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

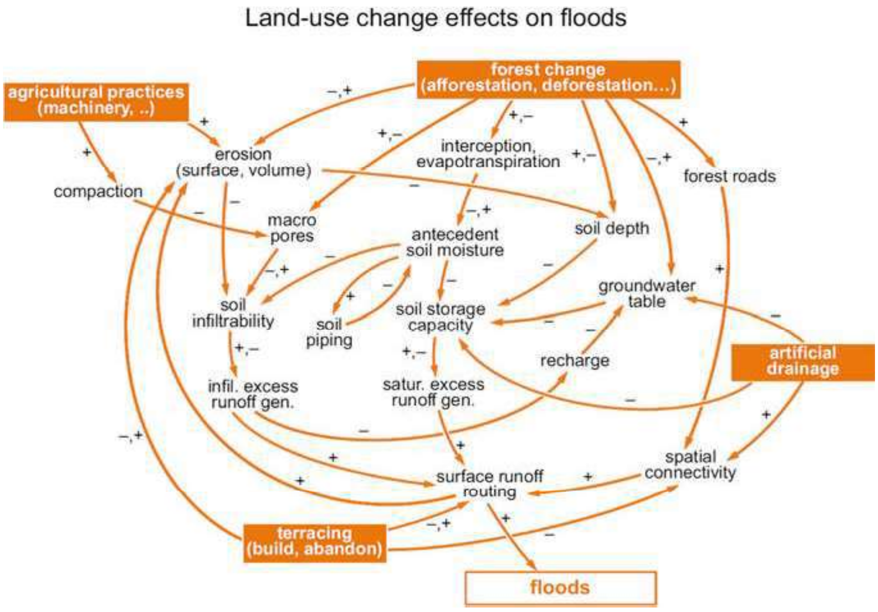

Fig. 1 Diagram of process interactions in land-use changing effects on floods at the catchment scale. Plus and minus signs indicate whether an increase in the variable increases or decreases another variable (*Source* Rogger et al. 2017)

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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Assessment of Forest Biomass and Carbon Stocks at Stand Level Using Site-Specific Primary Data to Support Forest Management

Luca Nonini, Calogero Schillaci and Marco Fiala

Abstract To quantify and map woody biomass (WB) and forest carbon (C) stocks, several models were developed. They differ in terms of scale of application, details related to the input data required and outputs provided. Local Authorities, such as Mountain Communities, can be supported in sustainable forest planning and management by providing specific models in which the reference unit is the same as the one reported in the Forest Management Plans (FMP), i.e. the forest stand. In the Lombardy Region (Northern Italy), a few studies were performed to assess WB and forest C stocks, and they were generally based on data coming from regional—or national—forest inventories and remote sensing, without taking into account data collected in the FMPs. For this study, the first version of the stand-level model "WOody biomass and Carbon ASsessment" (WOCAS) for WB and C stocks calculation was improved into a second version (WOCAS v2) and preliminary results about its first application to 2019 forest stands of Valle Camonica District (Lombardy Region) are presented. Since the model WOCAS uses the growing stock as the main driver for the calculation, it can be applied in any other forest area where the same input data are available.

Keywords Forest modelling · Woody biomass · Carbon stock · Forest management plan · Site-specific primary data · Climate change mitigation

1 Introduction

Forests provide several Ecosystem Services (ES), commonly classified as: (i) regulating, (ii) provisioning and (iii) cultural (Costanza et al. 1997; Bennett et al. 2009; Krieger 2011). The quantification of the demand (human society) and the supply (environment) of ESs is a key challenge to define the effective environmental management practices and to identify the best institutional scale for the decision-making

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processes (Daily and Matson 2008; Swetnam et al. 2011; Kroll et al. 2012; Marchetti et al. 2012; Garcia-Gonzalo et al. 2015). In the context of the current climate change scenario, the most important forest ESs are: (i) woody biomass (WB) supply and (ii) carbon (C) stock (Nabuurs et al. 2008; Ekholm 2016; Gren and Zeleke 2016). WB supply and C stock are indicators of provisioning and regulating services, respectively, and they are competing, as an increase in WB supply generally causes a reduction of C stock in the forest (Bottalico et al. 2016). To quantify and map these two ESs, several models were developed; they differ in terms of scale of application (single tree, whole stand, regional or continental level), details related to the input data required and outputs provided (Vanclay 1994; Pretzsch et al. 2009; Klein et al. 2013; Pilli et al. 2013). In the alpine forestry region, Mountain Communities are the main Local Authorities having a key role in forest planning and management (Cantiani 2012). At this purpose, stand-level models are particularly important because stands represent the reference unit of the Forest Management Plans (FMP). FMPs make available a wide range of primary (measured) data that can be used to estimate the current WB (and the corresponding aboveground and belowground C stock), the harvested mass and their variation over time. In the Lombardy Region (Northern Italy) only a few studies were performed to assess WB and forest C stocks, and they were generally based on data coming from regional—or national—forest inventories and remote sensing (Federici et al. 2008; Colombo et al. 2009). None of these studies took into account primary data collected in the FMPs. Considering all these elements, the aims of this study were: (i) to develop a model—based on site-specific primary data—to calculate WB and C stocks at the stand level, (ii) to test the model for the Valle Camonica District (Lombardy Region) and (iii) to map the spatial distribution of these stocks at different levels (from the stand, to the municipality and to the whole forest area under assessment).

2 Materials and Methods

2.1 The Model WOCAS

A first version of an empirical stand-level model called "WOody biomass and Carbon ASsessment" (WOCAS) was developed to calculate the annual WB and C stocks in different forest pools. This model was recently improved into a second version (WOCAS v2) by: (i) adding new information (FMPs new data), (ii) defining more accurate calculation methods and (iii) improving the general structure to increase the model's reliability and flexibility. For a generic (j) forest stand, for the year n, calculations are performed in the following pools: (i) aboveground woody biomass ($AWB_{n(j)}$), (ii) belowground woody biomass ($BWB_{n(j)}$) and (iii) dead organic matter ($DOM_{n(j)}$; dead woody biomass + litter) by applying a mass balance based on a "gain-loss" approach consistent with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006; Federici et al. 2008).

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For each of the j-stand, the input data required are: (i) starting ($YR_{S(j)}$) and final ($YR_{F(j)}$) year of the FMP, (ii) forest typology, (iii) forest function (e.g. production, environmental protection, recreational), (iv) forest structure (i.e. coppice, high forest), (v) area ($A_{(j)}$; ha), (vi) growing stock at $YR_{S(j)}$ ($GS_{(j)}$; t $year^{-1}$ dry matter, hereafter DM) and (vii) harvested growing stock over time ($H_{n(j)}$; t $year^{-1}$ DM).

For each harvesting operation, the corresponding woody residues ($HR_{n(j)}$; t $year^{-1}$ DM)—consisting in tree stumps, tops, branches, twigs and non-commercial parts—are also calculated (IPCC 2006). Woody residues represent a loss from the living $AWB_{n(j)}$ and $BWB_{n(j)}$ pools, and—if they are left on the ground and are not extracted from the stand—a gain for the $DOM_{n(j)}$ pool.

For the year n, starting from the growing stock of the previous year ($GS_{n\text{-}1(j)}$; t $year^{-1}$ DM), the gross annual increment ($GAI_{n(j)}$; t $year^{-1}$ DM) is calculated by applying the first derivative of the Richards growth function (Richards 1959; Pienaar and Turnbull 1973; Birch 1999; Federici et al. 2008). Then, the net annual increment ($NAI_{n(j)}$; t $year^{-1}$ DM)—defined as $GAI_{n(j)}$ minus growing stock losses within the same period of time due to natural mortality (UNECE/FAO 2011)—is quantified.

Two types of natural mortality are considered: (i) regular (RM), due to senescence, competition for light, water, nutrient and from the normal incidence of pests, diseases, and weather phenomena, and (ii) irregular (IM), due to wildfires, windstorms, avalanches, insect outbreaks or other disturbances (Vanclay 1994; Alenius et al. 2003). Regarding the former, the model assumes that the growing stock losses ($GS_{RMn(j)}$; t $year^{-1}$ DM) occur each year, whereas, regarding the latter, information about: (i) year of occurrence, (ii) type of disturbance and (iii) growing stock losses ($GS_{IMn(j)}$; t $year^{-1}$ DM) has to be defined by the user. As well as for the woody residues, natural mortality represents a loss from the living $AWB_{n(j)}$ and $BWB_{n(j)}$ pools, and a gain for the $DOM_{n(j)}$ pool. In more detail, for the regular mortality, the model assumes that all the $GS_{RMn(j)}$ are transferred to the $DOM_{n(j)}$ pool, whereas, for the irregular mortality, the model calculates the fraction of the $GS_{IMn(j)}$ transferred to the $DOM_{n(j)}$ pool according to the type of disturbance.

The growing stock in the year n ($GS_{n(j)}$; t $year^{-1}$ DM) is then calculated starting from the $GS_{n\text{-}1(j)}$ (t $year^{-1}$ DM), adding the $NAI_{n(j)}$ (t $year^{-1}$ DM) and subtracting losses due to the harvested growing stock , $H_{n(j)}$ (t $year^{-1}$ DM). The living $AWB_{n(j)}$ and $BWB_{n(j)}$ (t $year^{-1}$ DM) stocks are calculated by multiplying the $GS_{n(j)}$ for specific coefficients (Somogyi et al. 2007; Federici et al. 2008) defined according to the stand's characteristics.

The $DOM_{n(j)}$ in the year n is calculated by taking into account, as inputs: (i) $GS_{RMn(j)}$, (ii) $GS_{IMn(j)}$ and (iii) $HR_{n(j)}$, and as output, the $DOM_{n(j)}$ decomposition, by using specific decay rates (Harmon et al. 1986; Melin et al. 2009) defined according to the stand's characteristics.

Finally, the carbon stocks in: (i) $AWB_{n(j)}$ ($C_{AWBn(j)}$, t $year^{-1}$ C), (ii) $BWB_{n(j)}$ ($C_{BWBn(j)}$, t $year^{-1}$ C) and (iii) $DOM_{n(j)}$ ($C_{DOMn(j)}$, t $year^{-1}$ C) are calculated by multiplying the WB of each pool for the corresponding carbon fraction , k_C ($k_{C\_AWB(j)}$;

$k_{C\_BWB(j)}$; $k_{C\_DOM(j)}$). The sum of: (i) $C_{AWBn(j)}$, (ii) $C_{BWBn(j)}$ and (iii) $C_{DOMn(j)}$ allows to calculate the total carbon content of the j-stand.

2.2 *Case Study*

The model WOCAS was applied to the Valle Camonica District to estimate WB and C stocks of the public forests. The total forest area is equal to 6.5×10^4 ha (52% of the total area); the public forests (managed through FMPs) cover 4.2×10^4 ha, whereas the private forests (not managed through FMPs) cover the remaining 2.3×10^4 ha. Among the coniferous, the main species are *Picea abies* L. and *Larix decidua* Mill. (30% and 20%, respectively), whereas, among the broadleaves, the main species are *Alnus viridis chaix* D.C. and *Castanea sativa* Mill. (11% and 8%, respectively). Production forests cover about 60% of the total forest area, followed by protection and recreational forests (38% and 2%, respectively).

For the study, data related to 2019 forest stands (forest area equal to 3.7×10^4 ha, approximately) were extracted from 45 FMPs collected in the Cadastral FMPs database (CPA v2) made available by the Mountain Community. The dataset covered the period from 1984 (starting year of the oldest FMP) to 2016 (no more recent data were made available from the CPA v2).

To calculate the gross annual increment, specific growth parameters were used for each of the j-stand, according to species and type of management (Vitullo 2018); these parameters were made available by the Italian Institute for Environmental Protection and Research (ISPRA) and represent the ones used for the official UNFCCC National Inventory Report (NIR) for Land Use, Land Use Change and Forestry (LULUCF) sector for the Lombardy Region. The $GS_{RMn(j)}$ (t year^{-1} DM) were assumed equal to 9.25% of the $GAI_{n(j)}$ (Tabacchi et al. 2010; Magnani and Raddi 2014). As a preliminary assessment, no differences among the stands were introduced. The $GS_{IMn(j)}$ (t year^{-1} DM) were not considered because no data were made available from the CPA v2. To calculate the $HR_{n(j)}$ (t year^{-1} DM), as well as the $AWB_{n(j)}$ and the $BWB_{n(j)}$ (t year^{-1} DM), the coefficients suggested by Federici et al. (2008) for the Italian forests were used. To simulate the $DOM_{n(j)}$ decomposition, not having specific data related to the Italian forests, the values of decay rates suggested by Harmon et al. (2001) for temperate forests were applied. Specific values of $k_{C\_AWB(j)}$ were considered, by taking into account the stem of the leading species (Thomas and Martin 2012). Moreover, it was assumed that $k_{C\_AWB(j)} = k_{C\_BWB(j)} = k_{C\_DOM(j)}$.

3 Results and Discussion

The main results of the last 2 years of the analysis (2015 and 2016)—for which the data of all the stands were made available from the CPA v2—are shown in Table 1.

Table 1 WB and forest C stocks related to the 2019 stands considered in the case study

		Unit	Year	
			2015	2016
Harvested growing stock	H_n	t year^{-1} DM	1.5×10^4	4.1×10^3
Gross annual increment	GAI_n	t year^{-1} DM	8.6×10^4	8.6×10^4
Net annual increment	NAI_n	t year^{-1} DM	7.8×10^4	7.8×10^4
Growing stock	GS_n	t year^{-1} DM	3.1×10^6	3.2×10^6
Aboveground woody biomass	AWB_n	t year^{-1} DM	4.1×10^6	4.2×10^6
Carbon stock in the aboveground woody biomass	C_{AWBn}	t year^{-1} C	2.0×10^6	2.1×10^6
Belowground woody biomass	BWB_n	t year^{-1} DM	9.0×10^5	9.2×10^5
Carbon stock in the belowground woody biomass	C_{BWBn}	t year^{-1} C	4.4×10^5	4.5×10^5

For both the year 2015 and 2016, the harvested growing stock (H_{2015} and H_{2016}, respectively) is lower than the net annual increment (NAI_{2015} and NAI_{2016}, respectively) ($H_{2015} = 19.2\%\ NAI_{2015}$; $H_{2016} = 5.3\%\ NAI_{2016}$). The ratio between H_n and NAI_n represents the effective extraction rate (EER ≥ 0) and is one of the most important indicators for the sustainable forest management. In fact, if in the short term H_n can exceed NAI_n (EER > 1), i.e. for years characterized by a high demand of woody biomass (for energy and/or building purposes), in the medium-long term this condition should never occur (EER ≤ 1), to avoid the depletion of the growing stock over time and of the stand's productivity (UNECE/FAO 2011; Magnani and Raddi 2014). The EER values can be calculated with a higher accuracy by taking into account also the irregular mortality (disturbances), that strongly affects the NAI_n of the stands. Therefore, it is recommended to improve the data collection in the CPA v2 by including information about the natural disturbances. H_n, if performed in compliance with the sustainable forest management indicators, should be considered as a positive event because, besides allowing the rational use of an economically exploitable local resource, can promote a further increase of the annual increment and—as consequence—of the carbon sequestration. As a result, the homeostatic capacity of the forests can be enhanced, promoting a higher resistance to natural disturbances. The results provided by this study also show that the belowground woody biomass, generally not taken into account by the FMPs, is an important carbon pool, because it can stock about 22% of the total carbon of the aboveground biomass. These results can be obtained for each stand under analysis, single municipality, species, forest structure or function, making it possible to carry out a great deal of analysis and comparisons.

By integrating the model WOCAS with a Geographic Information System (ArcGIS®) a stand classification worksheet (SCW) was produced for each of the j-stand.

Each SCW provides two kinds of information (K_1 and K_2). K_1 contains general input information extracted from the CPA v2 (e.g. location, stands' owner); K_2 contains specific input (e.g. growing stock at the starting year of the FMP, harvested growing stock over time, forest typology, type of management) and output (calculated by the model) data, as well as information related to the mechanization (type of cutting performed and forestry machines that can be used according to the site-specific working conditions).

4 Conclusions

The use of management models able to calculate WB and forest C stocks is essential to analyze the contribution of these lands to climate change mitigation. In the alpine regions, the use of stand-level models based on data collected in the FMPs could be an interesting solution if the use of single-tree level models clashes with the technical-economic impossibility of the Local Authorities to provide the data required. In this study, the empirical stand-level model WOCAS was briefly presented and the main results about its application to a dataset of 2019 forest stands of Valle Camonica District were discussed. The main advantage of this model is that—besides being based on the international 2006 IPCC Guidelines—it uses the growing stock (generally available in any FMP) as the main driver for the calculation; as a result, it can be applied in any other forest area where the same input data are collected. Two aspects are currently under development: the first one concerns the definition of different management scenarios to quantify the masses of the woody assortments (and their carbon stock) that can be extracted from each stand and used for building and/or energy purposes. This aspect is very important, also considering that the commitments of the recent post-2012 agreements of the Kyoto Protocol include not only the need to report carbon emissions and removals related to forest management, but also the carbon stock in the harvested woody products. The second aspect consists in the definition of future scenarios based on both current and improved forest management practices (i.e. conversion of coppices to high forests) to test the model under different temporal and spatial scales and management conditions. In this way, it will be possible to make predictions and formulate prescriptions promoting an efficient use of the local forestry resources.

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