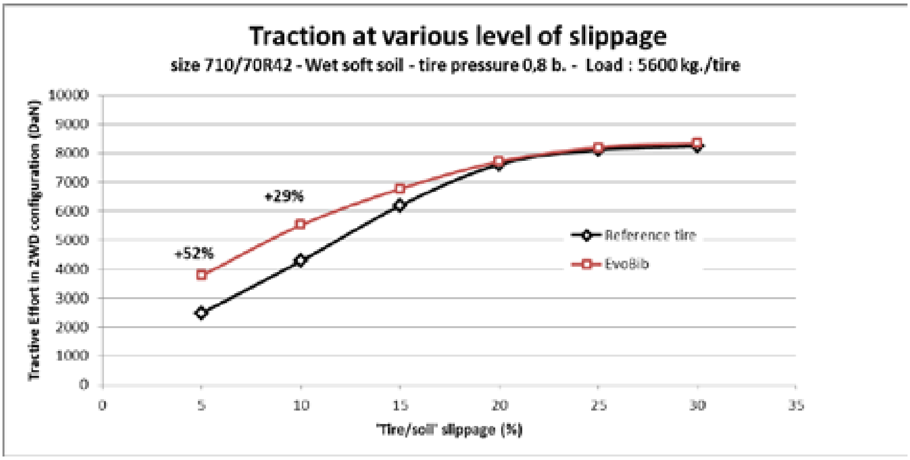


Fig. 7: traction efforts obtained at various slip level: comparison between EvoBib technology and the best tires of the previous art (AxioBib)

Tractive Efficiency : The quality of the tire/soil interface with the EvoBib technology induced a significant improvement in the relationship between the Net Traction ratio and the Tractive Efficiency. 'Classically', we obtain results showing an optimal NTR around 0,4 while, with the EvoBib technology, we observed that this optimum value is highly increased, at value significantly over 50%. We also observed significant improvement in the maximal tractive efficiency. This means an opening to significant changes in the tractor design; 3 directions may be followed

a - Use a given vehicle for a more intensive work

For example, the usage of VF710/70 R42 and VF600/70R30 EvoBib tyres, brings an additional available power at the drawbar of over 20 HP on a 300 HP tractor

b- Use a smaller engine on a given vehicle for the same work

The same work at the drawbar may be performed on the same tractor with a needed power at the engine reduced by some 15%

c- Use a lighter vehicle to transmit the same power

With the increase of optimal NTR from 40 to over 50%, it allows to have a lighter tractor to perform the same traction performance. For a given engine power, it has been estimated a possibility of

10% vehicle weight reduction (from change of ballast or vehicle design) with an increased effective traction. This allows additional gains on soil compaction and fuel economy.

4. Conclusions and next steps

- All along the history of agricultural machinery, the tire technology has evolved to allow the usage of more and more powerful vehicles. The latest steps of improvement were obtained by more intensive interaction between the tire and the vehicle through the continuous adaptation of inflation pressure according to the usage and through the design of new tires able to change their profile while operation. Major performance gains were obtained :
  - Increased footprint in the field ➔ less compaction and more traction
  - Higher energy efficiency from axle to drawbar
  - Increased road comfort
  - Lower rolling resistance
- Next steps
  - As showed with the CTIS technology and with the EvoBib, an important lever for improvement will be to adapt the tire and vehicle performances through the interaction between the tire and the vehicle. The first offers are entering the market, for example, the 'Zen@Terra offer' from Michelin allows a simple automatic choice of pressure from a simple description of the situation by the driver. There will be a rising challenge to define in real time the optimal tire setting through the gathering of additional relevant information about the soil and the usage. As the first point of contact of the vehicle with the soil, the tire is the perfect location for sensors capturing this kind of information.

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References

[1] F.Zoz and R.Grisso : 'Traction and tractor performance' ASAE distinguished lectures series, tractor design 27, 2003

[2] T.Keller : Keynote – ISTRO conference , Paris September 2018

[3] Michelin tire Databook 2017 : 520/85 R38 AgriBib – 580/70 R38 OmniBib – 650/65 R38 MultiBib - 710/70 R42 MachXBib

[4] Michelin tire Databook 2018 : 650/65 R42 MultiBib – VF 650/65 R42 AxioBib 2

[5] Terranimo ® - a web-based tool for evaluating soil compaction. (Stettler M., Keller T., Weisskopf P., Lamandé M., Lassen P., Schjønning P.) Landtechnik, 69, (3), 2014, 132-137.

[6] The contribution of tyre-evolution to the prevention of soil compaction (L. ten Damme, M. Stettler, F. Pinet, P. Vervaet, T. Keller, L. J. Munkholm, M. Lamandé) – ISTRO conference Paris September 2018.

[7] Effect of tire inflation pressure on soil properties and yield in a corn-soybean, rotation for three tillage systems in the Midwestern United States (Shaheb*, Grift, Godwin, Dickin, White1 and Misiewicz)

Evaluating the quality of work for single chisel plow tines

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Abstract

Chisel plow is commonly used in conservation tillage. However, there are a different chisel plow tine shapes such as curved or sweep. Curved is used to loosen the soil, break up compacted layers and leaving the plant residues near the soil surface without overturns it. Sweep and winged tines are used for weed control and soil crust breaking because of their mixing effect. Therefore, the work quality of a four standard single chisel plow tines was evaluated in this study consisting of heavy duty, double heart, double heart with wings and duck foot, the tine widths were 6.5, 13.5, 45 and 40 cm, respectively. Experiments were conducted in an indoor soil bin filled with a sandy loamy soil that had an average moisture content of 10.4% (dry basis) and an average bulk density of 1.37g/cm³. Tests were carried out to study the effect of tine width (tine shape) and operating conditions (speed, depth) on soil disturbance and force requirements. The soil disturbance parameters were considered in terms of furrow height, ridge height, ridge-to-ridge distance, maximum width of soil throw and soil loosening percentage remaining in the furrow (furrow backfill), while the force requirements were considered in term of specific force (force per unit area). New regression techniques (dummy variable, tine geometric parameters) were performed to predict the studied parameters. The results showed that the furrow height is highly affected by tine shape, while the soil loosening percentage is highly affected by adding wings. A good agreement between measured and predicted values for all tines with an average absolute variations less than 19%, 5% and 7% were found for ridge height, ridge-to-ridge distance and maximum width of soil throw, respectively by using the dummy and the geometric regression models. The specific force is highly affected by tine shape. It increases linearly with speed for all tines, while decreases linearly with depth for double heart and duck foot tines. Double heart with wing tine gives the best compromise of this parameter.

Keywords: soil bin, single chisel plow tines, soil profile parameters, specific force

1. Introduction

Recently, many changes in tillage practices have been established, where conservation tillage methods (CT) are replacing the moldboard plow by using tillage tools such as the chisel plow that keeps crop residue left on the soil surface after tillage, which is important to reduce soil erosion (Harrigan & Rotz 1995). Furthermore, the chisel plow can be used in the primary and the secondary tillage operation. Koolen & Kuipers (1983) classified tillage tools into a four categories: tines, plow bodies, discs and rollers, where the soil cutting effect of tines reaches further than the width of the tine body, while for the plow bodies the soil cutting effect is generally as wide as the body width. Godwin & O'Dogherty (2007) categorized tines into three types depending on the aspect ratio (depth/width), which are wide (blades), narrow (chisel) and very narrow (knife).

The soil profile after tillage is an important factor, indicates and shows the result of forces applied by tillage tools, which will give the knowledge about the soil movement and desired disturbance. Numerous analytical models (two or three dimensional in both static and dynamic), empirical methods (linear regression, multi-linear regression, orthogonal regression and reference tillage tools regression) and finite element method were used in design of tillage tools, (Payne 1956, Hettiaratchi et al. 1966, Hettiaratchi & Reece 1967, Godwin & Spoor 1977, McKyes & Ali 1977, McKyes 1985, Wheeler & Godwin 1996, Stafford 1979, Upadhyaya et al. 1984, Glancey & Upadhyaya 1995, Grisso et al. 1996, Glancey et al. 1996, Desbiolles et al.1997, Onwualu & Watts 1998, Ehrhardt et al. 2001, Sahu & Raheman 2006, Rosa & Wulfsohn 2008) and (Yong & Hanna 1977, Chi & Kushwaha 1990, Mouazen & Nemenyi 1999). Which focused on how to reduce the quantity of force without considering the resulting (soil profile).

From a practical point of view, the specific force (force per unit distance or area) is more useful than draft force only to evaluate the efficiency of tillage tools in soil plowing and loosening (Dedousis & Bartzanas 2010, Hettiaratchi 1993, McKyes & Desir 1984). Therefore, formed soil by the tillage tools need to be quantified.

Very few studies have been done to investigate the soil profile parameters or the soil loosening percentage as a function of the operating conditions. Liu & Kushwaha (2005) pointed out that the studying soil profile is very complex and progresses slowly because of many factors involved with it, such as soil types and properties, types of tillage tools and operating conditions. Sharifat & Kushwaha (1999) reported that the different tillage tools cause different geometries of soil profiles. Shinde et al. (2011) showed that the ridge width and depth increased with increasing speed and depth, and the ridge area was directly proportional to speed and depth, whereas furrow area decreased with increase in speed for both shovel and sweep tools in sandy loam soil. Manuwa et al. (2012) studied the effects of different tine width on soil profile parameters under soil bin conditions and they reported that the parameters of soil disturbance except height of ridge increased with increase in tine width.

This study aimed to assess the quality of work for the standard single chisel plow tines at varying speed and depth in controlled soil bin conditions, quantifying their capacities to estimate the soil profile parameters and the force requirements.

2. Materials and Methods

2.1. Soil bin description and soil preparation

The experiment was carried out in an indoor soil bin facility at the Chair of the Agricultural Systems and Technology (AST), Technische Universität Dresden (TU Dresedn), Germany. The soil bin was 28.6 m long, 2.5 m wide and 1.0 m deep. It was filled with a sandy loam soil (60.9% sand, 30.1% silt, 9% clay), that had an average moisture content of 10.4% (dry basis) and an average bulk density of 1.37g/cm³. The carriage was powered by an electric-hydraulic drive train with a maximum speed of 17 km/h delivering a maximum traction of 13kN, and was equipped with a radar sensor for measuring the ground speed (velocity ranged from 0.53 to 107 km/h ± 5%).

Before the test run, the soil bin was prepared to achieve the required levels of soil moisture content and bulk density. The first step was plowing the soil by a rotary plow at a depth of 20 cm, which was used to loosen the soil after watering to achieve the required moisture content. Following this process, the soil was levelled with the scraper and finally it was compacted by a 900 kg roller five times to attain the required bulk density. At the end of each preparation, soil samples were taken to verify the moisture content and the bulk density manually by using core sample at 15 locations evenly distributed along the soil bin.

2.2. Tillage tines used and measurements

A four standard single chisel plow tines were used in this study consisting of T1 heavy duty, T2 double heart, T3 double heart with wings and T4 duck foot (see Fig.1). Tine parameters were summarized in Table 1.

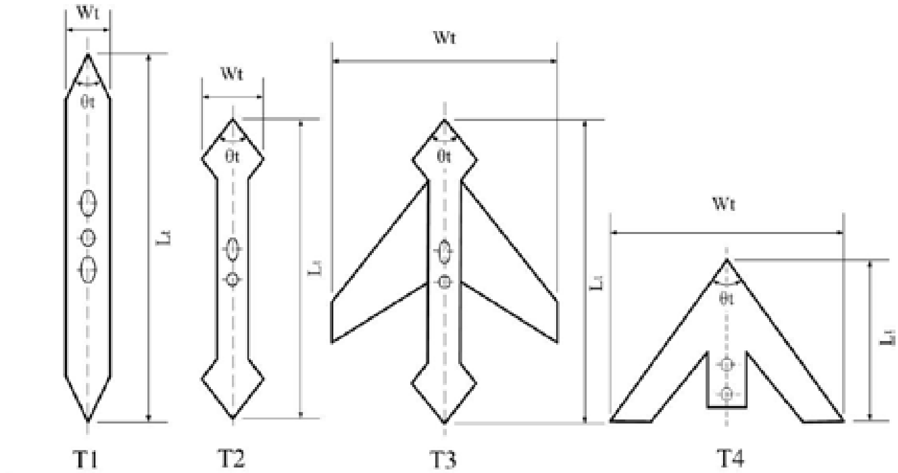

Fig.1. Tine shape and geometric parameters: Wt tine width; Lt tine length; θt tine angle.

The draft force (Fd) was measured by using six load cell sensors, two for the horizontal force, one for the vertical force and three for the lateral force (Guhr 2015). Sensor types were S9 and U9B (HBM GmbH) with a maximum load of 50 kN and 20 kN, respectively with an accuracy ± 5%. The soil profile was measured by using 2-D soil profile meter; which consisted of a laser spot sensor for the vertical coordinates and a draw-wire position sensor for the horizontal coordinates. The final soil profile was acquired in three steps: first, measured the soil surface before running the test; second, measured the soil modification immediately after running the test with 21 profile readings (1-meter-long every 5 cm); and third, acquired the profile after removing the loose soil manually.

Table 1. Tine parameters

Tines	Length [cm]	Width [cm]	Thickness [cm]	Radius [cm]	Tine angle [°]	Weight [g]
Heavy duty	47	6.5	2	30	60	3400
Double heart	44	13.5	2	30	65	3200
Double heart with wings	32	45	2	30	65	4200*
Duck foot	30	40	1	30	85	2900
* Wing only						

MATLAB based computer program was adopted to compute the soil profile parameters (distance, area), as detailed in (Al-Neama & Herlitzius 2018).

2.3. Soil profile parameters after tillage

For the purpose of analysis and study of soil tillage results, the soil profile after plowing was divided into two parts, the soil displaced above the original soil surface was called ridge, and below it was called furrow (Manuwa & Ogunlami 2010). The of soil profile parameters include: The distance parameters are; a maximum width of soil throw (MWT), ridge-to-ridge distance (RRD), the height of the ridge (HR) and the height of the furrow (HF). While the area Parameters are; the area of ridge (Ar), the area of the soil remaining in the furrow after tillage (Af), the all-free area (Aa) and the area of the furrow cut by tines (Aw) with Aw equal to Aa + Af as defined in Fig.2.

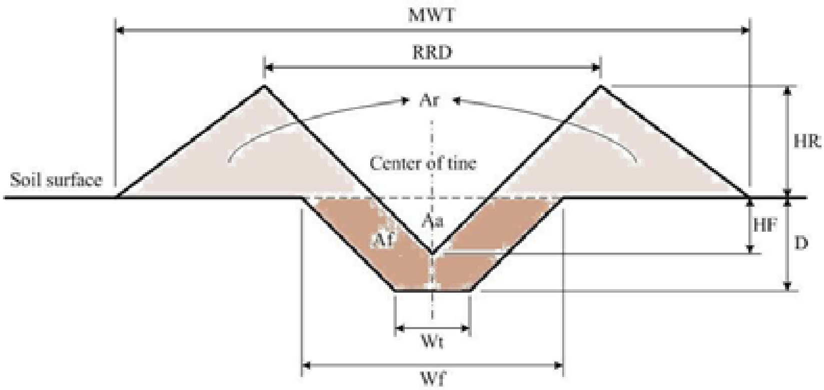

Fig.2. Soil profile parameters

2.4. Calculate Data

Glancey & Upadhyaya (1995) proposed a general form of the regression equation in a specific soil type under various operating conditions (speed and depth) Eq. (1).

$$Y = C_0 + C_1S + C_2D + C_3SD + C_4S^2 + C_5D^2 \tag{1}$$

Where, Y is the dependent variable, S is speed in km/h, D is depth in cm, and (C_0, C_1, C_2, C_3, C_4 and C_5) are the regression coefficients.

Al-Neama & Herlitzius (2016) added new terms to Eq. (1) related to the statistic dummy variable or by adding tines geometric parameters as given in Eq. (2) and (3), respectively.

$$Y = K + C_0 + C_1S + C_2D + C_3SD + C_4S^2 + C_5D^2 \tag{2}$$

$$Y = G_1Wt + G_2Lt + G_3\theta t + C_0 + C_1S + C_2D + C_3SD + C_4S^2 + C_5D^2 \tag{3}$$

Where, K is the dummy variable, which represents each tine regardless of the tine shape or geometry, Wt is the tine width in cm, Lt is the tine length in cm, θt is the tine angle in ° and G_1, G_2 and G_3 are tine geometric coefficients, respectively (see Fig.1). Note: the identical geometric parameters were excluded (see Table 1).

The soil loosening percentage under the original soil surface SLu% (Furrow backfill) can be represented by using Eq. (4), and represents all the area types of the soil profile parameters by one term.

$$SLu\% = \frac{Af}{At} \times 100 \tag{4}$$

Where, At is the total area of disturbed soil after tillage in cm², and equal to Aw + Ar (see section 2.3 and Fig.2). Barr et al. (2016) calculated SLu% as a ratio between Af and Aw. Therefore, it cannot define furrow backfill beyond 100%, whereby an extra-loosened soil above the original soil surface is not accounted for Ar.

The specific force (Fs) per unit area in kN/m² was calculated by using Eq. (5).

$$Fs = \frac{Fd}{Aw} \tag{5}$$

In addition, the variation % value was obtained according to Eq. (6).

$$Variation\ \% = \left(\frac{|X_1 - X_2|}{X_1}\right) \times 100 \tag{6}$$

Where, X_1 is the highest or measured valve, and X_2 is the lowest or predicted value, respectively.

2.5. Experiment design and statistics analysis

The test layout was designed as a factorial experiment within each tine with three replicates. The tines were operated at speeds of 4, 7, 10, and 13 km/h for T1 and T2, and of 4, 8.5 and 13 km/h for T3 and T4. With varying depths were 5, 10, 15 and 20 cm for T1 and T2, and 10, 15 and 20 cm for T3. The depth 5 cm was excluded from T3 because it was below the minimum operational depth of the tine. While T4 was run at depths of 5, 12.5 and 20 cm.

A multi-linear regression analysis with a stepwise selection at significance level 5% was performed using computer- based software SPSS package to evaluate the significant effects of the independent variables (speed, depth and their interaction).

3. Results and Discussion

3.1. Effects of speed and depth on the specific force

Effects of speed and depth on the Fs in kN/m² are presented in Fig. 3 for all tines under the soil bin conditions. The Fs is defined as a ratio between the Fd and the Aw. The minimum values of Fs are interesting here; it represents the less energy consumption with highest soil cutting and distributing. Fig. **3** and the regression model show that every tine having a different manner to achieve this characteristic.

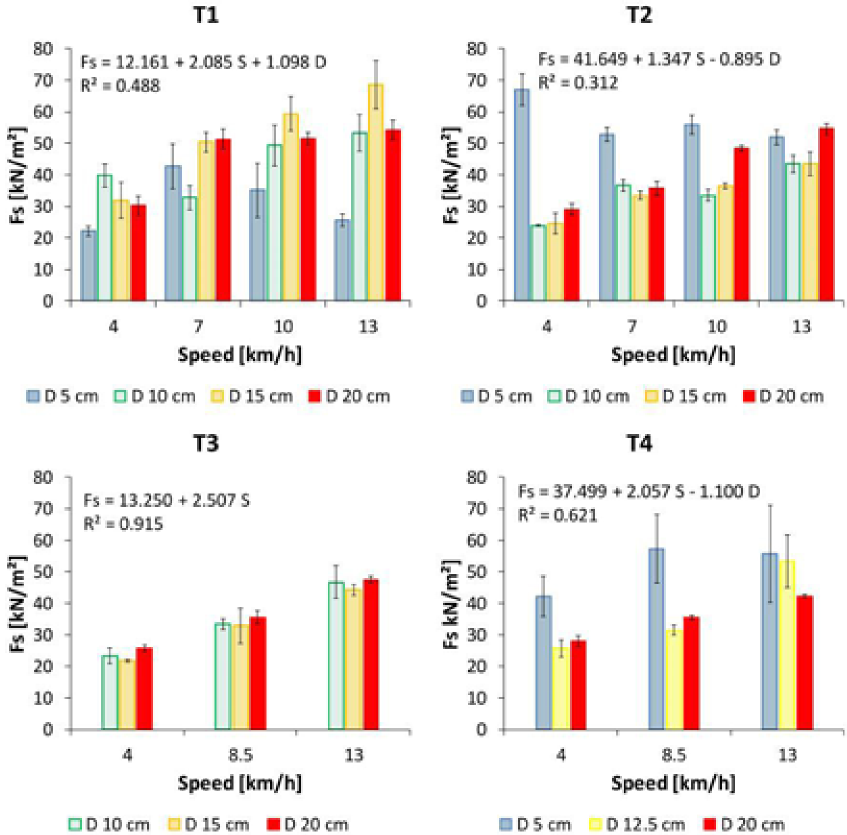

Fig. 3. Effects of speed and depth on Fs for all tines in the soil bin conditions (mean ± standard deviation).

The Fs increased with speed for all tines (positive value of C_1), while it decreased with depth for T2 and T4 (negative value of C_2) but not T1 (increasing). The minimum values for Fs were 21.7, 22.2, 23.9 and 25.6 kN/m² for T3, T1, T2 and T4, respectively, at a speed of 4 km/h and depth of 15, 5, 10 and 12.5 cm, respectively. The absolute variations were 2%, 10% and 18% between T3 and other tines, respectively. Therefore, it is preferred to use T2 with wings.

3.2. Effects of speed and depth on the soil profile parameters

The effects of speed and depth on the soil profile parameters (furrow height, ridge height, ridge-to-ridge distance and maximum width of soil throw) were detailed in (Al-Neama 2019).

3.3. Three regression models to predict the soil profile parameters

Three different regression techniques were performed to predict the soil profile parameters under controlled soil bin condition. The first model was based on the effect of the operational conditions speed and depth for each tine, the second model was employing a statistic dummy variable, it represents each tine regardless of the tine shape or geometry. The objective of using this method is to integrate the regression equations with one equation, which represents all tines by one coefficient *K*, and this coefficient have four values each value represents a specific tine. While the tine geometrics were base for the third model. The aim of using this method is to know which of the tine geometric had an enormous influence on study parameters. Note: these techniques were applied when the tines had the same-trained effect on study parameters.

Three regression models were used to predict HR in the soil bin conditions. The results are presented in Table 2. It is noticeable from this table that the coefficient of depth C_2 is the dominant factor influencing HR for each tine and for all regression models. In Table 2, it is obvious that HR increases with increasing depth (positive value of C_2) for all regression models. The coefficient C_2 has similar values in the operating conditions, dummy and geometric models. The similarity can be attributed to the stable test environment done in a specific soil type and conditions. The coefficient of determination had a good value $R^2 > 80\%$ for the operating conditions and dummy regression models and an acceptable value 77.1% for the geometric model. Table 2 shows that the coefficient K related to the dummy regression model is equal to zero for T2 and increased to 0.090, 0.172 and 1,406 for T1, T3 and T4, respectively. These increases are a randomly increasing. Therefore, the coefficient K cannot interpret this parameter. However, tine geometric coefficients

G_1, G_2 and G_3 for width, length, and tine angle, respectively did not have a significant effect on HR (Table 2).

Table 2. Regression models and coefficients for the ridge height (HR)

Regression model	Tines	Regression Coefficient									R²
					C_0	C_1	C_2	C_3	C_4	C_5	
Operating condition	T1				1.296	n.s.	0.242	n.s.	n.s.	n.s.	0.837
	T2				1.025	n.s.	0.256	n.s.	n.s.	n.s.	0.969
	T3				1.024	n.s.	0.268	n.s.	n.s.	n.s.	0.915
	T4				2.189	n.s.	0.276	n.s.	n.s.	n.s.	0.848
			K		C_0	C_1	C_2	C_3	C_4	C_5	**R²**
Dummy variable	T1		0.090								
	T2		0.000		1.016	n.s.	0.257	n.s.	n.s.	n.s.	0.874
	T3		0.172								
	T4		1.406								
Geometric variable		G_1	G_2	G_3	C_0	C_1	C_2	C_3	C_4	C_5	**R²**
	T	n.s.	n.s.	n.s.	1.356	n.s.	0.255	n.s.	n.s.	n.s.	0.771

n.s.: not significant

Three regression models were used to predict RRD in the soil bin conditions. The results are depicted in Table 3. It is obvious from this table that the coefficient of speed C_1 is the predominant factor influencing RRD for each tine and for all regression models. From this table it can be seen that RRD increased linearly with the speed for each tine and for all regression models (positive values of C_1). In addition, it can also be seen that the coefficient of speed C_1 has the same value 3.181 in the dummy and geometric models and is similar to the values in operating conditions. This similarity can be attributed to the stable test environment done in specific soil type and conditions. In addition, Table 3 showed that the coefficient K for the dummy regression model equal to zero for T1. Because, it was set as the reference tine, and it can also be seen that the coefficient K increased with increasing width of tines from 0.000 to 2.763 and to 11.068 and then to 17.634 for T1, T2, T4 and T3, respectively. As expected from dummy regression model, only the coefficient of tine width G_1 appeared in the geometric regression model with a good R^2 of 0.727 (Table 3).

Table 3. Regression models and coefficients for the ridge-to-ridge distance (RRD)

Regression model	Tines	Regression coefficient									R^2
					C_0	C_1	C_2	C_3	C_4	C_5	
Operating condition	T1				9.630	4.431	n.s.	n.s.	n.s.	n.s.	0.806
	T2				16.799	3.822	n.s.	n.s.	n.s.	n.s.	0.718
	T3				47.590	1.949	n.s.	n.s.	n.s.	n.s.	0.766
	T4				42.744	1.747	n.s.	n.s.	n.s.	n.s.	0.608
Dummy variable			K		C_0	C_1	C_2	C_3	C_4	C_5	R^2
	T1		0.000		19.483	3.181	n.s.	n.s.	n.s.	n.s.	0.736
	T2		2.763								
	T3		17.634								
	T4		11.068								
Geometric variable		G_1	G_2	G_3	C_0	C_1	C_2	C_3	C_4	C_5	R^2
	T	0.407	n.s.	n.s.	16.700	3.181	n.s.	n.s.	n.s.	n.s.	0.727

n.s.: not significant

Three regression models were used to predict MWT in the soil bin conditions. The results are shown in Table 4. It is clear from this table that MWT increased linearly with speed and depth for each tine and for all regression models (positive values of C_1 and C_2). Speed coefficient C_1 has an equivalent value of 8.454 in the dummy and geometric model; in addition, the coefficient of depth C_2 has the same value in the dummy and geometric model (2.532 and 2.522, respectively) and has similar values in operating conditions. This similarity can be attributed to the fixed experiment environment done in a specific soil type and conditions. Table 4 shows that the coefficient K for a dummy regression model is equal to zero for T4 because it was set as a tine reference, and it can be seen that the coefficient K decreased with increased tine length (see Table 1 in section 2.2). As expected from dummy regression model, only the coefficient of length of tine G_2 appeared in the geometric regression model with a negative value of -1.305 at $R^2 > 80$ % (Table 4).

Table 4. Regression models and coefficients for the maximum width of soil throw (MWT)

Regression model	Tines	Regression coeficient									R^2
					C_0	C_1	C_2	C_3	C_4	C_5	
Operating condition	T1				3.634	9.651	1.593	n.s.	n.s.	n.s.	0.934
	T2				-10.030	9.449	3.885	n.s.	n.s.	n.s.	0.971
	T3				52.784	7.728	1.103	n.s.	n.s.	n.s.	0.916
	T4				48.580	5.933	2.555	n.s.	n.s.	n.s.	0.806
Dummy variable			K		C_0	C_1	C_2	C_3	C_4	C_5	R^2
	T1		- 25.367		27.434	8.454	2.532	n.s.	n.s.	n.s.	0.892
	T2		- 12.100								
	T3		- 2.290								
	T4		0.000								
Geometric variable		G_1	G_2	G_3	C_0	C_1	C_2	C_3	C_4	C_5	R^2
	T	n.s.	-1.305	n.s.	67.740	8.454	2.522	n.s.	n.s.	n.s.	0.881

n.s.: not significant

3.4. Validation of the regression models

To substantiate the reliability of the regression models for HR, the observed values (soil bin) were plotted in Fig. 4 against the predicted values (regression) for all tines. From this figure, an excellent accordance between soil bin and regression models for HR for all tines can be seen. Tine T1 shows an excellent correlation between observed and predicted values of HR (Fig. 4). From this graph, it can be seen that the slopes of the best-fit line were 1.04 for geometric,

0.99 for dummy, and 0.98 for the operation condition. The regression equation model predicted the HR of the dummy, operating condition, and geometric regression with the average absolute variation of 1%, 2%, and 7%, respectively.

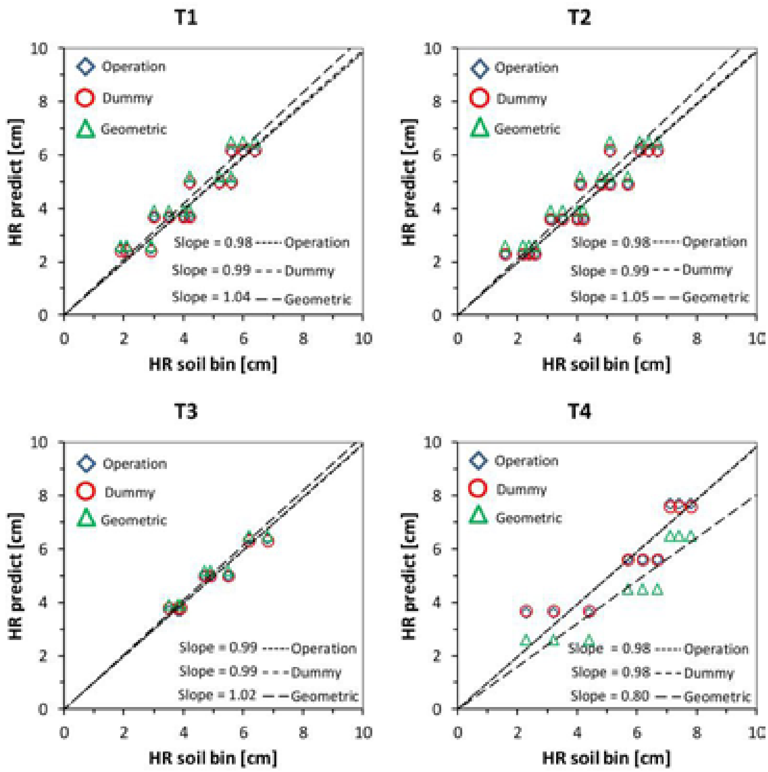

Fig. 4. Comparison between observed (soil bin) and predicted (regression) for HR for all tines.

Fig. **4** shows an excellent agreement between observed and predicted values of HR for T2 with slope 1.05, 0.99, and 0.98 for the geometric, dummy, and operating condition regressions, respectively. The average absolute variation between observed and predicted values of HR were found to be 2% for the operating condition, 3% for the dummy, and 11% for the geometric regression. An excellent acceptance between observed and predicted values of HR was found for T3 with slope 1.02, 0.99, and 0.99 for the geometric, dummy, and operating condition regressions, respectively, with average absolute variation between observed and predicted values of 2% for both the operating condition and the dummy and 3% for the geometric regression. From the comparison in Fig. 4, it is clear that there is a very good accordance between observed and predicted values of HR for T4 with slope 0.98, 0.98, and 0.80 for the operating condition, dummy, and geometric regressions, respectively. The average absolute variation between observed and predicted values of HR was calculated to be 4% for both the operating condition and the dummy and 18% for the geometric regressions.

To verify the accuracy of the regression models for RRD, the observed values (soil bin) and the predicted values (regression models) are plotted in Fig. 5 for all tines. From this figure, an excellent correlation between observed and predicted values of RRD for all tines can be seen. T1 shows an excellent accordance between observed and predicted values of RRD (Fig. 5). From this graphic, it can see that the slopes of the best-fit line were 0.99 for operation condition and 0.96 for both dummy and geometric regression. The regression equation model predicted the RRD of the operating condition, geometric, and dummy regression with average absolute variations of 1%, 4%, and 4%, respectively. Fig. **5** shows an excellent agreement between observed and predicted values of RRD for T2 with slope 0.98 for operating condition and 0.97 for both dummy and geometric regression. The average absolute variations between observed and predicted values of RRD were found to be 3% for the operating condition and 4% for the dummy and geometric regression.

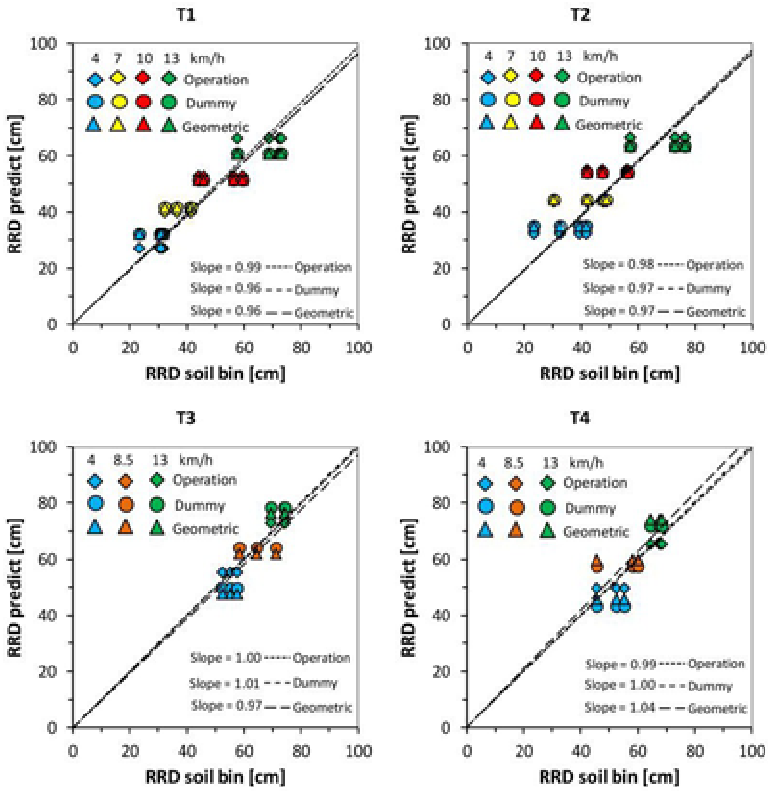

Fig. 5. Correlation between observed (soil bin) and predicted (regressions) for RRD at different speeds for all tines

An excellent acceptance between observed and predicted values of RRD was found (Fig. 5) for T3 with slope 1.00 for the operating condition, 1.01 for the dummy, and 0.97 for the geometric regression, with average absolute variation between observed and predicted values of 1%, 1%, and 4% for operating condition, dummy, and geometric regression, respectively. From the comparison in Fig. 5, it is quite clear that there is an excellent accordance between observed and predicted values of RRD for T4 with slope 1.00 for the dummy, 0.99 for the operating condition, and 1.04 for the geometric regression. The average absolute variation between observed and predicted values of RRD was calculated to be 1%, 1%, and 4% for dummy, operating condition, and geometric regression, respectively.

In order to confirm the accuracy of the regression models for MWT, the observed values (soil bin) are plotted versus the predicted values (regression models) in Fig. 6 for all tines. From this comparison, an excellent correlation between observed and predicted values of MWT for all tines can be seen. T1 shows an excellent agreement between observed and predicted values of MWT (Fig. 6). From this figure, it can be seen that the slopes of the best-fit line were 1.00, 0.99, and 1.02 for operation condition, dummy, and geometric regression, respectively. The regression equation model predicted the MWT of the operating condition, dummy, and geometric regression with average absolute variations of 1%, 1%, and 6%, respectively. Fig. **6** shows an excellent correlation between observed and predicted values of MWT for T2 with slope 0.99 for operating condition, 0.98 for dummy, and 0.94 for geometric regression. The average absolute variations between observed and predicted values of MWT were found to be 1% for the operating condition, 3% for the dummy, and 2% for the geometric regression. An excellent acceptance between observed and predicted values of MWT was found for T3 with slope 0.99 for the operating condition, 1.00 for the dummy, and 1.01 for the geometric regression, with the average absolute variation between observed and predicted values of 1% for all regression models.

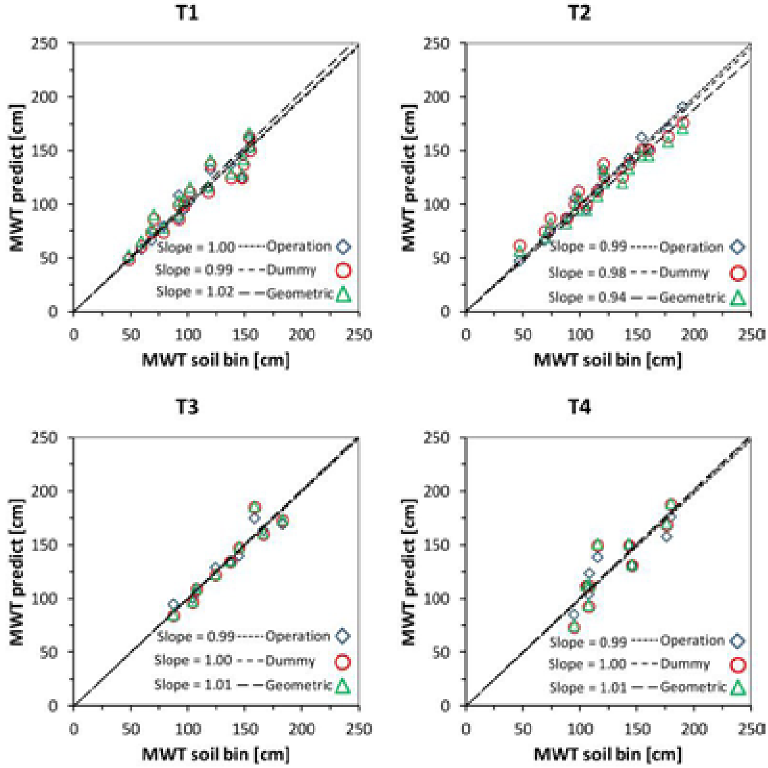

Fig. 6. Comparison between observed (soil bin) and predicted (regression) for MWT for all tines

From the comparison in Fig. 6, it is clear that there is an excellent accordance between observed and predicted values of MWT for T4 with slope 0.99 for the operating condition, 1.00 for the dummy, and 1.02 for the geometric regression. The average absolute variation between observed and predicted values of MWT was calculated to be 1% for all regression models.

3.5 Effects of speed and depth on the soil loosening percentage under the original soil surface (furrow backfill) Effects of speed and depth on SLu% are presented in Fig.7 for all tines under the soil bin conditions.

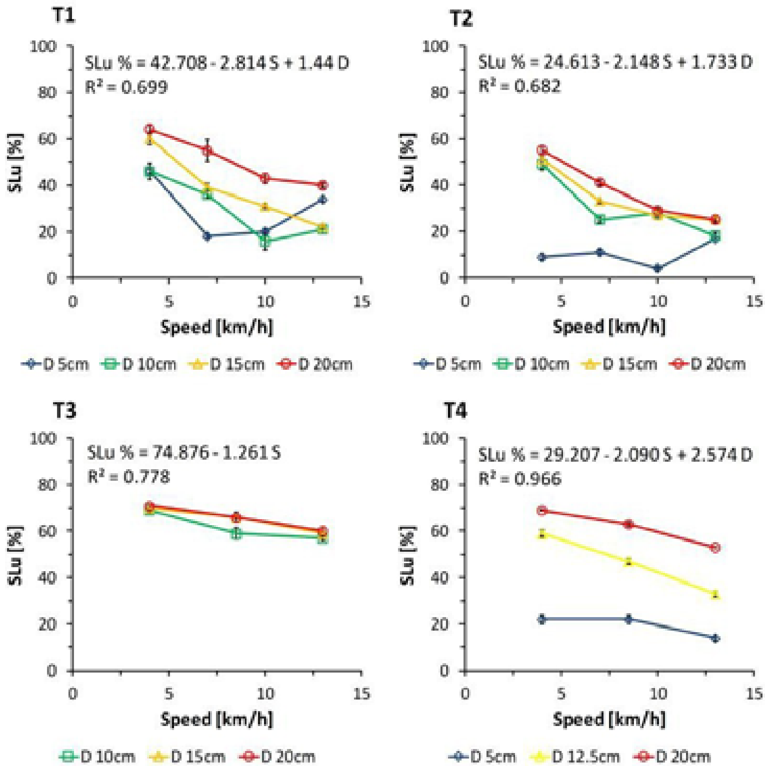

Fig.7. Effect of speed and depth on SLu% for all tines (mean ± standard deviation).

The SLu% refers to the amount of soil loosened under the original soil surface or so called furrow backfill (loosened soil remaining in the furrow) and it is a ratio between Af and At. Fig.7 and the regression model show a different behavior for every tine regarding this characteristic. The SLu% decreased with speed for all tines (negative value of C_1), while it increased with depth for all tines (positive value of C_2) except T3 (no effects). The maximum values for SLu% were 71%, 69%, 64% and 55% for T3, T4, T1 and T2, respectively, with absolute variations of 3%, 10% and 23% between T3 and the other tines, respectively. Therefore, adding wings to T2 had a significant effect on SLu% (increasing).

4. Conclusions

1. Specific force (Fs) is highly affected by tine shape. It increases linearly with speed for all tines, and decreases linearly with depth for T2 and T4, but increases for T1. The minimum value obtained at depth 15 cm with the lowest speed for T3.
2. A good agreement between measured and predicted values for all tines with an average absolute variations less than 19%, 5% and 7% were found for HR, RRD and MWT, respectively by using a dummy variable and tine geometric parameters regression technique.
3. Furrow backfill (SLu%) is highly affected by adding wings. It decreases with speed for all tines, while it increases with depth for all tines except T3 (no effects). Thus, T3 shows the maximum magnitude for this parameter.

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References

Al-Neama, A. K. A. (2019). *Evaluation of performance of selected tillage tines regarding quality of work.* Fortschritte Naturstofftechnik.Springer Vieweg, Berlin, Heidelberg.

Al-Neama, A. K. A., & Herlitzius, T. (2016). New regression model for predicting horizontal forces of single tines using a dummy variable and tine geometric parameters. *LANDTECHNIK*, 71(5), 168–174.

Al-Neama, A. K. A., & Herlitzius, T. (2018). Description of furrow shaping created by single standard tines. *Engineering in Agriculture, Environment and Food journal (EAEF), 11*(2), 43-50.

Barr, J., Desbiolles, J., & Fielke, J. (2016). Minimising soil disturbance and reaction forces for high speed sowing using bentleg furrow openers. *Biosystems Engineering*, pp. 151, 53–64.

Chi, L., & Kushwaha, R. (1990). A non-linear 3-d finite element analysis of soil failure with tillage tools. *Terramechanics*, pp. 27(4), 343-366.

Dedousis, A., & Bartzanas, T. (2010). *Soil Engineering*. Soil Biology, vol 20. Springer, Berlin, Heidelberg.

Desbiolles, J. M., Godwin, R. J., Kilgour, J., & Blackmore, B. S. (1997). A Novel Approach to the Prediction of Tillage Tool Draught using a Standard tine. *J. agric. Engng Res.*, 66 , 295 – 309.

Ehrhardt, J., Grisso, R., Kocher, M., Jasa, P., & Schinstock, J. (2001). Using the Veris Electrical Conductivity Cart as a Draft Predictor. *ASAE*, Paper No. 011012.

Glancey, J. L., & Upadhyaya, S. K. (1995). An improved technique for agricultural implement draught analysis. *Soil and Till. Res.*, 175-182.

Glancey, J. L., Upadhyaya, S. K., Chancellor, W. J., & Rumsey, J. W. (1996). Prediction of agricultural implement draft using an instrumented analog tillage tool. *Soil and Till.Res.*, 37:47-65.

Godwin, R., & O'Dogherty, M. (2007). Integrated soil tillage force prediction models. *Journal of Terramechanics*, pp. (44); 3–14.

Godwin, R., & Spoor, G. (1977). Soil failure with narrow tines. *J. of Agric. Eng. Res.* , pp. 22(4):213-228.

Grisso , R., Yasin , M., & Kocher , M. (1996). Tillage tool forces operating in silty clay loam. *Transactions of the ASAE*, 39,1977–1982.

Guhr, M. (2015). Experimentelle Untersuchung von Grubberscharen unter Laborbedingungen. Diplomarbeit thesis, TU Dresden, Germany.

Harrigan, T. M., & Rotz, C. A. (1995). draft relationships for tillage and seeding equipment. *Appl. Eng. Agric.*, pp. 11 (6), 773-783.

Hasimu, A., & Chen, Y. (2014). Soil disturbance and draft force of selected seed openers. *Soil and Till. Res. J.*, 140, 48– 54.

Hettiaratchi, D. (1993). The development of a powered low draft tine cultivator. *Soil and Tillage Res.*, pp. 28, 159-177. Hettiaratchi, D., & Reece, A. (1967). Symmetrical three-dimensional soil failure. *J.Terramechanics*, pp. 4(3):45-67.

Hettiaratchi, D., Whitney, B., & Reece, A. (1966). The calculation of passive pressure in two-dimensional soil failure. *J.Agric. Eng. Res.*, pp. 11(2):89-107.

Koolen, A., & Kuipers, H. (1983). *Agricultural Soil Mechanics.* Springer-Verlag, Berlin, Heidelberg.

Liu, J., & Kushwaha, R. L. (June 26 - 29, 2005). STUDY OF SOIL PROFILE OF A SINGLE SWEEP TOOL. *CSAE/SCGR Meeting* (pp. Paper No. 05-060). Canada,Winnipeg, Manitoba: CSAE/SCGR .

Manuwa, S. I., Ademosun, O. C., & Adesina, A. (2012). Regression Equations for Predicting the Effect of Tine Width on Draught and Soil Translocation in Moderately Fine Textured Soil. *J. of Environmental Sci. and Eng.*, pp. 820- 825.

Manuwa, S., & Ogunlami, M. (2010). Soil–tool interaction modeling of parameters of soil profile produced by tillage tools. *J. Eng. Appl. Sci.*, pp. 5 (2), 91–95.

McKyes, E. (1985). *Soil Cutting and Tillage.* Elsevier publishing, New York.

McKyes, E., & Ali, O. (1977). The cutting of soil by a narrow blade. *J. of Terramechanics*, pp. 14(2):43-58.

McKyes, E., & Desir, F. (1984). Prediction and field measurements of tillage tool draft forces and efficiency in cohesive soils. *Soil & Tillage Res.*, 4, 459-470.

Mouazen, A., & Nemenyi, M. (1999). Finite element analysis of subsoiler cutting in non-homogeneous sandy loam soil. *Agric. Eng. Res.*, pp. 5,1-15.

Onwualu, A., & Watts, K. (1998). Draught and vertical forces obtained from dynamic soil cuttting by plane tillage tools. *Soil and Till. Res.*, 48(4):239-253.

Payne, P. J. (1956). The relationship between mechanical properties of soil and the performance of simple cultivation implements. *J.Agric. Eng. Res.*, pp. 1, 23–50.

Rosa, U., & Wulfsohn, D. (2008). Soil bin monorail for high-speed testing of narrow tillage tools. *Biosystems Engineering J.*, (99), 444 – 454.

Sahu, R., & Raheman, H. (2006). Draught Prediction of Agricultural Implements using Reference Tillage Tools in Sandy Clay Loam Soil. *Biosystems Engineering, SW-Soil and Water*, 88 (2): 275–284.

Sharifat, K., & Kushwaha, R. (1999). Lateral soil movement by tillage tools. *ASAE*, p. Paper No. 991003.

Shinde, G. U., Badgujar, P. D., & Kajale, S. R. (2011). Experimental Analysis of Tillage Tool Shovel Geometry on Soil Disruption by Speed and depth of operation. (pp. 65-70). Singapore: IACSIT Press, Singapore.

Stafford, J. (1979). The Performance of a Rigid Tine in Relation to Soil Properties and Speed. *J. agric. Engng. Res.*, (24), 41-56.

Upadhyaya, S. K., Williams, T. H., Kemble, L. J., & Collins, N. E. (1984). Energy requirements for chiseling in coastal plain soils. *Transactions of the ASAE*, 27(6):1643-1649.

Wheeler, P. N., & Godwin, R. J. (1996). Soil Dynamics of Single and Multiple Tines at Speeds up to 20 km / h. *J. agric. Engng Res.*, 63 , 243 – 250.

Yong, R., & Hanna, A. (1977). Finite element analysis of plane soil cutting. *J. Terramechanics*, pp. 14(3), 103-125.

Kuhn Aurock 6000R / 6000RC

Philippe Potier [1], Vincent Hazenberg [2]

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Since the years 2000, farming practices have evolved considerably and led to the development of conservation agriculture. The latter is a practice based on three main principles: maximum soil cover, no ploughing, long and diversified rotations. There are numerous advantages to this technique: protection of the soil against erosion, improvement of its structure and biological activity, decreased compaction, improved moisture level... Conservation agriculture requires rethinking the whole cropping system by having a global overview and taking into account all the interactions of the system. For different historical or economic reasons, ploughing is replaced in rotation by varying degrees of shallow tillage, so conservation agriculture includes both minimum tillage and direct seeding. Seeding is therefore the crucial step in conservation agriculture. With over 40 years of experience in this field, KUHN launches the 6 m wide AUROCK 6000 R and AUROCK 6000 RC seed drills, equipped with triple discs for optimum establishment of crops under cover, in min-till or direct seeding systems.

The main requirements of conservation tillage on the seeding operation are:

- Direct seeding of cereals with minimum soil disturbance in a dense cover crop to avoid moisture evaporation and to keep vegetation cover on the surface. The canopy regulates the soil temperature, a high organic matter content is maintained in the cultivated horizon and the improved biodiversity allows for a better and faster breakdown of the organic matter.
- Farmers and agronomists want to adapt the seed mixture, the seed and fertilizer placement more and more to the local field conditions in order to optimize the agronomic potential of the field while keeping high moisture and organic matter contents in the soil and avoiding erosion.
- Incorporation of fertilizer in the soil at the time of seeding to reduce fertilizer evaporation and overall fuel consumption

Environmental protection is also a key benefit of direct seeding as soil biodiversity and moisture are preserved and maximized, erosion is eliminated, and soil compaction are greatly reduced.

Whilst there is a clear trend to conservation agriculture in Western Europe, it is equally obvious that at the farm level this translates into a transition phase from conventional practices to direct seeding of several years to revitalize the biodiversity of the soil and to understand the interaction of different combination of crops on the field ecosystem. For economic reasons, trials are carried out on pilot plots and then progressively extended to the rest of the farm. In this transition time, seeding in min-tillage and no-tillage crop establishment practices are required. This is the investment phase as organic matter is reincorporated into the soil and biodiversity is being regenerated.

The AUROCK with its outstanding versatility has been designed with this in mind. It can carry out all seeding operations without the need to keep another seed drill for the conventional seeding in the transition phase.

The AUROCK seed drill with a working width of 6 m is available in single (R) and dual metering unit (RC) versions for more possibilities. With this second model, it is thus possible to mix two different seed hybrids in one seeding unit or to sow each seed hybrid in every other row while managing the seeding depth independently. Provided with remarkable modularity, the AUROCK seed drill can be equipped with an integrated front cutter roller with adjustable pressure to operate efficiently in all cover types. The transport wheels are positioned between the opener disc and the coulter bar. The machine can also be equipped (optional) with a wheel train spanning over the entire width of the machine for seeding in a min-till cropping system.

The furrow is created at the front of the AUROCK by two rows of disc openers. They ensure the cutting of the residues in order to avoid having residues in the furrow and create a fine soil tilth on the seeding row.

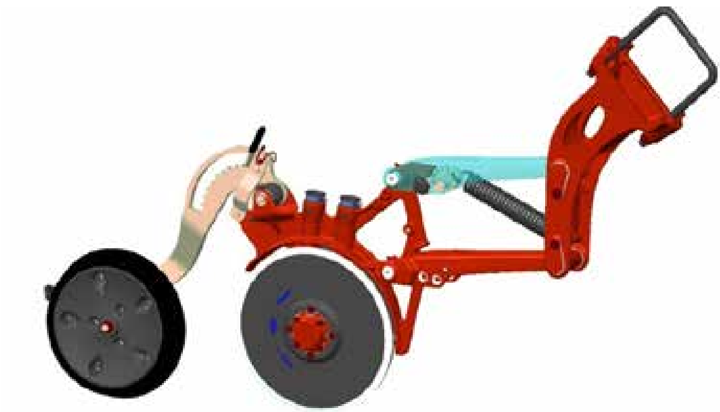
The KUHN solution allows for an adaptation of the furrow opening pressure fully independent from the seeding pressure. The maximum pressure can be set up to 250 kg per element. In order to adapt to various situations, two types of profiles are available:

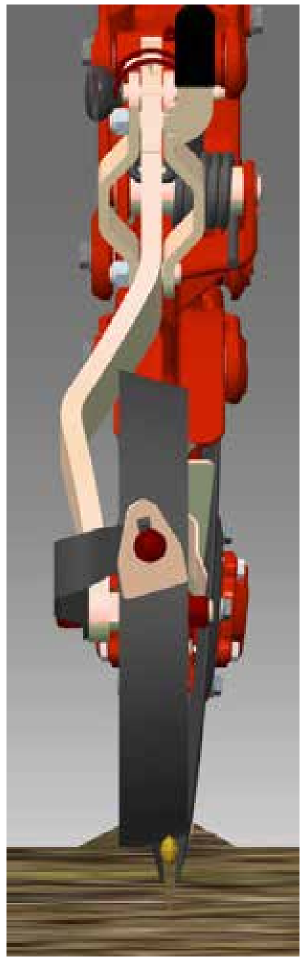
- A corrugated disc of diameter 460 mm for work on prepared soil with possible soil mixing,

- A 430 mm diameter embossed disc for cutting residues efficiently and minimizing soil ejection. It can be used in difficult conditions with a lot of residues.

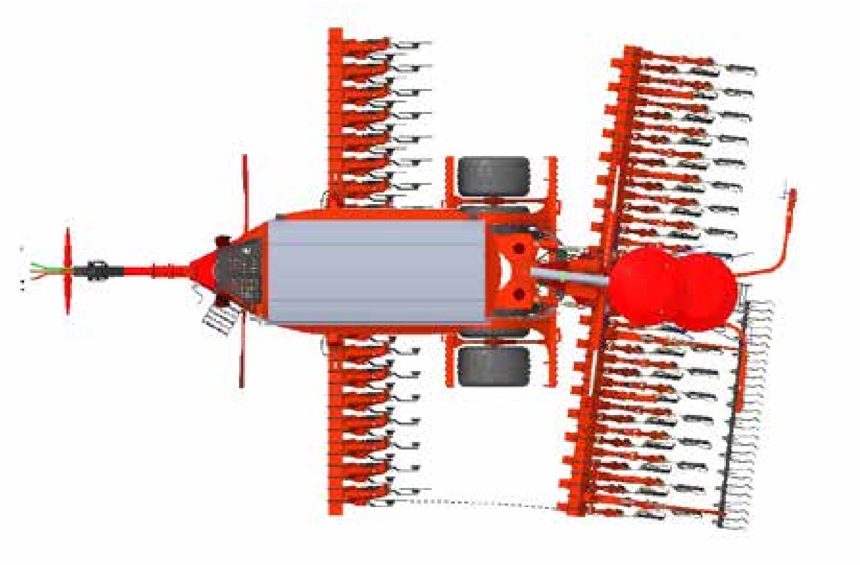
These solutions allow for the adaptation of the disc for different seeding techniques: low disturbance, direct seeding and minimum tillage seeding. The working depth is easily adjustable with spacers that are placed on the lifting/lowering ram of the opener's disc frame.

Seed placement is carried out by the double-disc seeding unit mounted on a parallel linkage for optimum delivery accuracy and perfect ground following. The seeding unit offers a good clearance for residues at the front and sides. The seeding depth is adjusted individually for each row unit without the need for tools, also offering the possibility to establish two crops at two different seeding depths with the RC version (2 metering units, 2 divider heads). The pressure adjustment with a spring on the seeding unit can also be done individually allowing the possibility to increase the pressure behind the tractor wheels for an optimum and even seed depth across the entire machine. When needed a kit is also available to lock the row unit in its upper position when only every other row is used for a given crop. The rear press wheels ensure an efficient closing of the furrow in all soil conditions and a perfect seed to soil contact. A scraper cleans the wheel in wet conditions. A rear covering harrow is available as an option

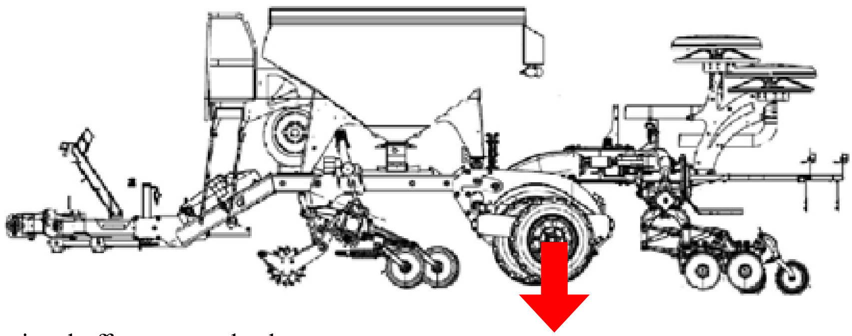




A central pivot between the coulter bar and the chassis ensures that the seeds are placed precisely in the furrows opened by the front coulter, both in a slope and in curves. The disc opener and seeding unit assembly form the so-called “triple disc” system.



The project team opted for a geometry of the chassis allowing a center of gravity on the transport wheel/press wheel train. With this weight balance, a large portion of the weight is located on the disc openers and the seeding bar making additional ballast unnecessary.



The optional offset press wheels prevent soil from building up at the front and amplify the versatility of the machine beyond direct seeding. They facilitate the flow of plant residues and reduce draft loads. Their large 900 mm diameter reduces rolling resistance. Their action is particularly appreciated in minimum tillage conditions. They level the soil in front of the seeding disc contributing to a perfect soil to seed contact.

An optional front cutter roller allows seeding in very dense cover crops in one path. It destroys the cover crop and creates a superficial mulch. The pressure is easily adjusted on the machine control terminal.

The AUROCK features a large capacity hopper of 3.500 L and 5.000 L respectively for the AUROCK R or AUROCK RC models. This allows for an excellent working autonomy. Thanks to its wide opening the hopper is easy to fill either with a loader bucket or big bags. Two movable sensors can be placed in the hopper at four different positions in order to monitor the seed level.

The AUROCK can be fitted with up to two metering units. The electrically driven metering unit is precise, multi-purpose and robust and can meter of small seeds without requiring the change of the metering roller. It also allows for variable rate application. It is easy to empty and clean.

The AUROCK RC with two metering unit and dual hopper offers numerous possibilities:

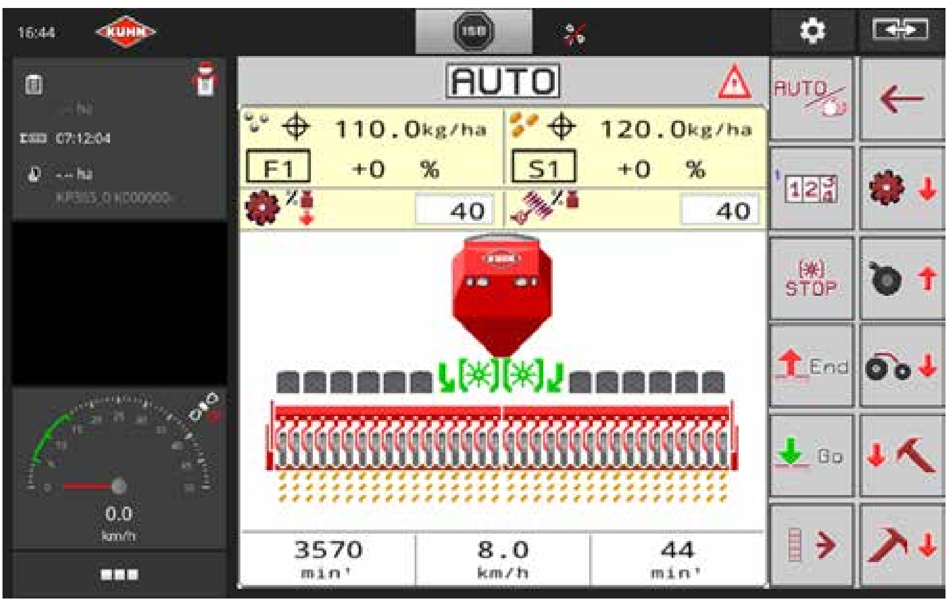
- One seed type on all rows
- One seed type every other row
- One seed type and fertilizer mixed on every row
- One seed type every other row, fertilizer placed every other row at a different depth if required
- One seed type A every other row, another seed type B every other row
- Association of different crops in the same row.

Universal tramlining with VISTAFLOW

The VISTAFLOW tramlining system enables automatic shutdown of seeding lines in order to create non-seeded lanes for later field operations such as fertilizer spreading or spraying. The VISTAFLOW system is especially valuable to contractors and farmers that share their seed drills or work with machinery co-operatives as their tramlining needs change (different sprayers and spreaders).

VISTAFLOW is a smart tramlining valve: all the tramlining configurations are possible and seed passage is monitored in each row.

The AUROCK seed drill is an ISOBUS compatible machine, available with CCI 1200 or CCI 50 terminals (ISOBUS certified by the AEF). For comfort, a joystick is also available as optional equipment. Regardless of the selected control terminal, the operator has a user-friendly and intuitive interface developed especially by KUHN. A simple press of a button at the headland activates successively the lifting of the front tools, then stops the metering unit(s), ensuring perfect seeding to the edge of the field. It is the assurance that no seed remains on the surface, a problem often encountered in the practice of direct seeding.



Technical specifications

AUROCK		6000 R		6000 RC	
Number of rows		32	40	32	40
Row spacing		187,5	150	187,7	150
Working width	m	6			
Transport width	m	3			
Length	m	8,3			
Hopper /Metering unit configuration		Single Hopper / metering unit		Double hopper / metering unit	
Number of divider heads		1		2	
Metering unit drive		Electric			
Metering range	kg/ha	1 to 430			
Hopper capacity	L	3500		5000	
Hopper filling height	mm	2900		3300	
Hopper width	mm	1350			
Hopper length	mm	2750			
Opening disc pressure	kg	250 - 300			
Opening disc dimensions: diameter / thickness	mm	corrugated 460 - embossed 430 / 4			
Longitudinal offset opening discs	mm	350			
Longitudinal distance between the 2 seeding element	mm	460			
Seeding disc diameter / thickness	mm	400 / 4			
Number of press wheels (optional equipment)		16	20	16	20
Press wheel dimensions: diameter x width	mm	900 x 210		900 x 270	
Transport wheel dimensions: diameter x width	mm	920 x 510		920 x 510	
Longitudinal offset of press wheels	mm	200			
Number of press wheels used for transport		6	8	6	8
Minimum tractor power requirement	hp	180			
Working speed	km/h	5-20 km/h			
Type of hitch		lower links / piton pin / drawbar			
Weight	kg	8600	9200	8700	9300
Minimum number of tractor spool valves		2			
Speed signal type		Machine radar / Tractor radar			
Number of hydraulic fan		1			
Seed clogging detection		Standard			

Sustainable Development, Digital Revolution and Human Change
A new Ecology of Work and Life, from Industry to Agriculture

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Abstract

The overall programme of the sustainable development since the outset is an attempt to conciliate several different and sometimes contradictory stakes : Development, Environment, Society and then Culture. The notion of sustainable development has been used and spread so widely that some claim for it to be regarded as an obsolete way and to be replaced by that of ecological tansition. Whatever the limits to sustainable development and its relation to the ecological modernisation, any project or business that seeks to undertake and foster this kind of complex multi-level change must account now for the innovations from the digital revolution. This is the case for the industry and also for the agriculture of the future where the use of computers, pads, robots, networks and smart systems is now viewed as a lever for change, adaptation and performance. The fast and intensive socio-technical change that the digital revolution brings about modifies the work of the farmers to the point that one can sometimes hardly make the difference with that of the engineers. Another aspect of this major change is its consequences on the life of the people and on their relationship to the environment and the society they live in. Hence some fierce criticisms from the supporters of alternative modes of production that advocate for a Low Tech (rather than High Tech) agriculture and industry. This is an issue that an *ecology of work and life* in an age of sustainable development and digital revolution can put on the agenda.

Keywords: Sustainable Development, Digital Revolution, Human Change, Socio-technical Change, Innovation, Ecology, Agriculture, Industry.

1. Introduction

You may know this famous joke about football : 'Football is a simple game. Twenty-two men chase a ball for 90 minutes and at the end, the Germans always win'. On could say the same in another field : 'Sustainable development is a simple game. Two-hundred countries chase pollution and poverty for decades and at the end, the business always wins'.

Sustainable development has been high on the agenda of many public and private actors since the time when the notion itself popped up in official reports and then has come down to actual projects. In *Our Common Future*, the report of the Bruntland Commission, it is thus defined as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts : (a) The concept of 'needs', in particular, the essential needs of the world's poor, to which overriding priority should be given; and (b) The idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs'. Hence the familiar vision of sustainable development as some kind of conciliation of several stakes and goals relating to three different spheres ('dimensions', 'domains', or 'pillars') : economy, ecology and society. This vision has evolved over the years in order to account for some other stakes and was given the shape of the four circles of sustainability : economy, ecology, politics and culture.

Despite those evolutions, sustainable development remains a collective attempt to find out a way that enables to face the various social and natural challenges under the flag of development. Dash (2001, p. 1022) stated that 'one of the greatest challenges facing humanity at the dawn of the twenty-first century is learning how to better meet human needs while restoring and nurturing the planet's life support systems. Achieving advances in specific sectors of human development such as food and energy is critically important, as is making progress in addressing individual environmental problems such as the loss of biodiversity and climate warming…These individual problems are better viewed as multiple dimensions of an increasingly interdependent relationship between society and environment. It is not the individual problems alone but rather their interactions that pose the greatest threats and opportunities for the twenty-first century. Therefore, the transcendent challenge before us is to craft a vision of the future that encompasses these interactions and to develop a strategy for action that addresses them.'

However, the primal vagueness of the term 'sustainable development' has not been helped by its opening up to some other new challenges and by its overuse in all kinds of contexts and speeches. Thus, the concept was shown to be an oxymoron on the ground that economic growth is not sustainable if accompanied by a depletion of natural resources and deterioration of environmental services (Spaiser et al., 2017). As to the new Sustainable Development Goals (SDGs), the International Council of Science showed that 'the framework as a whole might not be internally consistent - and as a result not be sustainable' (ICS, ISSC, 2015, p.9). The conflict between ecological sustainability and socio-economic progression was also put under scrutiny in order to give a more concrete and quantitative expression to the inconsistency of certain SDGs (id.).

Table 1 : Sustainable Developement Goals (SDGs)

The situation of sustainable development is a bit strange : on the one hand, it appears as a consensual program and ideology that functions worldwide as a compass for all countries and actors ; on the other hand, it is now viewed as an obsolete framework on the ground that it has failed to foster significant human changes. Obviously, after several decades, the way of sustainable development has not succeeded (or has succeeded very partly in some cases) in the struggle against climate change, air, water and soil pollution and the decline of ressources and species (WWF, 2018).

This is anyway the very problem of sustainable developement and more precisely, of any path of change labelled as *ecological modernisation* that remains dependent basically on technologies. Ecological modernization theory explicity rejects indeed the assumption that a fundamental reorganization of the core institutions of modern society is necessary for sustainable development (Mol, Spaargaren, 2000, p. 19). Instead, it holds that sustainable development can be attained through a modest reform of some of these institutions, most notably by incorporation of ecological principles into the economic system, from industry ro agiculture. The key to this reform is the development and introduction of new ecological technologies for industrial production - and if one expands the model, for agricultural production also. As Cohen puts it (id.), 'Ecological Modernization provides a theoretical framework for situating the emergence of new technology-intensive modes of environmental reform such as industrial ecology, environmentally conscious manufacturing, and ecological design'.

It may be that we are in 'The Age of Sustainable Development' (Sachs, 2015), but in the light of the limit or the failure of the process of ecological modernisation, many actors would suggest to replace this concept by that of 'sustainable growth', then opposing to that of 'de-growth'. Another view could be to replace it by that of *ecological transition* to be defined as the complex path of change articulating human and non-human factors (or dimensions) towards *ecological sustainability*. This view has the merit to take it for granted that the shift to new ways of life, including the working conditions, will be longer and more difficult that expected at the time when rulers or citizens still believed in the efficiency of sustainable development. The questions to be asked in an 'Age of Digital Revolution' that impacts all sectors of human activities, from industry to agriculture, are then the following : (1) *If the aim is* the *ecological sustainability, can the digital technologies be the solution to meet the variety of its goals ? (2) In this respect, can the digital technologies be applied to all sectors and be merely transfered from industry to agriculture - so that a farm can be like a factory* ? (3) *Is it fair to say that any process of change towards ecological sustainability must be based on 'High Tech' rather than 'Low Tech'* ? (4) *What are the impacts of the digital revolution on the work and the life of the people if most of their tasks is instrumented or replaced by automats* ?

These are big questions, of course, and the correct and justified answers to them would require hundreds of studies and reports, hence the choice to bound my (little) reflection to the main lines of the debate. I would like to suggest as my main hypothesis that it is important for the examination of these questions to specify the nature, the structure, the function and the use of such or such technological tool or device. I will take at the end the example of drones in order to show the varieties of possible relations to technologies, especially in the case of automation of human tasks in agriculture.

2. Materials and Methods

There is a debate about the actual ecological impacts of sustainable development, but there is also another debate about the contribution of the so-called 'digital revolution' to the implementation of a program of ecological sustainability. It is most significant that the on-going digital revolution, beyond the sector of services, impacts the two basic sectors of industry and agriculture, then suggesting that a farm could be something like a factory, and in some cases, an automated one.

The industrial revolution is now viewed as a succession of at least three stages – or four if one would go for the notion of 'Fourth Industrial Revolution'. The four stages of revolutions can be sketched out in order to show the parallels between industry and agriculture and what is specific to the so-called '4th industrial revolution':

	1st revolution	2nd revolution	3rd revolution	4th revolution
Industrial Revolutions	Mechanical production plants Water and steam power	Collaborative mass production Oil and electrical energy	Automation of production Electronics and ICT	Industry 4.0 Cyber-physical systems Internet of things
Key events	1771 : Arkwright's mill opens in Cromford 1829 : Test of the Rocket steam engine for the Liverpool–Manchester railway	1875 : The Carnegie Bessemer steel plant opens in Pittsburgh, PA 1908 : First Model-T comes out of the Ford plant in Detroit, MI	1971 : The Intel microprocessor is announced in Santa Clara, CA	-
Agricultural Revolutions	Crop rotation Livestock increase	Mechanisation and motorisation Chemical fertilizers and pesticides, hybrid seeds	Genetic engineering Simplified farming techniques	Agriculture 4.0 Cyber-physical systems applied to living species Internet of things
Key events	1774 : First theory on reversing ploug	1890 : First gasoline tractor engine 1915 : Fordson tractor based on Model T	1973 : first transgenesis in one bacteria	-

Table 2. Revolutions in industry and in agriculture
(adapted from Regnault et al., 2012, Lombardo et al., 2017)

The term Industry 4.0 refers to the fourth industrial revolution and is often understood as the application of the generic concept of cyberphysical systems (CPSs) to industrial production systems (cyberphysical production systems). The idea of the fourth industrial revolution (Herman, 2018) is to integrate production with the latest information and communication technologies (ICTs). This makes it possible to manufacture products according to individual customer requirements and to produce them in a batch size of one at the price of mass-produced goods. The technical basis is formed by intelligent, digitally networked systems and production processes, and the process framework determines the entire life phase of a product : the idea, the development, the production, the use and the maintenance up to the recycling of the product. In this frame, information is the driver of processes and is obtained thanks to (a) continue data acquisition from sensors deployed all around the place, (b) the availability of high performance communication networks, (c) high capacity of storage and (b) processing and analyses of the data to convert them in information.

The major aspect of changes in the digital revolution applied either to industry or to agriculture are the following:

- *Information and communication technology*: the ICTs are at the core of the new revolution, they connect to objects (Internet of Things) and they interconnect systems.
- *Adaptation of production systems*: the cyber-physical systems enable the production process to adapt changes in the context (demand, market, resources…).
- *Efficiency in the use of resources*: the performance of the systems makes it possible to save matter and energy and to lower the level of pollution.

- *Artificial intelligence*: in addition to command and control, many operations can be achieved though (big) data analysis (prediction, decision…) and with autonomous devices, help or even replace those of humans (self-optimization/configuration/diagnosis…).

The new industrial and agricultural revolution make use of many innovations that are derived from the digital revolution, like in the Factory of the Future ('Industry 4.0', 'Smart Factory') and the Farm of the Future ('Agriculture 4.0', 'Smart Farm'). One could say that a Smart Farm and a Smart Factory are two different models; but if it is assumed that they are using almost the same kind of technologies, then they are just two different applications of the same overall digital model. In the traditional factory, the aim is to provide a high quality of service or product with the least cost and for the firms to achieve as much performance as possible to increase their profit as well as their reputation. In a smart factory, components and systems gain in awareness and prediction and can therefore provide management with more insight on the status of the factory and on the opportunity of maintenance. This is more or less the same view about traditional farms, as compared to smart farms, even it can be objected that a farm is not a factory, for the context and the object of activity (living species) is different.

There is no doubt that technology can be useful in the processes of ecological transition, but one can really wonder if the socio-technical framework of the 4th industrial and agricultural revolution is not just a new version of the ecological modernization (from theory to practice, so to say). The radical limit to this kind of major technology-driven change lies in the paradox of taking technology to be the solution to some problems raised by… the massive use of (other) technologies. It can then be discussed whether the quest for an ecological sustainability is to be achieved though the massive use of sophisticated technologies in order to reduce the 'ecological footprint' of human businesses. This is exactly the kind of criticisms that are expressed, for instance, towards the whole framework of Rifkin's model of the *Third Industrial Revolution* (Rifkin, 2013).

The reason for that is, since the beginning, Ecological Modernisation as a theory that gives the primacy to technology-intensive levers of change must go through several challenges in order to achieve *ecological sustainability* in practice (York, Rosa, 2003) : (a) Ecological modernisation needs to go beyond merely demonstrating that societies modify their institutions in reaction to environmental problems and show that such modifications lead to ecological improvements. (b) It must show that late stages of modernizing processes lead to the ecological transformation of production and consumption at relatively high frequency. (c) It must demonstrate that industries or firms that are reducing their direct impact on the environment are not contributing to the expansion of negative impacts by other industries or firms. (d) It must show not only that economies are becoming more resource efficient but also that the pace of increase in efficiency exceeds the pace of increase in overall production.

3. Results and Discussion

The shortcomings of ecological modernisation open up options and alternatives and clearly ask the question in this big change towards ecological sustainabilty whether *:* (1) The technology used in the industry can or should be used also in the agriculture (2) A farm should then be (or not) technologically instrumented like a factory (3) Its equipment should be 'HighTech' rather than 'Low-Tech'. This is worth asking, for, while some experts hails 'the age of Low Tech' (Bihouix, 2014), some other ones praise the 'two percent solutions for the Planet' (White, 2015) or call for 'breaking away from industrial food and farming system' (Gliessman, IPES report, 2018).

The challenge of an ecological transition in agriculture (an 'agoecological transition') is presented in terms of *systemic change* and of *diversification strategy* (Altieri, Nicholls, Montalba, 2017, p.11): 'New designs of modern agroecosystems will require systemic change guided by the application of already well defined agroecological principles. These principles can be applied by way of various practices and strategies, each having different effects on productivity, stability and resiliency within the farm system. One of the key principles is diversification which occurs in many forms at the field (variety mixtures, rotations, polycultures, agroforestry, and crop–livestock integration) and at the landscape level (hedgerows, corridors, etc.), giving farmers a wide variety of options and combinations for the implementation of this strategy. Emergent ecological properties develop in diversified agroecosystems that allow the system to function in ways that maintain soil fertility, crop production, and pest regulation. Most of these systems optimize the application of agroecological principles thus increasing agroecosystem functional diversity as the foundation for soil quality, plant health, crop productivity and system resilience.'

But the question remains open whether agricultural ecology, alike industrial ecology, should or should not be based on digital technologies. The challenge of the LowTech approach (Bihouix, 2014) as opposed to the High Tech one is the following : 'Always ask : What can I do without ? Can I do less ? Can I do more simple ? And besides, why do I have to do it ? And can not I do with what already exists ?'. But some experts also call for a more cautious stance and challenge some 'clichés' about the relation between ecology and technology. They thus suggest three critical assertions (Bellon Maurel, Huyghe, 2017) : 'First, the adoption of new technology is a critical point, to be taken into account as soon as possible. Second, new technologies open up opportunities for collective working and solidarity. And, last, a misconception about the relationship between agroecology and machinery needs to be dispelled'.

There are basically two (or four) thesis relating to the role of digital technologies in the ecological transition - if we accept to call it so, rather than 'ecological modernization' :

Thesis I: A process of ecological transition (a) must be or (b) can be achieved through 'High-Tech' tools and devices.

Thesis II: A process of ecological transition (c) must be or (d) can be achieved through 'Low-Tech' tools and devices.

Clearly, if one think of ecological modernization as a non-relevant technology-dependent/intensive path for change in the future, the challenge is to prove that with 'HighTech' tools and devices, the ecological sustainability is better met than with the 'LowTech' approaches to ecological transition. This antilogy is somewhat a dispute as to who has now the burden of the proof…

Beyond this dilemma, ecology can be understood in a broader scope that also pays attention to the work and the life of the 'agents of the ecological transition' (different from those of the ecological modernization, Lippert, 2010) and to the 'technical practices' (Olivier, 2018) of those agents. This is basically the object of an *ecology of work and life*, ie a holistic vision that links the workstyles and the lifestyles to a setting of natural and cultural conditions of the milieu (human/non-human, local/global). This vision also questions the conditions for individuals and communities to reach an overall balance in their existence and in their relations to the milieu. It follows from the development and the impact of digital technologies than one wonder *what kind of human changes as far as workstyles and lifestyles are concerned are entailed by the digital revolution.*

Several major human changes can be identified that impacts the quantity and also the quality of work and life, that is, the fact and the norm that someone, according to the nature and the degree of his or her digital equipment : (a) will *work* less or more, or in a (very?) different way, (b) with a positive or negative impact on his or her *life* (c) with another *relationship*, probably more distant, to the territory, the land, the vegetal and animal species (d) and with a difference in the *significance* allowed to them, since they become a source of data to be processed by machines, some (most, all) of them automatic. To some extent, in a digital 'Farmtory' (the mixing or the merging of a Factory and a Farm), a farmer becomes something like an engineer (if not an operator…): he or she used to be an 'agent of nature and culture', and he or she becomes a 'pilot of machines' and a 'data analyst'.

In this view, it is highly possible that a farmer, alike a machine controller in a factory, spend his or her time in front of a screen without any physical contact with living species. In a 'Farmtory', it can be that you don't touch or smell corns and cows anymore, and this is no doubt a very big cultural and aesthetical change - if aesthetics means the 'realm of sensations'.

In the pessimistic view, the challenge of an ecology of work and life is to defend a human-sized activity against the empire of the digital (Biagini, 2012): 'The industrial revolutions of the 19th century, so-called processes of modernization and the digital revolution have destroyed our relationship to craft techniques and let technology triumph... Because where the techniques presupposes a meaningful human experience, relationships within a community of limited size based on a way of life providing spaces of solidarity, as well as a direction of work according to the needs and necessities of the moment, the technology implies a triple idleness: unemployment made unavoidable because of the replacement of the living work by the dead work of the automated devices, generalized loss of meaning produced by mechanical work independent of any purpose other than financial, and finally disappearance of lifestyles involving a human proximity and replace them with social organizations based on a strict hierarchical division of tasks and functions'.

The counter-project value the people's capacities and crafts and their meaningful engagement in their activity: 'We must claim for our material conditions of existence by exercising our capacities of sensation, reflection and action in activities that call upon know-how that as producers we can master - characteristics of what is called the craft. The craft requires knowing how to do a set of tasks in a particular field, after a period of learning, over time, gaining experience and being attached to its activity. This re-appropriation of the 'making' is the condition of genuine creativity and a real form of autonomy. It is the seed of a new form of society in which humans would have a true mastery of their activities, they would put to the service of the development of life without undergoing evolution, running behind their incessant development, being enslaved to their operation. This approach involves thinking of a society that is human-sized.'

In a less pessimistic view, the use of digital technologies in the daily functioning of a production unit is not an obligation, for various options are possible depending on the engineer or the farmers' choices, as shown by the problem of automation. A good deal of the equipment and of the functioning of the Smart Factory or the Smart Farm (or, if the two models merge: the 'Farmtory') is depending on automation of operations. But the automation does not imply necessarily a mere replacement of humans by robots, for there can be a 'cooperation' of human with 'cobots'; however it is not doubtful that the digital automation of a factory and to a greater extent of a farm has some consequences on the autonomy of the human agents.

In his classical paper, Parasuraman (Pasumaran, 1997) makes the difference between four types of human-machines interactions in the process of automation (use, misuse, disuse, abuse):

- *Use* : it refers to the voluntary activation or disengagement of automation by human operators. Trust, mental workload, and risk can influence automation use, but interactions between factors and large individual differences make prediction of automation use difficult.
- *Misuse* : it refers to overreliance on automation, which can result in failures of monitoring or decision biases. Factors affecting the monitoring of automation include workload, automation reliability and consistency, and the saliency of automation state indicators.
- *Disuse* : it refers to the neglect or underutilization of automation, is commonly caused by alarms that activate falsely. This often occurs because the base rate of the condition to be detected is not considered in setting the trade-off between false alarms and omissions.
- *Abuse* : Automation abuse, or the automation of functions by designers and implementation by managers without due regard for the consequences for human performance, tends

to define the operator's roles as by-products of the automation. Automation abuse can also promote misuse and disuse of automation by human operators.

For the author, the understanding of the factors associated with each of these aspects of human use of automation can lead to improved system design, effective training methods, and judicious policies and procedures involving automation use.

If one takes the example of drones used in agriculture by a farmer in order to collect information on the state of his crops, it seems that automation in this case is not just an obligation, but also a kind of choice. For it is possible in the use of drones to choose either (a) an automated system in which those flying machines effect their job of collecting information, or (b) a human system in which the drones are piloted by the farmer who keeps the control on their flight, direction, action, etc, or possibly (c) a combination of (a) and (b) in which the drones flights are automated, but the farmer can regain control at any time if needed. Or couse, this means that a technology is a flexible device and not a rigid system for the actions of humans, but provided it is designed this way since the very beginning, possibly through a process of *co-design*. Otherwise, technology as automation can also turn out a very constraigning framework of fixed compulsory rules that take all or most part of their freedom and judgement away from the people's work and life. So, when technology is presented as if it is a matter of choice, it is meant in the weak sense and also in the strong sense of the word : it is a choice between several technical options possible, but it is also a choice between several workstyles and lifestyles that also must be sustainable (Brey, 2017).

4. Conclusions

Sustainable development is often interpreted as a matrix for global and local human change that attempts to conciliating various stakes and goals. Ecological modernization can be viewed as a lever for implementing sustainable development without engaging major changes in socio-institutional frameworks.

In this respect, the digital revolution as applied to the sectors of industry and agriculture can be viewed as a technology-driven process of ecological modernization. But like any process of this kind, it faces some radical contradictions as to the use of materials and resources, the level of production and consumption or the freedom or equity of human action. Moreover, the processes of ecological modernization can borrow to ecology the notion of ecosystem, like in industrial or agricultural ecology (agroecology). But these eco-systemic versions of sustainability can be either 'High-Tech'- or 'Low-Tech'-oriented depending on the models of ecological transition. There is no reason to assert that, because it is a 'High-Tech' process, it will be more 'ecological' than a 'Low-Tech' one. This can be shown with Rifkin's model of Third Industrial Revolution (TIR) that at the same time solve and raise several ecological problems.

The achievement of the ecological transition based on smart technologies significantly impacts the workstyles and the lifestyles of the people, especially in the case of automation. But in the new division of labor between humans and machines, digital technologies are to be viewed as related to the specific form and content of such or such human activity. For example, the use of drones in agriculture can be conceived of as fully or partly automated, but then the famer is more a pilot of machines than an 'agent of nature and culture'. It seems that a technology-driven change towards sustainability cannot do without an ecology of work and life that locates technology within a system of *agency* and *existence* (experience, significance) for individuals and communities in relation to a certain natural and cultural milieu.

Technology is not neutral : there is clearly a problem of engineering and design of any 'Farmtory' if one admits that the implementation of it is not just a concern on ecological sustainability of the Planet, but also an issue for an *ecology of work and life*. This is probably a condition for the farmers, the most numerous profession of the Planet up to now, to become some genuine and sustainable agents of the ecological transition.

References

ALTIERI, M. NICHOLLS, C., MONTALBA, R. (2017) Technological Approaches to Agriculture at the Crossroads : An Agroecological Perspective, *Sustainability*, 9, 349.

BELLON MAUREL, V. HUYGHE, C. (2017) Putting agricultural equipment and digital technologies at the cutting edge of agroecology, OCL 24, 3.

BIAGIANI, C. (2012) *L'emprise numérique*, Editions L'Echappée.

BIHOUIX, P. (2014) *L'âge des Low Tech. Vers une civilisation techniquement soutenable*, Seuil, Paris.

BRAUN, A.-T., COLANGELO, E., STECKEL, T. (2018) Farming in the Era of Industrie 4.0., *Procedia CIRP*, 72.

BREY, P. (2017) Sustainable Technologies for Sustainable Lifestyles, in Kaplan, D. (ed). *Philosophy, Technology and the Environment*, MIT Press.

CLARK, W. (2001) A transition towards sustainability, *Ecology Law Quarterly*, 27.

CLASEN, M. (2016) Farming 4.0 und andere Anwendungen des Internet der Dinge, in A. Ruckelshausenetal. (Hrsg.): *Intelligente Systeme Stand der Technik und neue Möglichkeiten*, LectureNotes in Informatics(LNI), Gesellschaft für Informatik, Bonn.

DE CLERCQ, M., VATS, A., BIEL, A. (2018) *Agriculture 4.0: the future of farming technology*, World Government Summit, www.worldgovernmentsummit.org/api/

DEVERRE, C. (2004) Les nouveaux liens sociaux aux territoires, *Natures Sciences Sociétés*, 12.

DIGIT Ag (2017) Le numérique en agriculture, *Contribution de Digit Ag aux Etats Généraux de l'Alimentation*,

DURU, M., THEROND, O., FARES, M. (2015) Designing agroecologicol transitions : A review, *Agronomy for Sustainable Development*.

DU PISANI, J. A. (2006) Sustainable development. Historical roots of the concept, *Environmental Sciences*, 3, 2.

FISHER, D., FREUDENBURG, W.R. (2001), Ecological modernization and its critics : Assessing the past and looking toward the future, *Society and natural resources*, 14.

GLIESSMAN, S. (2018) Breaking away from industrial food and farming systems, Seven case studies of agroecological transitions, *IPES Food*.

HERRMANN, F. (2018) The smart factory and its risks, *Systems*, 6, 38.

INTERNATIONAL COUNCIL FOR SCIENCE AND INTERNATIONAL SOCIAL SCIENCE COUNCIL (2015) *Report: review of targets for the sustainable development goals: the science perspective*. Available from: http://bit.ly/1Vs9Q99

LATOUR, B. (2012) *Enquête sur les modes d'existence*. Paris, La Découverte.

LATOUR, B. (2004) *Politiques de la nature*, Paris, La Découverte, trans. *Politics of Nature*, Harvard University Press.

LOMBARDO, S., SARRI, D., CORVO, L. (2009) Approaching to the Fourth Agricultural Revolution: Analysis of Needs for the Profitable Introduction of Smart Farming in Rural Areas,

OLLIVIER, G., MAGDA, D., MAZE, A., PLUMECOCQ, G., LAMINE, C. (2018) Agroecological transitions: What can sustainability transition frameworks teach us? An ontological and empirical analysis, *Ecology and Society* 23 (2), 5.

RADJOU, N. N., PRABHU, J. J. & S. Ahuja (2013) *L'Innovation jugaad. Redevenons ingénieux!*, Paris, Editions Diateino.

REGNAULT, H. ARNAUD de SARTRE, X., REGNAULT ROGER, C. (2012) *Les revolutions agricoles en perspective*, Editions France agricole.

RIFKIN, J. (2015) *The Zero Marginal Cost Society*, Palgrave Macmillan.

RIFKIN, J. (2012), *The Third Industrial Revolution*, Palgrave Macmillan.

RIFKIN, J. (1995), *The End of Work*, GP Putnam's Sons.

RYLE, M., SOPER, K. (2016) The ecology of labour, *Green Letters*, 20, 2.

SACHS, J. (2015) *The age of sustainable development*, Columbia University Press.

SCHWAB, K. (2017) *The Fourth Industrial Revolution*, World Economic Forum.

SPAISER, V., RANGANATHAN, S., BALI SWAIN, R., SUMPTER, D.J.T. (2017) The sustainable development oxymoron: quantifying and modelling the incompatibility of sustainable development goals, *International Journal of Sustainable Development & World Ecology*, 24, 6.

WHITE, C. (2015) *Two percent solutions for the Planet*, Chelsea Green Publishing.

WWF (2018) *Living Planet Report*, wwf.panda.org/knowledge.../living_planet_report_2018

YORK, R., ROSA, E.A. (2003) Key Challenges to Ecological Modernization Theory: Institutional Efficacy, Case Study Evidence, Units of Analysis, and the Pace of Eco-Efficiency, *Acoustics, Speech, and Signal Processing Newsletter*, IEEE 16, 3.

ZACCAI, E. (2002) *Le développement durable. Dynamique et constitution d'un projet*, Presses Interuniversitaires Européennes, Peter Lang, Bern/Bruxelles.

Boosting agricultural scientific research and innovation through challenges: the ROSE Challenge example

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Abstract

The pending ban on glyphosate raises the general issue of long-term usability of chemical herbicides and pesticides. Torn between legitimate economic and ecological concerns, EU lawmakers and agri-food stakeholders need to rely on alternatives to chemicals, which entails a strong support to the development of new solutions. Autonomous weed killing solutions are among these concrete solutions, considering that navigation, vision and decision-making technologies have reached a level of mastery that allows considering realistically the deployment of such devices. However, the technical feasibility and overall usability of autonomous agricultural machines need yet to be confirmed.

In this regard, the French ministries of agriculture, ecology and research and the national research agency started in 2018 the four-year "ROSE Challenge". The Challenge addresses the weed killing of intra row of crops by autonomous robots. Four competing teams tackle the problem by developing autonomous solutions, which will be formally assessed throughout the Challenge.

This paper offers an overview of robotics challenges and presents the methodology of the real-life evaluation performed in the context of the ROSE Challenge. The overall object of this contribution aims at raising awareness in the agricultural community about the effectiveness of challenges to support innovation in the agricultural field.

Keywords: Testing, Digital agriculture, Robotics and automation, Performance evaluation, Phytosanitary reduction

1. Introduction

Herbicides account for 40% of crop protection products used in agriculture and are the main pesticides responsible for the contamination of waterways. Some weed control alternatives to herbicides already exist and are operational and used: redesign of crop systems and management methods or introduction of preventive practices. Alternative solutions also involve mechanical weeding solutions integrated with towed tool blocks or autonomous robots. They are constantly being improved through the joint efforts of technical institutes and agricultural professionals and are increasingly used. But these solutions usually concern the inter row of crops (between two rows), while in the intra row of crops (space between plants of the same row) few solutions allow dispensing completely with chemical products.

In 2018, the French ministries in charge of agriculture and ecological transition via the French Biodiversity Agency (AFB), in partnership with the Ministry of Research and the National Research Agency (*Agence Nationale de la Recherche*, ANR), started the "ROSE Challenge"[1]. Four competing consortia have been selected, and their four-year objective consists in developing innovative technological solutions that will help reducing the use of phytosanitary products.

1 Project website: http://challenge-rose.fr/en/home/

The teams focus on weeding the intra row in field vegetable crops and field crops with wide spacing. The projects have to push back the limits of the state of the art in several fields: sensors, modelling, robotics and their combination.

In the course of the challenge, the progress of the teams will be assessed on three components of weeding: observation, interpretation/decision and weeding action. The effectiveness of weeding, while respecting existing crops, will be the subject of annual evaluation campaigns conducted by the French national laboratory for metrology and testing (LNE) and the national research institute of science and technology for environment and agriculture (Irstea), with the participation of the VetAgro Sup engineering school for agronomy. Each year, the teams will face real field events, on experimental plots provided by the Irstea laboratory in Montoldre (France) to enable an agronomy evaluation.

The study will first present a literature review of the challenges carried out internationally in the robotic field and underline the specificities and the interest of the ROSE Challenge. Set in the context of the Challenge, the study will then provide the methods used to rigorously and reproducibly evaluate the performance of the different technological blocks of agricultural robotic systems, including infrared or hyperspectral cameras and their use in multimodal detection systems, dynamic mapping tools and automated platforms combined with precision processing strategies.

The ROSE Challenge constitutes a significant first step in the efforts to finance and support research on the targeted objectives of the national Ecophyto II plan carried out by the French Ministries in charge of Research, Agriculture and Ecology for the reduction of the use of phytosanitary products. The Challenge paves the way for other initiatives that will learn from it. The present contribution aims at raising awareness in the agricultural community about the effectiveness of challenges to support innovation in the agricultural field, by fostering collaborations between actors that are not necessarily accustomed to working together: researchers in agronomy and ecology, researchers in digital sciences and robotics, farm enginery manufacturers, farmers, or professional agricultural organizations.

2. Robotic challenges

2.1. Challenges: definition and objectives

Challenges aim at comparing different systems performing a same task. The comparison may concern the whole system or a module of it, and allows the estimation of its performance, its quality or its safety.

Challenges take different forms, according to several distinctions:

1. The initiation of the challenge. There can be a principal who asks for several systems to be tested, for example in a pre-purchase process. In this case, the principal commissions an expert for the organization of the evaluation. In another setting, the objectives of the challenge can also be set by the organizers themselves, for example for research purposes, so as to develop knowledge on specific topics. In Natural Language Processing domains for example, this type of evaluation campaigns is highly common; one can for example name the Interspeech challenges (Schuller et al., 2018), or the IWSLT evaluation campaigns (Jan et al., 2018). In this context, the organizers set the objectives of the evaluation, the comparison metrics, and provide the reference and test data. In other words, they are both the principals and the evaluation organizer.
2. The selection of candidates. Either the principal selects several systems of interest that need to be tested, or the participation to the evaluation is open to any candidates. In the latter context, the evaluation plan is not designed in line with the technologies developed by the

participants: since the specificities of the systems may not be anticipated, the systems must strictly match the specificities of the plan. The evaluation mainly concerns the overall behavior of the system, unless a common framework allows a more detailed comparison between the solutions. When one wants to boost creative solutions, one can also resort to closed challenges, where only a few selected participants tackle the proposed issue. This type of challenge encourages the development of creative solutions while still preserving the quality of the evaluation, since the reduced number of competitors allows an adaptation of the evaluation plan to encompass the variations in the technical choices made by the competitors.

3. The incentive to take part to the challenge. It may take the form of a final prize to the winner(s): participants may vie for a monetary prize, equipment, or contracts. Participants may also be funded throughout the challenge for the development of their solutions. There are also sometimes no specific incentive, except scientific or commercial recognition and development of knowledge in a community.

4. The program of the challenge. The evaluation performed during the challenge can take place in a single stage session: participants prepare to the challenge beforehand, and produce a solution that is evaluated at the moment of the competition. Participants can also be accompanied throughout the development of their solution, through regular evaluations that allows the estimation of their progression.

One may note that the organization of the process of comparing systems may be referred to as "challenges", "competitions" or "evaluation campaign". These terms are often used alternately in the community, depending on the finality of the comparison, the public addressed and the nature of the organizers.

2.2. Challenges in robotics

For more than twenty years, challenges have been booming in the robotic community. Fostered by the development of ICT technologies, the evolutions of artificial intelligence and the democratization of robotics components, challenges gather each year millions of participants, spectators and sponsors. The topics of the competitions are closely related to current scientific, societal and technical issues. As an example, the focus of the 2019 edition of RobotNation SeaPerch competition (https://www.seaperch.org/challenge) is directly inspired by Thailand events in 2018, when students got trapped in a submerged cave. The participants to SeaPerch 2019 are thus encouraged to develop solutions for underwater rescue and recovery.

Challenges are mainly organized by networks of expert roboticists (industrials, academics) who set the objectives of the contest and coordinate the definition of the rules and the evaluation process.

Several challenges are explicitly dedicated to the public dissemination of robotics, and rely on the organization of world-wide events, while others are meant for a more specialized audience of researchers and industrials in robotics.

The RoboCup (http://www.robocup.org), initiated in 1997, first focused on robotic soccer competitions (Kitano et al., 1997). The competition now addresses a wide range of robotic applications, including soccer, rescue, service, simulation and industry, where both students and senior researchers can compete.

The Defense Advanced Research Projects Agency (DARPA) regularly launches challenges in robotics and artificial intelligence. Among them, the DARPA Robotics Challenge (Pratt and Manzo, 2013) executed between 2012 and 2015 was addressed to teams of expert roboticists. The challenge aimed the development of semi-autonomous ground robots for disaster response, and participants were funded by DARPA.

The evaluation of both the RoboCup and the DARPA Challenges is partly organized by the National Institute of Standards and Technology (NIST), who relies notably on its expertise in the development of testing methods for robotics in hostile environment (Jacoff et al., 2012).

The Robotex International competitions (http://robotex.international), set during the Robotex festival, brings together beginners and experts who are invited to design algorithms and robots to perform activities such as sumo wrestling, line following, drone races, or basketball.

The competitions coordinated by RoboNation, Inc. (https://www.robonation.org/competitions) concern air, land and marine robots. They are addressed to undergraduate and graduate students and relate to topics such as manoeuvrability, speed, obstacle detection, or navigation. While some of RoboNation competitions impose that the teams use the affordable robot architecture provided by the organizers, the robot might be built from scratch by the students or commercially bought.

The FIRA RoboWorld Cup (http://www.firaworldcup.org) has brought together since 1996 skilled researchers and students for the development of autonomous soccer-robots on different robotic and simulation platforms. The competitions are now expanded to various tasks, such as drone emergency service or robot welding. One of the competitions focuses on the design of a robot using a limited set of materials, among which daily items such as rubber bands and scissors.

The SICK Robot Day competition (https://www.sick.com) has been organized periodically since 2007. The 2018 edition, for example, concerned the delivery of objects by autonomous robots, which implies object detection, grasping, navigation, path planning, collision avoidance and self-localization. The competition is open to any participants, and the teams may use a SICK LiDAR sensor to perform the tasks.

Introduced in 2008 as part of the ICRA conference, the ICRA Robot Challenges (Tee & Van Der Kooij, 2017) aim at addressing a large robotics community and drawing the attention of a general public. The topics cover service robotics, manipulation, mobile robots, microrobotics and soft robotics.

The European Robotics League (ERL), run by the European Union's Horizon 2020 project Sci-Roc, coordinates competitions on service, emergency, industrial and smart cities robotics applications, during national and European tournaments (https://www.eu-robotics.net/robotics_league). Participants are selected according to the number of available slots in the tournament and the quality of the research team.

This list, far from exhaustive, shows the wide range of topics covered by challenges in the robotic community. In comparison to challenges for industry, rescue or service, robotics competitions dedicated to agriculture are relatively scarce and recent.

The annual agBOT Challenge (http://www.agbot.ag), started in 2016 in the United States, focuses on topics such as unmaned crop seeder, pest and weed identification and eradication, and robotics harvest method. The competition is open to any participant upon the payment of a small participation fee, and winners are awarded a monetary prize. The judge team is composed of American scientists in multidisciplinary robotics fields and farm owners. The 2019 edition will address the identification of crops and weeds in corn culture, within and between the rows.

Another example is the Field Robot Event (http://www.fieldrobot.com/event) that started in 2003. The 2018 edition of this competition took place in Germany during the DLG Feldtage exhibition for farming professionals. Mostly dedicated to students, the competition addresses the sensing abilities of the autonomous robots, their navigation between rows of corn on naturally rough terrain and their weed control abilities. Robots are expected to detect colored markers meant to represent weed patches.

2.3. Benefits and limitations of challenges

Challenges represent remarkable opportunities for the robotics community:

- They stimulate the development of knowledge and innovative solutions for complex scientific and technical issues;
- They encourage the development and improvement of methodologies for the evaluation of new technologies;
- They help raising awareness among the public audience, the sponsors and public authorities on the present abilities and limitations of technologies;
- They foster an emulation among researchers, industrials and users;
- In terms of education, they allow students to gain practical experience on realistic industrial issues.

From the great variations of challenges offered by the community, one can notice several limitations. Firstly, most challenges are self-funded by the participants, which represents a hindrance for the development of the solutions. Although robotics is expected to become reasonably affordable along the years, scientific research and development need substantial funding. Besides, as stated in (Anderson et al., 2011), competitions need to be more than "one-off demonstrations" and adopt the form of repeatable and reproducible scientific experiments so as to assess their real impact on robotics development. In the recent past years, a major effort has been put on the dissemination of the benchmarking methods. So as to constitute concrete and measurable scientific advances, a challenge should guarantee the independence of the organizers, the coordinated selection of the competing teams and the evaluation plan needs to gradually accompany their progress.

3. The ROSE Challenge

3.1. Presentation of the ROSE Challenge

Four teams, each composed of at least one research institute and one company, have been selected for the development of robotic solutions aiming intra-row weed control in vegetable field crops and widely spaced large-scale crops. The objective is to offer an alternative to phytosanitary products, through an intelligent interpretation of the culture environment and an autonomous weeding action. The teams develop ground robotic solutions using RGB, hyperspectral and/or multispectral sensing, and mechanical or electrical weeding effectors. The movements of the robot can be tele-operated, so long as this control does not interfere with the detection, decision-making and weeding actions. The research work of teams is funded through the ANR Challenge funding program.

The Challenge is coordinated and organized by LNE and Irstea. LNE provides the ROSE Challenge with its skills in organizing evaluation campaigns as a trusted third-party, defining test scenarios and designing test environments and verified, annotated test databases. LNE also brings its expertise in metrology applied to Artificial Intelligence to measure the performance of the intelligent systems evaluated in a rigorous, repeatable manner using metrics and uncertainty analysis. Irstea provides its expertise in agricultural robotics, digital agriculture and spreading technologies, and contributes to the ROSE Challenge by allowing the use of the infrastructure at its research and experiment site (experimental plots, metrology, information systems, amenities, etc.), where the evaluation campaigns is organized. In addition, Irstea is calling on the agronomic skills of the Higher education and research institute VetAgro Sup, whose involvement includes annotating and interpreting field data.

3.2. Overall organization

Each year of the Challenge, teams are invited to test the aptitudes of their solutions on the experimental fields made available by the organizers on Irstea's site. The surface devoted to the Challenge is closely controlled by Irstea teams, who provide a detailed history of the past activities performed on the site (previous cultivations and potential soil treatments), and supervise the technical operations performed on the plots in the course of the Challenge (soil and seedbed preparation with thermal treatment, seeding, fertilizing, maintenance in the rows of crops and in the surrounding areas). In addition to the teams' plots, a "reference plot" is also maintained by the organizers with conventional weeding means, by using chemicals at the pre-emergence and post-emergence phases. This plot is used as a reference in the evaluation process, to help the appreciation of the efficacy of the robotic solutions.

Figure 1. ROSE Challenge, June 2018: first meeting with the teams on Irstea experimental field in Montoldre (France).

For each selected crop and weed combination, teams are assigned plots. The assignment of a plot may be random among teams. The teams are expected to deploy their technological solution with the objective of weeding their own plots.

3.3. An adaptative evaluation plan

The four-year Challenge is divided into two main phases: the first year (spanning from 2018 to 2019) is dedicated to the dry-run phase that allows the tuning of the evaluation protocol and tools, and the three remaining years constitute the effective competition phase.

During the dry-run phase, teams get prepared to the competition, in conditions as close as possible to the real evaluation so as to allow them to get familiar with the evaluation process. On this occasion, the teams may express the requirements and limits of their systems, discuss the evaluation plan, and proceed to several tests of their prototypes in the field and on data samples. Meanwhile, the organizers acquire or develop the tools that will be required for the evaluation process: tools for the preparation and annotation of the reference data, data collection platform to capture images in the field, cloud platform to share data with the teams, meteorological platforms to gather information on the environmental conditions, and tools to allow semi-automated comparisons between hypotheses and references. The organizers also design the most efficient crop patterns for the evaluation and test them in the fields.

The dry-run phase is a fundamental prerequisite for a smooth conduct of the Challenge. Indeed, this phase allows the organizers to prepare an evaluation plan that is both realistic with respect to the capabilities of the systems, and that is fair among the different technologies used by the teams.

Each year of the Challenge, participants will be invited to test their systems in real field conditions. The evaluation plan is adapted throughout the Challenge so as to accompany the evolutions of the teams' technological solutions. At more mature levels, the nature of the evaluations will turn toward the estimation of the acceptability of the solutions by potential users, the impact of the solutions on soil conditions (pollution, soil erosion and compaction, etc.) and technical and economic criteria such as the level of automation, energy usage and the cost of materials and techniques used.

3.4. Crops and weeds distribution

As mentioned above, the plots are expected to present combinations of crops and weeds. The Challenge addresses both large spacing crops and vegetable field crops. Different weeds are selected, so as to represent the "natural" weed environment of the crops, and several weeds are selected as "models" for the evaluation needs. The weed selection also represents the growth pattern of weeds: upright or spreading. Planting density varies uniformly along the stripes. The Table 1 presents the different plants that have been considered for the Challenge. Research and experimentations are carried out in order to establish relevant combinations of weeds and crops for the evaluation. During the dry-run, the teams are asked to focus on corn, beans, lamb's quarter and matricaria.

Table 1. Categories of crops and weeds envisioned for the ROSE Challenge.
The selection is experimented during the Challenge preparation.

<table>
<tr><th>Class</th><th>Type</th><th>Growth</th><th>Plant name</th><th>Alternatives</th></tr>
<tr><td rowspan="4">Crops</td><td rowspan="2">Large spacing</td><td rowspan="4"></td><td>Corn</td><td rowspan="4"></td></tr>
<tr><td>Field beans</td></tr>
<tr><td rowspan="2">Vegetable field crops</td><td>Beans</td></tr>
<tr><td>Peas</td></tr>
<tr><td rowspan="4">Weeds</td><td rowspan="2">Natural</td><td>Upright</td><td>Lamb's quarter</td><td>Foxtail, nightshade, crabgrass</td></tr>
<tr><td>Spreading</td><td>Matricaria</td><td>Knotweed</td></tr>
<tr><td rowspan="2">Model</td><td>Upright</td><td>Ryegrass</td><td>Oats, fescue, dactylis</td></tr>
<tr><td>Spreading</td><td>Wild mustard</td><td>Vetch, clover</td></tr>
</table>

The plan of the plots of land is established so as to present combinations of crops and weeds equally distributed into patches that are assigned to the competing teams. Figure 2 pictures a stripe of the experimental field.

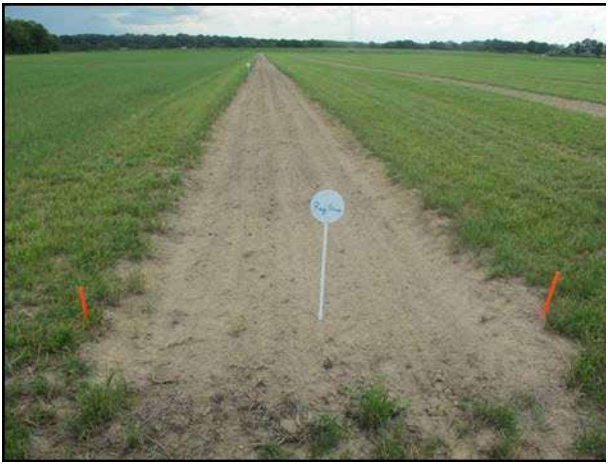

Figure 2. Each stripe is dedicated to a combination of specific crop and weed; the stripe is divided into four patches so as to allow each team to test their solution.

3.5. Evaluation process

The Challenge focuses on the performance of autonomous weed killing robots for the intra row of crops. The evaluation addresses the three main tasks of the sensorimotor loop performed by a robotic platform:

1. The detection of weeds and crops.
2. The robot's decision to proceed to weeding.
3. The weeding action in itself.

3.5.1. Detection task

The detection task is divided into two sub-tasks. The objective of the first one is to estimate the ability of the technological solution to use its detection system in order to perform the weeding action. This sub-task is evaluated on a test image dataset. The second sub-task aims at estimating the ability of the solution to use its detection system to facilitate decision-making. This is carried out in the field.

<u>First sub-task: detection on test dataset</u>

The evaluation on a dataset requires the collection of test images in the visible, multi-spectral and hyperspectral ranges. This collection is performed by the organizers. During the first phase of the dry-run, only images in the visible range were used. On each image in the dataset, the teams' detection system is expected to:

- detect the presence of plants (weeds and crops) and locate them on the image. Teams are expected to provide masks for each plant detected.
- determine their class (weed or crop).

The output data provided by the teams are called "hypothesis". The evaluation consists of a data mapping between the masks in the "hypothesis", and the plants identified in the "reference".

Figures 3, 4, 5 and 6 illustrate a sample of the test dataset, the annotation performed to produce the "reference", a fictional "hypothesis" that may be produced by a team's detection system, and a visual rendering of the comparison performed.

Figure 3. The "source" image shot in the fields.

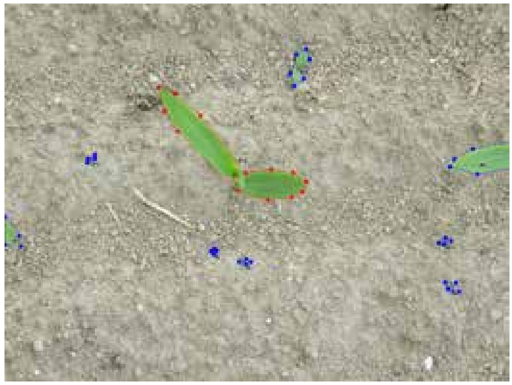

Figure 4. The "reference" image. Dots and lines represent the cutting performed by an expert labeller so as to mark out the plants. Tags indicate the class that has been selected by the labeller ("PI": crop, "A": weed).

Figure 5. A visual rendering of a "hypothesis" mask (fictional). One can notice that the full surface of the plant has not been detected.

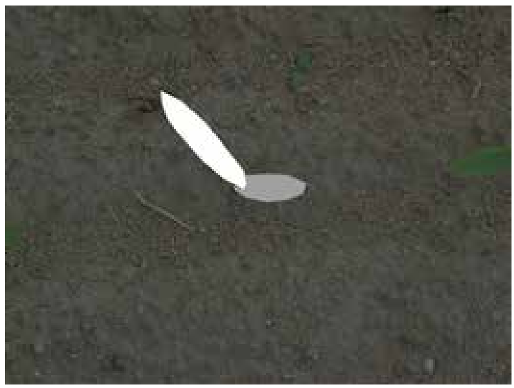

Figure 6. A visual rendering of the comparison process. The striped area represents the part of the plant that has been ignored by the detection system.

The performance of the detection system is scored through the EGER metric (Estimated Global Error Rate). Each plant in the reference is supposed to correspond to a plant of the same class in the hypothesis. The EGER metric takes into account if the system mistakes a plant type for another, forgets a plant, or on the contrary detects a plant where there is none. Each error type is weighted: for example, the confusion between plant types is considered as more important than ignoring a plant, since it may induce the destruction of crops.

In the course of the Challenge, the dataset is solely constituted for testing purposes; teams are expected to rely on their own training datasets. However, the characteristics of the test dataset are selected collaboratively with the teams (distance, sharpness, resolution, luminosity, etc.), so as to match the capabilities of the systems at best.

The whole ROSE Challenge dataset will be released to the community at the end of the Challenge, along with a full documentation on the collection, preparation and data qualification process. It will include aligned images in several ranges of wavelength, description of plants (cutting-out, class, name and growth stage) and description of the environmental conditions (timestamp, weather, etc.).

Second sub-task: detection in the field

The detection in real conditions constitutes the second part of the evaluation of the detection systems. In this context, the platforms are expected to pass over the culture rows and determine automatically the number of weeds and crop plants detected. So as to estimate the repeatability of the detection, the process is repeated several times.

Before the passage of the teams' platform, the organizers identify manually the number of weeds and crop plants on each patches; the evaluation consists in comparing the numbers provided by the human experts and the systems, for each class of plant.

3.5.2. Weeding action task

So as to evaluate their weeding ability, the platforms are expected to perform weeding actions on plots. A specific focus is given to the ability of the platform to perform the action on weeds while preserving the surrounding crops. The objective is to estimate the regrowth rate of the weeds, and to observe the behaviour of the potential damaged crops.

This task has to be as independent from the detection performance as possible. Indeed, the weeding action needs to be done autonomously, which implies that the system needs to localise the plant that needs to be neutralized. To that end, visual markers have been designed by the organizers and submitted to the approval of the teams, ensuring that all the systems are presumably able to easily spot the base of the plants and perform a weeding action. These markers take the form of plastic disks placed at the bottom of each plant (see Figure 7). These disks are color-coded: yellow represents a weed, and blue indicates a crop.

Figure 7. Markers on the base of three plants: on the left, two yellow markers indicate the presence of weeds. On the right, a blue marker signals the presence of a crop.

The evaluation consists in a comparison of the state of the plot before and after the weeding. So as to assess the effectiveness of the weed destruction and the impact of the surrounding crops, the observation of the plot is performed at several points in time, up to twenty-one days after the weeding. The scoring relies on:

- the count of weeds before and after the action, and the percentage of eliminated weeds,
- the count of undamaged crops before and after the action. The integrity of the crops will be qualitatively assessed.
- the density of weeds before and after the action,
- the density of crops before and after the action.

Since the density of weeds and crops varies across a same plot, the robustness of the weeding action is also estimated. The cost of action will be evaluated through a ratio between the total time of processing for a patch and the number of weeds killed on this patch; another estimation can be performed by computing the ratio between the speed of the platform and the density of weeds.

3.5.3. Global evaluation in the field

The evaluation of the specific decision-making aspect is to be carried out in the later phases of the Challenges. The relevance of performing a weeding action depends on various temporal and spatial considerations. Indeed, checking that the system takes the right decision implies considering several factors, like growth stage or proximity to other plants, which are not expected in the first stages of the Challenge.

In the first stages, the performance of the global detection – decision – action chain is determined through an estimation of the biomass of the plot twenty-one days after the realization of the action. Regularly updated on the state of the cultures, teams are expected to define at what time their platforms may be the most efficient. They are thus invited to have their platform proceed to weeding. In this context, systems are not necessarily expected to take a decision of action autonomously: a human operator may trigger the action. However, there are no markers present on plants to facilitate the detection. The evaluation thus allows assessing the detection system and the weeding effector, but also all the decisions taken during the intervention.

The global criterion for the evaluation is the biomass of the plot, compared to the biomass of the conventionally weeded reference plot. This criterion allows notably the appreciation of:

- the choice in the moment of intervention, which depends on constraints imposed by the culture (for example, the intervention needs to happen when weeds are young) and imposed by the robotic platform (for example, weeds need to be developed enough for detection),
- the choice in weeding or not, depending on the likelihood of deteriorating a crop.

Other criteria may be considered, such as work rate and environmental impact of the technological solution.

4. Conclusion

4.1. A challenge to accompany research on agricultural innovation

Financially supported by the French National Research Agency ANR, the participants to the ROSE Challenge are expected to develop technological solutions to face the limitation of chemical inputs, by designing automatic weed control robots for intra row of crops. During the four years of the Challenge, their progress will be objectively measured in real field conditions. To this end, the evaluation plan addresses the detection, decision-making and action abilities of the systems. The plan is meant to evolve according to the development of the robots' capabilities, so as to include eventually societal, economic and ecological criteria. This iterative evaluation procedure avoids the tunnel effect which could drive the development of a solution that does not meet in the end the targeted objective and needs.

The Challenge takes the research far from constrained evaluation in artificial conditions: it faces variety in the capabilities and limitations of the solutions progressively developed by the teams, and may face the potential occurrence of natural events affecting the experimental field (meteorological events, pests, diseases, etc.). The organization of the ROSE Challenge relies on the expertise of experts in metrology, evaluation and agronomy, who are able to adapt the evaluation protocol while still ensuring objective measures and evaluation methodology.

The evaluation procedure is not punitive and the whole process is not validated by a final prize; the overall objective is to push back the scientific limitations and establish objectively the abilities of autonomous systems in agriculture. The evaluation allows building cohesion in the comparison of different technical solutions, helps in the definition of measurable objectives, and quantifies the distance towards these objectives.

4.2. References for the evaluation of agricultural robots

The ROSE Challenge will provide the first global level campaign that addresses both an evaluation on image datasets and in real field conditions. The Challenge allows a modular evaluation of the technological solutions, an overall estimation of the weeding effectiveness and an analysis of the economical, sociological and ecological impact.

The tools developed in the context of the Challenge will constitute reference baselines for the characterization of future research in the domain. In particular, test datasets, through the richness of their contents, will present a high potential for reusability in the community. Indeed, the collection of a corpus of images in the visible, multi-spectral and hyperspectral ranges constitutes a novelty which will allows the comparative evaluation of different plant detection technologies. In the context of strong limitation of phytosanitary products, these databases will prove useful for the development of new weed management technologies endowed with the ability to detect automatically weeds.

The evaluation plan designed throughout the Challenge will serve as a baseline for the evaluation of agricultural robots. Dedicated to performance in ROSE, the evaluation procedure may adapt to address the evaluation of other global issues in robotics such as safety and security.

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References

Anderson, M., Jenkins, O. C., & Osentoski, S. (2011). *Recasting robotics challenges as experiments*. IEEE Robotics and Automation Magazine, 18(2), 10-11.

Jacoff A., Huang H.M., Virts A., Downs A., Sheh R., 2012. *Emergency Response Robot Evaluation Exercise*. Proceedings of the Workshop on Performance Metrics for Intelligent Systems, Pages, 145–154.

Jan, N., Cattoni, R., Sebastian, S., Cettolo, M., Turchi, M., & Federico, M. (2018). *The IWSLT 2018 Evaluation Campaign*. In International Workshop on Spoken Language Translation (pp. 2-6).

Kitano, H., Asada, M., Kuniyoshi, Y., Noda, I., & Osawa, E. (1997). *Robocup: The robot world cup initiative*. In Proceedings of the first international conference on Autonomous agents (pp. 340-347). ACM.

Pratt, G., & Manzo, J. (2013). *The DARPA robotics challenge [competitions]*. IEEE Robotics & Automation Magazine, 20(2), 10-12.

Schuller, B. W., Steidl, S., Batliner, A., Marschik, P. B., Baumeister, H., Dong, F., ... & Einspieler, C. (2018). *The Interspeech 2018 computational paralinguistics challenge: Atypical & self-assessed affect, crying & heart beats*. Proceedings of the INTERSPEECH International Conference, Hyderabad, India.

Tee, K. P., & Van Der Kooij, H. (2017). *The ICRA 2017 Robot Challenges [Competitions]*. IEEE robotics & automation magazine, 24(3), 15-21.

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