Potential Technologies to Measure Sugarcane Quality in the Field

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Abstract

The need for a reliable in-field quality measurement in sugarcane industry is growing as the industry is moving towards the adoption of Precision Agriculture (PA) technique. However, current monitoring systems in sugarcane industry only monitor crop yield and have no ability to measure product quality. This is a serious limitation in PA technologies due to considerable quality variation across the paddock. Most of the current technologies can only be used measure sugarcane quality in a laboratory. Thus, the purpose of this paper is to review current quality measurement technologies in sugarcane industry and their potential applications and limitations for field use. The new emerging technologies which have potentials to be applied for in-field quality measurement were also assessed.

Keywords: sugarcane, quality, in-field measurement, CCS, Precision Agriculture

1. Introduction

Precision agriculture (PA) is a valuable management tool to increase the profit through more efficient application of crop inputs and mapping the yield and quality variability (Robert et al., 1996). PA receives benefits from the emergence and convergence of several technologies, including the Global Positioning System (GPS), geographic information system (GIS), miniaturized computers, automatic control, in-field and remote sensing, information processing, and telecommunications (Gibbons, 2000). Nowadays, PA techniques are being studied and adopted in many cropping systems especially grain crops. Substantial studies have also been carried out to adapt the PA technologies in the sugarcane industry (Bramley, 2009).

Yield monitoring and mapping are the key elements of PA technique (Heacox, 1998). Yield mapping is the first step of PA methods (Erickson, 2006). However, current PA technologies only monitor the yield and have no ability to measure the product quality. This is a serious limitation because product quality is another important parameter for sugarcane industry. Johnson & Richard (2005) conducted a study to find a relationship between yield and CCS, and reported that there was no relationship between these parameters. Thus, there is a critical need to generate a quality map to compliment a yield map for PA purposes.

To date, there is no reliable method available to measure sugarcane quality in the field. Thus, there is a need for in-field monitoring system which can accurately determine the yield and quality of sugarcane during harvesting. Thus, the purpose of this paper is to review current quality measurement methods in sugarcane industry and their potential applications and limitations for field use. The new emerging technologies which have potentials to be applied in sugarcane industry will also be assessed. The quality measurement technologies in other crops will also be reviewed and their potential for sugarcane industry will be discussed. Specifically, the objective of this review is to highlight the most feasible method for in-field quality measurement for sugarcane industry.

2. The Needs to Measure Sugarcane Quality in the Field

Lately, there is a growing interest to measure sugarcane quality in the field. The information of the quality level measured in the field will be important input for the adoption of PA technique in this industry. Besides, measuring sugarcane quality in the field is also important to improve the current payment system and data collection system by eliminating consignment errors. Ability to measure quality values in the field would also bring benefit for clonal evaluation (Berding et al., 1991). In-field measurement of sugarcane quality, known as Commercial Cane Sugar (CCS) is also important for the optimization of sugar value at harvest through the identification of cane block that have the highest in-field CCS. The in-field CCS values would also allow the optimization of production inputs and harvest schedules (Staunton et al., 2011).

3. Laboratory Methods to Measure Sugarcane Quality and Their Limitation for Field Use

Sugarcane quality is determined based on its sugar content, known as CCS. CCS is derived from Brix, Pol and fibre. The routine analysis of measuring sugar content in a laboratory is conducted using standard refractometric and polarimetric methods (Mehrotra & Seisler, 2003). Besides, sugar content can also be measured by chromatographic methods (Campbell et al., 1999). The use of biosensor has also been proposed (Kennedy et al., 2007). The spectroscopic method can also be used for both qualitative and quantitative measurements in sugar industry (O'Shea et al., 2011).

TABLE 1: Comparison of common methods for sugarcane quality determination

Method	Sampling time (min)	Sample form	Amount of samples required	Approximate cost of equipment
Refractrometry	5 - 20	Juice (raw or clarified)	50 - 100 ml	Hand-held (A$700) Laboratory (A$5k)
Polarimetry	10 -20	Juice (clarified)	100-200 ml	A$16k
Chromatography	30	Juice (clarified)	100-200 ml	A$13-33k
Biosensor	5	Raw juice must be mixed with a mediator	50 up to 200 mmol L^{-1}	A$6k
Brix hydrometer	15-20	Juice (raw or clarified)	100-200 ml	A$40
Wet chemical methods	20	Prepared juice	Each 0.0047g of sucrose to be mixed with 1 ml of Fehling's solution	No specific equipment is needed
Spectroscopy	0.2 to 1 (after calibration)	Raw or clarified juice or macerated cane samples, or possibly billet samples	50 - 100 ml	A$10~18k (350 to 1075 nm) A$100~140k (350 to 2500 nm)

The common technologies for measuring sugarcane quality in a laboratory and the characteristics of these technologies are shown in Table 1. Sampling time, sample form, amount of sample required and cost of equipment are among the key factors needing to be considered if these technologies are to be successfully used in the field. This table shows that except for the spectroscopy which can be used on both juice and non-juice (macerated) samples, all of the above other methods need a juice sample for the measurement.

Unfortunately, having sufficient juice samples in the field is very difficult. Another problem for juice sampling is to process a raw juice into clarified juice which requires the use of chemical reagents. For example, in polarimetric method, clarified juice is obtained when raw juice is treated with lead acetate and then filtered to remove impurities (Mehrotra & Seisler, 2003). A mediator is needed for the juice analysis using biosensor (Kennedy et al., 2007).

Overall, most of these common technologies are not suitable for field use because they require a high skilled personnel and expensive equipment. They are also often time consuming, operator-dependent, involving the use of hazardous reagents and can only be done in the laboratory (Mehrotra & Siesler, 2003). For example, the polarimetric method requires complex sample preparation prior to sucrose analysis and it is often not robust due to the high levels of contaminants. The chromatographic methods can be affected by the presence of interfering compounds requiring laborious sample pre-treatment (Filho et al., 1996).

4. Potential Uses of Existing Methods in the Field

There are a few existing technologies which have a potential to be used to measure sugarcane quality in the field. For example, McCarthy & Billingsley (2002) developed a robust low-cost refractometer together with signal conditioning algorithm to determine sucrose content in the field. This system was developed to determine the optimum topping height on a sugarcane stalk during harvesting. This refractometer worked well in the laboratory conditions. However, subsequent field trials showed limited results due to insufficient juice sample being deposited onto the sensor during harvesting. The poor results of this study were also caused by trash and leaf materials that hindered the freshly topped stalks from wiping across the sensor. Hence, a mechanism which can discriminate trash from samples and squeeze sufficient juice amount is needed for field measurement.

Another potential technology is a spectroscopic method. Spectroscopy is an established technique for determining chemical constituents in various agricultural products (Carlini et al., 2000). Spectroscopic methods have been used in sugarcane industry for many purposes including fibre analysis, cane payment system, cane-quality schemes and process control (O'Shea et al., 2011). Even though most of the studies reported the use of spectroscopic methods based on juice samples, some of them also reported the use of this technology for solid (non-juice) samples (Nawi et al., 2012, Mehrotra & Seisler, 2003).

5. In-Field Quality Measurement Methods for Other Crops

The previous section shows that all of the studies to measure crop quality on harvester were conducted using a spectrometer. A spectrometer is however sensitive to environmental and physical factors, including sample presentation, mechanical vibration, temperature, humidity and plant debris. Recently, due to advancements in the hardware and statistical methods, it is now possible to apply spectroscopic methods during harvesting on a harvester (Welle et al., 2005). Several studies have been successfully conducted in the field using a spectrometer mounted on harvester for different crops as summarized in Table 2.

Welle et al. (2003) published results of quality parameters measured on a forage plot harvester using a spectrometer. A spectrometer was mounted behind the rollers 120 mm above the sample surface. A diode-array spectrometer was also integrated by Digman & Shinners (2008) into the spout of a self-propelled forage harvester to measure crop moisture. The harvester's spout was fitted with the spectrometers for collection of field spectra during harvest. The authors reported that the system was able to predict forage moisture adequately. However, the biggest constraints for the use of spectrometer in forage crops are the need of specific calibrations for each species and technical configuration in the harvesting machine (Kormann & Auernhammer, 2000). The texture and moisture variability in forages also put some difficulties to the use of spectrometer (Kosh & Koshla, 2003).

Table 2: Summary of the studies for spectroscopic applications in the fields

Authors	Wavelength used (nm)	Crop	Quality parameters	Results	Comments
Montes et al. (2006)	960 – 1690	Maize	Dry matter (DM) Crude protein (CP) Starch content (SC)	DM (R^2 = 0.95) CP (R^2 = 0.88) SC (R^2 = 0.79)	This study scanned the granulated samples which is very different with the cane sample. So, it is not directly applicable to this project
Wright et al. (2002)	400 -1700	Grain	Moisture content Starch content Protein content	Not results reported (This is the US patent document, not a journal)	This study also carried out on grain samples.
Digman & Shinners (2008)	950 - 1680	Forage	Crop moisture	R^2 = 0.96	This study scanned the chopped forage for scanning. Thus, this approach is applicable for cane stalk scanning.
Welle et al. (2003)	960 – 1690	Maize forage	Dry matter (DM) Starch content (SC) Soluble sugar (SS)	DM=1.18% (SECV) SC=2.36% (SECV) SS=1.38% (SECV)	The method of this study can be applied for cane scanning

Legend: R^2 = Coefficient of Determination, SECV= Standard Error of Cross-Validations

The advent of near infrared (NIR) sensors on harvester gives growers the opportunity to measure the grain protein concentration of wheat during harvest (Long et al., 2008). Wright et al. (2002) developed a rugged on-harvester NIR system to measure grain constituents in real time. By analyzing the intensities and wavelengths of the received radiation, the amount of major grain constituents can be determined. Montes et al., (2006) developed a spectroscopic system to determine dry matter content, crude protein and starch content in maize directly on plot combine harvester. The authors concluded that this system is a promising technology for the determination of quality parameters of maize grain during harvesting.

Even though many quality monitoring systems are available for other crops such as grains and forages, these technologies cannot be simply adopted into sugarcane industry due to a different measurement configuration requirements. For example, the quality assessment of other crops is performed directly on its harvested form. However, a sugarcane quality can only be measured from juice samples which are obtained when harvested stalk (billet) is squeezed. Thus, a mechanical means is needed to extract billet samples from the billet stream on harvester before the samples can be squeezed to produce juice.

The development of sampling and measurement systems is one of the most important factors for the success of in-field quality measurement system (Welle et al., 2003). The sampling system requires proper sampling, preparation and presentation mechanisms. Sampling mechanism has to extract sufficient billet samples from the billet stream on harvester. Preparation mechanism is either to hold samples for solid scanning or to squeeze them for juice measurement. Presentation mechanism is to present samples to a sensor in a uniform, homogeneous and well defined portion to the sensor. Measurement system is to perform real-time measurement on selected samples. A sensor used in the measurement system must be able to survive mechanical vibration, contamination and harsh field environment on harvester. Overall, the proposed system must be able to function in a wide variety of operating conditions (i.e., different harvesting speeds, varying field conditions and crop yields).

6. Conclusion

In-field quality measurement is very important for sugarcane industry. This paper has reviewed the potentials and limitations of various existing measuring technologies for in-field quality measurement. A spectroscopy and refractometer have been found to be the promising methods to measure sugar content in the field. However, a robust and efficient sampling and measurement systems would need to be designed to accommodate the particularly unfavorable measuring environment. Thus, the major focus of the next research is to design and develop the sampling system which can automatically collect representative billet samples and squeeze them to obtain sufficient juice for the measurement system. Finally, it can be concluded that research towards the development of measuring technologies for the in-field analysis of sugarcane quality are likely will add more values to the sugar industry.

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