Ricardo Yassushi Inamasu; Ladislau Martin Neto. "INSTRUMENTATION AND AUTOMATION IN THE SUGARCANE-ETHANOL CHAIN: SOME OPPORTUNITIES FOR AGRICULTURAL MANAGEMENT", p.477-486. In Luis Augusto Barbosa Cortez (Coord.). **Sugarcane bioethanol — R&D for Productivity and Sustainability**, São Paulo: Editora Edgard Blücher, 2014.
http://dx.doi.org/10.5151/BlucherOA-Sugarcane-SUGARCANEBIOETHANOL_44

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INSTRUMENTATION AND AUTOMATION IN THE SUGARCANE-ETHANOL CHAIN:

SOME OPPORTUNITIES FOR AGRICULTURAL MANAGEMENT

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PRECISION AGRICULTURE

General aspects

Agriculture is a highly complex production system when one includes the production of a live system in a live medium, interacting with the environment and society. Capacity and technology are fundamental for the effective planning, management and operation of all the aspects of agriculture. The viability and sustainability of the chain depend on the efficiency of the entire system.

Mechanization has been an essential tool in the process of expansion and large scale production. Due to the intrinsic characteristics of Brazil's sugarcane cultivation, as well as the absence of importable solutions, the country's sugarcane sector has made exceptional efforts to adapt and innovate its operations using planters and harvesters.

Precision Agriculture – PA was considered a step forward and even a refinement of the conventional process. The first phase of PA focused on machines equipped with GPS – Global Positioning Systems, and productivity maps. The world today has advanced on the theme beyond the cultivation of grains, and the concept is also applicable to crops that display spatial variability. The objective of PA is to manage spatial variability and maximize economic return while minimizing the effects on the environment. Therefore, PA can be considered a management strategy that uses information technologies to compile data from multiple sources and support decisions about vegetal production.

The application of Precision Agriculture is founded on three steps: reading, interpretation and action, which closes the circle. Reading is characterized by the indexation of the parameter of interest in a geographic position, i.e., the data contain additional parameters such as geographic coordinates (latitude and longitude), as well as other information such as historical data (time).

Geographically indexed data can be interpreted and analyzed by means of maps and supported by geostatistical tools. Studies of the spatial dependence of information and correlations with other parameters require thematic maps and a huge amount of data. Therefore, Geographic Information System – GIS, tools are part of the arsenal integrated to Information Technology – IT.

The first data that impressed everyone were productivity maps. The instantaneous productivity-related information stored with its respective geographic coordinates (latitude and longitude) enabled production maps to be drawn up. The initial interpretation of these maps was intuitive. Areas of low productivity were easily recognized and delimited. The impact on the results of the property was immediate if the cause of low productivity was easy to solve. The first machines equipped with harvest monitors were grain combines, favoring advances in the PA of corn, soybean and wheat cultivation. These were followed by efforts to devise productivity maps for other crops, since this was believed to be the most important parameter for guiding crop management actions. Current efforts are focusing on understanding quality-related parameters. Although higher economic returns are sought by increasing quality or production, it is also possible to strive for the rational use of inputs such as fertilizers and agrochemicals in general. The process of identifying subareas with their respective input needs has advanced substantially, as in the case of soil fertility and weed infestations.

Advances in the use of PA in sugarcane cultivation have been more modest that in corn cultivation, despite the technological advantage of sugarcane for ethanol production. The market availability of harvest monitors for combines is recent (MOLIN and MENEGATTI, 2004) (MAGALHÃES and CERRI, 2007) and a commercial response is not yet available, since the number of machines operating in the field is still insufficient.

Very likely due to the difficulty of obtaining tools and support to aid in measuring spatial variability in crop performance, the use of PA in sugarcane has been limited predominantly to soil correction. This involves recommending the application of inputs at varied rates based on a sample composed of two or more hectares, which has reported resulted in significant savings in fertilizers (MENEGATTI *et al.*, 2008; BARBIERI *et al.*, 2008; SANCHEZ *et al.*, 2008). PEZETO *et al.* (2008) and BARBIERI *et al.* (2008) report the successful use of topography as the basis for determining management zones and for guiding sampling and recommendations for soil correction.

The role and potential of automation in the agricultural process

The role of automation has been to replace human labor in the quest for greater efficiency and competitiveness. Despite the ongoing search for innovative technologies to maintain the competitiveness of sugarcane cultivation, there is still much room for conventional mechanization to advance in the stages of cultivation, planting and harvesting, as discussed even before automation arrives on the scene.

However, with Precision Agriculture, errors that were considered negligible in view of magnitudes in the field become significant. Overlapping applications of inputs and gaps left by machines begin to be registered. Operational quality becomes economically measurable. Field monitoring and measuring processes tend to intensify, which requires qualified labor that is scarce in the Brazilian work market. Thus, there is a potential for automated sensing.

In our reality, automation tends to involve the search for quality and minimization of errors. Another important role of Precision Agriculture is in inputs savings. Inputs can be applied at varying rates provided there are automated machines that can apply them according to a recommendation map or the indications of an on-the-go sensor.

Challenges of instrumentation and automation for the sector

Precision Agriculture has required the development of a substantial number of instruments for automation, as reported by AUERNHAMMER and SPECKMAN (2006). Remote sensing techniques, soil sampling strategies, GPS and GIS, among many others, are being adapted and developed for agricultural use. More recently, the use of reflectance sensors to observe some light spectra has proved feasible for identifying nitrogen levels (SCHARF and LORY, 2000), organic matter (ANOM *et al.*, 2000), insects (MICHELS *et al.*, 2000), and invader plants (BILLER and SCHICKE, 2000), among other correlatable factors, by means of light scattering spectroscopy. In addition, new instruments such as Veris[1] for measuring and mapping soil electrical conductivity have appeared on the market.

The use of on-the-go sensors is one of the major targets of industry and research in this area. The technique is employed during farming activities to inspect or monitor the crop, aiming to avoid additional operational costs. However, it is not always applicable, and cases such as monitoring pests, diseases, nitrogen levels in plants, and other variables of the cultivated area require the use of ground-based instruments in the plantation, which greatly hampers efficient sampling. For example, to build a soil property map with a resolution of 20 meters in an area of 200 hectares requires collecting 5 thousand samples, making the process unfeasible if carried out by hand.

[1] Available at: <http://www.veristech.com>.

Allied to this reality are other factors such as the high cost of labor, aging rural populations without prospects of renewal, the need to minimize the exposure of workers to unhealthy activities, and concerns about the conservation of environmental balance. All these factors have motivated and justified research on mobile agricultural robots by several groups such as KEICHER and SEUFERT (2000), REID *et al*. (2000) and TORII (2000). The need for environmental preservation and recovery, in particular, has led to a growing number of researches in this area. Works such as those of HAGUE *et al*. (2000) and BLACKMORE and GRIEPENTROG (2006) have proposed viable solutions for the development of semi-autonomous or autonomous agricultural machinery that allows for more precise operations to reduce costs and minimize the environmental impact of farming tasks such as the application of agrochemicals. Moreover, mobile agricultural robots can dispense with elements of "comfort and ergonomics" and the costs of the electronics required for the construction of such vehicles are becoming increasingly accessible. These electronics include microprocessors, video cameras, digital communication, and GNSS receivers, among others.

For the aforementioned reasons, companies such as AGCO and John Deere have searched for solutions to render viable the technologies of mobile agricultural robots. Moreover, the international standard ISO 11 783 for electronics in agricultural machinery and implements includes characteristics for the use of navigation devices (AUERNHAMMER and SPECKMANN, 2006). In his conclusions about electronic trends in Precision Agriculture, AUERNHAMMER (2004) cites the potential of robotics in farming machinery and implements for agricultural operations in the search for efficiency.

Photographic services by satellite and aircraft have also emerged on the market, including the recent appearance of unmanned aerial vehicles – UAVs, for photographic services for the construction engineering sector. Significant advances have been made in the last few decades. The various studies and contributions to remote sensing methods have made it possible today to gain a better understanding of how the reflectance and emittance of leaves change in response to the leaf's thickness and age, the plant species, the shape of the crown, and the plant's nutritional and moisture status. The presence of chlorophyll and its preferential absorption at different wavelengths provides the basis for the use of satellite broadband radiometric platforms or hyperspectral sensors that measure narrow-band reflectance. Understanding the reflectance of leaves leads to different vegetative indices to quantify a variety of agronomic parameters of plantations, e.g., foliar area, vegetative cover, biomass, type of crop, nutritional status, and yield. Canopy emittance is a measure of foliar temperature and infrared thermometers have enabled the creation of crop stress indices currently used to quantify water needs. In the case of sugarcane, there is still a lack of studies and of a methodology to determine spatial variability.

Communication networks have proliferated in digital electronic systems embedded in a variety of vehicles and installations. Nevertheless, despite the existence of accepted and adopted solutions, the recent development of wireless sensor networks may further expand the presence of electronic technology in the field. The use of radio or infrared data transmission instruments in the agricultural environment became widespread several decades ago. Today the market offers several options of climate stations and automated irrigation systems that use these means of communication. The obvious advantage is the extremely easy installation and maintenance of wireless systems operating in the field. However, in face of the possible applications of what has been dubbed pervasive or ubiquitous computing established by means of wireless sensor networks distributed in the field and crossing borders, the benefits will be uncountable (WANG *et al*., 2006). The practice of PA in the current models allows for potential savings of inputs and less environmental contamination, but this positive impact can be even more significant if the control of processes such as spraying is aided by an ample grid of wireless sensors monitoring plants, soil and environment with real-time spatial information.

The adoption of Precision Agriculture requires a change in management attitudes and a shift to observing variability as one of the elements to be considered and managed. This attitude is considered by many as a natural paradigm shift, but this change requires commitment and heavy investments. An investment is not made if the return is considered uncertain or if the moment is not the right one. Opportunities and the return potential for this crop are still being explored, and further research is still needed in order to propose creative and applicable solutions.

The sugarcane sector faces an additional challenge due to the historical and conservative nature of the production system. Despite the evident change in management with the advent of modern and nontraditional companies in the sector, the field is still managed in a way that can be considered traditional and fearful of a too radical change. Therefore, the large majority of companies only absorb well-known and economically proven technologies. The sector's participation in breaking paradigms or developing long term knowledge is scanty, but it is the role and challenge of Science and Technology to involve the sector so that it increases its innovation potential through knowledge.

The advent of PA brought into play a relatively large number of electronic instruments for aiding navigation and for the application of inputs. Electronic technology embedded in agricultural machinery has evolved very intensively in the wake of other sectors. The computational power available for the new machines allows for integration of agricultural operations with the company's Information System. Interchangeable electronic connections and automatic recognition of active functions in tractors and implements may become common mass-produced instruments. However, what one sees is the manufacturer's proprietary solution resulting from his efforts to meet the demand. This leads to the creation of incompatible equipment and file formats.

Online connections in the field with machines produced by different manufacturers would make it possible to carry out coordinated operations in real time, reducing unproductive time, eliminating unnecessary costs, and increasing efficiency. This would only be possible if there were a single standard of communication. The ISO-11783 protocol is being drawn up with this approach. The potential for use of the standard is real, since it is of interest to the entire chain.

Standardization of embedded electronics

Worldwide efforts have focused on standardizing electronics embedded in agricultural machinery. Since the advent of Precision Agriculture, the standardization of information and communication system data between electronic devices has been pinpointed as a challenge to be overcome so that the technology can be widely adopted (INFORMATION, 1997). Groups composed predominantly by manufacturers of agricultural machinery in Europe and the U.S. have dedicated their efforts to drawing up the ISO-1178 code (also known as the ISOBUS). The objective of this standard is to promote a standard interconnection of electronic devices embedded in agricultural machines and implements through a serial control and communication network. In 2009, eleven of the fourteen parts foreseen for the standard had already been published. Each part specifies important topics for the interconnection and covers not only the specification of connectors and electric values but also the communication between intelligent elements, composing them into a multipoint digital network.

Although the protocol has resulted in complex and voluminous details with specifications ranging from the motor to file formats, the network will work transparently for the user. All the user will have to do is switch on the agricultural machine, connect it, and insert the file without worrying about possible incompatibilities between manufacturer models. The immediate implication this protocol brings to automation in the sugarcane chain is the reduction of its implementation cost and the possibility of installing a more up-to-date technological system. Therefore, standardization precludes the possibility of the sector being obliged to accept an obsolete and outdated technology. As with any protocol of this nature, this one is also not closed and the committees are prepared to receive contributions. The sector has the opportunity to point out the peculiarities of sugarcane cultivation

FIGURE 1 Comparative images of a tractor with proprietary solutions – left, and with ISOBUS – right, presented by Hans Jürgen Nissen of John Deere AMS Europe in 2007.

and to dictate an international standard for sugarcane production. Figure 1 illustrates the interior of two tractor cabins presented by Hans Jürgen Nissen of John Deere AMS Europe at the ISOBUS Workshop 2007 in Brazil[2]. The image on the left is of a cabin with panel installations of various implements. Because it is a proprietary solution, a display/command is installed for each implement. The cabin on the right shows an ISOBUS solution in which both the display and commands are reconfigured for a new compatible implement. The solution tends to involve a lower final cost.

Agricultural robotics

Lastly, robotics is one of the emerging technologies in Precision Agriculture, with a strong potential for application in all the stages of sugarcane production.

The areas under development, such as autopilots, embedded electronics (standardization) and information systems, channel and potentiate robotics technology toward the search for greater precision in agricultural operations, operator safety and higher quality in the field and of the material delivered to the mill.

The autopilot system is expected to evolve rapidly to automation of headland maneuvers and to synchronization of the harvester with the transshipment. Robotics technology can be employed to improve the harvesting process, rendering it more selective using less power. Efficient mechanisms, sensors and actuators for removing stalks during harvesting and planting are a challenge to be overcome with a great deal of creativeness. Robotics may help handle these elements productively.

Consonant with the development of soil and plant moisture sensors, remote sensing and image interpretation technology, applications are being developed for aerial robots (Unmanned Aerial Vehicles – UAVs) or even land robots (Autonomous Agricultural Vehicles – AAVs). In other crops and other countries, factors such as the extremely high cost of labor, aging rural populations without prospects for renewal, the need to minimize the exposure of workers to unhealthy activities, and concerns about the conservation of environmental balance have driven and justified research into robotics. The need for environmental preservation and recovery, in particular, has led to a growing number of researches in this area. Authors such as

[2] ISOBUS Workshop 2007 in Brazil, http://www.isobus.org.br/workshop2007.

HAGUE *et al*. (2000) and ÅSTRAND and BAERVELDT (1999) have presented viable solutions for the development of semi-autonomous or autonomous agricultural machines that allow for more precise operations to reduce costs and minimize the environmental impact of farming tasks such as the application of agrochemicals. One should also keep in mind that a robot can dispense with elements of "comfort and ergonomics" and that the costs of the electronics required for the construction of an autonomous vehicle are becoming increasingly accessible. These electronics include microprocessors, video cameras, digital communication, and GNSS receivers, among others.

As mentioned earlier, large tractor manufacturers such as AGCO, John Deere and Yanmar have pursued solutions to render AAV technologies feasible. The ISOBUS standard for farming machines and implements foresees requirements for the use of guidance devices and autonomous navigation systems (JAHNS, 1997). In their conclusions about electronic trends in Precision Agriculture, AUERNHAMMER (2001), PEDERSEN *et al*. (2005) and BLACKMORE *et al*. (2008) cite the potential of robotics in farming machines and implements for agricultural operations aimed at efficiency and quality. Figure 2 shows a conception of AGCO presented by BLACKMORE *et al*. (2008), which was also featured on the cover of the October 2008 edition of the journal *Crop, Soil, Agronomy News* under the teaser "the future of Precision Agriculture". The article cites features such as agility, nocturnal activities and the ability to perform a large number of repetitive operations accurately. The reality in the sugarcane sector is no different. Monitoring crop quality (soil and plant status, insect and invader plant populations) to identify the need for interventional actions is a potential.

Source: BLACKMORE, 2008.

FIGURA 2 Artistic conception of an agricultural robot.

UAVs and AAVs are low-impact tools since they are light and can perform tasks that would involve high costs if carried out by manned vehicles.

OPPORTUNITIES FOR RESEARCH INTO INSTRUMENTATION FOR HANDLING STRAW

Issues of global climate change are of great interest and represent major challenges for life on Earth. In general, these issues have been decisively influenced by the consumption of nonrenewable fossil fuels, which have contributed to increase the concentration of carbon gas in the atmosphere and augment the greenhouse effect. Therefore, the sugarcane-ethanol theme is directly connected to the issue, since it represents a feasible alternative, especially in Brazil, for the production of renewable fuel such as bioethanol. However, it is vital for the productive system to use conservation farming practices in tune with sustainable development. One of the relevant changes taking place in agricultural management is the extinction of burning during sugarcane harvesting, which is advancing with the use of machines, and which is commonly known as raw sugarcane harvesting.

In mechanized harvesting, a considerable amount of sugarcane straw is now left on the field and the destiny of this material is a current and relevant issue in the improved management of sugarcane production as well as with regard to the complete use of the biomass produced. There is intention and interest in making use of sugarcane straw in the near future by generating bioethanol through lignocellulose conversion, which is an item on the renewable energy agenda of several countries. However, the economic cost of this conversion is still an obstacle to its use. Therefore, the current destination of straw at Brazilian sugar and alcohol mills has been to leave it in the field instead of burning it to generate steam and electrical power at industrial plants. The recovery and transportation of straw still presents challenges due to the large volumes of low-density material that are produced. However, it should be pointed out that leaving sugarcane straw on the field may have an extremely positive effect on the soil and on management, since this material can keep the soil covered, minimizing the impact of raindrops and hence of erosion. Moreover, upon decomposing, part of the straw biomass may remain in the soil and become incorporated as organic matter, recycling part of the nutrients and improving the soil structure. Nevertheless, evidences of potential benefits such as increased soil organic matter (which could represent soil carbon sequestration) and the ideal quantity of straw to be left in the field, among other aspects, are current challenges for research. In this context, several Brazilian groups and institutions already use equipment and techniques to monitor organic matter and changes in soil and its properties in field conditions, such as aspects of fertility, including increased cation exchange capacity and nutrient availability, soil compaction, water retention and infiltration etc. (MARTIN-NETO *et al.*, 1998; VAZ *et al.*, 2001, 2005).

With regard to issues related to soil organic matter, a series of researches have been conducted using advanced instrumentation such as elemental analyzers (CHNS), chemical and physical fractionation of soils, spectroscopic methods such as electron paramagnetic resonance, nuclear magnetic resonance, UV-Vis fluorescence, and laser-induced fluorescence etc. These researches have provided fresh information in studies about soil organic matter content and quality under different types of management, including no-till farming, application of sludge and effluents from sewage treatment plants, crop rotation, reactions with pesticides and heavy metals, effects of precipitation on the humification of organic matter etc. (MARTIN-NETO *et al.*, 1994, 1998; BAYER *et al.*, 2000, 2004, 2006; MILORI *et al.*, 2002, 2006; PEREZ *et al.*, 2004, 2006). More recently, SEGNINI (2007) and MARTIN-NETO *et al.* (2008) have reported an increase in soil carbon content in areas of pastureland and sugarcane in comparison with reference areas, demonstrating the potential for soil carbon sequestration. This is an indicator that points to the high sustainability of production systems, especially as they relate to issues of augmented greenhouse effects. Thus, future researches on the agenda of the development of the production system of the sugarcane-ethanol chain, instrumentation and automation tools will be used more systematically and will be able to bring to light new information about the behavior of soil and its key constituents, such as organic matter under different types of management with different quantities of straw left on the field, crop rotation, especially in the replanting of sugarcane, among other relevant aspects.

INDICATIONS OF OPPORTUNITIES FOR RESEARCH INTO PRECISION AGRICULTURE, AUTOMATION AND INSTRUMENTATION

In summary, there are numerous opportunities for the application of precision agriculture, automation and instrumentation in the sugarcane-ethanol chain, such as:

- soil and plant sampling and monitoring;
- imaging techniques;
- harvest monitoring using sugarcane quantity and quality monitors;
- cultivation interventions, such as the application of solid and liquid agricultural inputs;
- cultivation, which includes the design of new machines;
- the use of course-planning autopilots;
- mathematical and computational resources to use all the information;
- environmental assessments;
- use and application of agricultural and agro-industrial by-products;
- development of tracking sensors and tools for traceability;
- development of the ISOBUS as a fundamental aspect to expand versatility in the use of equipment from different manufacturers;
- automation of sugarcane irrigation, which is needed in several regions in Brazil;
- more efficient Brix analyzers;
- planter sensors;
- the use of advanced instrumentation methods for studies of the dynamics and reactivity of organic matter and soil properties as a function of straw handling in areas of raw sugarcane harvesting, and in crop rotation.

This is a set of actions with the potential to expand and capitalize the sector, and the channeling of public and private investments is expected to increase the number of opportunities in instrumentation and automation.

ACKNOWLEGMENTS

This chapter was based on a Round Table entitled “Precision Agriculture in the Sugarcane – Ethanol Chain”, held during a Workshop on Instrumentation and Automation of the Sugarcane – Ethanol Chain (http://www.apta.sp.gov.br/cana/ver_work.php?work_id=64) on 29 November 2009 at Embrapa Instrumentação Agropecuária, in São Carlos, SP, Brazil. Participating at the round table were debaters Drs. José Paulo Molin of ESALQ/USP, Piracicaba, SP, Maurício dos Santos Simões of the Companhia Nacional de Açúcar e Álcool – CNAA, and Ariovaldo Luchiari of Embrapa Meio Ambiente, Jaguariúna, SP. The authors of this chapter thank the Debaters for their contributions.

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