Lecture Notes in Civil Engineering

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Innovative Biosystems Engineering for Sustainable Agriculture, Forestry and Food Production

International Mid-Term Conference 2019 of the Italian Association of Agricultural Engineering (AIIA)

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Preface

The Mid-Term Conference of the Italian Association of Agricultural Engineering (AIIA) is part of a series of conferences, seminars and meetings that AIIA periodically promotes and organizes, also together with other entities and associations, involving stakeholders, public and private, with the aim of facilitating the encounter of research and training, innovation and development demand, and to promote the creation and dissemination of new knowledge in the sector.

This particular 2019 Mid-Term AIIA Conference will deal with the following major topic:

Innovative Biosystems Engineering for Sustainable Agriculture, Forestry and Food Production

The specific subjects will include the following:

- Agricultural hydraulics;
- Water resources management in agriculture and forestry ecosystem;
- Design and management of Farm and District-Scale Irrigation Systems;
- Remote Sensing in agricultural and forestry systems;
- Monitoring and modelling of the interactions among soil hydrological, plant and atmosphere;
- Processes, and agricultural management practices;
- Soil and contaminant hydrology;
- Forestry hydraulics and hydraulics protection of agricultural and forestry systems;
- Bioengineering Techniques for soil protection and slope stabilization;
- Rural buildings, facilities and territory;
- Spatial and landscape analysis;
- Planning and design of rural areas;
- Mechanization and technologies for agricultural production;
- Agricultural electrification and energy usage;

- Ergonomics and work organization;
- Computer and communication technologies;
- Machines and facilities for agricultural products and food processing.

The sustainable development of agriculture, forestry and food production sectors is closely related to the research developments in the field of biosystems engineering.

On one side, biosystems research is oriented to efficiently produce and process biological resources to satisfy the demand of consumers and a wide range of industries for food, feed, bioenergy and bio-based products. At the same time, it provides and develops engineering-based methodologies and decision support tools for management and protection of soil, water and environmental resources; design of structures, facilities, equipment and infrastructures; planning and design of rural areas and landscape; mechanization and technologies for agricultural production; agricultural electrification and energy usage; ergonomics and work organization and safety; computer and communication technologies.

The aim of this Conference is to stimulate contributions related to the engineering technological applications to the agriculture, forestry and agri-food sectors. Researchers involved in activities related to Biosystems and Agricultural Engineering, as well as Agricultural, Forestry and Food Engineers, farm and food company managers have been invited to present their contributions at the Conference.

This book focuses on the challenges to implement sustainability in diverse contexts in the fields of biosystems engineering for sustainable agriculture, forestry and food production. As the production systems are mainly based on the agricultural sector, the research has taken up the challenge of the sustainable use of renewable and non-renewable resources showing some possible solutions in order to have a sustainable production.

The book consists of seven parts, offering a broad and multidisciplinary approach of some interesting solutions in the field of innovative biosystems engineering, each part corresponds to the seven technical sections composing the AIIA association.

- Part I—Land and Water Use;
- Part II—Rural Buildings, Equipment and Territory;
- Part III—Mechanization and Technologies for Agricultural Production;
- Part IV—Agricultural Electrification and Use of Energy;
- Part V—Ergonomics and Work Organization;
- Part VI—Machines and Plants for Processing Agricultural Production;
- Part VII—Information and Communication Technologies.

We wish to thank colleagues and technicians who participated in the Conference and supported us. We would like also to thank all the authors who have presented their contributions to the Conference. Finally, we would like also to express our gratitude to the President of the AIIA Association and to the Presidents of the seven AIIA Sections who have taken the responsibility to organize the review and revision of the presented works making thus possible the realization of this book.

Potenza, Italy

Antonio Coppola
Giovanni Carlo Di Renzo
Giuseppe Altieri
Paola D'Antonio

Introduction

The contribution of agricultural and biosystems engineering to meet the sustainable agriculture challenges and contributing to economic growth

The Italian Association of Agricultural Engineering (AIIA)

AIIA was founded in 1959, as a national association belonging to the Commission Internationale du Génie Rural (CIGR). AIIA adheres to the CIGR in all its direct and indirect forms and represents it nationally. AIIA also adheres to the European Society of Agricultural Engineers (EurAgEng), a European member of the CIGR. Furthermore AIIA, along with other scientific societies pertaining to the agricultural, forestry, agro-industrial and environmental sectors, is a part of the Italian Society of Agricultural Scientific Societies (AISSA). The AIIA coordinates and develops all the activities in the field of agricultural and biosystems engineering, i.e. those scientific and technical disciplines related to engineering applied to agricultural and forestry systems. Moreover, AIIA promotes the exchange of experiences and research results among scholars and professionals. AIIA fosters initiatives involving the application of engineering principles to the processes at the basis of land use and territorial development in order to study, model and enhance biological systems for sustainable agriculture, food production, land use and environment safety. AIIA is particularly active in networking between scholars and experts in the various sectors of agricultural and biosystems engineering, with reference to research, innovation, development, technology transfer and training. AIIA periodically promotes and organizes, also together with other institutions and associations, conferences, seminars and meetings involving stakeholders, public and private, with the aim of facilitating the encounter of research and training, innovation and development demand, and to promote the creation and dissemination of new knowledge in the sector.

In particular, the Italian Association of Agricultural Engineering pursues the following aims:

- Bring its technical and scientific contribution to questions of general interest in the field of agricultural engineering;
- Foster relations between scholars and operators dedicated to agricultural engineering;
- Promote the development of agricultural engineering in its various branches;
- Encourage, coordinate and perform—also on behalf of third parties—research in the field of agricultural engineering, also by setting up specific centres;
- Encourage the training of technicians specialized in agricultural engineering by means of teaching courses, scholarships and similar facilities;
- Promote activities and events for dealing with historical and cultural issues concerning agricultural engineering;
- Promote and maintain connections with similar Italian and foreign institutions;
- Promote study events for dealing with issues and problems of a scientific and technical nature relevant to agricultural engineering.

The *Journal of Agricultural Engineering* (JAE), an international journal with peer review and open access, is the official organ of the Association.

The Italian Association of Agricultural Engineering is divided into the following Technical Sections:

- Part I—Land and Water Use;
- Part II—Rural Buildings, Equipment and Territory;
- Part III—Mechanization and Technologies for Agricultural Production;
- Part IV—Agricultural Electrification and Use of Energy;
- Part V—Ergonomics and Work Organization;
- Part VI—Machines and Plants for Processing Agricultural Production;
- Part VII—Information and Communication Technologies.

Members of AIIA are professors and researchers of Universities and Research Institutes, and scholars, experts, technicians, professionals, companies active in research and training in the field of agricultural and biosystems engineering in Italy.

Giacomo Scarascia Mugnozza
President of the Italian Association
of Agricultural Engineering (AIIA)

The Context

In the past century, considerable advances were made in discovering fundamental principles in several scientific disciplines, which created major breakthroughs in management and technology for agricultural systems. However, in the twenty-first century, agricultural research has more difficult and complex problems to solve. Growing environmental awareness of the general public is challenging producers to change farm management practices and protect water, air and soil quality, while staying economically profitable. At the same time, market-based global competition in agricultural production and global climate change are threatening the economic viability of traditional agricultural systems, and now require the development of dynamic new production systems. Site-specific optimal management of spatially variable soils and available water resources, associated with optimal selection of crops, can help achieve both production and environmental objectives. Fortunately, new technologies can provide a vast amount of real-time information about soil and crop conditions via remote sensing or ground-based instruments which, combined with near-term weather forecasting, can be utilized to develop a whole new level of site-specific management.

Agricultural engineering recognizes the importance of multidisciplinary approaches to develop and deliver know-how and technological solutions in tackling problems at full scale, in real-time and on real-life systems, (Munack 2000).

The used approaches share much common ground with environmental concerns, and the development of methods and systems to deal with the underlying biological system complexity and uncertainty is a major scientific challenge. Agricultural systems are often sensitive to many interacting environmental variables and processes, and solutions frequently involve understanding, monitoring and controlling complex processes in order to improve productivity and minimize environmental emissions and impacts.

The Vision in the Twenty-First Century

There is today real demand for further innovation and its translation into practice in the agricultural context. A wide range of physical sciences and engineering disciplines can make a substantial contribution to the future of agriculture. The following Table 1 provides a synopsis of the sciences involved in different agricultural/environmental applications.

Table 1 Agricultural engineering applications in the context of wider sciences (*Source* Munack 2000)

	MATHEMATICAL MODELING	SENSORS	REMOTE SENSING	NANOTECHNOLOGY	FLUID DYNAMICS	SOIL PHYSICS	DATA MINING AND PATTERN	ROBOTICS	SURFACE CHEMISTRY
PRODUCT QUALITY	X	X						X	X
ENVIRONMENTAL POLLUTION	X	X	X		X	X			
LOGISTICS	X							X	
ENVIRONMENTAL CONTROL	X	X			X				
IRRIGATION MANAGEMENT	X	X	X		X	X	X	X	
FERTILIZERS AND PESTICIDES				X			X		X
WITHIN-FIELD PRECISION		X					X	X	
SELECTIVE HARVESTING			X					X	
POST-HARVEST MANAGEMENT		X							
LIVESTOCK SYSTEMS	X	X	X	X	X		X	X	
SOIL AND WATER MANAGEMENT	X	X	X		X	X	X		X

Advances in sensing, control engineering, mechanical and hydraulic engineering, robotics and mechatronics, data management, will all contribute to global challenges solutions (Cavalli and Monarca 2011; Scarascia Mugnozza et al. 2011; Gandolfi and Lenzi 2011). Similarly, the ways in which engineering advances will demonstrate their impact is very varied. The sections below serve to emphasize opportunities in different areas of application.

Precision Agricultural Management

Precision Crop Management and Harvesting

(i) Advanced sensing techniques will provide real-time information on the health status of crops (nutrient levels, presence of disease) and soils (nutrient levels); (ii) Appropriate combination of data with crop and system models, will provide early warning of risks and suggest mitigation strategies; (iii) Appropriate interpretation of the relationship between spatial variability of biochemical–physiological response of plants and vegetation, which can be detected by remote sensing observation, and of the stress factors (water, nutrient and salinity stress) may help to adopt spatially variable crop management to maximize productivity and minimize wastage of inputs; (iv) With robotics systems increasingly available, crop quality sensing at harvest will allow to optimize harvest time and sorting to be integrated with the harvesting process.

Precision Control of Pest and Disease

(i) Biosensors will provide early warning of pest or disease outbreaks; (ii) Further improvements to chemical application, through innovative atomization and improved spray handling, will allow optimizing target coverage and efficacy by minimizing losses and environmental impact; (iii) Mechatronics and automation technologies will allow crop management with autonomous machines, including the identification and eradication of weeds by non-chemical means.

Precision Livestock Management

Controlling Animal Health and Welfare

(i) Guidance to animal management both in the field and in housed systems will be improved by animal monitoring systems, including environmental sensors, machine vision, acoustic monitors and gas detectors; (ii) Biosensors will be actively used for monitoring key health and welfare indicators in real time; (iii) Coupling direct observations on the performance of individual animals and animal growth models, will provide early health warning systems to identify and control nutrition and environmental problems.

Controlling Environmental Impacts

(i) Innovative housing and aeration design will improve the control of ventilation and the aerial environment for animals; (ii) Greenhouse gases and other emissions in livestock housing systems will be minimized by environmental control sensors; (iii) Innovative chemical engineering techniques will improve waste treatment and recycling of water and nutrients.

Agriculture and Environment: New Challenges for Engineers

Progress in biological sciences, associated with engineering research and innovations will provide many benefits for agricultural systems, which can be summarized as follows:

Balancing Future Demand and Supply Sustainably

Innovation in agricultural engineering is going to be a crucial contributor to the delivery of agricultural outputs under sustainable intensification conditions. New science and innovative technologies will open up new practices that will both increase production and reduce or reuse waste streams.

Advances in Precision Farming to Enhance Crop Productivity

Advances in precision farming are already supplying considerable understandings of the variability of current production systems (yields can vary considerably in different regions of the same field), Anyway, more precisely controlled input (at scales down to a few meters or individual plants) may still produce benefits in terms of increased productivity, reduced inputs and lower environmental impacts. Timings and quantities of fertilizers and pesticides can be adjusted to much current locally crop state and can be coupled to predictions of future changes in growth rates or disease pressure. Future advances in application technologies and in crop management regimes will allow minimizing gas emissions from soils. Better planning and scheduling of machine operations have the potential to reduce costs by 20%.

Improved Animal Health and Welfare Through Real-Time Monitoring and Diagnostics

Real-time monitoring will allow recognizing health and welfare problems. Biosensors to identify changes in physiological state or exposure to pathogens will become feasible for use in intensive systems, and even in extensive ones through the use of remote tracking and monitoring systems. This real-time monitoring can improve productivity and quality, while also addressing welfare and environmental impact issues. Improved dairy cow fertility management through estrus sensing has been estimated to be able to deliver 15% reduction in methane emissions, for example.

Meeting the Challenges of a Low Emission World

Concerns about energy demand and climate change require that improvements be made in environmental control and emissions from the biological processes on which farming depends. Engineering advances to optimize performance in energy use for land management and in renewable energy production will be crucial if agriculture is to play its part in averting damage to climate and environment. The complexity of farming systems calls for an interdisciplinary approach to these problems, and combinations of new biological concepts and new engineering techniques are needed.

Reduced Emissions and Other Waste from Livestock

Innovative approaches to managing and handling waste, both on-farm and through cooperative actions with other waste generators, have the potential to enhance the return of plant nutrients to the land and maximize crop nutrient value while minimizing liquid and gaseous emissions of pollutants, including greenhouse gases. Effective management of livestock waste may also provide on-farm energy, e.g. through anaerobic digestion and pyrolysis.

Sensors based on simple physical methods or on more sophisticated techniques using near-infrared spectroscopy or hyperspectral reflectance analysis may be used to determine the nutrient content of the waste stream before land spreading, or even in real time during land spreading, so that application rates can be matched to local crop nutrient requirements within the field. Optimizing application systems will allow the manure in the soil to be distributed appropriately, to control losses of gases such as ammonia or nitrous oxide, and ensure rapid nutrient availability for the crop. High capacity distribution machinery will allow timely application within narrow periods when crop requirements, soil conditions and the demands of regulations come together.

Optimizing Energy Use in Farm Machines

Fuel economy has become a major concern to the industry following price increases, and is now strongly studied. Tractors and other agricultural machines mostly use diesel engines. These are characterized by more sustained and often continuous full-power operation and cooling concerns due to slower vehicle speed and often dusty operating conditions.

New Contributions to Assess the Interactions Among Soil Physical Processes, Plant and Atmospheric Processes, Agricultural Water Management, Soil Environment and Climate Change

Interpreting and controlling the interaction between farming systems and management processes, including soil and water processes, will allow innovative technologies to deliver real benefits to maintain ecosystem services for feeding the world.

The Soil–Plant–Atmosphere Continuum as a Hydraulic System

Water uptake is a key component of the soil hydrological balance and is of concern for a range of hydrological, agricultural and ecological applications, as it controls, either directly or indirectly, the partitioning of infiltrating water into evaporation, transpiration and deep percolation fluxes. It is a dynamic process influenced by soil, plant and climate conditions. It depends on a number of factors such as soil water pressure head, soil hydraulic conductivity, osmotic head (in saline condition), evaporative demand, rooting depth, root density distribution and plant properties. Soil physicists and hydrologists have skills to apply analytical and numerical techniques to model water flow in hydraulic systems and to quantify water transport in plants. The challenge to modelling water uptake and transport in plants is that water flow is controlled by a biological entity, the plant, which senses environmental conditions such as light, temperature and humidity, and continuously adjusts flow rates to maintain its own internal water status. Water potential gradients between the soil and the atmosphere drive the flow. This results in a dynamic hydrologic flow system controlled by both physical and biological parameters. Since plant hydrology and plant structure are closely tied, an understanding of plant hydraulic relationships is essential if we are to model plant properties like leaf and stem sizes and arrangement. A sophisticated approach to the issue would be to combine plant hydrology with an L-Systems description of plant architecture (Prusinkiewicz and Lindenmayer 1990). Forestry researchers have made advances in modelling such systems, but more work is necessary, especially in the area of xylem hydraulics (Sperry et al. 2003).

Transpiration and Carbon Dioxide Fluxes at the Vegetation-Atmosphere Interface

Most of the models simulating agro-hydrological systems should be improved with respect to the effect of water stress on transpiration, C assimilation (photosynthesis), C allocation, canopy temperature and the resulting water use efficiency for production. So far, simple stress factor approach has been mostly adopted to simulate transpiration. In some models, daily crop water stress is calculated as 1—AT/PT, where AT is the daily actual water uptake and PT is daily potential transpiration (Hanson 2000; Sudar et al. 1981). In principle, models should rely on stomatal resistance to simulate transpiration (see for example RZWQM model, Farahani and Ahuja 1996). Stomatal behaviour is an important regulator of water flow from the soil and plant to the atmosphere and control mechanisms are still largely unknown.

Are stomata responsive to leaf water potential or soil water potential or both, or other factors such as temperature and chemical signals? Coupled models of photosynthesis and transpiration with an energy balance hold the greatest potential to appropriately model and analyse these issues (Buckley et al. 2003; Tuzet et al. 2003). This would provide a more physiologically based approach taking into account processes that plants have developed to optimize C assimilation and minimize water loss under all conditions of water availability and especially water-deficit situations. Application of such models in forestry has provided good representations of plant response to water stress (Misson et al. 2004). Many of the parameters in these models can be determined using photosynthetic gas flux equipment and sap flow measurements.

Agricultural engineers are well qualified to tackle the above biophysics and energy balance problems.

Better Use of Irrigation Water to Support Production

Water scarcity and quality degradation are set to become the main environmental problems for all countries in the Mediterranean region in the near future. Due mainly to population growth, pressure on agriculture and demand for water to irrigate food crops have also increased. In Mediterranean countries the irrigated area has more than doubled in 40 years, totalling 24,200,000 ha in 2009 (17.8 million in Mediterranean Europe and 6.4 million in Northern Africa). However, in many countries, irrigation practice is often wasteful and highly inefficient. In an attempt to tackle the problem in Italy and other Mediterranean regions, open-channel irrigation systems have been (or are going to be) converted into pressurized pipeline networks. In most cases, the "on-demand" method for water distribution has been adopted to replace the old rotational schedule (Lamaddalena and Sagardoy 2000; D'Urso 2001; Schultz and De Wrachien 2002; Galelli et al. 2010; Coppola et al. 2019).

However, experience shows that even for on-demand pressurized irrigation systems the performance of distribution networks is still frequently far from acceptable in terms of efficiency for both (1) economic/political and (2) technical reasons.

In this context, the use of decision support systems (DSS) may significantly enhance the management of on-demand irrigation systems. Advanced technical tools are nowadays available for monitoring and simulating the various physical processes involved in an irrigation system. Such tools can be used in an integrated way for estimating irrigation water demand and scheduling water use, and thus for simulating the operation of on-demand irrigation networks, under varying soil and weather conditions, crop management options and irrigation technologies.

In general, by integrating the above technical tools with economic instruments, such systems may facilitate the decision-making process on the quantities of water to be allocated to agricultural consumers. Such tools may take into account the most profitable cropping patterns given any water restrictions imposed by existing hydrological conditions, as well as the potential yields in each irrigation district according to its production characteristics, irrigation efficiency, economic scenario and external factors such as agricultural policies.

Processes at the Watershed Scale

Going from field to watershed scale, several processes come into play, such as subsurface flow of water and chemicals to a channel or a stream, flow of field surface runoff through riparian zones, chemical transport in channels and streams. In addition, there may be related to soil erosion processes. Agricultural engineers and soil physicists can contribute to quantification and modelling of some of these processes at this scale as well. Some examples of past contributions in this area are the work on subsurface interflow (Lehman and Ahuja 1985), tile flow (Johnsen et al. 1995), gully erosion (Zheng et al. 2000), and buffer strips (Seobi et al. 2005). Watershed models have been developed that include the above processes, such as the SWAT, AnnAGNPS and REMM models (Arnold et al. 1998; Lowrance et al. 2000; Bingner and Theurer 2001). These models simplify the simulation of physical processes for large simulation units. However, agricultural engineers and soil hydrologist can help improve these simulations by ensuring that field-scale effects are appropriately aggregated up to the watershed scale.

Modelling Climate Change, Soil Environment and Agriculture

Agricultural engineers may significantly contribute to the evaluation of the contribution of agricultural practices on global warming and, inversely, the impact of climate change on soil agricultural systems. Specifically, important contributions may come in the following issues: (i) Quantifying the impact of agricultural soils and current management practices to climate change; (ii) Assessing the effects of climate change on the soil environment, crop growth and agricultural systems, and to identify potential management changes to mitigate the adverse effects.

Agricultural soils and management contribute to climate change primarily through the emission of greenhouse gases, such as CO_2, CH_4, N_2O, NO and NH_3. Models are needed to quantify these emissions as functions of several dynamic variables and aggregate the results over large spatial areas and long timescales. Some models are available (Li 2000) that need more extensive evaluation and improvement.

Climate changes have impacts on the soil environment, especially soil water and temperature, and a number of related processes, such as evapotranspiration, runoff and erosion. Models are needed to quantify these influences in different agricultural systems and to identify strategies for mitigating any adverse effects (e.g. Tubiello et al. 2000).

Land-Use Change Impacts on Floods at the Catchment Scale

Agricultural engineers may also contribute to quantify the land-use change effects on floods. The intensification of agricultural practices has heavily modified natural landscapes. Tillage has frequently created dense soil layers inducing preferential lateral flow and reducing the filtering and buffering potential of soil horizons. Hillslopes have been modified for agricultural production, thus changing flow paths, flow velocities and water storage, and consequently flow connectivity and

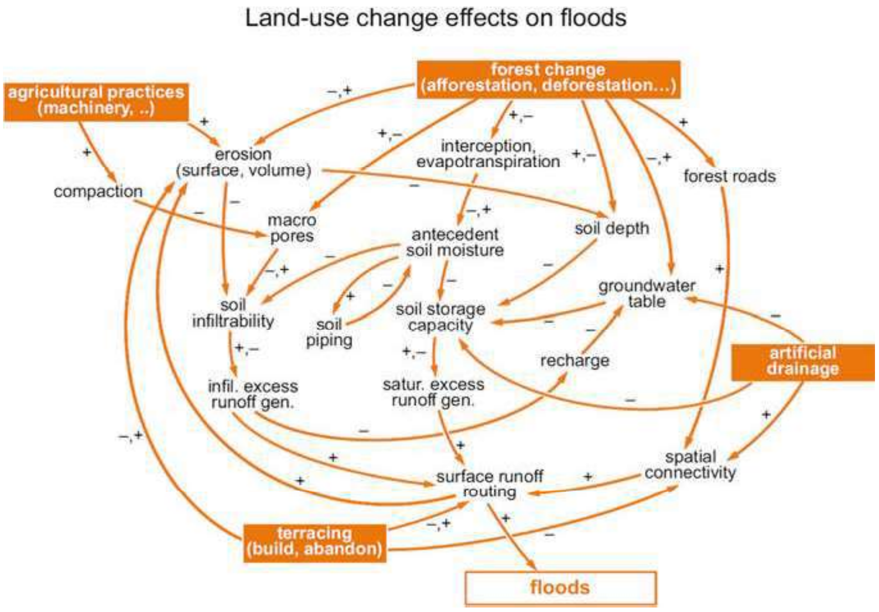

Fig. 1 Diagram of process interactions in land-use changing effects on floods at the catchment scale. Plus and minus signs indicate whether an increase in the variable increases or decreases another variable (*Source* Rogger et al. 2017)

concentration times. Large areas have been deforested or drained, thus either increasing or decreasing antecedent soil moisture and triggering erosion. In general, an increase in vegetation cover is expected to lead to a decrease in mean streamflow due to increased canopy interception and vegetation transpiration, and that a decrease in vegetation cover will lead to an increase in streamflow. However, the exact role of land-use change in modifying all these processes and thus the hydrological behaviour of a river basin is still to be determined. Also, our ability to predict the impacts of vegetation changes on streamflow regimes (e.g. low flow) across different spatio-temporal scales is still limited. The complexity of the issue is clearly illustrated in Fig. 1 (Rogger et al. 2017).

Concluding Remarks

The above review describes, in our judgment, the most important knowledge gaps that have been encountered by developers of agricultural and environmental system models. Acquisition of more knowledge in the above areas and its calibration will require both innovative experimental research and the development of new concepts, theories and models. Exciting and potentially high-impact areas of further research lie at the interface of several disciplines. Agricultural engineers are uniquely qualified to tackle such challenges and make highly original and much-needed contributions. Integrated within agricultural systems, such research will create breakthroughs in the knowledge that will help solve the main practical problems that agriculture is facing in the twenty-first century. To take advantage of the opportunities indicated above it will require a supply of high-quality researchers, educators innovators, and technicians along with appropriate facilities. Therefore, we need to develop education, research and training in engineering for agriculture.

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References

Arnold, J. R., Srinivasan, R., Muttiah, R. S., & Williams, J. R. (1998). Large area hydrologic modeling and assessment, Part 1: Model development. *Journal of the American Water Resources Association*, *34*, 73–89.

Bingner, R. L., & Theurer, F. D. (2001). AnnAGNPS: Estimating sediment yield by particle size by sheet and rill erosion. p. I-1-I-7. In *Proceeding Sediment Monitoring, Modeling, and Managing, 7th Federal Interagency Sedimentation Conference*, Reno, NV. 25–29 March, 2001. U.S. Dep. of Interior, U.S. Geological Survey, Reston, VA.

Buckley, T. N., Mott, K. A., & Farquhar, G. D. (2003). A hydro mechanical and biochemical model of stomatal Conductance. *Plant, Cell & Environment*, *26*, 1767–1785.

Cavalli, R., & Monarca, D. (2011). Lo stato e le prospettive della ricerca nel settore AGR/09. Convegno di Medio Termine dell'Associazione Italiana di Ingegneria Agraria Belgirate, 22–24 settembre 2011.

Enquist, B. J. (2003). Cope's Rule and the evolution of long-distance transport in vascular plants: Allometric scaling, biomass partitioning and optimization. *Plant, Cell & Environment*, *26*, 151–161.

Farahani, H. J., & Ahuja, L. R. (1996). Evapotranspiration modeling of partial canopy/residue-covered fields. *Transactions of the ASAE*, *39*, 2051–2064.

Gandolfi, C., & Lenzi, M. A. (2011). Stato e prospettive della ricerca nel settore Idraulica Agraria e Sistemazioni Idraulico-Forestali. Convegno di Medio Termine dell'Associazione Italiana di Ingegneria Agraria Belgirate, 22–24 september 2011.

Hanson, J. D. (2000). Generic crop production model for the root zone water quality model. p. 529–556. In L. R. Ahuja et al. (Ed.). *The root zone water quality model*. Highlands Ranch, CO: Water Resources Publications LLC.

Johnsen, K. E., Liu, H. H., Dane, J. H., Ahuja, L. R., & Workman, S. R. (1995). Simulating fluctuating water tables and tile drainage with the Root Zone Water Quality Model and a new model WAFLOWM. *Transactions of the ASAE*, *38*, 75–83.

Lehman, O. R., & Ahuja, L. R. (1985). Interflow of water and tracer chemical on sloping field plots with exposed seepage faces. *Journal of Hydrology (Amsterdam)*, *76*, 307–317.

Li, C. S. (2000). Modeling trace gas emissions from agricultural ecosystems. *Nutrient Cycling in Agroecosystems*, *58*, 259–276.

Lowrance, R. R., Altier, L. S., Williams, R. G., Inamdar, S. P., Bosch, D. D., Hubbard, R. K., et al. (2000). The riparian ecosystem management model. *Journal of Soil and Water Conservation*, *55*, 27–36.

Meinzer, F. C., Clearwater, M. J., & Goldstein, G. (2001). Water transport in trees: Current perspectives, new insights and some controversies. *Environmental and Experimental Biology*, *45*,239–262.

Misson, L., Panek, J. A., & Goldstein, A. H. (2004). A comparison of three approaches to modeling leaf gas exchange in annually drought-stressed ponderosa pine forests. *Tree Physiology*, *24*, 529–541.

Munark, A. (2000). Tasks for agricultural engineering research: New challenges-new trends? *Modelling and Control in Agricolture, Horticolture and Post-Harvest Processing*, Wageningen, The Netherlands.

Prusinkicwicz, P., & Lindenmayer, A. (1990). *The algorithmic beauty of plants*. New York: Springer.

Rogger, M., Agnoletti, M., Alaoui, A., Bathurst, J. C., Bodner, G., Borga, M., et al. (2017). Land use change impacts on floods at the catchment scale: Challenges and opportunities for future research. *Water Resources Research*, *53*, https://doi.org/10.1002/2017WR020723.

Rosenzweig, V., & Hillel, D. (1995). Updated 2004. Potential impacts of climate change on agriculture and food supply. Consequences 1(2). U.S. Climate Change Information Office, Washington, DC.

Scarascia Mugnozza, G., Cascone, G., & Tassinari, P. (2011). Stato dell'arte e prospettive della ricerca nel settore delle Costruzioni Rurali e Territorio Agroforestale. Convegno di Medio Termine dell'Associazione Italiana di Ingegneria Agraria Belgirate, 22–24 september 2011.

Schultz, B., & De Wrachien, D. (2002). Irrigation and drainage systems research and development in the 21st century. *Irrigation and Drainage*, *51*(4), 311–327 https://doi.org/10.1002/ird.67.

Seobi, T., Anderson, S. H., Udawatta, R. P., & Gantzer, C. J. (2005). Influence of grass and agroforestry buffer strips on soil hydraulic properties for an Albaqualf. *Soil Science Society of America Journal*, *69*, 893–901.

Sperry, J. S., Stiller, V., & Hacke, U. G. (2003). Xylem hydraulics and the soil-plant-atmosphere continuum: Opportunities and unresolved issues. *Agronomy Journal*, *95*, 1362–1370.

Tardìeu, V., & Davies, W. J. (1993). Integration of hydraulic and chemical signaling in the control of stomatal conductance and water status of drought plants. *Plant, Cell & Environment*, *16*, 341–349.

Tubiello, E. N., Donatelli, M., Rosenzweig, C., & Stockle, C. O. (2000). Effects of climate change and elevated CO, on cropping systems: Model predictions at two Italian locations. *European Journal of Agronomy*, *12*, 179–189.

Tuzet A., Perrier A., & Leuning R. (2003). A coupled model of stomata conductance, photosynthesis and transpiration. *Plant, Cell & Environment*, *26*, 1097–1116.

Tyree, M. T. (1997). The Cohesion-Tension theory of sap ascent: Current controversies. *Journal of Experimental Botany*, *48*, 1753–1765.

Zheng, F. L., Huang, C., & Darrell Norton, V. (2000). Vertical hydraulic gradient and run-on water and sediment effects on erosion processes and sediment regimes. *Soil Science Society of America Journal*, *64*, 4–11.

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High Accuracy Site-Specific Secondary Data for Mechanical Field Operations to Support LCA Studies

Marco Fiala and Luca Nonini

Abstract The aim of the study was to quantify site-specific secondary data of mechanical field operations for EU barley cropping. By the model ENVIAM v2, each operation was subdivided into 13 working times and, for each of them, the amount of total consuming inputs (fuel, lubricant and AdBlue®) and emissions of exhaust gases into the atmosphere were calculated. The amount of partial consuming inputs (machinery mass) and emissions of heavy metals into the soil were also quantified. Three scenarios (S) were identified: $S_1 = 50$ ha, $S_2 = 100$ ha, $S_3 = 200$ ha, with the same: agronomic conditions, operations sequence, type of machines used and cropping inputs. For each scenario, two barley ideotypes were analyzed: (i) currently in use (BarNow, 2018) and (ii) future (BarPlus, 2030). BarPlus is characterized by: (i) higher grain and straw yield, Nitrogen fertilization rate and machinery Effective Field Capacity, (ii) use of TIER 5 fuel engines, (iii) lower specific minimum fuel consumption. BarNow inputs ($kg \cdot ha^{-1}$) were: fuel = 67 ÷ 74, lubricant = 0.56 ÷ 0.73, mass = 7.9 ÷ 8.8. BarPlus inputs ($kg \cdot ha^{-1}$) were: fuel = 55 ÷ 60, lubricant = 0.53 ÷ 0.69, AdBlue® = 2.8 ÷ 3.0, mass = 7.2 ÷ 8.0. The highest fuel and mass consumptions were in both cases related to tillage operations.

Keywords Barley cultivation · Mechanical field operation · Working time · Site-specific secondary data · Environmental inventory

1 Introduction

The most widespread methodology to quantify the potential environmental impacts of agricultural processes is the Life Cycle assessment (Life Cycle Analysis, LCA) (Notarnicola et al. 2017). Among the LCA phases, the Life Cycle Inventory (LCI) is the most complex to accomplish because all the system inputs (fuel, lubricant,

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masses) and outputs (emissions into the atmosphere, water and soil) have to be identified and quantified. Often, these data are not easy to collect experimentally, and long and expensive sampling are needed (Dyer and Desjardins 2003; Ossés de Eicker et al. 2010). To limit this problem, many commercial Databases that provide information about different agricultural processes (e.g. Ecoinvent, Danish LCA food, EU and DK input and output Database, Agri-footprint Database) were developed (Jannick et al. 2010; Ecoinvent 2015). Nevertheless, they usually provide simplified information about some processes and, therefore, their main deficiency is the lack of reliability. This represents a major problem for mechanical field operations, which are performed in very different conditions, both pedological (texture, water content, slope, shape and size of the field and its distance from the farm), and climatic (temperature and rainfall) (Lovarelli et al. 2016, 2017). Mechanical field operations play a crucial role in determining the environmental impacts of agricultural processes (Keyes et al. 2015) but, due to the abovementioned problems, performing reliable LCA studies using site-specific primary data is a key challenge. Therefore, it is necessary to develop models able to calculate secondary data with high accuracy, according to the different site-specific conditions (Bengoa et al. 2014). Several studies were performed to evaluate the environmental impacts of cereal cropping (Murphy and Kendall 2013; Achten and Van Acker 2016), including those related to barley cultivation (Dijkman et al. 2017). Barley is a great source of nutrients, carbohydrates and fiber (Baik and Ullrich 2008), and it is primarily used for animal feedstock and malt production (Schmidt Rivera et al. 2017). This crop is the 12th most important agricultural commodity in the world, and Europe is the largest producer (62% of the world production). The aim of the study was to quantify site-specific secondary data related to mechanical field operations for EU barley cropping (from soil tillage to grain and straw transport) to support LCA studies.

2 Materials and Methods

2.1 The Model ENVIAM V2

The model ENVIAM v1 (“ENVironmental Inventory of Agricultural Machinery operations”) was developed some years ago (Lovarelli et al. 2016) to calculate site-specific secondary data related to mechanical field operations, by taking into account specific working times (t_j; h) (Reboul 1964). These data refer to both the amount of total (fuel and lubricant) and partial (mass of machinery) consuming inputs, as well as the emissions of exhaust gases (CO_2, CO, HC, PM and NO_x) into the atmosphere, resulting from fuel combustion. ENVIAM v1 was recently implemented into a second version (ENVIAM v2); the main improvements are: (i) calculation of the working times (13 in total) in separate worksheets, specifically developed for each type of implement used. To make the further calculations feasible and accurate, a value of engine load (λ; % tractor’s maximum engine power) must be assigned to each working time. This is a fundamental step, since fuel consumptions—and thus exhaust gases emissions into the atmosphere—strongly depend on both tractor's engine loads and duration of each working time (Lovarelli et al. 2018). The time for transfer farm-to-field and field-to-farm (including the one for lunch breaks) was included in the calculation: it cannot be neglected for operations carried out over one day and for long distances between the farm center and the fields; (ii) calculation of AdBlue® consumption if the tractor is equipped with a Selective Catalyst Reduction (SCR) system; (iii) calculation—for tractors—of the mass required for production, consumption, maintenance and repair, by introducing a repair factor according to the Ecoinvent v3.2® Database documentation (Nemecek and Kägi 2007); (iv) calculation of the mass of tire abraded during the operation and the corresponding mass of heavy metals (Cd, Pb, Zn) released into the soil (Nemecek and Kägi 2007); (v) improvement of the general structure of the model, by removing some demanding tests, to provide a more intuitive and user-friendly interface. Other aspects are instead still under investigation: (i) calculation of the tractor's engine power losses in the case of hydraulic/mixed transmissions and (ii) calculation of consumptions and emissions for operations performed under slope conditions.

2.2 *Barley Cultivation Scenarios*

The analysis was based on the following assumptions about barley production in Europe: (i) the crop is cultivated on a wide range of farms whose Agricultural Area Used (AAU; ha) ranges from a few tens to a few hundred hectares (European Commission 2018); (ii) the sequence of mechanical field operations is simplified compared to other herbaceous crops and involves the use of the same types of machines; (iii) the production factors (inputs) are limited in terms of both quality and quantity (Marinussen et al. 2012); (iv) the crop is not irrigated (barley has a good resistance to drought and, usually, uses only natural water supplies); (v) grain (Y_G; $t{\cdot}ha^{-1}$) and straw (Y_S; $t \cdot ha^{-1}$) yields show limited variations among different cultivation areas (Marinussen et al. 2012). Three different scenarios (S) were compared (Fiala et al. 2019): (i) S1: small size cereals production farm ($AAU_1 = 50$ ha); (ii) S2: medium size cereals production farm ($AAU_2 = 100$ ha); (iii) S3: medium-large size cereals production farm ($AAU_3 = 200$ ha). These scenarios were all characterized by the same: (i) cultural conditions (fields characteristics and length, distance from the farm center); (ii) cultivation operations timeline and type of machines used and (iii) cropping inputs (Table 1).

Tractors and implements technical characteristics referred to EU agricultural machinery market; cropping inputs amounts referred to EU conditions. S1, S2 and S3 scenarios were different for the tractors (number, type, engine power) and implements (size) fleet. For each scenario, two barley ideotypes were taken into account: (i) currently in use (year 2018, BarNow; $S1_{NOW}$, $S2_{NOW}$, $S3_{NOW}$) and (ii) a future

Table 1 Agronomic parameters used for the different scenarios

	Unit	S1	S2	S3
Agricultural area used	ha	$AAU_1 = 50$	$AAU_2 = 100$	$AAU_3 = 200$
Barley area (60% AAU)	ha	$AAU_{B1} = 30$	$AAU_{B2} = 60$	$AAU_{B3} = 120$
Other crops (35% AAU)	ha	$AAU_{O1} = 17.5$	$AAU_{O2} = 35$	$AAU_{O3} = 70$
Green crops (5% AAU)	ha	$AAU_{G1} = 2.5$	$AAU_{G2} = 5$	$AAU_{G3} = 10$
Fields distance	km	D = 2.0		
Fields characteristics	–	Soil texture: medium; area: flat; shape: rectangular		
Fields length	m	$b_L = 800$		
Cropping sequence	–	(1) NPK fertilization, (2) ploughing, (3) harrowing, (4) sowing, (5) chemical weed control, (6) N fertilization, (7) grain harvesting and (8) transport, (9) straw collection and (10) transport		
Cropping inputs	$kg \cdot ha^{-1}$	Seeding rate: 190; herbicide rate: 1.45		

ideotype (year 2030, BarPlus; $S1_{PLUS}$, $S2_{PLUS}$, $S3_{PLUS}$). BarNow and BarPlus cultivations were compared by introducing, for the latter, cropping and technological improvements.

2.2.1 Cropping Improvements

Grain and straw yield and dry matter (DM) content of both barley ideotypes are shown in Table 2.

The improvement of the performance of the BarPlus ideotype was pointed out in the Project "*BARPULS—Modifying canopy architecture and photosynthesis to maximize barley biomass and yield for different end-uses*" (EU FACCE-SURPLUS ERA-NET, 2015–2018). According to the results of this Project—which takes into account future climate changes in EU, as well as the evolution of barley genotype and phenotype—the increase of the biomass yield (for both grain and straw) can be achieved by a higher rate in Nitrogen mineral fertilization ($\Delta N = 20\ kg \cdot ha^{-1}$ of N) (Table 3).

Table 2 BarNow and BarPlus scenarios: grain and straw characteristics and yields

Product	BarNow (year 2018)		BarPlus (year 2030)	
	Dry matter (%)	Yield ($t \cdot ha^{-1}$) ($t \cdot ha^{-1}$ DM)	Dry matter (%)	Yield ($t \cdot ha^{-1}$) ($t \cdot ha^{-1}$ DM)
Grain	$DM_G = 81.5\%$	$Y_G = 6.5$ (5.3)	$DM_G = 88.0$	$Y_G = 7.5$ (6.6)
Straw	$DM_S = 84.5\%$	$Y_S = 6.5$ (5.5)	$DM_S = 86.3$	$Y_S = 7.3$ (6.3)

Table 3 BarNow and BarPlus scenarios: NPK requirements and fertilizer rates (R)

Agronomic aspects	Unit	BarNow (year 2018)	BarPlus (year 2030)
Requirements	$kg \cdot ha^{-1}$	(N) 100; (K_2O) 20; (P_2O_5) 40	(N) 120; (K_2O) 20; (P_2O_5) 40
1st mineral fert.	$kg \cdot ha^{-1}$	$R_1 = 150$ (NPK 20-20-20)	$R_1 = 150$ (NPK 20-20-20)
2nd mineral fert.	$kg \cdot ha^{-1}$	$R_2 = 220$ Urea (46%)	$R_2 = 265$ Urea (46%)

Table 4 BarNow and BarPlus scenarios: technological improvements in fuel engines

Technical aspects	Unit	BarNow (year 2018)	BarPlus (year 2030)
Emission stage	–	TIER 3B	TIER 5
Equipment	–	None	SCR and AdBlue® (#)
Specific fuel consumption	$g \cdot kWh^{-1}$	$cs_{MIN} = 200 \div 250$	$\Delta cs_{MIN} = -10\%$

Note: (#) AdBlue® consumption = 5% of fuel consumption

2.2.2 Technological improvements

Compared to BarNow, for the BarPlus scenarios the following improvements were considered (Table 4): (i) use of internal combustion (i.c.) fuel engines at TIER 5 (Emission Stage V, in force since January 2019); (ii) reduction of NO_x emissions into the atmosphere (use of SCR systems and AdBlue®); (iii) decrease of 10% of the specific minimum fuel consumption (cs_{MIN}; $g \cdot kWh^{-1}$), due to improved performance of i.c. engines (Diesel cycle, in particular).

In addition, for the BarPlus scenarios, due to the technological innovations in the agricultural machinery sector, an increase of the Effective Field Capacity (EFC; $ha \cdot h^{-1}$) of the implements was introduced: $\Delta EFC = +10\%$ for less complex machines (shovels plough, rotary harrow, dumper for grain and trailer for straw) and $\Delta EFC = + 15\%$ for more complex ones (mineral fertilizer spreader, row seeder, herbicide sprayer, combine harvester and round baler).

2.2.3 S1, S2, S3 Machines (Tractors and Implements)

Information about the tractor fleets of S1, S2 and S3 scenarios are shown in Table 5.

For all scenarios, the following implements were used: n.1 mineral fertilizer spreader, n.1 shovel plow, n.1 rotary harrow, n.1 row seeder (mechanical type for S1; pneumatic type for S2 and S3), n.1 herbicide sprayer, n.1 combine harvester, n.1

Table 5 S1, S2 and S3 scenarios: farm tractor fleets

	Farm tractor fleet				
Scenario	Number and type	Power range (kW)	Total power (kW)	Mechanization index (kW·ha^{-1})	Annual use (h·year^{-1})
S1	3 4WD, 1 2WD	30–100	240	$Pm_{AAU1} = 4.8$	$H_{n1} = 1000$
S2	4 4WD, 1 2WD	50–150	400	$Pm_{AAU2} = 4.0$	$H_{n2} = 1000$
S3	6 4WD, 1 2WD	50–200	780	$Pm_{AAU3} = 3.9$	$H_{n3} = 1000$

dumper (for grain transport), n.1 baler (round bales), n.1 trailer (for straw transport). It was assumed that all the operations were carried out by using farm machines, except for grain harvesting (n.1 combine harvester), carried out by a contractor.

3 Results and Discussion

The Total Time (T_{TOT}; h) spent for barley cultivation in the different scenarios were:

- S1: $T_{TOT1} = 226$ h and 209 h, for $S1_{NOW}$ and $S1_{PLUS}$, respectively. Consequently, the whole machinery chain Effective Field Capacity (EFC_1) increases from 0.13 ha · h^{-1} ($S1_{NOW}$) to 0.14 ha · h^{-1} ($S1_{PLUS}$);
- S2: $T_{TOT2} = 304$ h and 281 h, for $S2_{NOW}$ and $S2_{PLUS}$, respectively. The whole machinery chain Effective Field Capacity (EFC_2) increases from 0.20 ha · h^{-1} ($S2_{NOW}$) to 0.21 ha · h^{-1} ($S2_{PLUS}$);
- S3: $T_{TOT3} = 461$ h and 430 h, for $S3_{NOW}$ and $S3_{PLUS}$, respectively. The whole machinery chain Effective Field Capacity (EFC_3) increases from 0.26 ha · h^{-1} ($S3_{NOW}$) to 0.28 ha · h^{-1} ($S3_{PLUS}$).

The EFC_3 is practically double compared to EFC_1; moreover, within each scenario, the EFC related to S_{PLUS} is only 5–8% higher than the EFC related to S_{NOW}.

Fuel consumption—and thus the emissions of exhaust gases into the atmosphere—strongly depend on both tractor's engine loads and duration of each working time. The widespread assumption that engine load is constant (generally, close to 80%) for each working time (that means to assume a constant low specific fuel consumption during the whole field operation), often leads to underestimate the emissions of exhaust gases into the atmosphere.

Inputs and emissions of exhaust gases into the atmosphere amounted to (kg·ha^{-1}):

- BarNow scenarios: fuel FC = 67 ÷ 74, lubricants LC = 0.56 ÷ 0.73, mass MC = 7.9 ÷ 8.8, emissions of CO $EM_{CO} = 0.37 \div 0.61$, emissions of HC $EM_{HC} = 0.09 \div 0.11$, emissions of NO_x $EM_{NOx} = 1.11 \div 1.62$, emissions of PM $EM_{PM} = 0.01 \div 0.02$, emissions of CO_2 $EM_{CO2} = 210 \div 232$;

- BarPlus scenarios: fuel FC = 55 ÷ 60, lubricants LC = 0.53 ÷ 0.69, AdBlue® AdB = 2.8 ÷ 3.0, mass MC = 7.2 ÷ 8.0, emissions of CO EM_{CO} = 0.29 ÷ 0.47, emissions of HC EM_{HC} = 0.08 ÷ 0.10, emissions of NO_x EM_{NOx} = 0.22 ÷ 0.33, emissions of PM EM_{PM} = 0.01 ÷ 0.02, emissions of CO_2 EM_{CO2} = 174 ÷ 189.

The highest fuel (i.e. CO_2 emissions) and mass consumptions are—in any scenario—related to soil tillage (ploughing) operations (hotspot). Even if the results seem to be similar to those obtained by Niero et al. (2015), Dijkman et al. (2017) and Schmidt Rivera et al. (2017), it is not possible to do an absolute comparison because of the specificity of the methodology used in this study.

4 Conclusions

Although the use of primary data is always preferable to perform reliable LCA analysis, the collection of this type of data can be expensive and time-consuming. An alternative is the use of secondary data, related to the local working conditions, calculated by using specific models. In this study the model ENVIAM v2 was applied to calculate site-specific secondary data related to the mechanical field operations for barley cropping in EU conditions. The correct tractor-implement coupling is essential to assess the environmental performances of barley cultivation, especially if—as in this study—high accuracy calculations based on the relation between engine loads and working times are performed. By using ENVIAM v2—and commercial software—it is possible:

- to produce accurate local inventories containing complex information (mainly consumptions and emissions), thanks to the possibility of choosing—among the set of tractors and implements defined in the model—the coupling that best simulates the local working conditions;
- to quantify the potential environmental impacts related to the whole production cycle. The data provided by ENVIAM v2 can be used to carry out an LCA analysis focused on one specific operation or on the full sequence of operations composing the crop cycle. Therefore, it is possible to identify the phases (or operations) to which the highest potential impacts on the environment are associated (hotspots);
- to identify mitigation solutions: this means to re-analyze the system assuming, on one hand, to use different machines to achieve the same goal and, on the other hand, to re-define the sequence of the mechanical field operations. In the first case, different machines designed to perform the same operation could be associated with different working times, consumptions and emissions, whereas, in the second case, the same agrotechnical objective can be achieved with a different sequence of operations, making it possible to define strategies (at the farm or landscape level) with lower potential environmental impacts.

References

Achten, W. M. J., & Van Acker, K. (2016). EU-Average impacts of wheat production. A meta-analysis of life cycle assessments. *Journal of Industrial Ecology 20*(1), 132–144.

Baik, B. K., & Ullrich, S. E. (2008). Barley for food: characteristics, improvement, and renewed interest. *Journal of Cereal Science, 48*(2), 233–242.

Bengoa, X., Rossi, V., Humbert, S., Nemecek, T., Lansche, J., & Mouron, P. (2014). Methodological guidelines for the life cycle inventory of agricultural products. Version 2.0, July 2014. World food LCA database. *Quantis and Agroscope, Lausanne and Zurich, Switzerland*, 1–79.

Dijkman, T. J., Birkved, M., Saxe, H., Wenzel, H., & Hauschild, M. Z. (2017). Environmental impacts of barley cultivation under current and future climatic conditions. *Journal of Cleaner Production, 140,* 644–653.

Dyer, J. A., & Desjardins, R. L. (2003). Simulated farm fieldwork, energy consumption and related greenhouse gas emissions in Canada. *Biosystems Engineering, 85*(4), 503–513.

Ecoinvent (2015). Ecoinvent database. http://www.ecoinvent.org/database/.

European Commission (2018). Eurostat handbook for annual crop statistics, revision 2018. https://ec.europa.eu/eurostat/cache/metadata/Annexes/apro_cp_esms_an1.pdf.

Fiala, M., Nonini, L., & Marveggio, D. (2019). Environmental assessment. Task 4.3 final report, project *"BARPLUS–Modifying canopy architecture and photosynthesis to maximize barley biomass and yield for different end-uses"*, (Internal FACCE-SURPLUS ERA-NET Project report, June 2019) (pp. 122).

Jannick, H. S., Weidema, B. P., Munõz, I., Dalgaard, R., Merciai, S., & de Saxcé, M. (2010). 2.0 LCA Consultants. www.lca-net.com.

Keyes, S., Tyedmers, P., & Beazley, K. (2015). Evaluating the environmental impacts of conventional and organic apple production in Nova Scotia, Canada, through life cycle assessment. *Journal of Cleaner Production, 104,* 40–51.

Lovarelli, D., Bacenetti, J., & Fiala, M. (2016). A new tool for life cycle inventories of agricultural machinery operations. *Journal of Agricultural Engineering, 47*(1), 40–53.

Lovarelli, D., Bacenetti, J., & Fiala, M. (2017). Effect of local conditions and machinery characteristics on the environmental impacts of primary soil tillage. *Journal of Cleaner Production, 140,* 479–491.

Lovarelli, D., Fiala, M., & Larson, 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.

Marinussen, M., van Kernebeek, H., Broekema, R., Groen, E., Kool, A., van Zeist, W. J., et al. (2012). LCI data for the calculation tool feedprint for greenhouse gas emissions of feed production and utilization. http://www.blonkconsultants.nl/wpcontent/uploads/2016/06/Cultitvation-cereals-D03.pdf.

Murphy, C. W., & Kendall, A. (2013). Life cycle inventory development for corn and stover production systems under different allocation methods. *Biomass and Bioenergy, 58,* 67–75.

Nemecek, T., & Kägi, T. (2007). Life cycle inventories of Swiss and European agricultural production systems. Final report ecoinvent V2.0 No. 15a, Agroscope Reckenholz-Taenikon Research Station ART, Swiss Centre for Life Cycle Inventories, Zurich and Dübendorf, CH. Retrieved from www.ecoinvent.ch.

Niero, M., Ingvordsen, C. H., Peltonen-Sainio, P., Jalli, M., Lyngkjær, M. F., Hauschild, M. Z., et al. (2015). Eco-efficient production of spring barley in a changed climate: a life cycle assessment including primary data from future climate scenarios. *Agricultural Systems, 136,* 46–60.

Notarnicola, B., Sala, S., Anton, A., McLaren, S. J., Saouter, E., & Sonesson, U. (2017). The role of life cycle assessment in supporting sustainable agri-food systems: a review of the challenges. *Journal of Cleaner Production, 140,* 399–409.

Ossés de Eicker, M., Hischier, R., Kulay, L. A., Lehmann, M., Zah, R., & Hurni, H. (2010). The applicability of non-local LCI data for LCA. *Environmental Impact Assessment Review, 30*(3), 192–199.

Reboul, C. (1964). Temps des travaux et jours disponibles en agriculture. *Economie Rurale, 61,* 50–80.

Schmidt Rivera, X. C., Bacenetti, J., Fusi, A., & Niero, M. (2017). The influence of fertiliser and pesticide emissions model on life cycle assessment of agricultural products: The case of Danish and Italian barley. *Science of Total Environment, 592,* 745–757.