

**University of São Paulo
“Luiz de Queiroz” College of Agriculture**

**Use of crop canopy sensors in the measurement of sugarcane
parameters aiming site-specific nitrogen fertilization management**

Gustavo Portz

Thesis presented to obtain the degree of Doctor in
Science. Area: Agricultural Systems Engineering

**Piracicaba
2015**

Gustavo Portz
Agronomist

**Use of crop canopy sensors in the measurement of sugarcane parameters
aiming site-specific nitrogen fertilization management**
versão revisada de acordo com a resolução CoPGr 6018 de 2011

Advisor:
Prof. Dr. **JOSÉ PAULO MOLIN**

Thesis presented to obtain the degree of Doctor in
Science. Area: Agricultural Systems Engineering

**Piracicaba
2015**

**Dados Internacionais de Catalogação na Publicação
DIVISÃO DE BIBLIOTECA - DIBD/ESALQ/USP**

Portz, Gustavo

Use of crop canopy sensors in the measurement of sugarcane parameters aiming site-specific nitrogen fertilization management / Gustavo Portz. - - versão revisada de acordo com a resolução CoPGr 6018 de 2011. - - Piracicaba, 2015.

103 p. : il.

Tese (Doutorado) - - Escola Superior de Agricultura "Luiz de Queiroz".

1. Agricultura de precisão 2. Variabilidade espacial das culturas 3. Taxa variável
I. Título

CDD 633.61
P853u

“Permitida a cópia total ou parcial deste documento, desde que citada a fonte – O autor”

I DEDICATE

God who has not failed to bless me with health and enlighten me in important decisions during life. All my family, especially my parents Carlos and Ilâine that went to great lengths to help me regardless of difficulties, also my girlfriend Marisol and brothers Cristiano and Elenice for the unconditional support during my journey.

ACKNOWLEDGMENTS

To Professor and friend PhD José Paulo Molin, for the opportunity to work together, trust, patience and guidance throughout this years of work.

To the "Luiz de Queiroz" College of Agriculture, from the University of São Paulo, through the Agricultural Systems Engineering Graduate Program, for the opportunity of achieving this PhD title.

To the National Council for Scientific and Technological Development (CNPq) for financial support, essential to conduct this work.

To the company Yara, through its Research Centre Hanninghof , Duelmen – Germany, specially by researchers Joerg Jasper and Stefan Reuch. And the company Jacto Agricultural Machines, Pompéia – SP, in particular to engineer Denis Yukio Sakuma. Partner companies and people essential to the realization of this project.

To São Martinho Mill S.A., for all the field support in the project implementation, specially to the staff members of the agricultural quality sector; René de Assis Sordi, Marcos Marcari, and Carlos Sardão, and the staff of field cultivation; Pedro, Ailton and Sandro.

To professor PhD Viacheslav I. Adamchuk and his team for welcome me at McGill University and for the assistance and patience during the work.

To classmates: Mark Spekken, André F. Colaço, Adriano Anselmi, Matheus Eitelwein Rodrigo G. Trevisan and Natanael Vilanova and especially to college Lucas R. Amaral for the experiences exchange.

To my friends and colleagues of "ESALQ" Luiz Gottardo, Rodrigo Almeida, Thiago Tezotto, Rodrigo Sorgatto, Bruno Lago, and Paulo Lazzarini for the friendship.

To the Group of Mechanization and Precision Agriculture (gMAP) for shared experiences.

To all professors of ESALQ, in specially Prof. Vettorazzi for revising this research project.

To the staff of research assistance; Davilmar, Ângela, Fernanda, Chicão, Afonso, Aginaldo and Zé Geraldo. Special to the Electronic Instrumentation Lab staff: Áureo and Juarez.

To the ESALQ Library for the revision on the thesis.

Finally, all of those who, even indirectly helped me during or on part of the way of achieving this PhD title, my special THANKS!

EPIGRAPH

“For those of us on the food production front, let us all remember that world peace will not – and cannot – be built on empty stomachs. Deny farmers access to modern factors of production – such as improved varieties, fertilizers, smart and efficient machinery and crop protection chemicals – and the world will be doomed – not from poisoning, as some say, but from starvation and social chaos”

Adapted from Norman E. Borlaug, Nobel Peace Prize, 1970.

SUMMARY

RESUMO.....	11
ABSTRACT	13
1 INTRODUCTION.....	15
References	17
2 OPTIMUM SUGARCANE GROWTH STAGE FOR CANOPY REFLECTANCE SENSOR TO PREDICT BIOMASS AND NITROGEN UPTAKE.....	21
Abstract	21
2.1 Introduction.....	21
2.2 Materials and methods	22
2.3 Results and discussion.....	24
2.4 Conclusions.....	31
References	31
3 REAL-TIME SUGARCANE VARIABLE RATE NITROGEN APPLICATION STRATEGIES BASED ON OPTICAL CROP CANOPY SENSOR	33
Abstract	33
3.1 Introduction.....	33
3.2 Material and methods	35
3.3 Results and discussion.....	38
3.4 Conclusions.....	50
References	50
4 COMPARISON OF SUGARCANE STALK AND ULTRASONIC CANOPY HEIGHT WITH OPTICAL REFLECTANCE BY ESTIMATING CROP BIOMASS AND NITROGEN UPTAKE.....	53
Abstract	53
4.1 Introduction.....	53
4.2 Materials and methods	55
4.3 Results and discussion.....	58
4.4 Conclusions.....	70
References	70
5 ULTRASONIC PROXIMITY AND OPTICAL REFLECTANCE SENSING OF CROP CANOPY TO ESTIMATE SUGARCANE GROWTH INDICATORS	73

Abstract.....	73
5.1 Introduction	73
5.2 Materials and methods.....	75
5.3 Results and discussion	79
5.4 Conclusions	93
References	94
6.0 OVERALL SUMMARY AND SUGGESTIONS FOR FUTURE WORKS.....	97
APPENDICES.....	99

RESUMO

Uso de sensores de dossel na mensuração de parâmetros em cana-de-açúcar visando ao gerenciamento localizado da adubação nitrogenada

Sensores de dossel tem se apresentado como uma nova ferramenta para a predição espacialmente localizada, em tempo real, de forma indireta e indestrutiva da biomassa vegetal e extração de nitrogênio (N) pelas culturas como base para a aplicação de fertilizantes nitrogenados em taxas variáveis. Sensores baseados na combinação de faixas específicas de reflectância do espectro eletromagnético constituem a grande maioria dos sensores de dossel sendo este princípio já validado para uso em muitas culturas. Alternativamente a este conceito, a medição da altura do dossel cultural com o uso de sensor ultrassônico se apresenta como uma alternativa para a estimativa de biomassa vegetal. Com base nisso o objetivo desta tese foi de validar e aperfeiçoar sistemas sensores para a automação do diagnóstico visando à aplicação de fertilizante nitrogenado em função da necessidade da cana-de-açúcar. Para tanto, foi necessário: 1) validar a previa calibração feita ao sensor de reflectância (PORTZ et al., 2012) assim como estabelecer o melhor momento para uso do sensor na cultura; 2) ensaiar o uso do sensor em faixas comparativas entre taxa fixa e variável testando algoritmos de aplicação com inclinação positiva e negativa para dose de N mensurando produtividade; 3) obter a relação entre altura de dossel da cultura com, biomassa acumulada e extração de nitrogênio pela planta; 4) explorar a altura de plantas mensurada com um sensor ultrassônico comparando os resultados de predição de biomassa e extração de nitrogênio com aqueles obtidos com sensor de reflectância. Os experimentos foram conduzidos em talhões comerciais de cana-de-açúcar e em forma de faixas da cultura, com aplicação em taxa variada de doses de N. Os experimentos foram instalados em solos de textura argilosa e arenosa nas épocas seca e chuvosa do ano sendo todos avaliados com o sensor Yara N-Sensor, modelo ALS (N-Sensor[®] ALS, Yara International ASA), e em parte comparando com um sistema sensor ultrassônico Polaroid 6500 (Polaroid, Minnetonka, MN, EUA) quando a cultura apresentava altura de colmos entre 0,2 e 0,9 m. Os dados coletados para a calibração do sensor de reflectância se encaixaram exatamente aos dados já publicados mostrando-se o intervalo entre 0.3 e 0.5 m o mais indicado ao uso deste sensor. O algoritmo com inclinação positiva se mostrou superior ao negativo exceto na situação de solo argiloso em estação chuvosa onde a resposta do algoritmo negativo foi maior. A altura de planta de cana-de-açúcar se mostrou altamente correlacionável com biomassa e extração de nitrogênio pela cultura, sendo possível estimar a altura do dossel das plantas de forma indireta pelo uso do sensor ultrassônico. Comparando-se os sistemas sensores, reflectância de dossel se mostrou melhor em estádios iniciais da cultura enquanto altura de dossel se mostrou mais indicada para estimar os parâmetros culturais quando as plantas já recobriam as entrelinhas (+0.6 m colmo), mostrando-se os sistemas sensores complementares quando o período de fertilização for mais amplo na fase inicial da cultura.

Palavras-chave: Agricultura de precisão, Variabilidade espacial das culturas, Taxa variável

ABSTRACT

Use of crop canopy sensors in the measurement of sugarcane parameters aiming site-specific nitrogen fertilization management

Plant canopy sensors have emerged as a new tool for in field on-the-go spatially localized prediction of plant biomass and nitrogen (N) uptake by crops in an indirectly and plant indestructible way as base for N variable rate fertilization. Sensors based on the combination of specific reflectance bands from the electromagnetic spectrum constitute the vast majority of canopy sensors, and this principle has already been validated in many crops. Alternatively to this concept, the use of ultrasonic distance sensors to measure crop canopy height has been presented as an option to estimate biomass. Based on that, the aim of this thesis was to validate and refine canopy sensor systems on automated diagnosis of plant parameters aimed the application of N fertilizer according sugarcane needs. Therefore, it was necessary to: 1) validate the prior calibration made for the reflectance sensor (Portz et al., 2012) and to establish the best time to use the sensor over the crop; 2) test the use of the reflectance sensor in comparative strips trials of uniform and sensor based N variable rate application testing algorithms with positive and negative slope and measuring productivity at the end of the season; 3) obtain the relationship between crop canopy height with accumulated biomass and N uptake by the crop during the initial growing season; 4) explore the plant height measured with an ultrasonic sensor comparing the results of biomass and N uptake prediction with those obtained with the reflectance sensor. The experiments were conducted on commercial sugarcane fields, and in strips of the crop with N variable rate application. The experiments were installed over clayey and sandy soils in dry and rainy seasons being all evaluated with the reflectance sensor Yara N-Sensor model ALS (N-Sensor[®] ALS, Yara International ASA) and partly in comparison with an ultrasonic sensing system Polaroid 6500 (Polaroid, Minnetonka, MN, USA), when the crop had stalk height between 0.2 and 0.9 m. The reflectance sensor calibration fitted with the previous published data showing the interval between 0.3 - 0.5m as the most appropriate to use this sensor over sugarcane. The positive slope algorithm was superior to the negative, except in the situation of clayey soil in rainy season where the response from the negative slope algorithm was higher. The sugarcane plant height was highly correlated with biomass and N uptake by the crop, being possible to estimate the plants canopy height indirectly by the use of an ultrasonic sensor. Comparing the sensor systems, canopy reflectance was better in the early stages of crop as canopy height was more suitable for estimating the cultural parameters when the plants already covered soil in between the rows (+ 0.6 m stalk height), being the sensor systems complementary when fertilization is widely spread in the early crop growth period.

Keywords: Precision agriculture; Crop spatial variability; Variable rate

1 INTRODUCTION

According to FAO (2014), Brazil is the worldwide main sugarcane (*Saccharum ssp.*) producer, with 739 million Mg of stalks over 9.84 million hectares averaging 75.16 Mg ha⁻¹. India follows it with 341 million Mg from a global production of 1877 million Mg on the same year. Sugarcane is the main crop for sugar supply, providing around 80% of the world sugar production of 177.6 million Mg on the year of 2013, being Brazil responsible for nearly a fourth of it (38.2 million Mg) (UNICA, 2014).

Sugarcane also provides around 35% of the world ethanol production having Brazil leading sugarcane ethanol production with 23.2 billion liters (UNICA, 2014) and the USA as the first ethanol producer (50.3 billion liters) mainly from maize (USDA-FAS, 2014). These numbers summarize the current importance of sugarcane for the world as a food and energy supply, despite bio-electricity from the bagasse and products that are being generated on small scale like bio-plastic and second generation ethanol, which will increase the importance of the crop in a near future.

This important crop is a robust semi-perennial large-sized grass (Poaceae) native from Southeast Asia and cultivated worldwide on tropical and subtropical areas. Sugarcane also have a physiological advantage, as it uses the C4 photosynthetic pathway, characterized by high internal CO₂ concentration, low respiration rate and the capacity to perform photosynthesis at high temperatures (> 35°C), exhibiting a higher net photosynthetic rate compared to C3 plants (MAGALHÃES, 1987; PIMENTEL, 1998) such as wheat and soybean. It has high biomass (stalks) production capacity, which is rich on saccharose (10 to 15% of stalks content), base of the sugar and ethanol production (DINARDO-MIRANDA et al., 2010). But, to support such high biomass synthesis the crop requires more nitrogen (N) that soil can provide from its organic matter, despite some biological N fixation (BODDEY et al., 2003) to enable commercial and economical sugarcane production for consecutive years without crop rotation on the same areas (ORLANDO FILHO et al., 1983).

As a grass, the sugarcane demand of N is higher, extracting 1.43 kg of N per produced Mg, only behind potassium (1.74 kg t⁻¹) (VITTI & MAZZA, 2002), on productions that can reach 200 Mg ha⁻¹ on the first three cuts on commercial fields.

Sugarcane growers, despite decades of research on the nitrogen nutrition, continue with the challenge of making better use of this input. In addition the crop

presents an extra challenge showing variability on N application response (KORNDORFER et al., 2002; CANTARELLA et al., 2007; ROSSETO et al., 2010) caused by many factors as low mineralization during dry periods and biological fixation as organic N (URQUIAGA et al., 1992; FRANCO et al., 2011; SCHULTZ et al., 2012). In addition, there is no reliable soil analysis to determine N availability to the crop on tropical and sub-tropical conditions (CANTARELLA, 2007).

Despite being N only circa 1% of the crop dry biomass, its deficiency causes amino acids and chlorophyll synthesis reduction bringing low carbohydrates production and affecting crop development and final yield (MALAVOLTA et al., 1997).

Deal with such complicated fertilization system is a challenge for sugarcane growers. The crop takes one year on the field from regrowth of the ratoon until the next harvest, being exposed to a wet and dry season on Brazilian conditions along the year, on big fields that show spatial variability, often in short distances (SOLIE et al., 1999).

According to Bramley and Quabba (2002), there are many opportunities for improving the management of sugarcane production through the adoption of precision agriculture. Another research conducted by Silva et al. (2011) shows that the sugarcane industry is increasingly seeking technologies that improve crop management, yield and product quality at lower costs and environmental impact. This study also indicated that 96% of asked sugarcane mills intend to widen the use of precision agriculture practices.

One of the opportunities to improve crop nitrogen use efficiency (NUE) is to manage the fertilizer application rate according to the spatial variability of the nutrient and soils found in production areas following the precision farming concepts (SOLARI, 2006), as uniform N application based on soil samples is not suitable to manage efficiently sugarcane N nutrition.

Alternatively, plant canopy sensors have emerged as a new tool for in field real-time, and spatially localized prediction of plant biomass and N uptake by the crops as basis for N variable rate application and a better N nutrition management (RAUN et al., 2001; BERNTSEN et al., 2006; SOLARI et al., 2008).

Plant canopy sensors can be based on different technologies (GITELSON et al., 2001) such as plant optical reflectance (REUSCH, 1997), ultrasonic plant height (KATAOKA et al., 2002) and laser-induced chlorophyll fluorescence (BREDEMEIER, 2005). Sensors based on the plant optical reflectance of two or more bands of the

electromagnetic spectra are the majority of the crop canopy sensors. These are on the market for more than a decade and already in use for many important crops such as wheat (RAUN et al., 2005), maize (HOLLAND; SCHEPERS, 2010), cotton (SUI et al., 2005), rice (XUE et al., 2013), among others.

On sugarcane, investigations with such sensors are recent; Molin et al. (2010) and subsequently Amaral and Molin (2011) showed that optical canopy sensors could recognize different amounts of applied N. Portz et al. (2012) correlated biomass and N-uptake with an optical canopy sensor vegetation index, verifying a good relation between sensor and sugarcane variables. In the USA, Lofton et al. (2012) showed that an optical canopy sensor was able to measure sugarcane N response. But no one of this studies show results of N variable rate application approaches based on the crop canopy sensors technology. Also no one of the sugarcane studies on crop canopy has used ultrasonic plant height to predict plant biomass and N-uptake during the crop fertilization period, being those, the new approaches of this investigation.

Therefore, it was necessary to: 1) validate the prior calibration made for the reflectance sensor (PORTZ et al., 2012) and to establish the best time to use the sensor over the crop; 2) test the use of the reflectance sensor in comparative strip trials of uniform and sensor based N variable rate application, testing algorithms with positive and negative slope and measuring productivity at the end; 3) obtain the relationship between crop canopy height with accumulated biomass and N uptake by the crop during the initial growing season/ fertilization period; 4) explore the plant height indicator measured with a distance ultrasonic sensor, comparing the results of biomass and N uptake prediction with those obtained with the optical reflectance sensor.

To present that, this thesis is organized on chapters, being each of the above topics one chapter, written in scientific paper format.

References

AMARAL, L.R.; MOLIN, J.P. Sensor óptico no auxílio à recomendação de adubação nitrogenada em cana-de-açúcar. **Pesquisa Agropecuária Brasileira**, Brasília, v. 16, n. 1, p. 1633–1642, 2011.

BERNTSEN, J.; THOMSEN, A.; SCHELDE, K.; HANSEN, O.M.; KNUDSEN, L.; BROGE, N.; HOUGAARD, H.; HØRFARTER, R. Algorithms for sensor-based redistribution of nitrogen fertilizer in winter wheat. **Precision Agriculture**, Dordrecht, v. 7, n. 2, p. 65–83, 2006.

BODDEY, R.M. Endophytic nitrogen fixation in sugarcane: present knowledge and future applications. **Plant and Soil**, The Hague, v. 252, n. 1, p. 139-149, May 2003

BRAMLEY, R.G.V.; QUABBA, R.P. Opportunities for improving the management of sugarcane production through the adoption of precision agriculture: an Australian perspective. **International Sugar Journal**, Glamorgan, v. 104, n. 1240, p. 152, 2002.

BREDEMEIER, C. **Laser-induced chlorophyll fluorescence as a tool for site-specific nitrogen fertilization**: evaluation under controlled environmental and field conditions in wheat and maize. Munique: Die Deutsche Bibliothek, 2005. 219 p.

CANTARELLA, H.; TRIVELIN, P.C.O.; VITTI, A.C. Nitrogênio e enxofre na cultura da cana-de-açúcar. In: YAMADA, T.; ABDALLA, S.R.S.; VITTI, G.C. (Ed.). **Nitrogênio e enxofre na agricultura brasileira**. Piracicaba: IPNI Brasil, 2007. p. 355-412.

CANTARELLA, H. Nitrogênio. In: NOVAIS, R.F.; ALVAREZ, V.H.; BARROS, N.F.; FONTES, R.L.F.; CANTARUTTI, R.B.; NEVES, J.C.L. (Ed.). **Fertilidade do solo**. Viçosa: SBCS, 2007. p. 375-470.

DINARDO-MIRANDA, L.L.; VASCONCELOS, A.C.M.; LANDELL, M.A.G. **Cana-de-açúcar**. Campinas: Instituto Agrônomo, 2010. 882 p.

FAO. **Faostat**. Disponível em: <<http://faostat.fao.org/>>. Acesso em: 05 out. 2014.

FRANCO, H.C.J.; OTTO, R.; FARONI, C.E.; FARONI, C.E.; VITTI, A.C.; OLIVEIRA, E.C.A.; TRIVELIN, P.C.O. Nitrogen in sugarcane derived from fertilizer under Brazilian field conditions. **Field Crops Research**, Amsterdam, v. 121, n. 1, p. 29–41, 2011.

GITELSON, A.A.; MERZLYAK, M.N.; ZUR, Y.; STARK, R.; GRITZ, U. Non-destructive and remote sensing techniques for estimation of vegetation status. In: EUROPEAN CONFERENCE ON PRECISION AGRICULTURE, 3., 2001, Montpellier. **Proceedings...** Lincoln: University of Nebraska, 2001. p. 205–210.

HOLLAND, K.H.; SCHEPERS, J.S. Derivation of a variable rate nitrogen application model for in-season fertilization of corn. **Agronomy Journal**, Madison, v. 102, n. 5, p. 1415–1424, 2010.

KATAOKA, T.; OKAMOTO, H.; KANEKO, T.; HATA, S. **Performance of crop height sensing using ultra sonic sensor and laser beam sensor**. **American society of agricultural engineers**. St. Joseph: ASAE, 2002. (ASAE Paper, 02-1184).

KORNDÖRFER, G.H.; COLOMBO, C.; CHIMELLO, M.A.; LEONE, P.L.C. Desempenho de variedades de cana-de-açúcar cultivadas com e sem nitrogênio. **STAB - Açúcar, Álcool e Subprodutos**, Piracicaba, v. 20, p. 28-31, 2002.

LOFTON, J.; TUBANA, B.S.; KANKE, Y.; TEBOH, J.; VIATOR, H. Predicting sugarcane response to nitrogen using a canopy reflectance-based response index value. **Agronomy Journal**, Madison, v. 104, n. 1, p. 106–113, 2012.

MAGALHÃES, A.C.N. Ecofisiologia da cana-de-açúcar; aspectos do metabolismo do carbono na planta. In: CASTRO, P.R.C., FERREIRA, S.O., YAMADA, T.Y. (ed.) **Ecofisiologia da produção agrícola**. Piracicaba: POTAFOS, 1987. p.113-118.

MALAVOLTA, E.; VITTI, G.C.; OLIVEIRA, S.A. **Avaliação do estado nutricional das plantas: princípios e aplicações**. 2. ed. Piracicaba: Potafós, 1997. 319 p.

MOLIN, J.P.; FRASSON, F.R.; AMARAL, L.R.; POVH, F.P.; SALVI, J.V. Capacidade de um sensor ótico em quantificar a resposta da cana-de-açúcar a doses de nitrogênio. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 14, n. 12, p. 1345–1349, 2010.

ORLANDO FILHO, J. (Coord.). **Nutrição e adubação da cana-de-açúcar no Brasil**. Piracicaba: IAA/Planalsucar, 1983. 369p.

PIMENTEL, C. **Metabolismo de carbono na agricultura tropical**. Seropédica: Edur, 1998. 150 p.

PORTZ, G.; MOLIN, J.P.; JASPER, J. Active crop sensor to detect variability of nitrogen supply and biomass on sugarcane fields. **Precision Agriculture**, Dordrecht, v. 13, n. 1, p. 33–44, 2012.

RAUN, W.R.; SOLIE, J.B.; JOHNSON, G.V.; STONE, M.L.; LUKINA, E.V.; THOMASON, W.E.; SCHEPERS, J.S. In-season prediction of potential grain yield in winter wheat using canopy reflectance. **Agronomy Journal**, Madison, v. 93, p. 131–138, 2001.

RAUN, W.; SOLIE, J.; STONE, M.; MARTIN, K.; FREEMAN, K.; MULLEN, R.; ZHANG, H.; SCHEPERS, J.; JOHNSON, G. Optical sensor-based algorithm for crop nitrogen fertilization. **Communications in Soil Science and Plant Analysis**, New York, v. 36, n. 19/20, p. 2759–2781, 2005.

REUSCH, S. **Entwicklung eines reflexionsoptischen Sensors zur Erfassung der Stickstoffversorgung landwirtschaftlicher Kulturpflanzen**. Thesis (Ph. D) - Kiel, 1997.

ROSSETO, R.; DIAS, F.L.F.; LANDELL, M.G.A.; CANTARELLA, H.; TAVARES, S.; VITTI, A.C.; DEREÇIN, D. N and K fertilization of sugarcane ratoons harvested without burning. In: INTERNACIONAL SOCIETY OF SUGAR CANE TECHNOLOGISTS CONGRESS, 27., 2010, Veracruz. **Proceedings...** Veracruz: ISSCT, 2010. 1 CD-ROM.

SCHULTZ, N.; MORAIS, R.F. de; SILVA, J.A.; BAPTISTA, R.B.; OLIVEIRA, R.P.; LEITE, J.M.; PEREIRA, W.; CARNEIRO JÚNIOR, J.B.; ALVES, B.J.R.; BALDANI, J.I.; BODDEY, R.M.; URQUIAGA, S.; REIS, V.M. Avaliação agronômica de variedades de cana-de-açúcar inoculadas com bactérias diazotróficas e adubadas com nitrogênio. **Pesquisa Agropecuária Brasileira, Brasília**, v. 47, n. 2, p. 261–268, 2012.

SILVA, C.B., DE MORAES, M.A.F.D.; MOLIN, J.P. Adoption and use of precision agriculture technologies in the sugarcane industry of São Paulo state, Brazil. **Precision Agriculture**, Dordrecht, v. 12, n. 1, p. 67–81, 2011.

SOLARI, F. **Developing a crop based strategy for on the go n management in irrigated cornfields**. 2006. 157 p. Thesis (PhD) – Graduate College at the University of Nebraska, Lincoln, 2006.

SOLARI, F.; SHANAHAN, J.; FERGUSON, R.; SCHEPERS, J.; GITELSON, A. Active sensor reflectance measurements of corn nitrogen status and yield potential. **Agronomy Journal**, Madison, v. 100, n. 3, p. 571–579, 2008.

SOLIE, J.B.; RAUN, W.R.; STONE, M.L. Submeter spatial variability of selected soil and Bermuda grass production variables. **Soil Science Society of America Journal**, Madison, v. 63, n. 6, p. 1724-1733, Nov./Dec. 1999.

SUI, R.; WILKERSON, J.B.; HART, W.E.; WILHELM, L.R.; HOWARD, D.D. Multispectral sensor for detection of nitrogen status in cotton. **Applied Engineering in Agriculture**, St. Joseph, v. 21, n. 2, p. 167-172, 2005.

UNIÃO DA INDÚSTRIA DE CANA-DE-AÇÚCAR. **Setor sucroenergético**. Disponível em: <http://www.unicadata.com.br/historico-de-area_ibge.php?idMn=33&tipoHistorico=5> . Acesso em: 3 nov. 2014.

UNITED STATES DEPARTMENT OF AGRICULTURE. Foreign Agricultural Service. Disponível em: <<http://www.fas.usda.gov/data>>. Acesso em: 3 nov. 2014.

URQUIAGA, S.; CRUZ, K.H.S.; BODDEY, R.M. Contribution of nitrogen-fixation to sugar-cane - n-15 and nitrogen-balance estimates. **Soil Science Society of America Journal**, Madison, v. 56, n. 1, p. 105-114, 1992.

VITTI, G. C.; MAZZA, J. A. Encarte técnico planejamento, estratégias de manejo e nutrição da cultura de cana-de-açúcar. **Informações Agronômicas**, Piracicaba, n. 19, p. 1–16, 2002.

XUE, L.; LI, G.; QIN, X.; YANG, L.; ZHANG, H. Topdressing nitrogen recommendation for early rice with an active sensor in south China. **Precision Agriculture**, Dordrecht, v. 15, p. 95–110, 2013.

2 OPTIMUM SUGARCANE GROWTH STAGE FOR CANOPY REFLECTANCE SENSOR TO PREDICT BIOMASS AND NITROGEN UPTAKE

Abstract

The recent technology of plant canopy reflectance sensors can provide the status of biomass and nitrogen nutrition of sugarcane spatially and in real time, but it is necessary to know the right moment to use this technology aiming the best predictions of the crop parameters by the sensor. A study involving eight commercial fields located in the state of São Paulo, Brazil, varying from 16 to 21 ha, planted with four varieties, was conducted during two growing seasons (2009/10 - 2010/11). Conditions varied from sandy to heavy soils and the previous harvesting occurred in May and October (early and late season), including first to fourth ratoon stages. Fields were scanned with the reflectance canopy sensor (N-Sensor[®] ALS, Yara International ASA) three times in the first season (approximately at 0.2, 0.4, and 0.6 m of stalk height) and two on the second season (0.3 and 0.5 m), followed by tissue sampling for biomass, crop height and nitrogen uptake on ten spots inside the area, guided by the different values shown by the canopy sensor. At 0.2 m of field average stalk height, sugarcane biomass is low for a good sensor prediction of the parameters; at 0.6 m height starts the saturation, where the ability of the sensor to predict biomass and nitrogen begins to be affected. Between 0.3 and 0.5 m of stalk height results show the best correlation between real and sensor predicted biomass and nitrogen uptake for sugarcane crop, indicating that this is the right period for using the sensor to guide variable rate nitrogen application.

Keywords: nitrogen management, proximal sensing, N-Sensor.

2.1 Introduction

The recent technology of canopy sensors using vegetation reflectance at certain wavelengths can provide georeferenced information about biomass and nitrogen nutrition of the crop in real time, which can guide the implementation of variable N application. The sugar-ethanol industry in São Paulo state, which produces 60% of the commercial sugarcane of Brazil, indicated that precision agriculture technologies can provide improvements, higher yield, lower costs, minimize the environmental impacts and bring improvements in sugar cane quality, suggests a research made by Silva et al. (2011), that also says that 96% of the sector wants to expand the use of precision agriculture practices.

One of the existing canopy sensors for nitrogen management is the N-Sensor (N-Sensor[®] ALS, Yara International ASA). According to Jasper et al. (2009) and Reusch (2005), it uses an optimum waveband selection to generate a vegetation index (VI) to determining the nitrogen uptake from crops by active remote sensing. In

particular, the resulting relationship seemed to be largely independent of growth stage and variety, and showed less saturation at high N uptake levels. This optimized VI used by the sensor takes the beginning of the near infrared (NIR) at 760 nm and the slope of reflectance between the red and the NIR named REIP (Red Edge Inflection Point), at 730 nm.

According to Singh (2006), there is a great scope for the use of the N-Sensor for optimize nitrogen application in sugarcane cultivation, but the sensor needs to be tested and validated for sugarcane cropping systems. This research activity is already being done in Brazil since 2009 (PORTZ et al., 2012), showing that the sensor is capable to predict biomass and nitrogen uptake with accuracy independent of soil, variety and year season during a long period of the initial development of the crop, also showing the first data set capable to provide an algorithm to guide variable rate application of N over commercial sugarcane fields.

Other studies, such as Mutanga and Skidmore (2004), Heege et al., (2008) and Mokhele and Ahmed (2010), showed that the red edge area contains more information on biomass quantity as compared to other parts of the electromagnetic spectrum and that narrow wavelengths located in the red edge slope contain information at full canopy cover. As consequence, it has the highest correlation coefficients with biomass if obtained with a waveband located in the shorter red edge portion (706 nm) and a band located in the longer red edge portion (755 nm) for a better estimation of biomass at high canopy density. However Portz et al. (2012) indicate that in high biomass sugarcane, at 0.6 m average of stalk height, saturation starts to appear on the sensor signal using the VI from red edge.

This paper shows an improvement and validation of the results presented by Portz et al. (2012) by proposing the right growth stage to use the N-Sensor aiming to indicate biomass accumulation and nitrogen application demands based on the N-uptake on commercial sugarcane fields.

2.2 Materials and methods

During the 2009/10 and 2010/11 growing seasons eight commercial fields of sugarcane located around the São Martinho Sugar Mill (21°19'11"S, 48°07'23"W), in the state of São Paulo, Brazil, were evaluated. Conditions varied from sandy to clayey soils, with all crops being mechanically green harvested (without burn). On the four fields, harvesting of the previous crop occurred at the beginning of the season

(May/June) corresponding to the dry time of the year, and on the other four fields, in late season (October/November), corresponding to the wet time of the year. The crops under investigation included first, second and third ratoon stages in 2009/10 and second, third and fourth ratoons in 2010/11. The first four fields were planted with the varieties CTC 9 over sandy soil and RB 855453 over clayey soil and all were harvested in the dry season. The last four fields were planted with the varieties CTC 2 on sandy soil and SP 80–3280 on clayey soil, and harvested during the wet season (Table 1).

Table 1 - Variables of the studied areas

Field	1	2	3	4	5	6	7	8
Variety	CTC 9		RB 855453		CTC 2		SP 803280	
Size (ha)	21	16	18	17	20	18	21	16
Harvest	may/jun (dry season)				oct/ nov (wet season)			
Soil	sandy		clayey		sandy		clayey	
Ratoon 09/10	1 st	2 nd	1 st	3 rd	1 st	2 nd	1 st	3 rd
Ratoon 10/11	2 nd	3 rd	2 nd	4 th	2 nd	3 rd	2 nd	4 th

Shortly after harvesting all fields were fertilized with a uniform dose of 100 kg ha⁻¹ of nitrogen using ammonium nitrate (30% N) as the N source, spread over the sugarcane rows surface. The sugarcane fields were scanned using the N-Sensor (Jasper et al., 2009), being the sensor mounted behind the cabin of a high clearance vehicle (Uniport NPK 3000, Jacto Agricultural Machinery, Pompéia, SP).

The target parameter for the agronomic calibration of the sensor readings is the N-uptake of the above-ground biomass of the crop (Link et al. 2005). As the relationship between sensor readings and crop N uptake might be growth stage specific, each of the eight fields was scanned with the sensor three times in the 2009/10 growing season (at 0.2, 0.4, and 0.6 m average stalk height) and two times during the 2010/11 (at 0.3 and 0.5 m average stalk height) (Figure 1). The sugarcane crop height of each sample plot was defined as the average stalk distance from the soil to the insertion of the Top Visible Dewlap leaf (TVD) (Dillewijn, 1952).

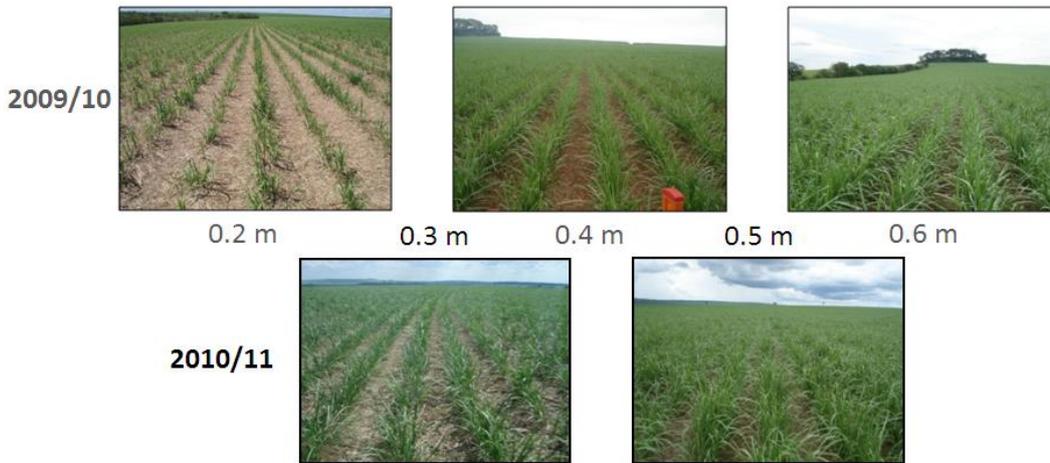


Figure 1 - Growth status of sugarcane at the measurement moments

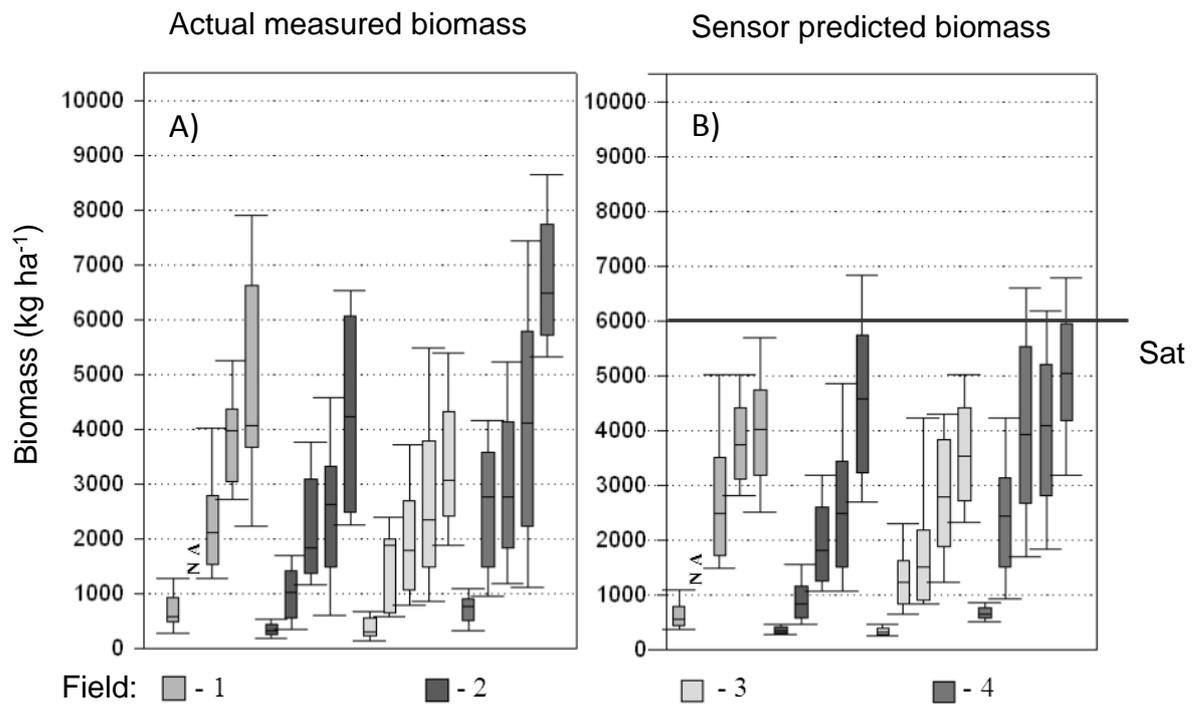
The sensor was connected to a GPS receiver and the vehicle was driven through the whole field spaced by 10 rows of 1.5 m. After the scanning, the sensor data was processed generating sensor VI index maps of the fields. Over these maps 10 sample plots were located guided by the different values shown by the canopy sensor and followed by tissue sampling for biomass, crop height and nitrogen uptake as explained by Portz et al. (2012).

Sensor readings of the respective sample plots were related to the crop parameters, specific calibration functions were derived, and the capacity of the sensor measurements to predict the actual crop biomass and N-uptake was investigated.

An exploratory analysis of the data was done running box plot test. Sensor data of each field were correlated with biomass and nitrogen uptake from the respective sample points. Also simple linear regression models were used to compare N-uptake collected data against sensor predicted N-uptake for each of the field stalk average height evaluated.

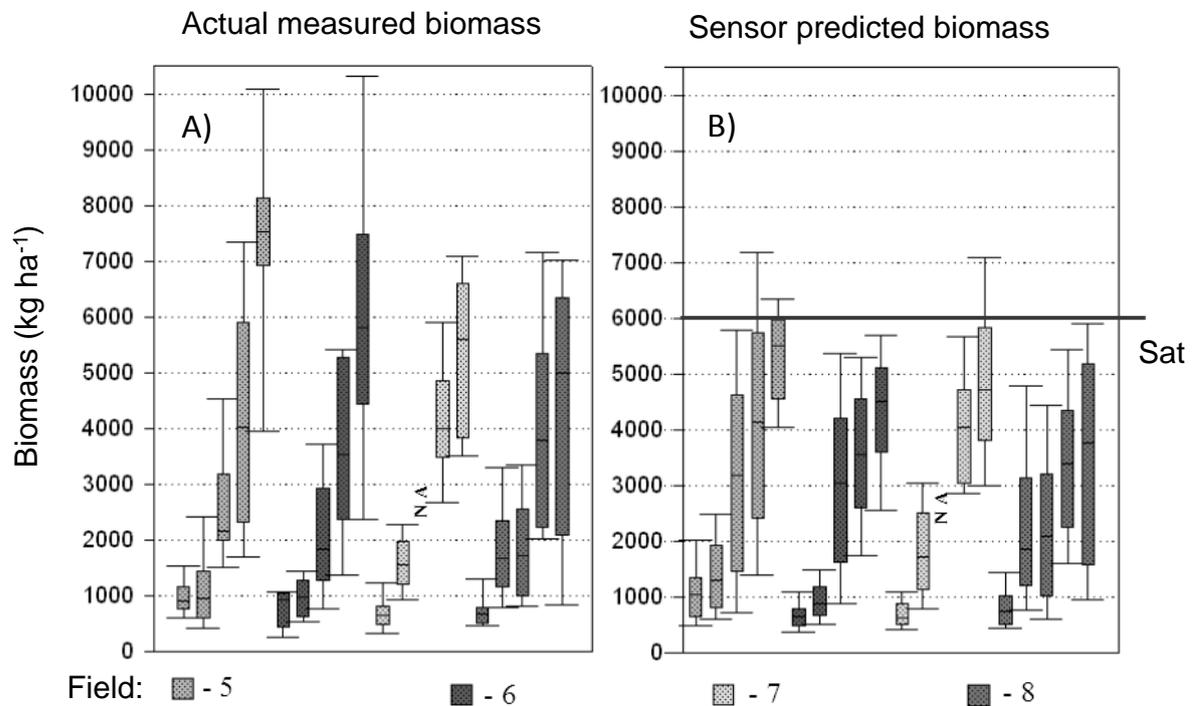
2.3 Results and discussion

To observe the individual behavior of the variables in each of the eight fields evaluated in five crop heights during two years, the data from the studied fields were compared first independently, side by side, by box plot analyses for biomass (Figures 2 and 3) and for N-uptake (Figures 4 and 5).



Observations: Sat = saturation point, NA = Not available data.

Figure 2 - Actual measured sugarcane biomass (A) compared to sensor predicted biomass (B) for the four fields of the early season (dry season).



Observations: Sat = saturation point, NA = Not available data.

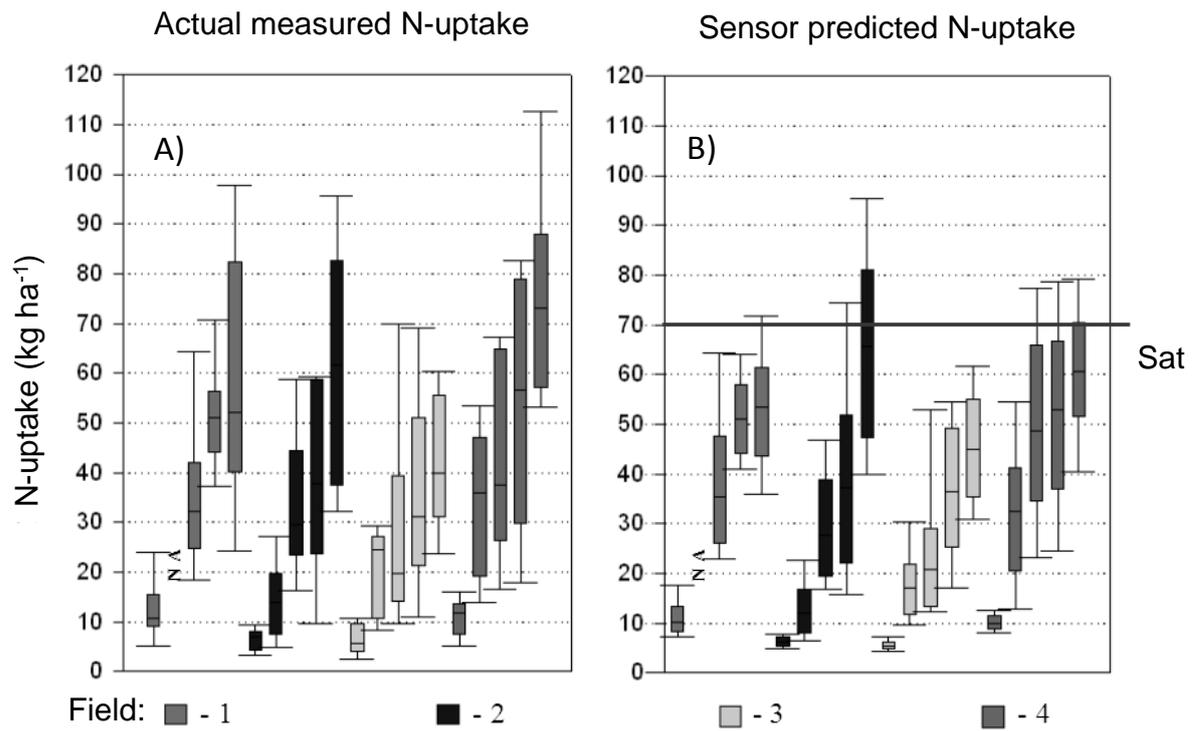
Figure 3 – Actual measured sugarcane biomass (A) compared to sensor predicted biomass (B) for the four fields of the late season (wet season).

Analyzing the biomass data it is possible to see that the 2010/11 data (0.3 and 0.5 m) fitted right in the 2009/10 data (0.2, 0.4 and 0.6 m), even with climate differences between years (Appendix A) and one ratoon older crop.

The first measurement (0.2 m) shows low and concentrated values, usually below 1000 kg ha^{-1} of dry matter, especially in the early season that is in the dry and colder period of the year.

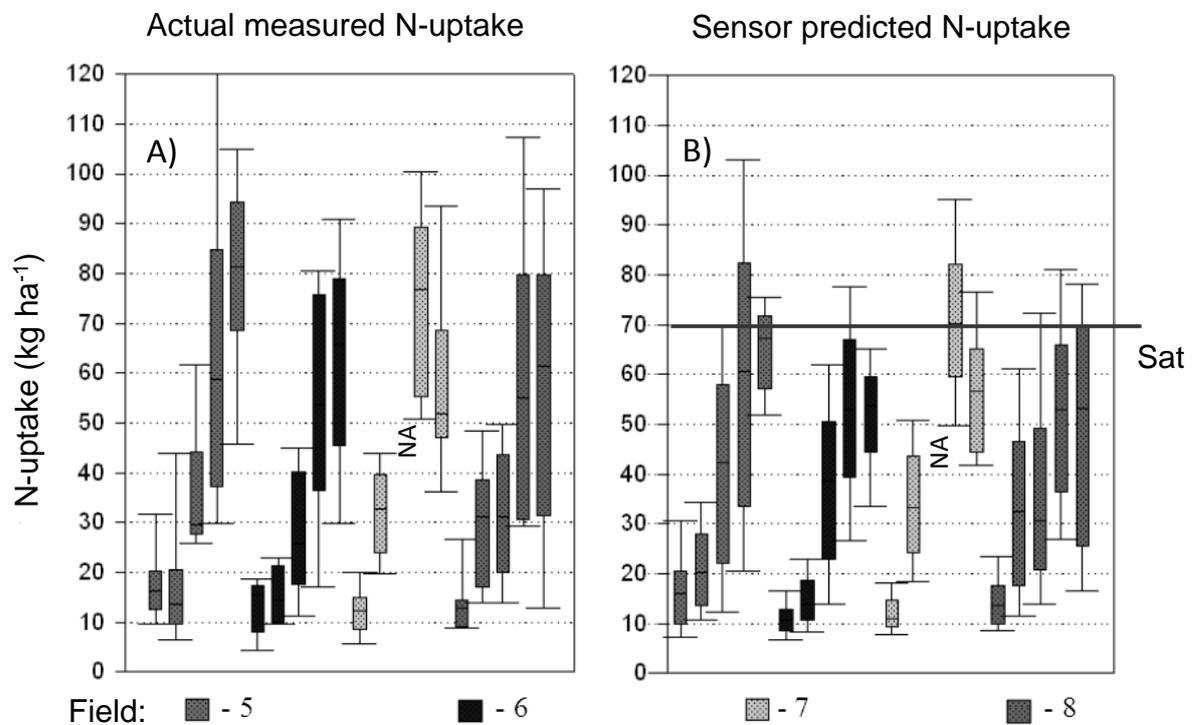
The actual biomass measured in field (A) for the early season (Fig. 2) and for the late season (Fig. 3) reached around 8000 kg ha^{-1} of dry matter, with higher values in the late season, that is in the rainy and warmer period of the year. However when we analyze the sensor predicted values for the same field points (right graph), at around 6000 kg ha^{-1} of dry matter an upper limit is achieved, indicating that the phenomenon of sensor saturation begins ("Sat" line).

The sensor saturation happens when the biomass increases but the values of the sensor for the same biomass increase in a lower rate or stop to increase. The saturation is related to the VI used by the sensor and also to the narrow bands involved on it. The major limitation of using vegetation indices based on the red and NIR portion of the electromagnetic spectrum is that they asymptotically approach a saturation level after a certain biomass density (TUCKER, 1977, TODD et al. 1998, THENKABAIL et al., 2000). The results are indicating that the red edge sensor used is accurately working until biomass covers the entire surface, as happens when the sugarcane is at 0.6 m of stalk height (Fig. 1). For N-uptake the behavior is similar, as shown on Figures 4 and 5.



Observations: Sat = saturation point, NA = Not available data.

Figure 4 - Actual measured sugarcane N-uptake (A) compared to sensor predicted N-uptake (B) for the four fields of the early season (dry season)



Observations: Sat = saturation point, NA = Not available data.

Figure 5 - Actual measured sugarcane N-uptake (A) compared to sensor predicted N-uptake (B) for the four fields of the late season (wet season).

The N-uptake values follow the biomass trend as they are the dry matter multiplied by the N concentration of the field samples. But the sensor saturation is not so clear on the N-uptake, partly explained because when the plant grows the biomass increases but the N concentration decreases (Appendix B). In this way sensor saturation does not show so early when the intention is to predict nitrogen and not biomass, what is good because the main target is to predict N use by the crop.

The sensor can predict N-uptake until around 70 kg N ha^{-1} with high accuracy, but having deviations in some fields and heights. There is an explanation for the second field (Fig. 4) not showing saturation at the 0.6 m height like the others; the sensor scanning was made in a very warm day in the afternoon (2:00 pm) during a very drought period and the crop was presenting closed leaves to preserve water. This plant reaction led to a decrease in canopy cover reducing the values read by the sensor without biomass decrease.

On the wet season (Fig. 5), fields 5 and 7 had predicted N-uptake values over the proposed sensor saturation line of $70 \text{ kg of N ha}^{-1}$ on the 0.5 m measurement, but at the 0.6 m stalk average height both field presented lower values, indicating that the sensor saturation phenomenon appears.

At 0.5 m stalk height the sugarcane canopy is almost closed (Fig. 1). Further increase of biomass is mainly due to stalk elongation and not to the development of additional leaves. This is a crop characteristic that also has a negative impact on the sensitivity of the sensor reading, and contributes to the signal saturation at 0.6 m crop height.

Aiming to solve all doubts about a the N-uptake during the growth stages and the performance of the sensor, a second analyses was done comparing directly real N-uptake and sensor predicted N-uptake by regressions as shown in Figure 6.

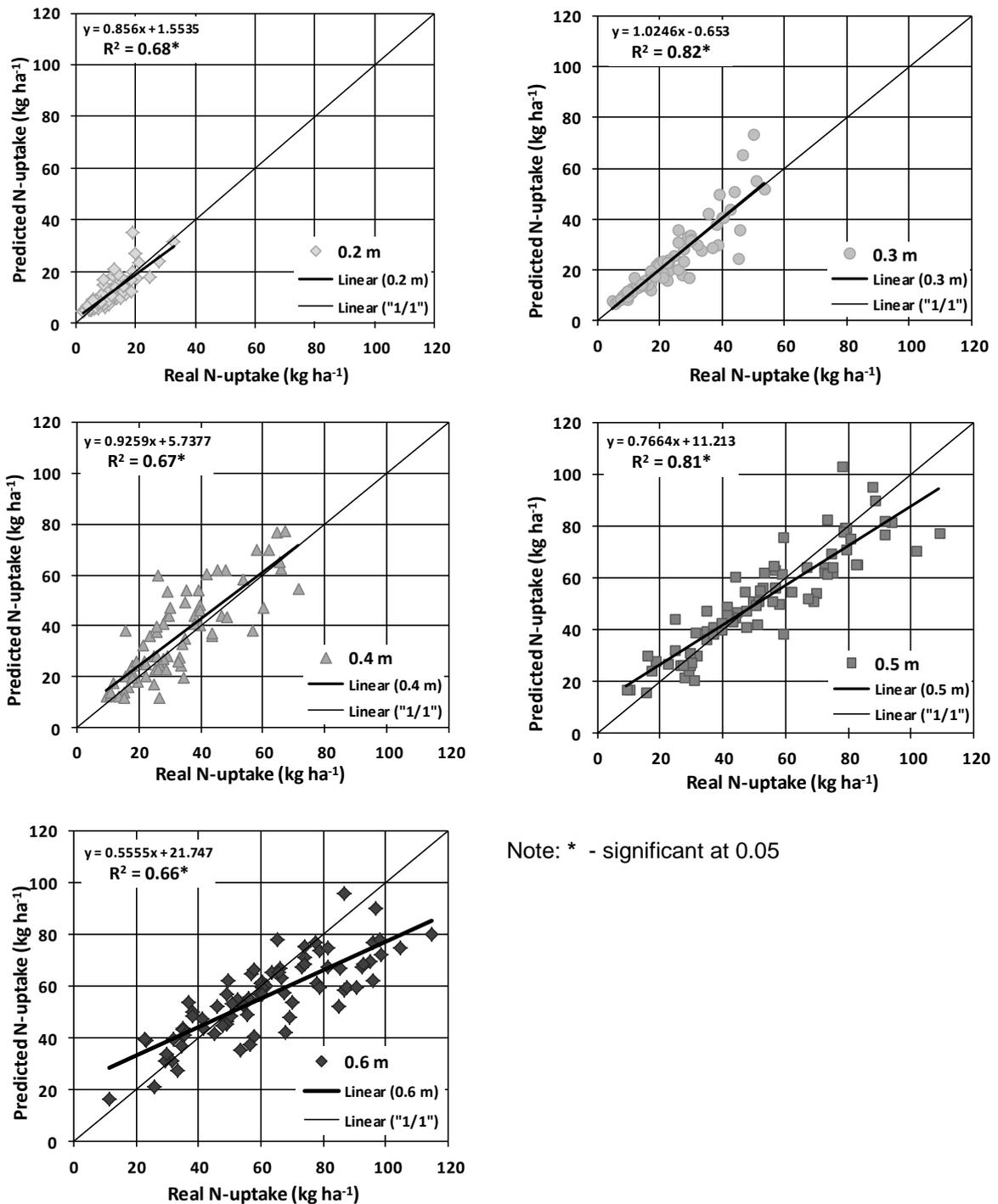
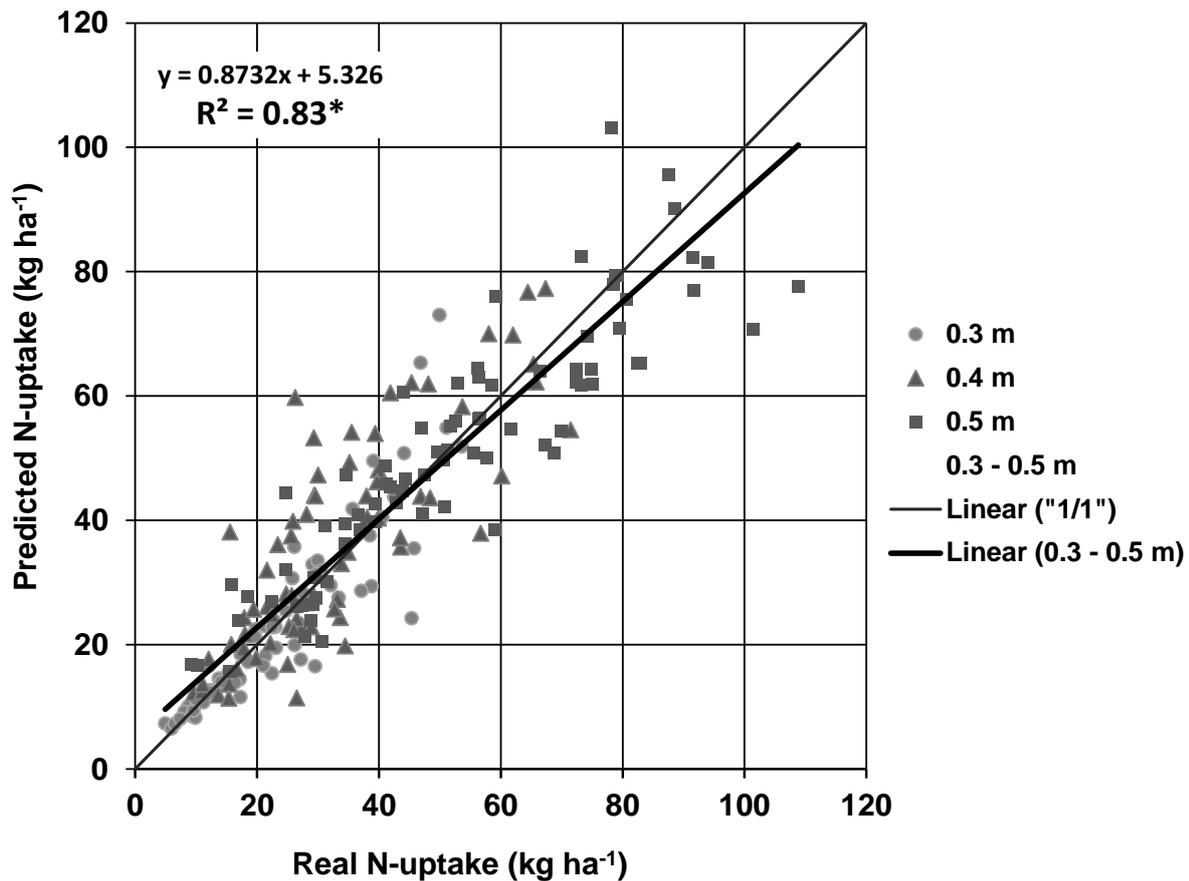


Figure 6 - Sugarcane real measured N-uptake compared to sensor predicted N-uptake for the five measurement heights.

As noted by Portz et al. (2012), pooling the data of different fields in a single set is possible, as the relationship is not affected by soil and variety properties and season effects. This is very important when looking for agronomic algorithms to guide nitrogen application, because there is no need for growth stage or soil specific

algorithms, which simplifies the task. At 0.2 m stalk height the values are low and concentrated, with most values under 20 kg N ha⁻¹, indicating that measurements at this height are too early to obtain good information about in-field variability from the sensor. The 0.3 m and 0.4 m crop height data show a good N uptake prediction from 10 to 60 kg N ha⁻¹ and 15 to 70 kg N ha⁻¹ respectively. The 0.5 m crop height data represent a wider range of N-uptake predictions (20 to almost 100 kg N ha⁻¹), but the saturation phenomenon starts to appear. At 0.6 m average crop height many spots exist in the field with even higher crop, i.e. stalk heights of 0.7 to 1.0 m, what causes saturation on the sensor decreasing the sensor accuracy on these places. The data of the three most suitable measurement heights combined in a single data set are presented in Figure 7.



Note: * - significant at 0.05, NS - not significant

Figure 7 - Integration of sugarcane real measured N-uptake compared to sensor predicted N-uptake for the 0.3 to 0.5 meter heights.

Using only the crop heights of 0.3 to 0.5 m there is an improvement in the prediction of nitrogen uptake initially presented by Portz et al. (2012). Not by a higher

coefficient of determination (R^2) for the correlation, but by its slope that is closer to the 1 to 1 line, indicating less deviation of the predicted N uptake from real values. These results also corroborate with what AMARAL & MOLIN (2014) found working with a similar optical canopy sensor on sugarcane.

2.4 Conclusions

At 0.2 m of field average stalk height, sugarcane biomass is too short for sensor-based prediction of in-field variability of crop biomass and N-uptake. At 0.6 m crop height the phenomenon of sensor signal saturation begins to affect the ability of the sensor to accurately predict biomass and nitrogen uptake.

Between 0.3 and 0.5 m of average stalk height results show the best correlation between real and sensor predicted biomass and nitrogen uptake for a sugarcane crop, indicating that this is the right period for using the sensor to guide variable rate nitrogen application.

References

AMARAL, L.R.; MOLIN, J.P. The Effectiveness of three vegetation indices obtained from a canopy sensor in identifying sugarcane response to nitrogen. **Agronomy Journal**, Madison, v. 106, n. 1, p. 273–280, 2014.

DILLEWIIJN, C. VAN. **Botany of sugarcane**. Waltham: Chronica Botanica. 371 p. 1952.

HEEGE, H.J.; REUSCH, S.; THIESSEN, E. Prospects and results for optical systems for site-specific on-the-go control of nitrogen-top-dressing in Germany. **Precision Agriculture**, Dordrecht, v. 9, n. 3, p. 115-131. 2008.

JASPER, J., REUSCH, S. AND LINK, A. Active sensing of the N status of wheat using optimized wavelength combination – impact of seed rate, variety and growth stage. In: EUROPEAN CONFERENCE ON PRECISION AGRICULTURE, 7., 2009, Wageningen. **Precision agriculture '09: proceedings...** Wageningen, 2009. p. 23-30.

LINK, A.; JASPER, J.; REUSCH, S. Suitability of different crop parameters for the determination of site-specific nitrogen fertilizer demand. In: 7th EUROPEAN CONFERENCE ON PRECISION AGRICULTURE, 5., 2005, Uppsala. **Precision agriculture' 05: proceedings...** Wageningen, 2005. p. 297-302.

MOKHELE, T.A.; AHMED, F.B. Estimation of leaf nitrogen and silicon using hyperspectral remote sensing. **Journal of Applied Remote Sensing**, Amsterdam, v. 4, p. 18, Nov. 2010.

MUTANGA, O.; SKIDMORE, A.K. Narrow band vegetation indices overcome the saturation problem in biomass estimation. **International Journal of Remote Sensing**, Amsterdam, v. 25, n. 19, p. 3999-4014, Oct. 2004.

PORTZ, G.; MOLIN, J.P.; JASPER, J. Active crop sensor to detect variability of nitrogen supply and biomass on sugarcane fields. **Precision Agriculture**, Dordrecht, v. 13, n. 1, p. 33–44, 2012.

REUSCH, S. Optimum waveband selection for determining the nitrogen uptake in winter wheat by active remote sensing. In: 7th EUROPEAN CONFERENCE ON PRECISION AGRICULTURE, 5., 2005, Uppsala. **Precision agriculture' 05: proceedings...** Wageningen, 2005. p. 261-266.

SILVA, C.B.; DE MORAES, M.A.F.D.; MOLIN, J.P. Adoption and use of precision agriculture technologies in the sugarcane industry of São Paulo state, Brazil. **Precision Agriculture**, Denver, v. 12, n. 1, p. 67-81, 2011

SINGH, I. Crop sensors for efficient nitrogen management in sugarcane: Potential and constraints. **Sugar Tech**, New York, v. 8, n. 4, p. 299-302, 2006.

THENKABAIL, P. S., SMITH, R. B., AND DE PAUW, E. Hyperspectral vegetation indices and their relationships with agricultural crop characteristics. **Remote Sensing of Environment**, 71, 158–182, 2000.

TODD, S. W., HOFFER, R. M., AND MILCHUNAS, D. G. Biomass estimation on grazed and ungrazed rangelands using spectral indices. **International Journal of Remote sensing**, 19, 427–438. 1998.

TUCKER, C. J. Asymptotic nature of grass canopy spectral reflectance. **Applied Optics**, 16, 1151–1156. 1977.

3 REAL-TIME SUGARCANE VARIABLE RATE NITROGEN APPLICATION STRATEGIES BASED ON OPTICAL CROP CANOPY SENSOR

Abstract

Nitrogen (N) management is a challenge for sugarcane growers as soil N analysis on tropical soils conditions are unreliable, crop response to N fertilization is variable, N recovery normally under 40 % and in field crop variability can be high. To deal with such problems researchers are studying the use of crop canopy optical sensors to guide N real-time variable rate application technology (VRT). Aiming to test the canopy optical sensor approach, five fields (one used as study case) located in the state of São Paulo-Brazil during the 2011/12 and 2012/13 growing seasons were investigated using a strip trial approach. The fields were located over sandy and clayey soils and harvested in the dry and wet seasons of the year. In each field 16 strips on a randomized design were established, being eight treated with a uniform rate (100 kg ha^{-1} ammonium nitrate), four right after cut and the other four when the crop was with 0.4 m of stalk height. Also at 0.4 m the other eight strips receive N fertilizer on real-time VRT based on an optical canopy sensor, four using a positive slope approach and the last four a negative slope. On each field, yield data of individual strips was collected, filtered, statistically analyzed and compared between treatments. On a global analyses the delay of N application from after cut to 0.4 m of stalk height decrease yield, but the VRT approach increase yield on the dry season fields and over sandy soil in the wet season field using the positive slope, and also using the negative slope on the clayey soil field of the wet season. On the study case field, established on the wet season, it was also possible to obtain a higher nitrogen use efficiency using the VRT approach with positive slope of its sandy part and the negative slope over the clayey part of the field.

Keywords: Spatial variability, strips trial, soil fertility, yield map

3.1 Introduction

Sugarcane is a semi-perennial crop that stays in the field and grows the entire year in tropical conditions, but must be exposed to stress situation through a dry season and/or cold temperatures (under 20°C) to achieve maturation, and promote sugar (sucrose) accumulation for commercial production, but if exposed to frost the plant itself or its apical meristem can die (MOLIN et al., 2013).

In southeast Brazil conditions sugarcane is harvested from March to November (fall, winter and spring, being winter the dry time of the year), and summer, the wet period when the crop grows more. Therefore the crop is not harvested on summer and lived to growth as sugarcane have a physiological advantage, it uses the C4 photosynthetic pathway, characterized by high internal CO_2 concentration, low respiration rate and the capacity to perform photosynthesis at

high temperatures ($> 35^{\circ}\text{C}$), exhibiting a higher net photosynthetic rate compared to C3 plants (MAGALHÃES, 1987; PIMENTEL, 1998).

Sugarcane fertilization has to follow harvest and be done from fall until beginning of summer, what brings on extra challenge for growers, as it has to be done on dry and wet climates with medium and high temperatures that influence on soil nitrogen (N) dynamic and consequent N availability, showing the crop variability on N application response (KORNDORFER et al., 2002; CANTARELLA et al., 2007; ROSSETO et al., 2010) caused by many factors as low mineralization during dry periods and biological immobilization as organic N (URQUIAGA et al., 1992; FRANCO et al., 2011; SCHULTZ et al., 2012). In addition, there is no reliable soil analysis to determine N availability to the crop on tropical and sub-tropical conditions (CATARELLA, 2007).

Nevertheless, sugarcane demand of N is high, extracting 1.43 kg of N per produced Mg, only behind potassium (1.74 kg t^{-1}) (VITTI & MAZZA, 2002), on productions that can reach 200 Mg ha^{-1} on the first cuts on commercial fields, being so N management a challenger for sugarcane growers world wide as N recovery normally is around 40 % (CATARELLA, 2007) and in field crop variability can also be high, sometimes in short distances (SOLIE et al., 1999).

To deal with such problems researchers are studying the use of crop canopy optical reflectance sensors (ORS) to guide N variable rate application technology (VRT). Portz et al. (2012), Lofton et al. (2012), and Amaral et al. (2014) showed that canopy optical sensors are able to detect the sugarcane in field variability with high accuracy in early stages of crop development.

Canopy optical sensors are in the market for more than a decade having many studies published mainly on wheat and maize, showing better performance compared to farmer practices (SCHARF et al., 2011), increase on nitrogen use efficiency (NUE) (RAUN et al., 2002) and profitability (BOYER et al., 2011).

Revising the available N sensors in the market, Singh et al. (2006) said that it is a great opportunity to use such sensors aiming N application economy on sugarcane plantations in development countries, but for that these sensors have to be calibrated, tested and validated for the sugarcane crop.

Portz et al. (2012), in a previous work with the optical Yara N-Sensor found the relations between the sensor readings and the crop biomass and N-uptake being these results used to produce an N application algorithm for the N-Sensor on sugarcane,

as previous research from Link et al. (2005) indicate that information on the in-field variability of N-uptake is most valuable for the derivation of site-specific N fertilizer recommendations.

To test and validate the canopy optical sensors guiding real-time N VRT fertilization, the approach of in field strips trial (RZEWNICKI et al., 1988; HICKS et al., 1997; WUEST et al., 1994) is accepted and used by many researches in different crops. Also using the Yara N-Sensor, Bragagnolo et al. (2013), testing sensor based VRT on field strips of maize on South Brazilian conditions, concluded that the sensor based fertilization approach increased NUE.

Despite all the researches of optical canopy sensor on sugarcane, we still see a lack of publications showing results of N VRT over sugarcane fields guided by optical canopy sensors aiming increase of productivity and/or NUE. Based on that, the propose of this paper is to evaluate real-time N VRT approaches based on optical canopy sensor over sugarcane commercial fields on different soil and season conditions of Southeast Brazil.

3.2 Material and methods

During the 2011/12 and 2012/13 growing seasons five sugarcane commercial fields located around the São Martinho Sugar Mill (21°19'11"S, 48°07'23"W), in the state of São Paulo, Brazil, were evaluated with the use of an real-time N VRT approach based on a canopy optical reflectance sensor (N-Sensor[®] ALS, Yara International ASA) described by Jasper et al. (2009).

Field conditions varied from sandy to clayey soils, with all crops being mechanically green harvested (with no burn). On two fields, harvest of the previous crop occurred at the beginning of the season (May/Jun), corresponding to the dry time of the year, and on the other three fields, in late season (Oct/Nov), rainy season (Table 1).

Table 1 - Distribution of the fields according soil type and season.

Season	Soil type		
	Clayey		Sandy
Dry	Field 1		Field 2
Wet	Field 3	Field 5	Field 4

To test the VRT strategy against local practice (uniform rate) on commercial field condition was implemented a strips trial design (Figure 1) for all the studied fields.

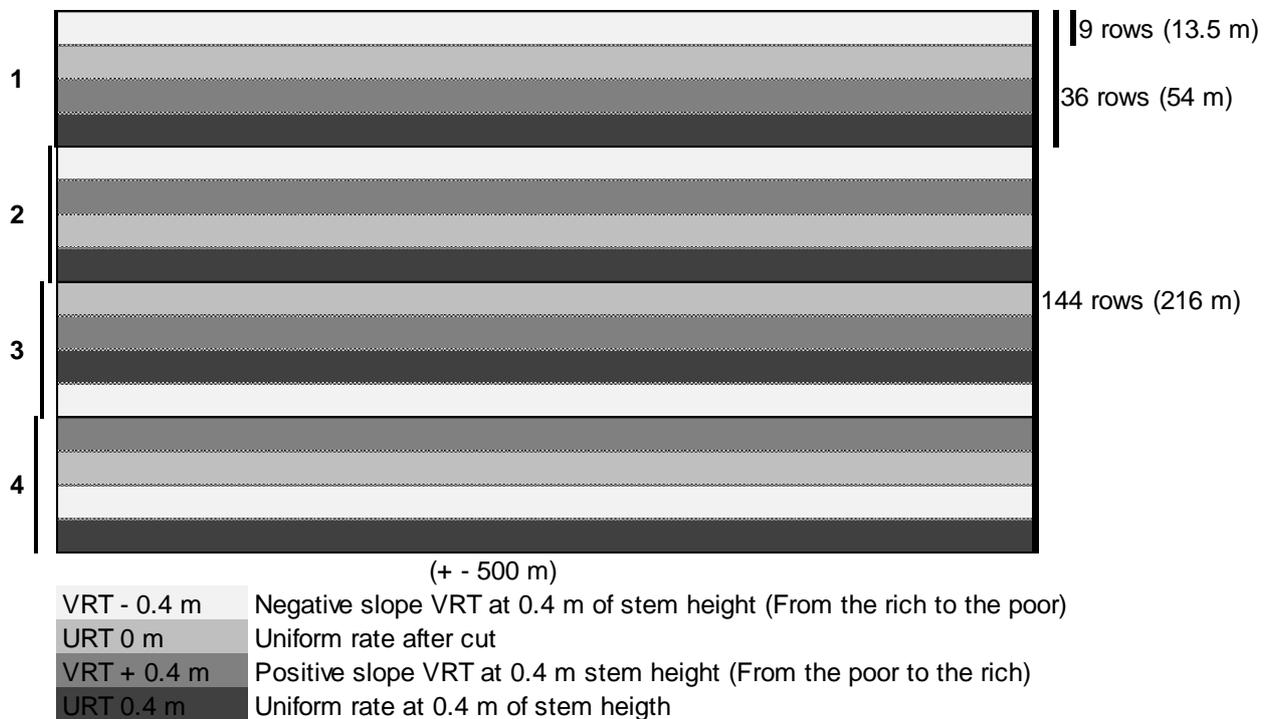


Figure 1 - Strips trial design.

The design consisted of four blocks with randomized strips containing four treatment strips each block. The first treatment consisted of a uniform rate (URT 0 m) right after cut (farm practice). But for sensor use, the crop must be present and evaluated, so was also implemented a uniform rate at 0.4 m of stalk height (URT 0.4 m) and two VRT treatments; one with the negative slope approach (VRT - 0.4 m) where the fertilizer rate was increased on field regions of poor crop, and one with positive slope (VRT +0.4 m) where the rate was higher where the crop was in a better condition showed by an higher sensor vegetation index.

The VRT real-time approach was based on the algorithms derived from the previous calibration for the sensor on sugarcane (PORTZ et al., 2012). All the fields were fertilized with a URT or VRT goal rate of 320 kg ha^{-1} of ammonium nitrate (32% N) that correspond the recommend rate of 100 kg ha^{-1} of N based on response curves for ratoon sugarcane in southeast Brazil (RAIJ et al., 1997). As managers decision field 5 (study case) received vinasse on the dose of $50 \text{ m}^3 \text{ ha}^{-1}$ right after crop harvest, corresponding to approximately 20 kg N ha^{-1} . After harvest and before any fertilizer application all the fields were soil sampled on 0.5 ha regular grid for chemical and physical parameters being the data presented as buffer correlations with sensor and yield for field 5.

The sensor was mounted behind the cabin of a high clearance row solid fertilizer spreader (Uniport NPK 3000, Jacto Agricultural Machinery, Pompéia, SP) (Figure 2).

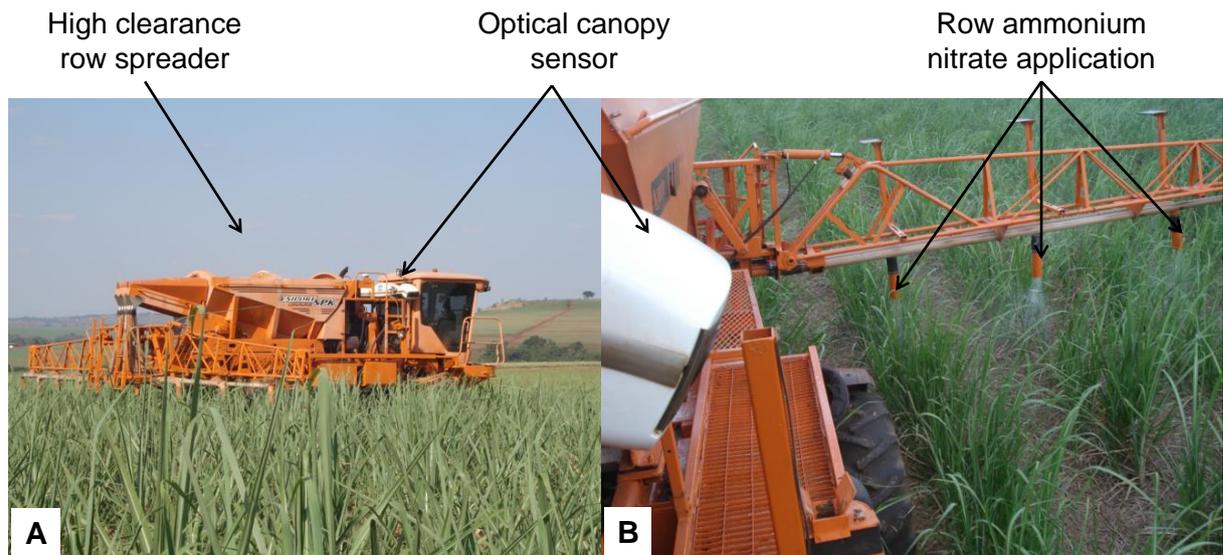


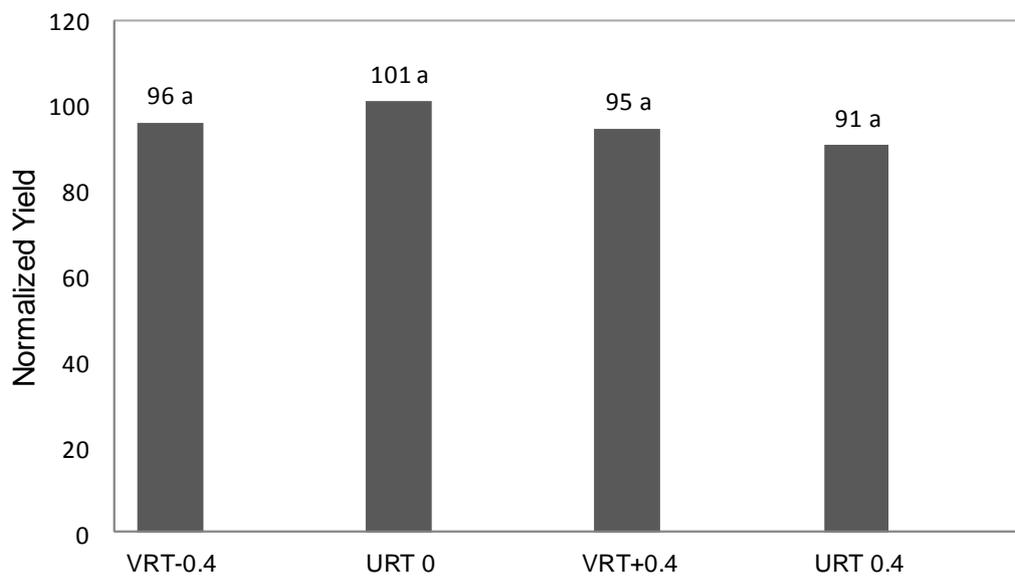
Figure 2 - (A) High clearance spreader with sensor mounted. (B) Detail of on row fertilizer application and sensor reading in front.

The areas were harvested with a CASE IH harvester (CNH, Piracicaba, Brazil) equipped with an yield monitor SIMPROCANA (Enalta Technology Solutions, São Carlos, Brazil) described by Magalhães and Cerri (2007). Yield points were recorded every two seconds. Data outliers were excluded and productivity data of the treatments was compared statistically, as well as maps of georeferenced productivity where made and presented for field 5. As it was located over a unique soil situation (over a soil transition area) field 5 was taken as a study case and deeper investigated

comparing yield and nitrogen use efficiency (NUE, productivity per unit N) among treatments and soil conditions.

3.3 Results and discussion

The combined analyze of the average yield per treatment on the five studied fields is showed on figure 3.

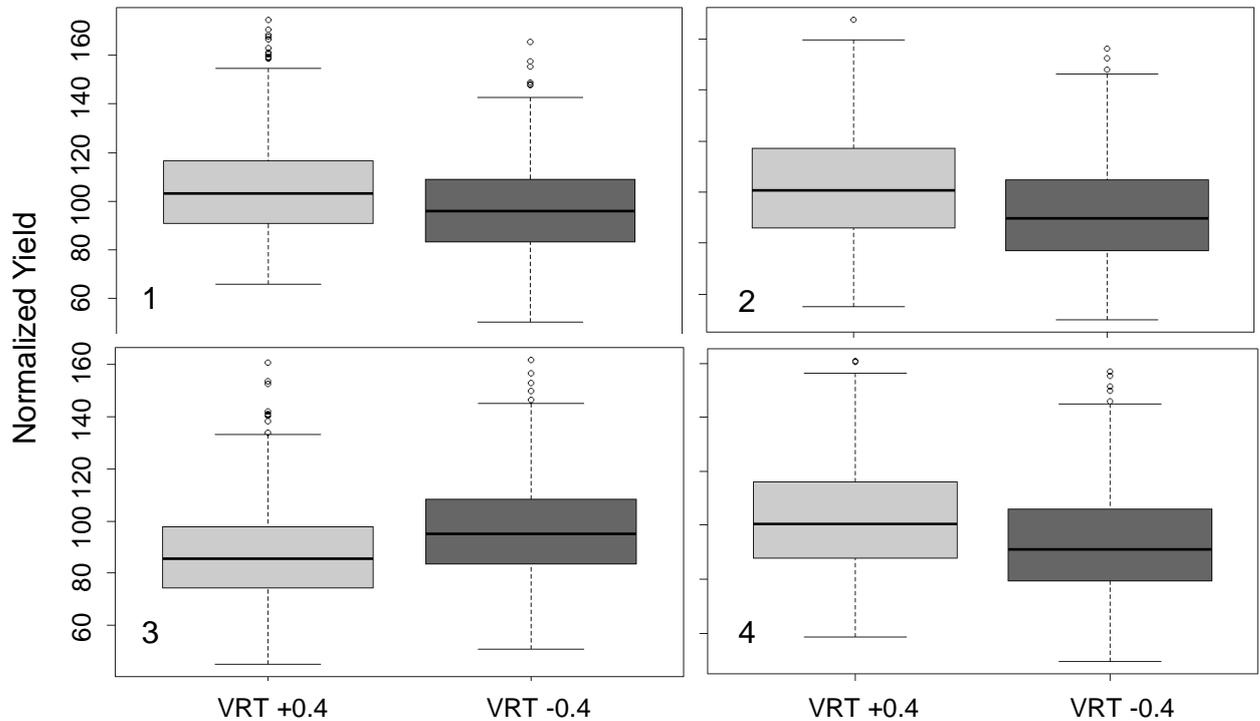


Note: Average values followed by the same letter are not different at 5% Tukey test.

Figure 3 - Overall treatments productivity.

Despite no statistical significance comparing strips, URT 0 m (field practice) presented the highest yield and on the other hand the URT 0.4 m presented the lowest yields. It probably happened because the N fertilizer delay from after cut to 0.4 m of field average stalk height increase competition for N with the soil biota in this no burn harvest system with circa 10 Mg ha^{-1} of straw on the surface after cut, even with an low crop N-uptake at this initial period. According Franco et al. (2011) in the initial development stages of sugarcane, fertilizer plays a key role in N nutrition of the crop. In this period, up to 70% of N in the plant is derived from fertilizer (NDFP) in ratoon sugarcane. Due to the increasing contribution of other N sources during sugarcane development, NDFP decreases along the cycle and, at harvest, reaches values 10–35% for the ratoon. These low values explains why is so difficult obtain consistent response to N fertilization in sugarcane.

But on all the five fields average, the two VRT approaches presented productivities above the URT 0.4 m. To find out in which situation the positive and negative slopes perform better, an individual field analysis comparing the total yield points between strips was made (Figure 4).



Treatment	Field			
	1	2	3	4
VRT + 0.4	99.48 a	102.1 a	85.05 b	97.74 a
VRT - 0.4	91.68 b	91.43 b	94.13 a	89.01 b

Note: Average values followed by the same letter are not different at 5% Tukey test on individual fields.

Figure 4 - Yield VRT approach comparison among fields 1 to 4.

Fields 1 and 2, harvested and fertilized during the dry season, also field 4, located on sandy soil during the wet season, presented higher yields using the positive approach. In other words, when weather or soil was poor, invest on the areas that already present a better condition seems to be the best approach. In the other hand, field 3, harvested on the wet season and located over clayey soil, responded better to the negative slope, so when situation is favorable, pay of to invest on poor areas of the field.

To explore more these evidences, field 5 was taken as a study case and deeper investigated as it was located over a unique soil situation (Figure 6). During

the test a 0.5 ha soil grid sampling, 0.2 m deep, for texture and chemicals was made (Figure 5). Interpolating the clay content of the sampling points was observed that the area is in a transition of soil where the clay content rises from 20% to 60%, presenting the field three distinct areas (sandy, middle texture and clayey soils), providing a unique possibility of analyses. After cut field 5 received uniform N application on four of its strips (Figure 7).

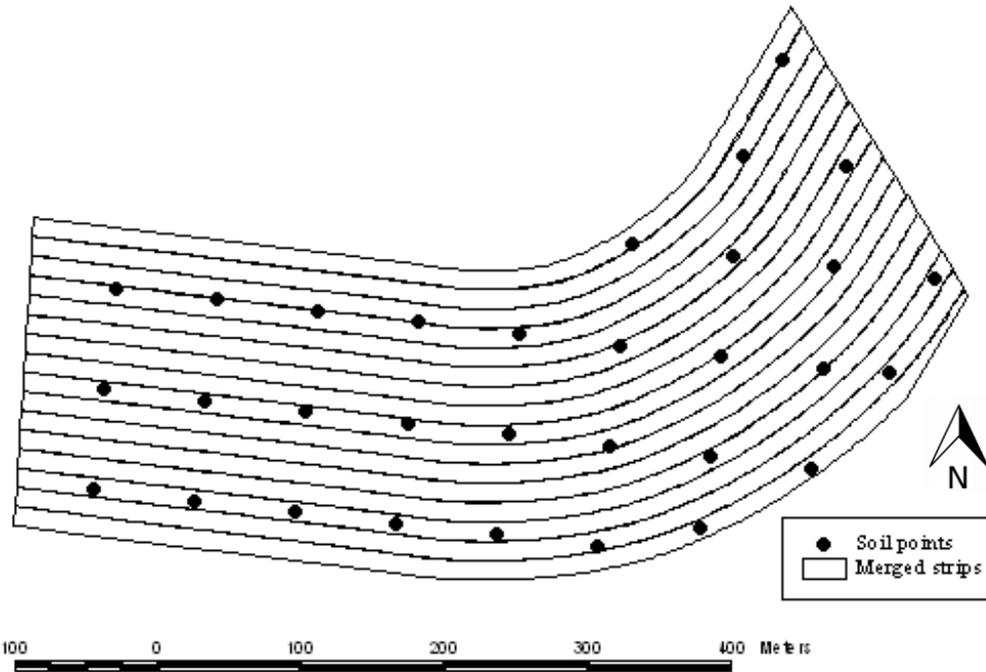


Figure 5 - Soil sampling grid and treatment strips on field 5

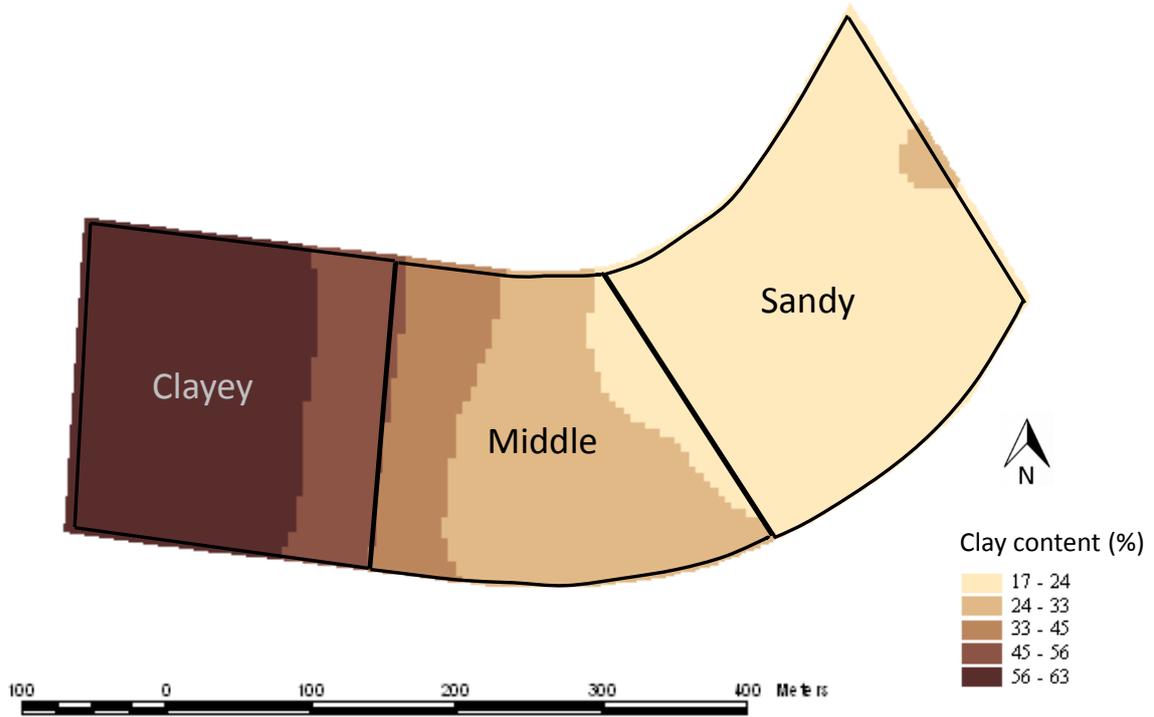


Figure 6 - Soil texture map and division of individual analyzed areas.

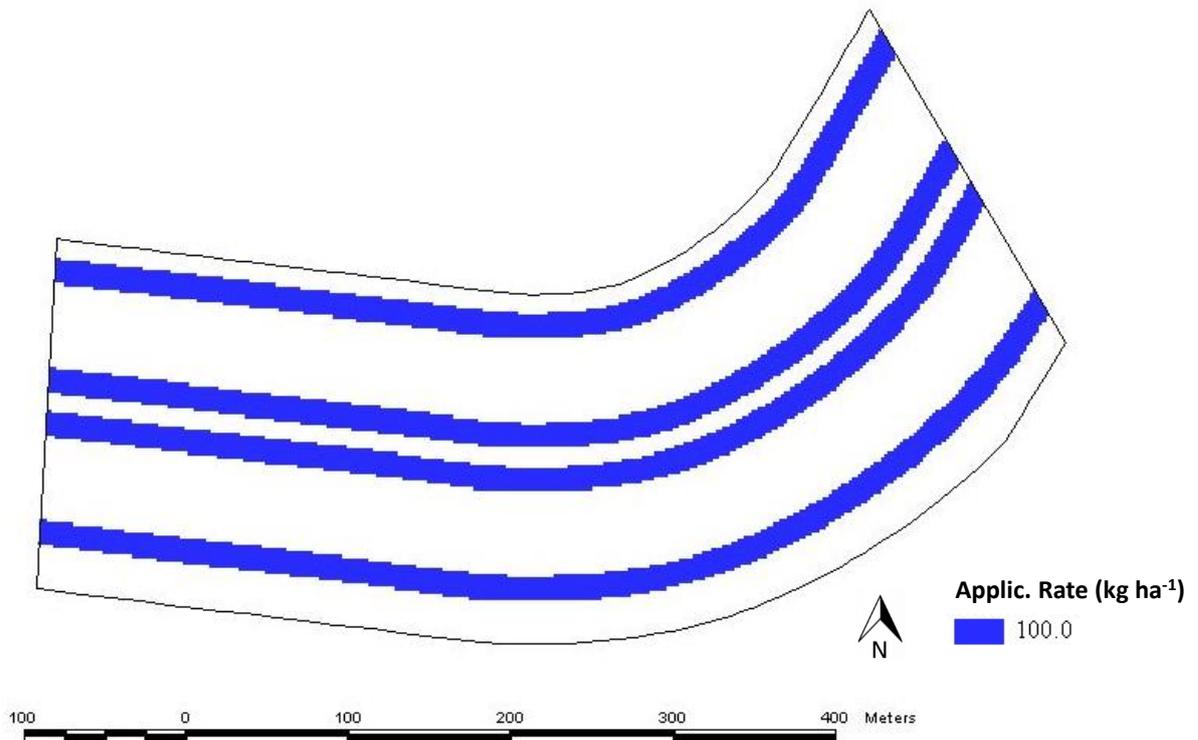


Figure 7 - URT strips application after sugarcane harvest

Few weeks later, when the field was with an average of plant stalk height around 0.2 m, a sensor scanning was made to evaluate the initial field variability (Figure 8). It can be seen that the infield variability showed by the sensor is high, but not necessary follows the texture showed by the soil, instead at this stage is more relevant the crop sprouting vigor that is strongly related to harvest practices, among others. Portz et al. (2012) also showed that this stage is too early to use the canopy ORS to guide N VRT fertilization as the N-uptake is too low to provide a good estimation of crop nutrition. Results reinforced by the box plot analyses (Figure 9) show that it is difficult to make assumption on the sensor vegetation index for the strips segmentations located in each of the three texture parts of the field.

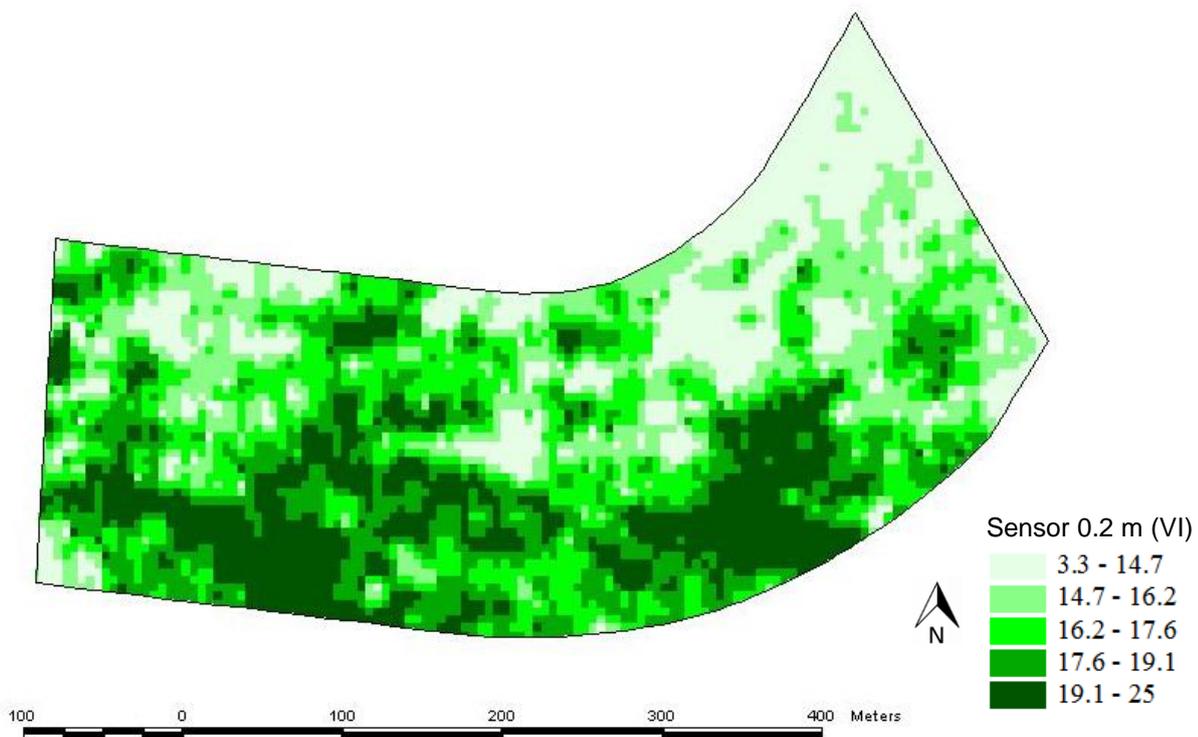


Figure 8 - ORS VI measurement at 0.2 of stalk height

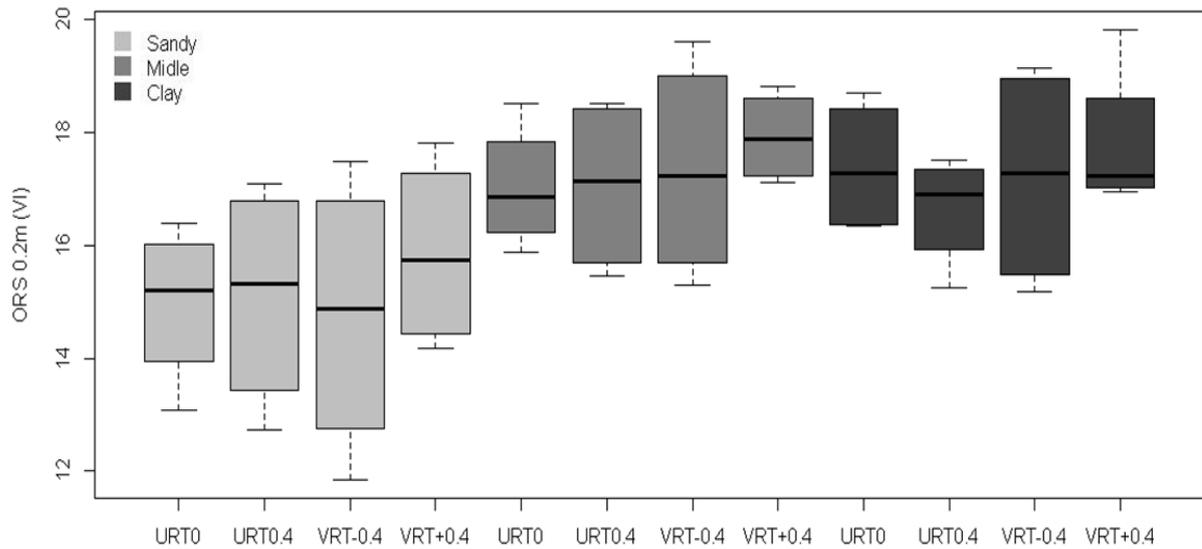


Figure 9 - Vegetation index of the ORS at 0.2 m of crop stalk height

At 0.4 m of crop stalk height, ideal moment to use the sensor on sugarcane (PORTZ et al., 2012) start be clear the capacity of the sensor on detect biomass and N-uptake (Figure 10) as it is possible to see the difference between sandy and clayey areas and also can be identified the initial four URT applications. This result can also be seen on a clear way on the box plot analyze of figure 11, where the four URT treatments show values well above the rest of the area.

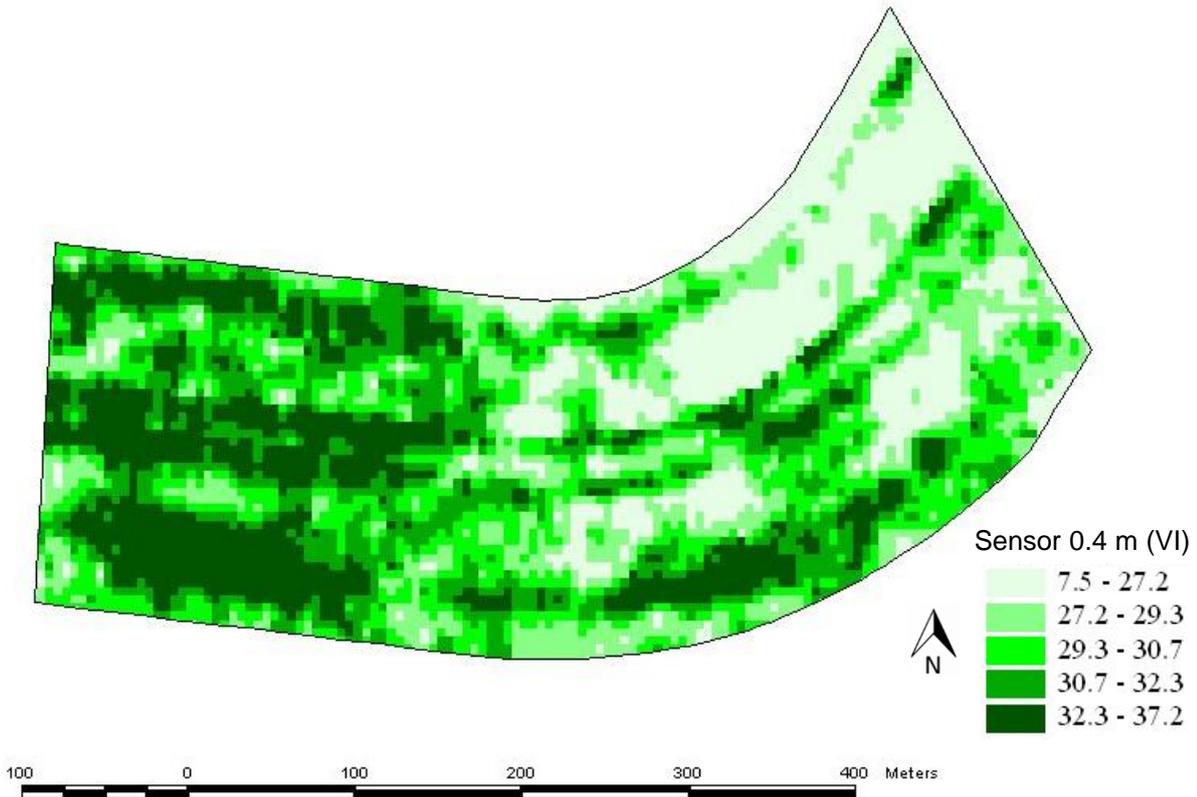


Figure 10 - ORS VI measurement at 0.4 m of stalk height of field 5

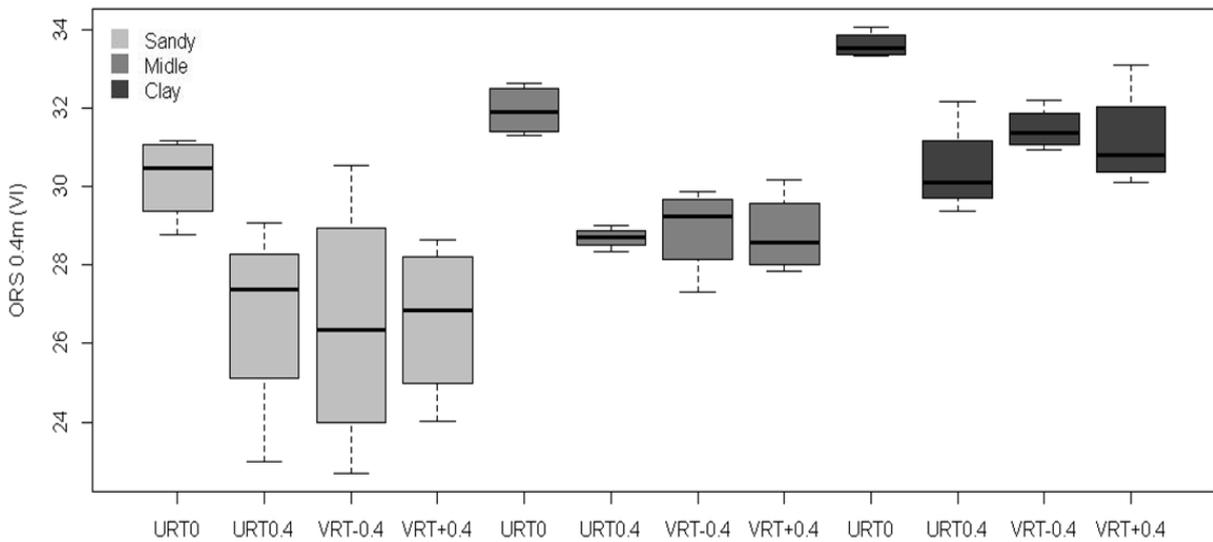


Figure 11 - Vegetation index of the ORS at 0.4 m of crop stalk height

At this same moment the VRT treatments of N application (Figure 12) and the URT late application were performed, being the N dose used for every treatment in every field soil situation showed on figure 13.

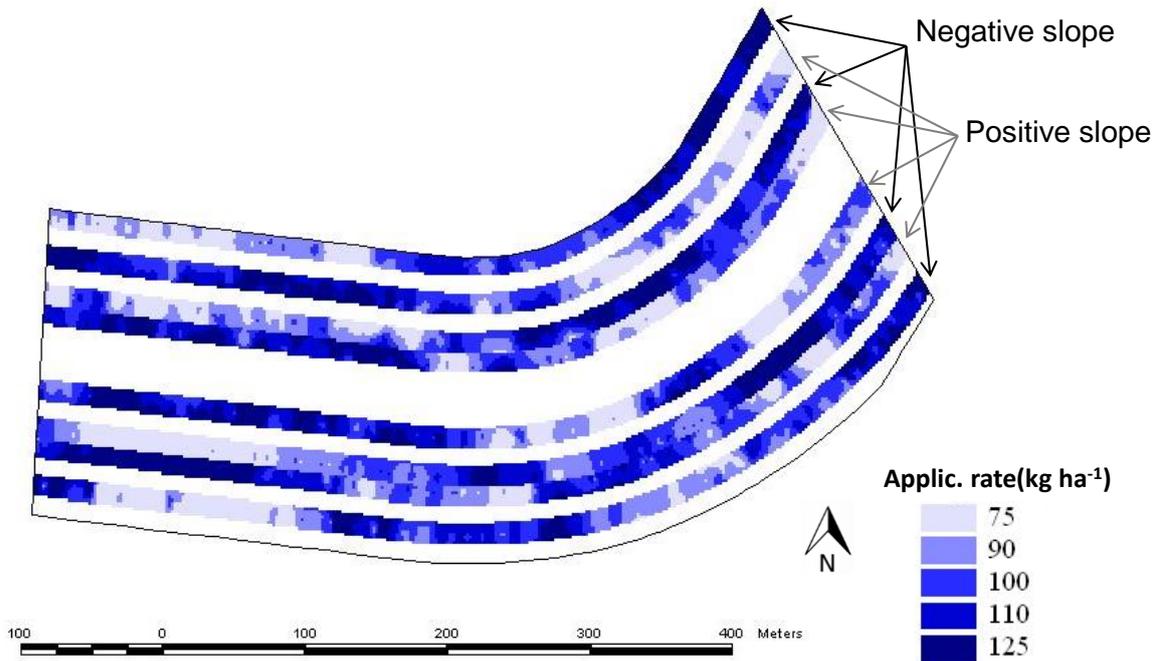


Figure 12 - Positive and negative slopes VRT application at 0.4 m of stalk height of field 5.

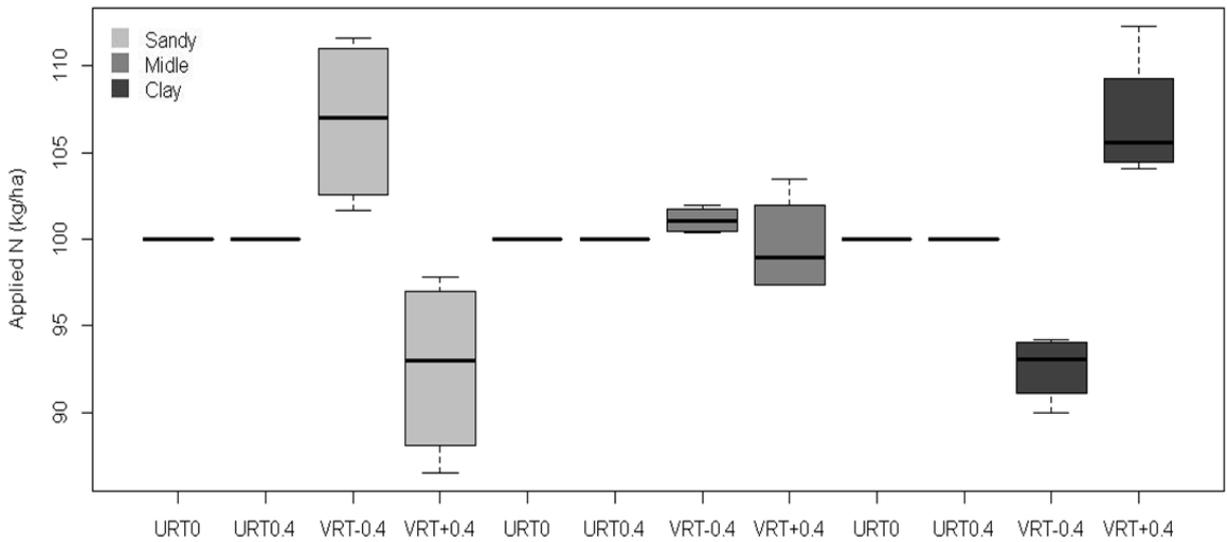


Figure 13 - Applied Nitrogen on the treatments over the three soil situations

The applied dose shows the inverted behavior of N amount applied on the positive and negative algorithm slopes on the sandy and clayey soil parts of the field. The middle part almost receive a uniform rate being less expressive the use of one or other approach.

At 0.6 m of field stalk height one last scanning (Figure 14) was performed to evaluate the field. With the N application on the rest of the field, the initial four strips

advantage disappears being not possible anymore to differentiate it on the map. Numerically, by the box plot analyses, at 0.6 m of stalk height (Figure 15) the URT 0 m treatment seem now to have the lower VI values.

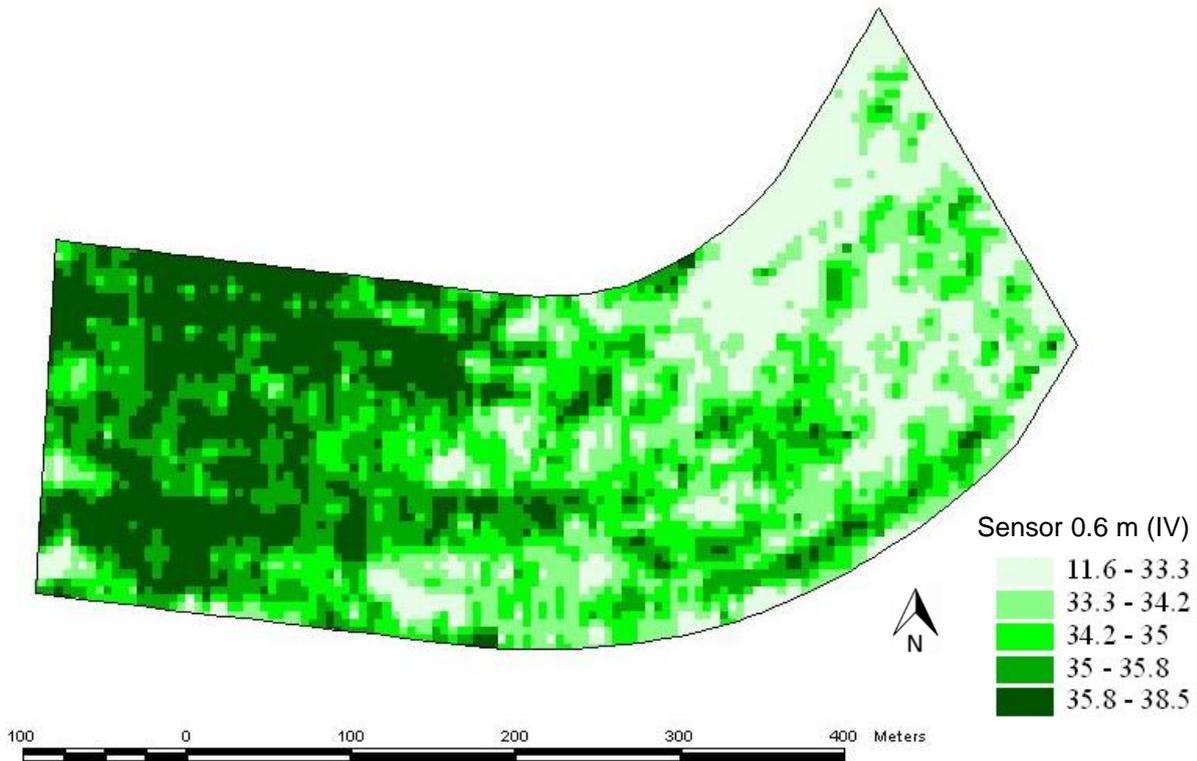


Figure 14 - ORS VI measurement at 0.6 m of stalk height of field 5.

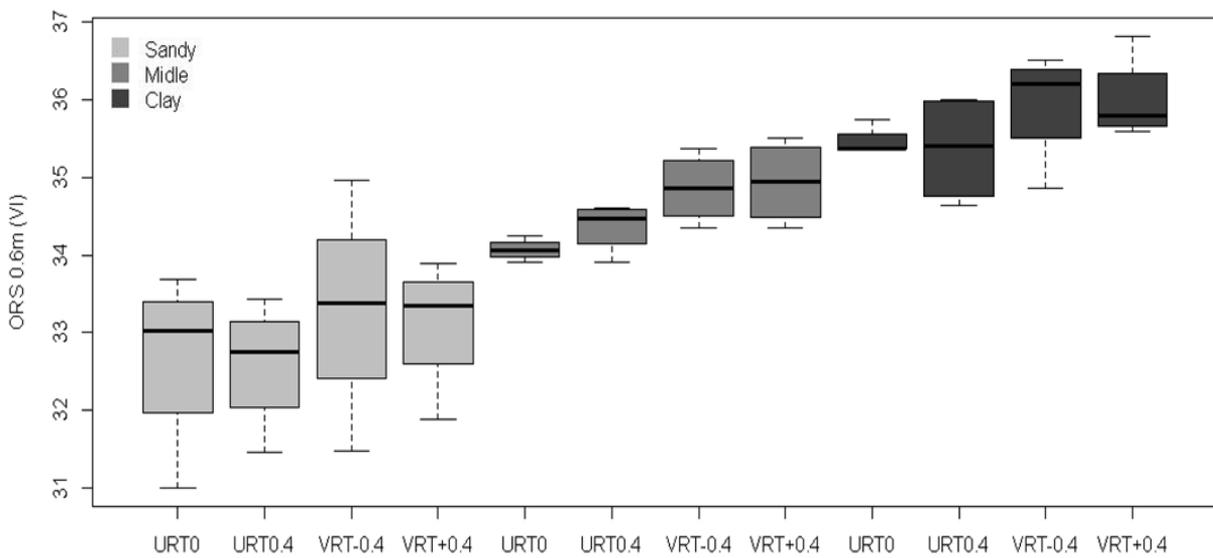


Figure 15 - Vegetation index of the ORS at 0.6 m of crop stalk height

Eight months after N applications, the field was harvested and with the adoption of the yield monitor it was possible to generate a yield map (Figure 16) and also evaluate yield per treatment and soil location (Figure 17).

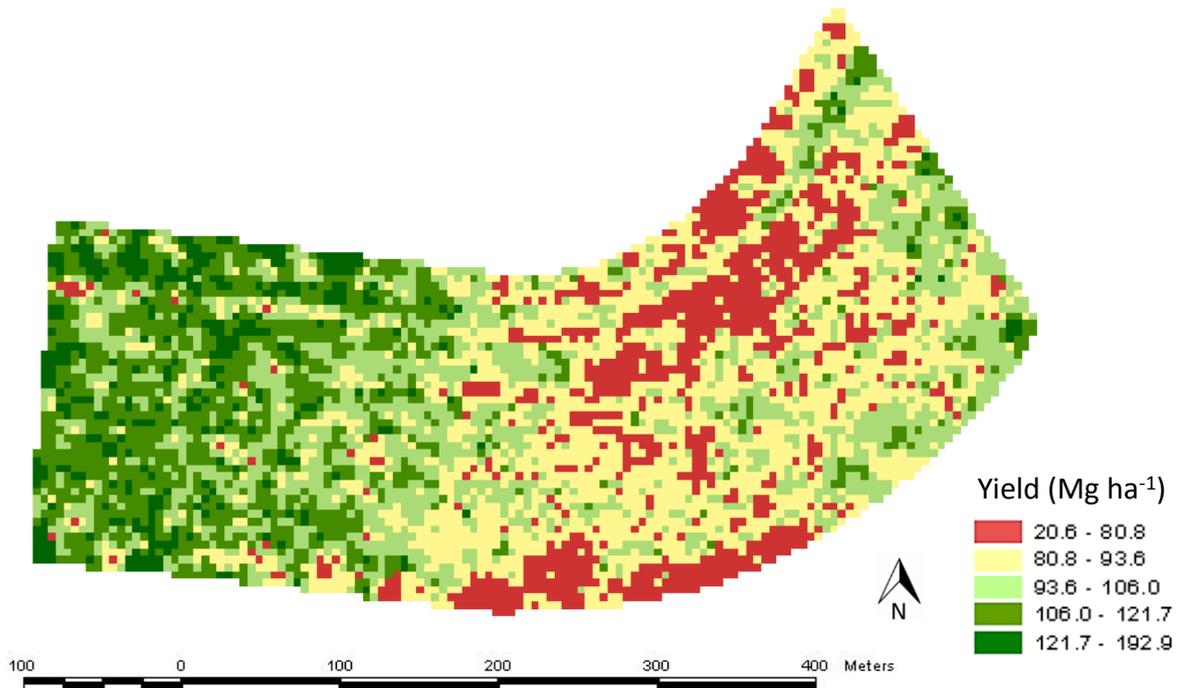


Figure 16 - Yield of field 5

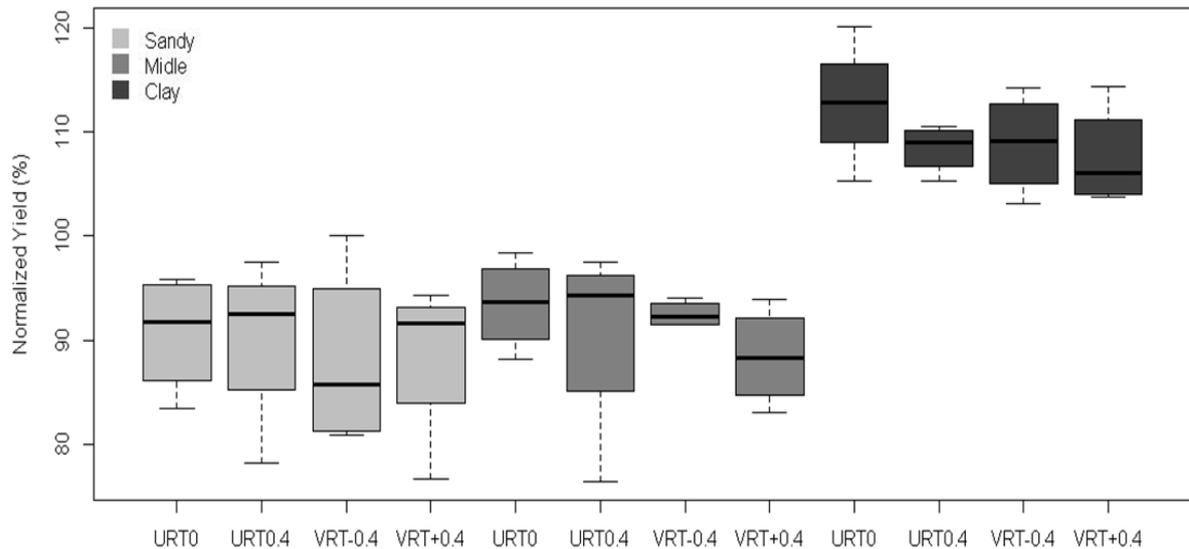


Figure 17 - Normalized yield of the treatments over the three soil situations

The final yield showed a statistically significant greater productivity over the high clay content part of the field and similar productivities between middle part and sandy part. Analyzing yield, also is possible to see that the vinasse application was

able to provide sufficient N on the sandy and middle part of the field in the initial growth, until 0.4 m of stalk height (fertilizer application moment), being similar the productivity of the URT 0 m and URT 0.4 m. On the other hand, on the clayey part of the field, the after cut application was more productive than the 0.4 m late application. Probably because at the clayey part of the field biological N fixation was higher and also N-uptake by the crop at this initial period.

The nitrogen use efficiency analyses are showed on Figure 18. On the sandy part of the field, the positive slope approach showed a better NUE and in the clayey part the negative slope seems to be better, corroborating these results with those from the other fields. On the middle texture field, the VRT approach seems not to increase yield or NUE because the applied rates were also close to the uniform rate treatments.

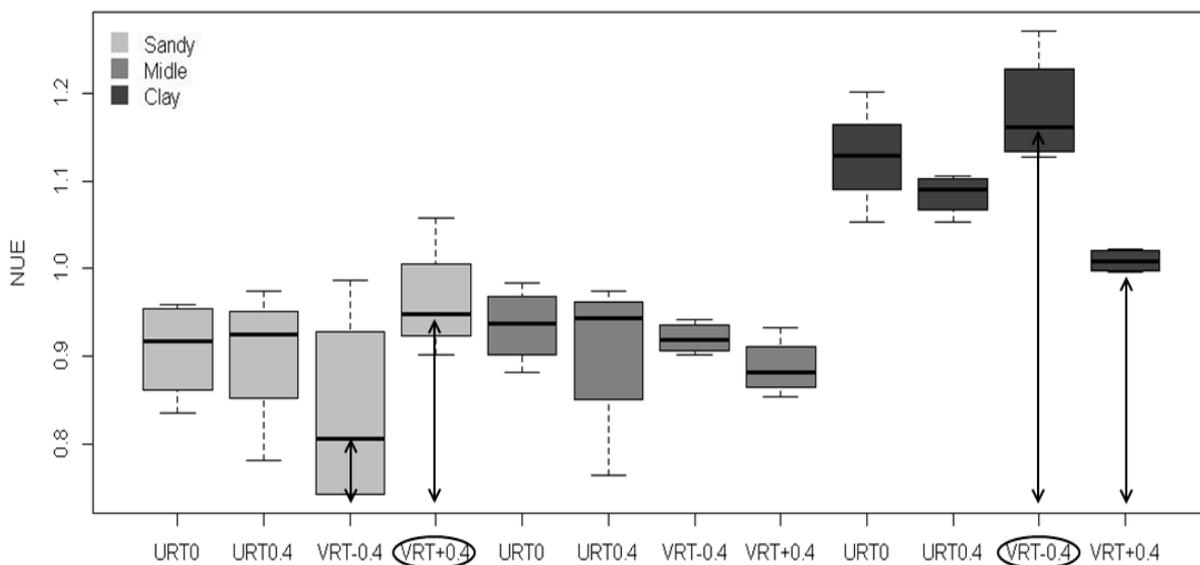


Figure 18 - Nitrogen use efficiency on the treatments over the three soil situations

Evaluate N performance in field conditions is very difficult, especially spatial variability, as many factors can influence on yield. Trying to understand the factors playing on this field, a buffer analysis was made correlating the soil sampling points with sensor readings and final yield (Table 2).

Table 2 - Correlation matrix of soil attributes, sensor and productivity

Attributes	pH	OM	P	S	Ca	Mg	K	H - Al	CEC	CLAY	VI 0.2 m	VI 0.4 m	VI 0.6 m	YIELD
VI 0.2 m	0.14	0.39	0.11	0.16	-0.05	0.17	0.43	0.27	0.10	0.37	1.00			
VI 0.4 m	0.13	0.54	0.14	0.10	0.22	0.33	0.61	0.45	0.39	0.66	0.85	1.00		
VI 0.6 m	0.25	0.56	0.27	0.17	0.39	0.41	0.65	0.40	0.52	0.69	0.69	0.89	1.00	
YIELD	0.30	0.73	0.34	0.26	0.64	0.60	0.72	0.51	0.78	0.89	0.21	0.53	0.56	1.00

On the second and third scans (0.4 and 0.6 m), about eight months before harvest, the sensor was able to see the same patterns and predict productivity, also it correlates with the other soil attributes in the same way as productivity as it can read biomass.

Organic matter, which contains N, correlates with sensor VI and yield, what explain the results obtained on the research. On the other hand third factors also correlated with yield as Ca and Mg (lime issues), K, H-Al (acidity) and clay followed by CEC, as expected.

So, making use of VRT for other nutrients can reduce variability on the area and increase the effectiveness of the sensor approach with a higher certainty for nitrogen.

Based on those results a combination of the positive and negative slopes should be used (Table 3).

Table 3 - Summarize of the best slope approach by field condition.

Conditions	Sandy soil	Clayey soil
Dry season	Positive	Positive
Wet season	Positive	Negative

Further research should combine the canopy sensors use after a previous application of organic fertilizers (vinasse and filter cake compost) or one split approach of the mineral N supply. It should be applied right after cut to provide initial nutrition, until crop canopy sensors can be implemented to avoid losses on yield, because even with a very low N uptake at this initial period, data indicates that the early presence of the nutrient seams to stimulate the crop and increase productivity.

3.4 Conclusions

On the global analyses the results have not shown statistical difference between treatments with or without the use of the VRT technology.

On three of the studied field situations (sandy soil for wet and dry seasons, and clayey soil dry season) the positive slope approach presented better results in deeper analyses. Over clayey soil on the wet season, where all the conditions are good, the negative slope presented to be the better approach.

The use of the optical canopy sensor technology increased nitrogen use efficiency on the studied area.

References

- AMARAL, L.R.; MOLIN, J.P. The Effectiveness of three vegetation indices obtained from a canopy sensor in identifying sugarcane response to nitrogen. **Agronomy Journal**, Madison, v. 106, n. 1, p. 273–280, 2014.
- BOYER, C.N.; BRORSEN, B.W.; SOLIE, J.B.; RAUN, W.R. Profitability of variable rate nitrogen application in wheat production. **Precision Agriculture**, Dordrecht, v. 12, p. 473-487, 2011.
- BRAGAGNOLO, J.; AMADO, T.J.C.; NICOLOSO, R.S.; SANTI, A.L.; FIORIN, J.E.; F.M. TABALDI, F.M. Optical crop sensor for variable-rate nitrogen fertilization in corn: II. Indices of fertilizer efficiency and corn yield. **Revista Brasileira de Ciência do Solo**, v. 37, p. 1299-1309, 2013.
- CANTARELLA, H. Nitrogênio. In: NOVAIS, R.F.; ALVAREZ, V.H.; BARROS, N.F.; FONTES, R.L.F.; CANTARUTTI, R.B.; NEVES, J.C.L. (Ed.). **Fertilidade do solo**. Viçosa: SBCS, 2007. p. 375-470.
- CANTARELLA, H.; TRIVELIN, P.C.O.; VITTI, A.C. Nitrogênio e enxofre na cultura da cana-de-açúcar. In: YAMADA, T.; ABDALLA, S.R.S.; VITTI, G.C. (Ed.). **Nitrogênio e enxofre na agricultura brasileira**. Piracicaba: IPNI Brasil, 2007. p. 355-412.
- FRANCO, H.C.J.; OTTO, R.; FARONI, C.E.; FARONI, C.E.; VITTI, A.C.; OLIVEIRA, E.C.A.; TRIVELIN, P.C.O. Nitrogen in sugarcane derived from fertilizer under Brazilian field conditions. **Field Crops Research**, Amsterdam, v. 121, n. 1, p. 29–41, 2011.
- HICKS, D.R., R.M. VANDEN HEUVEL, AND Z.Q. FORE. Analysis and Practical Use of Information from On-Farm Strip Trials. **Better Crops with Plant Food**. Vol. 81, No. 3. Potash and Phosphate Inst. ISSN-0006-0089. 1997.

JASPER, J.; REUSCH, S.; LINK, A. Active sensing of the N status of wheat using optimized wavelength combination: impact of seed rate, variety and growth stage. In: EUROPEAN CONFERENCE ON PRECISION AGRICULTURE, 7., 2009, Wageningen. **Precision agriculture '09: proceedings...** Wageningen: Wageningen, 2009. p. 23-30.

KORNDÖRFER, G.H.; COLOMBO, C.; CHIMELLO, M.A.; LEONE, P.L.C. Desempenho de variedades de cana-de-açúcar cultivadas com e sem nitrogênio. **STAB - Açúcar, Álcool e Subprodutos**, Piracicaba, v. 20, p. 28-31, 2002..

LINK, A., JASPER, J. AND REUSCH, S. Suitability of different crop parameters for the determination of site-specific nitrogen fertilizer demand. In: EUROPEAN CONFERENCE ON PRECISION AGRICULTURE, 5., 2005, Uppsala. **Precision agriculture '05: proceedings...** Wageningen: Wageningen Academic Publ., 2005. p. 297-302.

LOFTON, J.; TUBANA, B.S.; KANKE, Y.; TEBOH, J.; VIATOR, H. Predicting sugarcane response to nitrogen using a canopy reflectance-based response index value. **Agronomy Journal**, Madison, v. 104, n. 1, p. 106–113, 2012.

MAGALHÃES, A.C.N. Ecofisiologia da cana-de-açúcar; aspectos do metabolismo do carbono na planta. In: CASTRO, P.R.C., FERREIRA, S.O., YAMADA, T.Y. (ed.) **Ecofisiologia da produção agrícola**. Piracicaba: POTAFOS, 1987. p.113-118.

MAGALHÃES, P.S.G.; CERRI, D.G.P. Yield monitoring of sugar cane. **Biosystems Engineering**, Amsterdam, v. 96, n. 1, p. 1–6, 2007.

MOLIN, J.P.; PORTZ, G.; AMARAL, L. R. Precision agriculture in sugarcane production. In: OLIVER, M.; BISHOP, T.; MARCHANT, B. **Precision Agriculture for Sustainability and Environmental Protection**. Routhledge. New York. 2013. p. 233-242.

PIMENTEL, C. **Metabolismo de carbono na agricultura tropical**. Seropédica: Edur, 1998. 150 p.

PORTZ, G.; MOLIN, J.P.; JASPER, J. Active crop sensor to detect variability of nitrogen supply and biomass on sugarcane fields. **Precision Agriculture**, Dordrecht, v. 13, n. 1, p. 33–44, 2012.

PORTZ, G.; AMARAL, L.R.; MOLIN, J.P.; JASPER, J. Optimun sugarcane growth stage for canopy reflectance sensor to predict biomass and nitrogen uptake. In: INTERNATIONAL CONFERENCE ON PRECISION AGRICULTURE, 11., 2012, Indianápolis. **Proceedings...** Monticello: ISPA, 2012. CD-ROM.

RAUN, W.R.; SOLIE, J.B.; JOHNSON, G.V.; STONE, M.L.; MULLEN, R.W.; FREEMAN, K.W.; THOMASON, W.; LUKILA, E. Improving nitrogen use efficiency in cereal grain production with optical sensing and variable rate application. **Agronomy Journal**, Madison, v. 98, p. 815-820, 2002.

RAIJ, B. van; CANTARELLA, H.; QUAGGIO, J.A.; FURLANI, A.M.C.
Recomendações de adubação e calagem para o Estado de São Paulo. 2. ed.
Campinas: IAC, 1997. 279 p. (IAC. Boletim Técnico, 100).

ROSSETO, R.; DIAS, F.L.F.; LANDELL, M.G.A.; CANTARELLA, H.; TAVARES, S.; VITTI, A.C.; DERECIN, D. N and K fertilization of sugarcane rations harvested without burning. In: INTERNACIONAL SOCIETY OF SUGAR CANE TECHNOLOGISTS CONGRESS, 27., 2010, Veracruz. **Proceedings...** Veracruz: ISSCT, 2010. 1 CD-ROM.

RZEWNICKI, P.E.; THOMPSON, R.; LESOING, G.W.; ELMORE, R.W.; FRANCIS, C.A.; PARKHURST, A.M.; MOOMAW, R.S. On-farm experiment designs and implications for locating research sites. **American Journal of Alternative Agriculture**, Cambridge, v. 3, n. 4, p. 168-173, 1988.

SCHARF, P.C.; SHANNON, D.K.; PALM, H.L.; SUDDUTH, K.A.; DRUMMOND, S.T.; KITCHEN, N.R.; MUELLER, L.J.; HUBBARD, V.C.; OLIVEIRA, L.F. Sensor-based nitrogen applications outperformed producer-chosen rates for corn in on-farm demonstrations. **Agronomy Journal**, Madison, v. 103, p. 1683-1691, 2011.

SCHULTZ, N.; MORAIS, R.F. de; SILVA, J.A.; BAPTISTA, R.B.; OLIVEIRA, R.P.; LEITE, J.M.; PEREIRA, W.; CARNEIRO JÚNIOR, J.B.; ALVES, B.J.R.; BALDANI, J.I.; BODDEY, R.M.; URQUIAGA, S.; REIS, V.M. Avaliação agronômica de variedades de cana-de-açúcar inoculadas com bactérias diazotróficas e adubadas com nitrogênio. **Pesquisa Agropecuária Brasileira**, Brasília, v. 47, n. 2, p. 261–268, 2012.

SINGH, I.; SRIVASTAVA, I.A.; CHANDNA, P. & GUPTA, R. Crop sensors for efficient nitrogen management in sugarcane: Potential and constraints. **Sugar Tech**, New York, v. 8, n. 4, p. 299-302, 2006.

SOLIE, J.B.; RAUN, W.R.; STONE, M.L. Submeter spatial variability of selected soil and Bermuda grass production variables. **Soil Science Society of America Journal**, Madison, v. 63, n. 6, p. 1724-1733, Nov./Dec. 1999.

URQUIAGA, S.; CRUZ, K.H.S.; BODDEY, R.M. Contribution of nitrogen-fixation to sugar-cane - n-15 and nitrogen-balance estimates. **Soil Science Society of America Journal**, Madison, v. 56, n. 1, p. 105-114, 1992.

VITTI, G. C.; MAZZA, J. A. Encarte técnico planejamento, estratégias de manejo e nutrição da cultura de cana-de-açúcar. **Informações Agronômicas**, Piracicaba, n. 19, p. 1–16, 2002.

WUEST, S.B.; MILLER, B.C.; ALLDREDGE, J.R.; GUY, S.O.; KAROW, R.S.; VESETH, R.J.; WYSOCKI, D.J. Increasing plot length reduces experimental error of on-farm tests. *Journal of Production Agriculture*, Madison, v. 7, n. 2, p. 211-215, 1994.

4 COMPARISON OF SUGARCANE STALK AND ULTRASONIC CANOPY HEIGHT WITH OPTICAL REFLECTANCE BY ESTIMATING CROP BIOMASS AND NITROGEN UPTAKE

Abstract

The use of optical canopy sensors is already being intensively studied in the sugarcane crop, but it seems to saturate the sensor signal when the crop achieves stalk heights over 0.6 – 0.7 m. The measurement of plant's height is another possibility to estimate the spatial variability of biomass and nitrogen (N) uptake by the crop during the possible fertilizer application period. Different from other grasses (*Poaceae*) like winter cereals, sugarcane presents a linear growth at this stage. To test the feasibility of crop height as biomass and N nutrition indicator two researches were made. In the first, eight fields were monitored during two growing seasons. Conditions varied involving four varieties, soils from sandy to clayey and the previous harvesting occurred in May and October (early and late season), including first to fourth ratoon stages. Each field was scanned with an optical canopy sensor three times in the first season and two on the second season, followed by tissue sampling for biomass, crop stalk height and N uptake on ten spots inside each area and scanning. In the second investigation, an ultrasonic sensor system was tested on measuring crop canopy height and related to canopy optical reflectance sensor data aiming its ability to identify the spatial variability in two commercial fields scanned simultaneously with both sensor systems, and after manually sampled for biomass and N-uptake on twenty sample points inside each field. Data were statistically analyzed, compared, and subsequent maps were generated for crop height and reflectance, sensors data was also correlated to the measured parameters. The height of the crop stalk presented high correlation with biomass and N uptake until late stages of crop growth. The sensors data presented consistent relation, generating similar maps for canopy reflectance and ultrasonic canopy height, also the sampled variables correlate with canopy reflectance and height.

Keywords: Canopy sensors; Canopy height; Plant reflectance; Biomass; N-uptake.

4.1 Introduction

Sugarcane producers, despite research on the nitrogen nutrition contributions, continue with the challenge of making better use of the input, especially due to the spatial variability of the nutrient and soils found in production areas, often in short distances (SOLIE et al., 1999).

In the last decades, vehicle-based sensor solutions for the detection of crop canopy parameters have been investigated. Most researchers measured the spectral reflection properties of crop stands, being only a few of those technical solutions

commercialized, including site-specific applications of nitrogen-based fertilizers and crop-protection agents (DWORAK et al., 2011).

Canopy reflectance sensors are already accepted as a tool to manage nitrogen variable rate applications on many crops, and are being intensively studied in sugarcane (AMARAL & MOLIN 2011; PORTZ et al., 2012; LOFTON et al., 2012). But the sensor signal seems to saturate when the crop achieves stalk heights over 0.6 – 0.7 m (PORTZ et al., 2012; AMARAL & MOLIN, 2014).

Sugarcane, different from other grasses presents a linear growth at this stage, and is far away from its maturity period when it grows over 2.0 m of stalk and stores saccharose (sugar). As a strategy to gain time on field operations, Brazilian sugarcane producers normally apply nitrogen (N) right after harvesting, or in an early stage when sugarcane starts to really uptake N. But at the late season (wet time of the year) the crop grows very fast and is common to growers apply fertilizers until sugarcane height achieve the machines clearance limit trying to make better use of the available machinery on vast areas with logistical issues, and in some years even living areas behind without fertilization. On those late stages the use of canopy reflectance sensors can be limited by sensor signal saturation (MUTANGA & SKIDMORE, 2004). During an earlier phase of this work Portz et al. (2012) observed that there is a relationship between plants heights measured during biomass samplings and N-uptake. This fact instigated a research on this subject.

The first studies to measure crop canopy by ultrasonic sensors report from 1980's (SHIBAYAMA et al., 1985) and Sui et al. (1989) developed a measurement system using ultrasonic ranging modules to provide cumulative plant volume, plant width and height for a variety of bush-type plants, such as cotton and soybean. In the 2000's, AZIZ et al., (2004) showed again that the estimates of individual leaf heights from ultrasonic measurements using the time of flight calculation method were positively correlated with manually measured heights.

Sui and Thomasson (2006) combined plant reflectance sensor and ultrasound sensor to determine the nutritional status of N in cotton. The results showed that the spectral information and plant height was significantly correlated with the concentration of nitrogen contained on cotton leaves. Working with a reflectance sensor on maize Freeman et al. (2007), also took measurements of plant height during the investigation and concluded that plant height alone was a good predictor of plant biomass at all stages of growth sampled. On wheat research, Reusch (2009)

also showed that crop height and biomass parameters can be estimated using ultrasonic sensors as they present good and largely linear relationships between the ultrasonic reading and the aboveground dry matter sampled manually at the time of measurement.

Shiratsuchi et al. (2009) reported correlations between height, biomass and nitrogen in corn and presented results from the merge of sensors on canopy reflectance and ultrasonic measurement of plant height to estimate N-uptake by maize during the growing season. The results showed that at growth stages V10 to V13 plant height data using an ultrasonic and reflectance sensors were significantly correlated, both having the same ability to predict N-uptake, but the simultaneous use of two sensors did not increase the correlation with N-uptake.

Fricke et al. (2011) also was able to show a positive forage mass-height relationship on legume-grass mixtures using ultrasonic sensors. As *Poaceae* species like wheat, maize and forage grass can be assessed by canopy height, is expected that this behavior is similar on sugarcane. Based on this hypothesis, the goal of this study was to see if the parameter sugarcane height measured manually and by an ultrasonic distance system could estimate biomass and N-uptake during the growing season or be complementary to an optical plant reflectance sensor.

4.2 Materials and methods

On the first phase eight commercial sugarcane fields located around São Martinho Sugar Mill (21°19'11"S, 48°07'23"W), in the state of São Paulo, Brazil, were evaluated during the 2009/10 and 2010/11 growing seasons. Conditions varied from sandy to clayey soils, with all crops being mechanically green harvested (without burn). On four fields, harvesting of the previous crop occurred at the beginning of the season (May/June) corresponding to the dry time of the year, and on the other four fields, in late season (Oct/Nov), corresponding to the wet time of the year. The crops under investigation included first, second, and third ratoon stages at 2009/10 and second, third and fourth at 2010/11. The first four fields were planted with the varieties CTC 9 over sandy soil and RB 855453 over clayey soil and all were harvested in the dry season. The last four fields were planted with the varieties CTC 2 on sandy soil and SP 80–3280 on clayey soil, and harvested during the rainy season (Table 1).

Table 1 - Variables of the studied fields

Field	1	2	3	4	5	6	7	8
Variety	CTC 9		RB 855453		CTC 2		SP 803280	
Size (ha)	21	16	18	17	20	18	21	16
Harvest	may/jun (dry season)				oct/ nov (wet season)			
Soil	sandy		clayey		sandy		clayey	
Ratoon 09/10	1 st	2 nd	1 st	3 rd	1 st	2 nd	1 st	3 rd
Ratoon 10/11	2 nd	3 rd	2 nd	4 th	2 nd	3 rd	2 nd	4 th

Shortly after harvesting all fields were fertilized with a uniform dose of 100 kg ha⁻¹ of nitrogen using ammonium nitrate (30% N) as the N source, spread over the sugarcane rows surface.

Each of the eight fields was scanned three times in the 2009/10 growing season (at 0.2, 0.4, and 0.6 m average stalk height) and two times during the 2010/11 (at 0.3, and 0.5 m average stalk height) using the N-Sensor ALS[®] (Yara International ASA, Duermen, Germany) logging its own vegetation index (1 Hz) on a cab mounted console (Jasper et al., 2009) connected to a GPS L1 receiver. The Sensor was mounted behind the cabin of a high clearance vehicle (Uniport NPK 3000, Jacto Agricultural Machinery, Pompéia, SP).

The vehicle was driven through the whole field spaced by 10 rows of 1.5 m. After scanning, the sensor data was processed generating sensor vegetation index maps of the fields and over this maps 10 sample plots were located, guided by the different values shown by the canopy sensor and followed by tissue sampling for biomass, crop height and nitrogen uptake as explain by Portz et al. (2012). The sugarcane crop height of each sample plot was manually measured and defined as the average stalk distance from the soil to the insertion of the Top Visible Dewlap leaf (TVD) (Dillewijn, 1952).

Sugarcane height data of each field were combined on seasons and years and evaluated by correlating with biomass and nitrogen uptake from the respective sample points. Simple linear regression models were used.

On the second phase two commercial sugarcane areas were evaluated, both located in the vicinity of the São Martinho Mill: One (1) planted with the variety SP80

-1816 over a clayey soil on seventh cut having area of 6.43 ha, and a second (2) with the variety CTC 2 over a sandy soil on third cut, 4.96 ha.

An ultrasonic system compound of two ultrasonic sensors (O'SULLIVAN., 1986) model 6500 (Polaroid, Minnetonka, Minnesota, USA) was mounted (Figure 1). Sensor heads were mounted on each side of the vehicle and together with the Yara N-Sensor, simultaneously evaluated each field. Data from the canopy height sensor was georeferenced with a GPS L1P receiver via NMEA 0183 communication protocol and logged using a CR 1000 data logger (Campbell Scientific, Logan, Utah, USA).

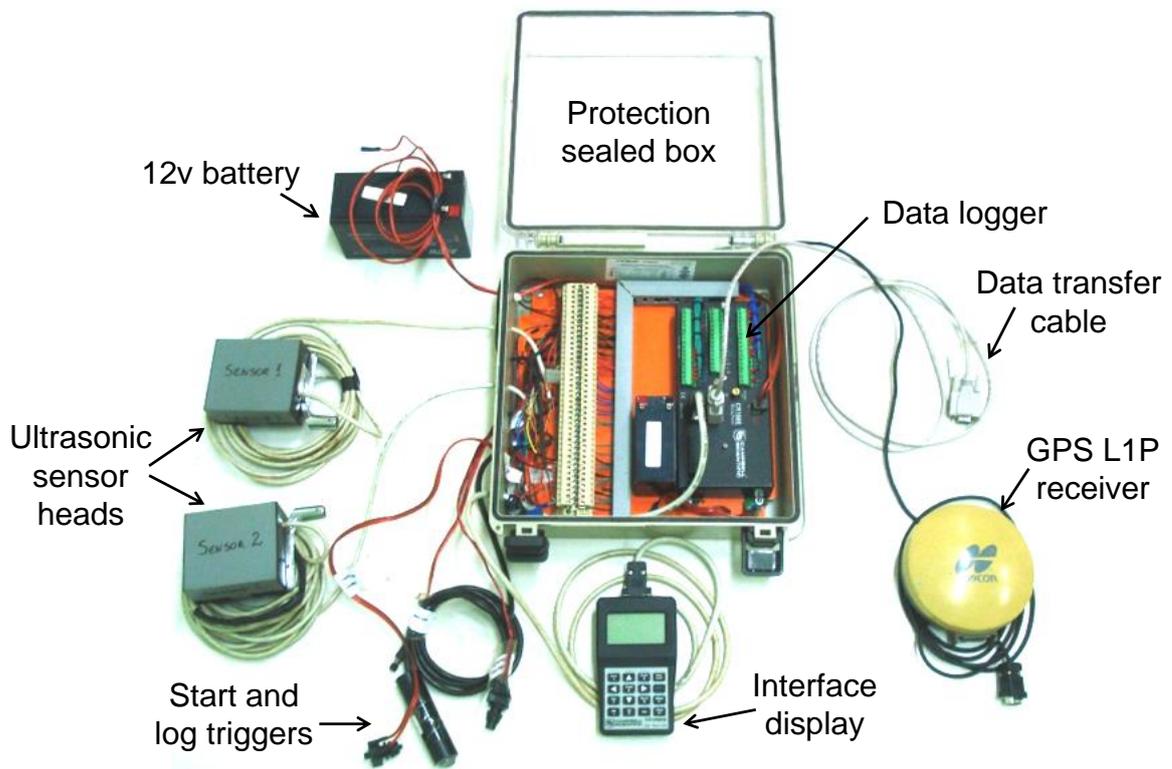


Figure 1 - Ultrasonic system assembled with detail of components.

The sensors were installed on the high clearance vehicle. The N-sensor reflectance data collected at oblique view, integrating data from about six sugarcane rows on its two sensor heads, assembled facing the side of the vehicle. Similarly the two ultrasonic sensor heads were installed on nadir view, one in each side of the vehicle, reading each one a single row. For both sensor systems the data of the two side units was averaged as a unique value, being data collected at 1 Hz and associated to its central geographic coordinates (Figure 2).



Figure 2 - Vehicle equipped with optical reflectance sensor (N-Sensor) and canopy height sensor (ultrasonic), with detail of the nadir view of the sugarcane row.

The collected data readings from each area were filtered to remove outliers (± 3 SD) and values outside field boundaries. Descriptive statistical analysis was performed with subsequent interpolation (square inverse distance) of the data in 5 m pixels (raster) with classification into five classes generated by equal areas using the GIS SSToolBox (SST Development Group, Stillwater, OK, USA). Twenty sampling points were allocated on each area, four per class, distributed at locations where maps of both sensor systems presented values in the same classes. At each sample point, 1.5 m of three rows was harvested summarizing 4.5 m, weighing the fresh biomass on the field. A small sample (250g) of this total was sent to the laboratory where it was dried, reweighed and analyzed for total nitrogen content.

The sensor data was correlated using the values of the interpolated pixels. Similarly, data from the two sensors (ultrasonic and reflectance) were related with the sample points using the respective pixel where the sample point has been allocated, and then correlated with biomass and N-uptake.

4.3 Results and discussion

First phase of the investigation showed that as well as the canopy reflectance sensor data (Portz et al., 2012), the height of the sugarcane crop manually measured presented high relation with biomass and nitrogen uptake. Figure 3 presents the

results of height compared to biomass (dry matter) and N-uptake for the first year. All eight fields had data combined showing a unique tendency despite the differences on soil, variety and ratoon.

For the early season (dry season) measuring the field average heights of 0.2, 0.4 and 0.6 m the height amplitude found was between 0.1 and 0.8 m. The coefficient of determination reached values of $R^2 = 0.80$ for biomass and $R^2 = 0.81$ for N-uptake. Dry biomass was above 6000 kg ha^{-1} at 0.8 m and N-uptake of 80 kg ha^{-1} .

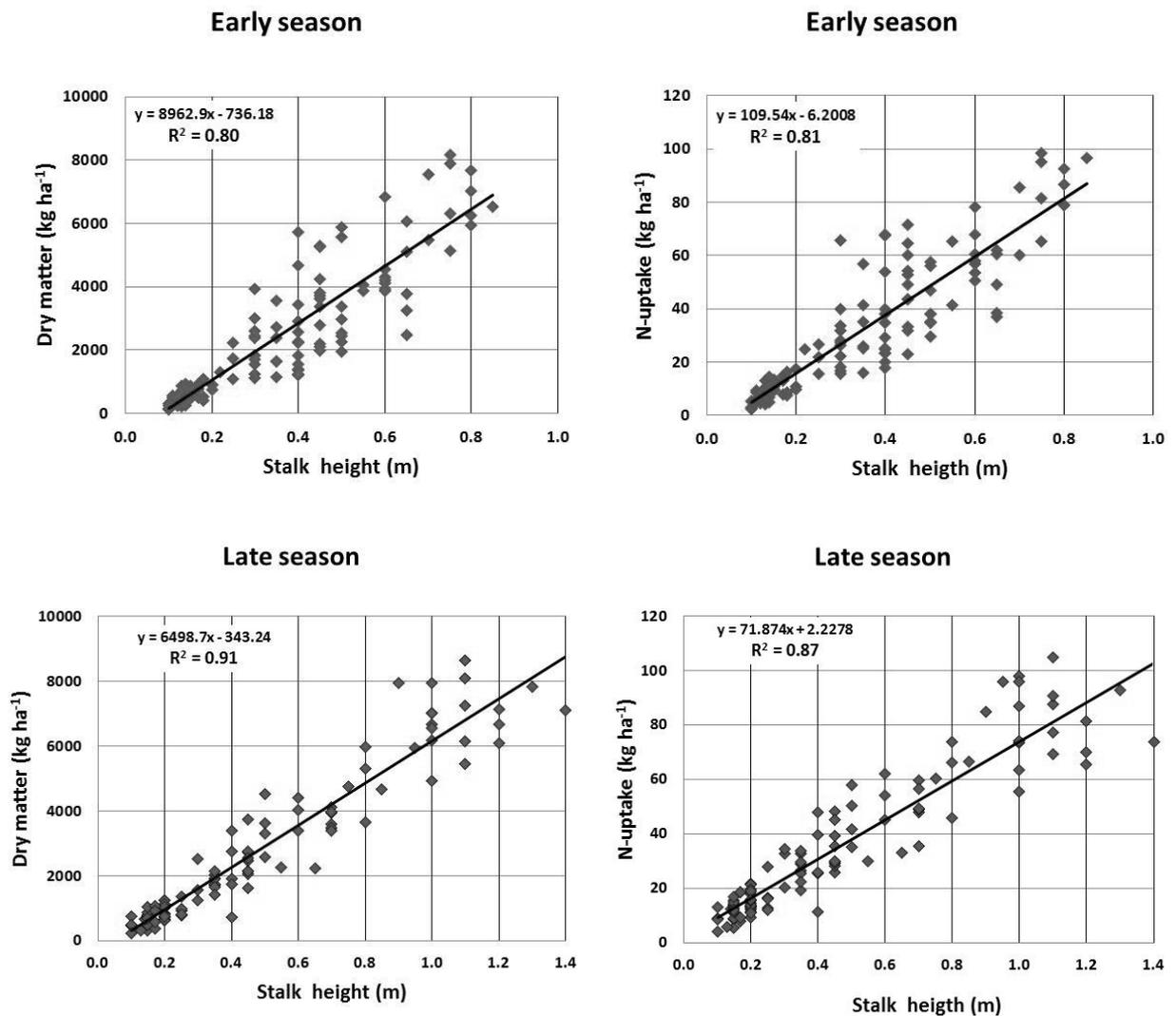


Figure 3 - Biomass and N-uptake for early and late seasons sampled on the 2009/10 crop for 0.2, 0.4 and 0.6 m of average stalk height.

During the late season (wet season) measurement heights got up to 1.4 m because of a delay on sampling the 0.6 m height, especially at the sandy soil fields that presented a very rapid stalk growth rate. Despite that, the late season measurement presents high coefficient of determination ($R^2 = 0.91$) for biomass and

for N-uptake ($R^2 = 0.87$) in an amplitude of 1.3 m of stalk height with a linear tendency. These results show; that with sugarcane stalk height is possible to predict biomass and N-uptake without the limitation of sensor saturation signal.

During the second year (2010/11) the field average heights of 0.3 and 0.5 m were sampled (Figure 4). Lower coefficients of determination were observed on the early season ($R^2 = 0.69$ for biomass and $R^2 = 0.60$ for N-uptake) even with almost the same amplitude of measured heights (0.2 to 0.8 m) as from the first year. The explanation may be related to the fact that the early season (May to August) of the second year had lower precipitation than normal, with less available water than the previous year (Appendix A), resulting in less biomass and especially a lower and uneven N-uptake.

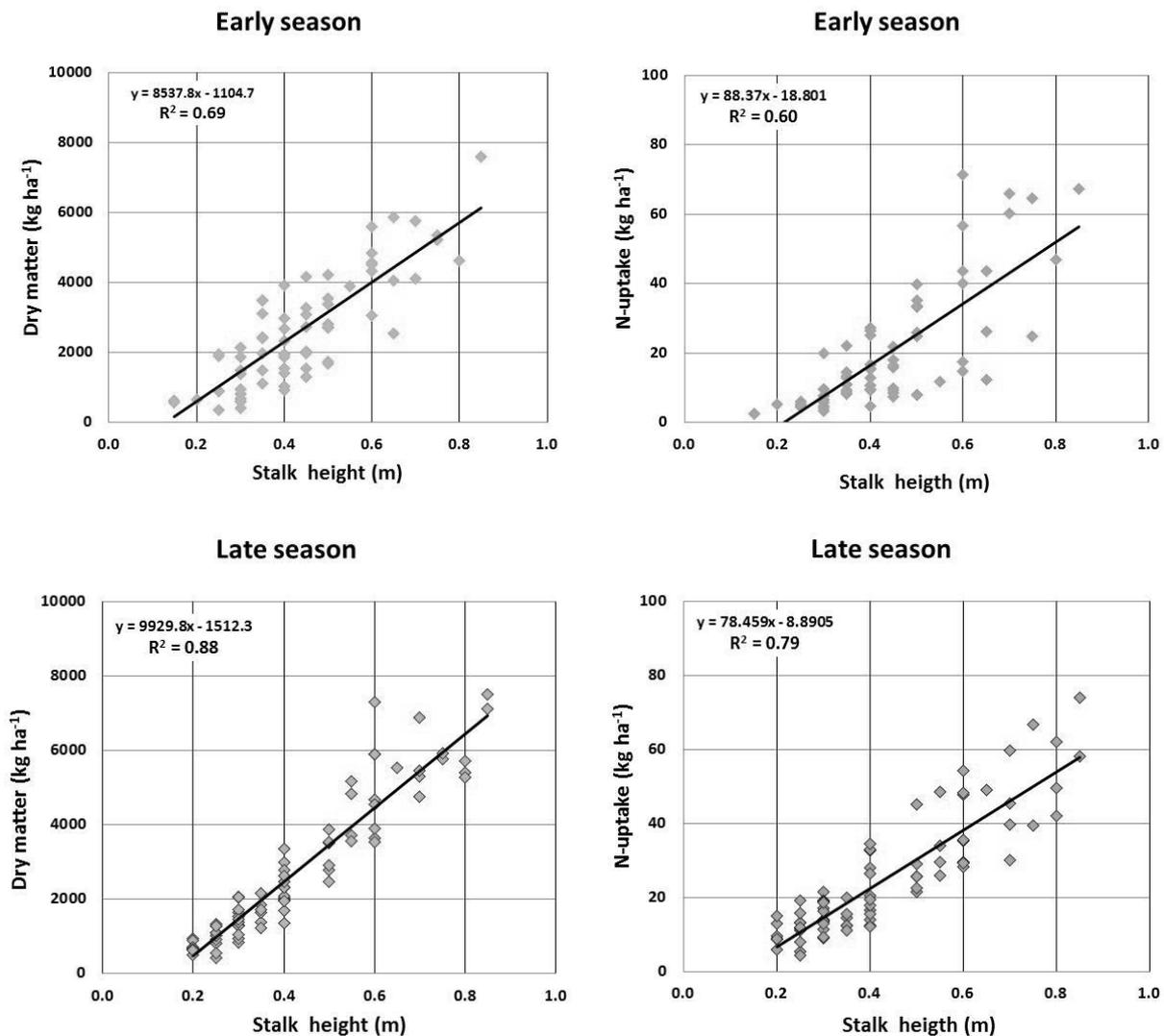


Figure 4 - Biomass and N-uptake for early and late seasons sampled on the 2010/11 crop season for 0.3 and 0.5 m of average stalk height

On the late season, with the return of the rains, the quality of the correlations improved again. With no delays on sampling, stalk height amplitude was between 0.20 and 0.85 m and coefficients of determination raised to $R^2 = 0.88$ for biomass and $R^2 = 0.79$ for N-uptake. Figure 5 shows the combination of data from the two sampled years for biomass and N-uptake against stalk height.

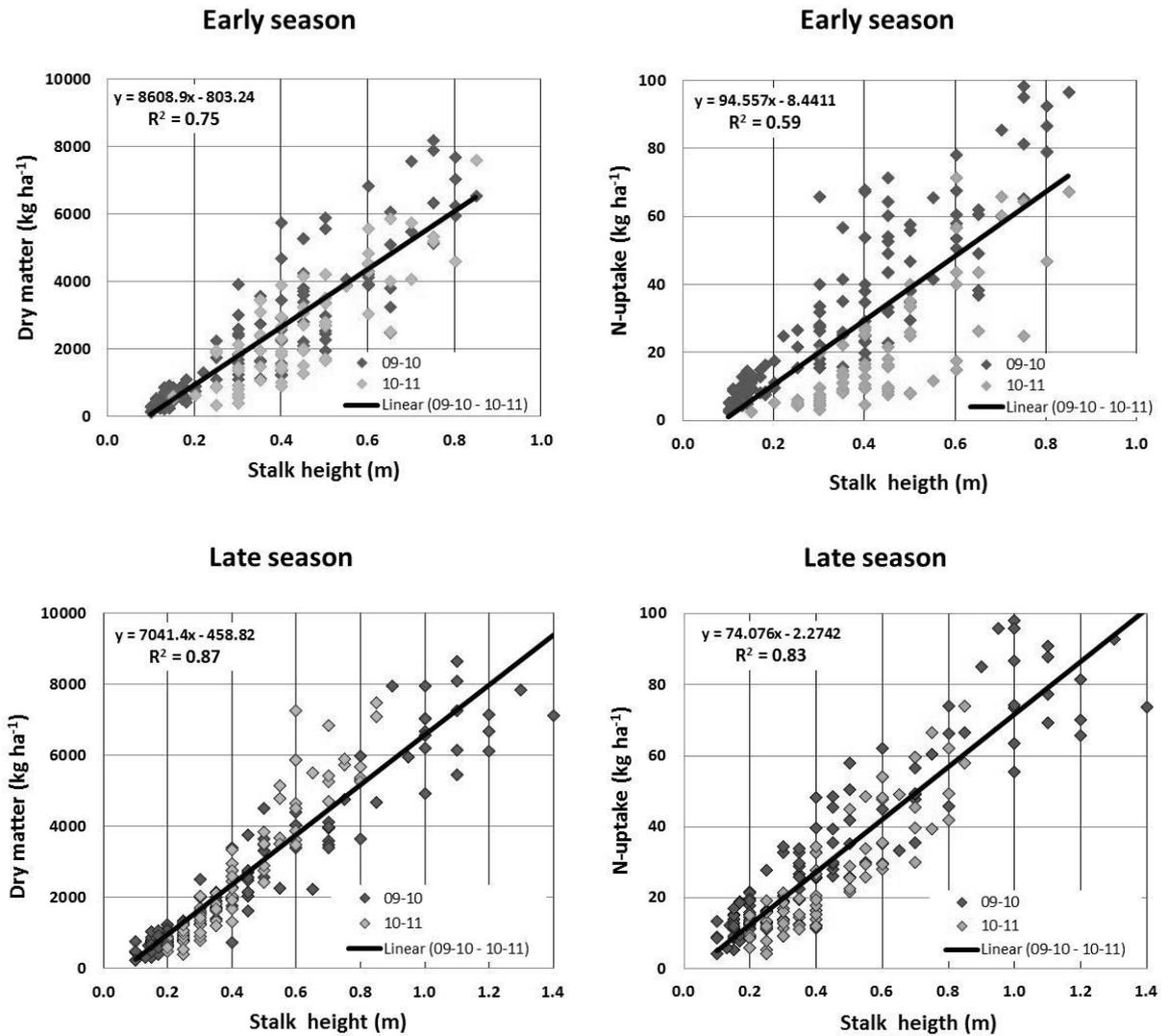


Figure 5 - Biomass and N-uptake for early and late seasons sampled on the 2009/10 and 2010/11 crops for 0.2 to 0.6 m of average stalk height

The overlay of data from the two years shows an early season with lower coefficients of determination ($R^2 = 0.75$ for biomass and $R^2 = 0.59$ for N-uptake). Despite the drought, biomass does not show discrepant values for the two years. On

the other hand N-uptake presents different tendencies for the two years, probably related to effects of the drought.

The experimental data comes from a region where the late season offers regular rain. Under those conditions coefficients of determination ($R^2 = 0.87$ for biomass and $R^2 = 0.83$ for N-uptake) were high. For biomass the two years data is comparable, with some deviation. Unlikely, for N-uptake the two years data had almost a unique tendency, with those from late season showing good results to predict N-uptake by the sugarcane crop stalk height.

Figure 6 presents the joint of the entire data set separated on biomass and N-uptake by crop stalk height. The union of the good data of the late season with the less accurate data from the early season decreases the overall data quality as can be seen by the coefficients of determination ($R^2 = 0.80$ for biomass and $R^2 = 0.70$ for N-uptake). For better predictions of biomass and N-uptake by the sugarcane height, data should be season dependent.

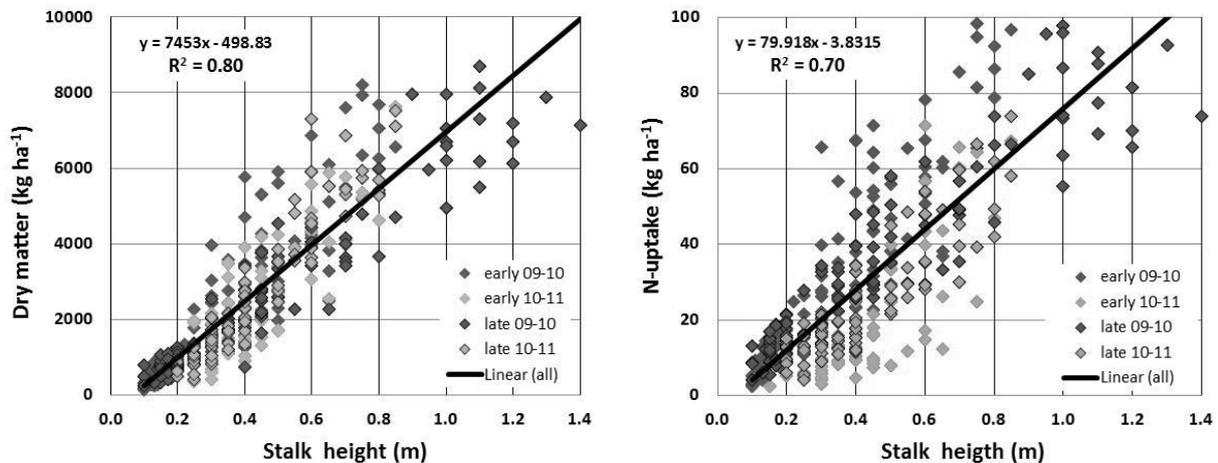


Figure 6 - Biomass and N-uptake for both seasons sampled on the 2009/10 and 2010/11 crops for 0.2 to 0.6 m of average stalk height

For both years, the best correlation between height, biomass and N-uptake occurred in the late season (rainy season) where sugarcane growth is faster and where plant covers ground quickly. Exactly at this time, with high stalk heights, the reflectance sensor shows the lowest correlations for biomass and N-uptake (Portz et al., 2012) suggesting that crop height can complement crop reflectance.

For the second phase of the investigation, boundaries and data points for the two sensors studied fields are shown in figure 7. The fields were completely covered by the sensor systems with little data loss due to failures such as loss of GPS signal receiver or system communication.

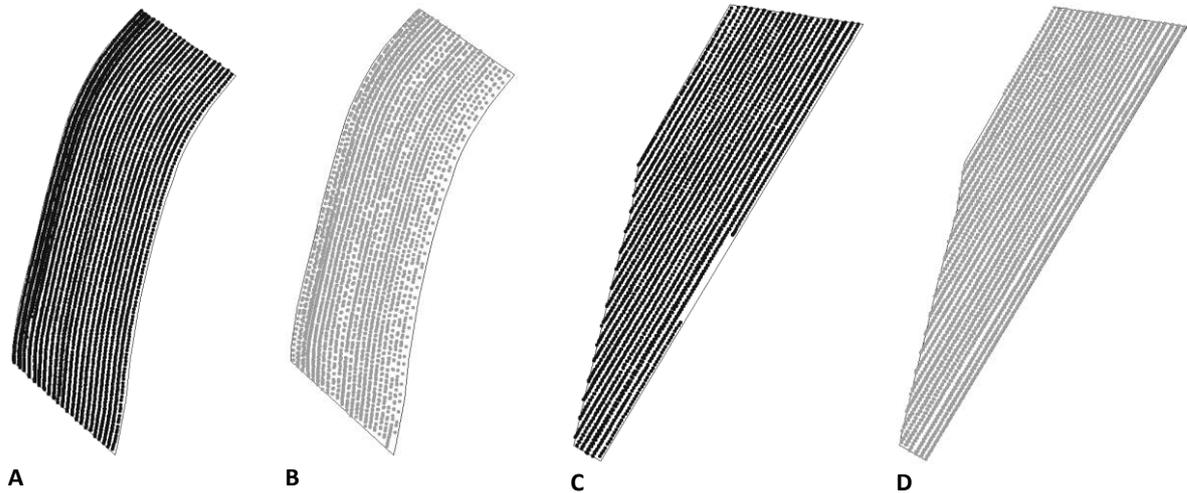


Figure 7 - Reflectance data points of field 1(A) and field 2 (C), and ultrasonic canopy height of field 1 (B) and field 2 (D).

Table 2 shows the values of descriptive statistics of the data collected in both fields after filtering three standard deviations.

Table 2 - Descriptive statistics of the ultrasonic (height) and optical sensor (Reflectance) data.

Parameter	Field 1		Field 2	
	Ultrasonic (m)	Reflectance (VI)	Ultrasonic (m)	Reflectance (VI)
Mean	0.920	25.459	1.203	34.782
Standart error	0.003	0.052	0.002	0.028
Median	0.950	25.900	1.218	35.045
Mode	1.010	23.590	1.269	35.580
Standart deviation	0.206	3.761	0.100	1.791
Sample variance	0.042	14.147	0.010	3.209
Kurtosis	1.243	0.539	4.276	11.603
Asymmetry	-0.748	-0.696	-1.246	-2.014
Interval	1.493	25.890	1.025	21.240
Minimum	-0.030	8.350	0.411	17.260
Maximum	1.463	34.240	1.436	38.500
Count	5276	5232	3990	4026

In the field 1, the mean height and optical VI obtained from the respective sensors were smaller than in field 2, but the data range was higher in field 1. This can be explained by the higher age of first ratoon area (7th cuts) in relation to the field 2 that only received three cuts. The oldest area tends to have more budding gaps, which are expressed in a smaller vigor, represented by the lower canopy height and lower reflectance. This fact can also be seen by comparing the minimum values where lower values can be seen in field 1, including zero height that characterizes the absence of plants (failure) and very low values of VI, not reaching null values due to the largest area covered by the reflectance sensor (footprint). In the other hand, the maximum values were similar, indicating the presence of well-nourished and sprouted areas even after seven cuts in field 1.

Analyzing the kurtosis, field 2 presented higher values, which indicates a higher concentration of data in intermediate values, coming in the same direction as the lower amplitude observed in the range between minimum and maximum values.

Figure 8 shows the interpolated maps for the variables in the two studied areas. It is observed on the maps that despite differences in the two fields, areas separated by classes are the same for the reflectance sensor and ultrasonic sensor. It is also observed only minor variations between the maps. In part those are due to the greater smoothing of the optical sensor due to its oblique view and big footprint, which increases the number of scanned rows (6), while the ultrasonic system evaluates only two rows on nadir view.

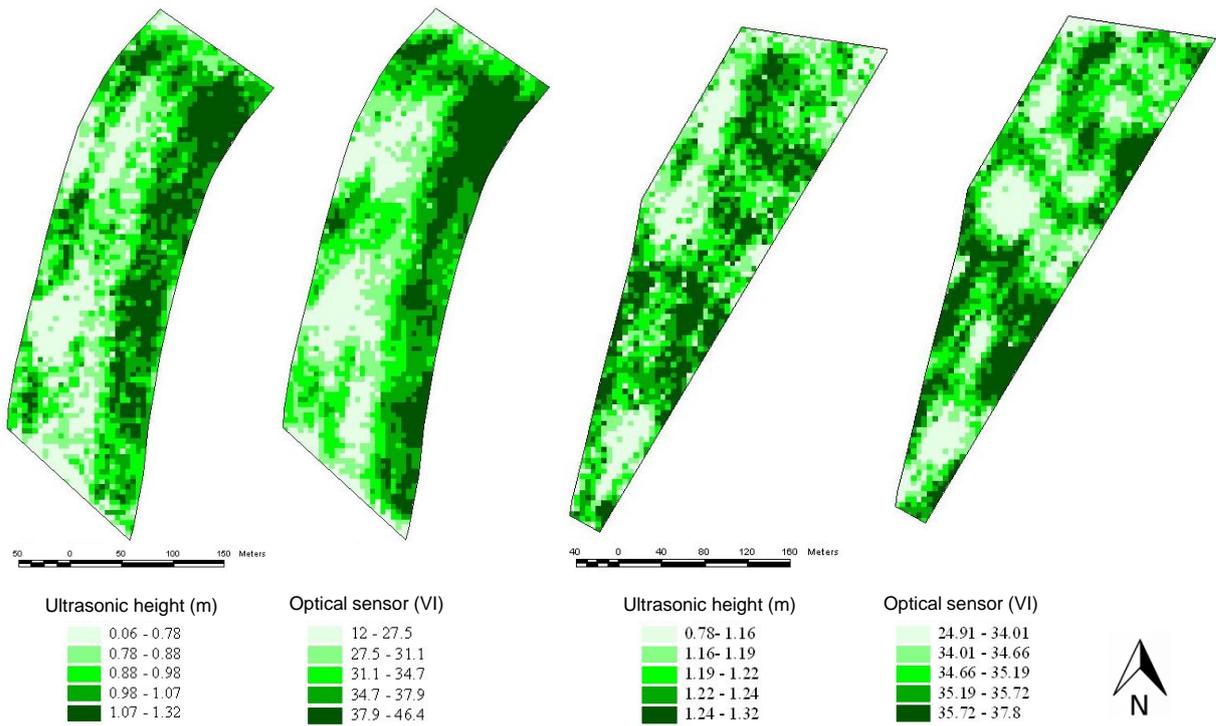


Figure 8 - Interpolated images of height and reflectance data for field 1(A, B) and 2 (C, D).

Figure 9 shows the same results of these observations, but graphically, not using the original data. In this case the data comes from the interpolation of height and VI maps for the two areas using canopy height versus reflectance pixels, directly relating pixel by pixel.

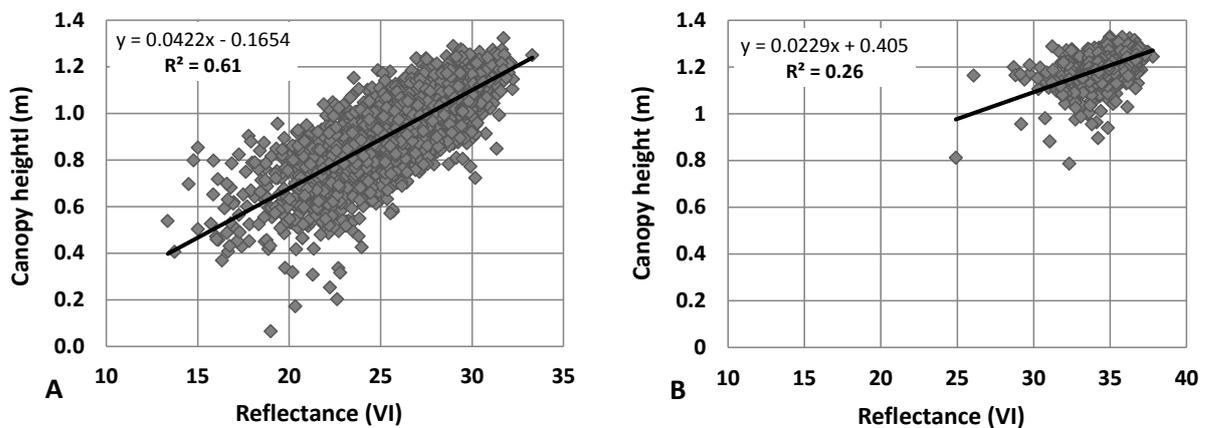


Figure 9 - Pixel by pixel correlation of optical sensor (VI) and ultrasonic (height) data on field 1 (A) and field 2 (B).

Field 1 data shows the large data amplitude achieved by canopy height values, and reflectance presented as vegetation index (VI). This amplitude showed a height/reflectance relation with $R^2 = 0.61$, significant at 5% by t test, where 61% of reflectance data is explained by the crop height. For field 2 (B) the coefficient of determination was lower ($R^2 = 0.26$), due to the low amplitude of the height and reflectance values, that in general were larger and more concentrated than in field 1. Figure 10 shows the distribution of sampling points used to compare biomass and nitrogen uptake by the sugarcane crop with two different sensor systems.

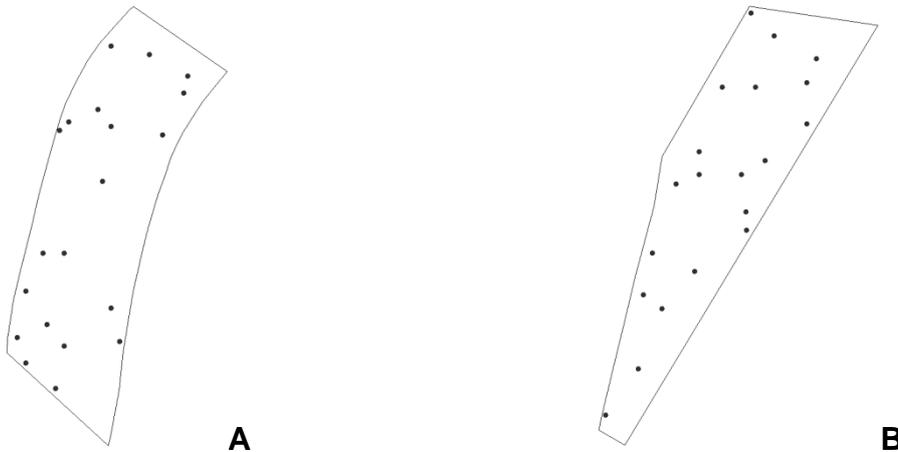


Figure 10 - Sample points located in area 1 (A), and area 2 (B).

Twenty different locations of sample points were placed in each field for the sensors readings as shown Figure 10, which allowed the distribution of sample points to the full extent of the two studied areas. The relations of the two sensors technology based on the sample points for the two areas are showed on figure 11.

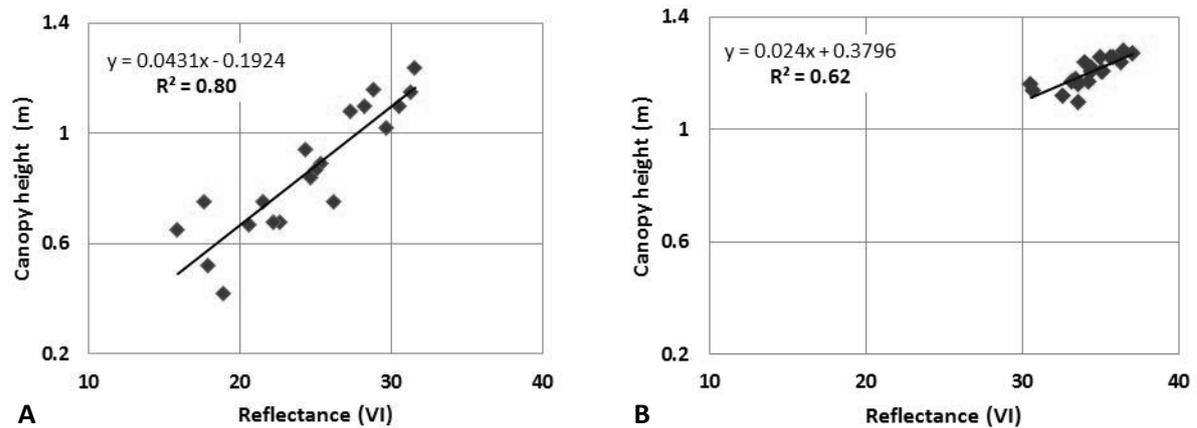


Figure 11 - Sample points correlation of optical sensor (VI), and ultrasonic (height) data on area 1 (A) and area 2 (B).

The good distribution of the points on the areas and also the number of samples allowed the reproduction of the relations from figure 9, but only with the samples, even with superior R square values, showing that the sample method is accurate for the purpose of compare sensors and crop parameters. Figure 12 shows the relationship between reflectance and canopy height with dry biomass on the twenty sampling points of area 1.

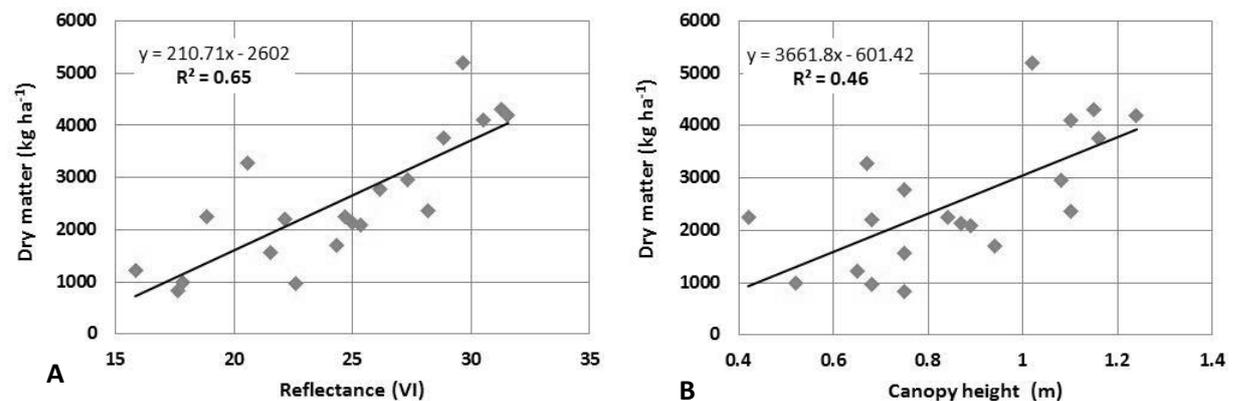


Figure 12 - Reflectance readings (A) and canopy height (B) related to dry biomass on field 1.

Relating biomass with reflectance and canopy height resulted on $R^2 = 0.65$ for reflectance and biomass, and $R^2 = 0.46$ for canopy height and biomass measured with the ultrasonic sensor. We note that in field 1, which presents a greater range of data and lower overall canopy height, that the reflectance sensor was better related to biomass.

Figure 13 shows the relationship between reflectance and canopy height with the biomass harvested on the twenty sampling points of field 2. This area had lower data amplitude for reflectance and canopy height as it was more homogeneous and, on average, more developed crop than in field 1, what dropped the relation values between reflectance and biomass ($R^2 = 0.46$) and canopy height and biomass ($R^2 = 0.59$).

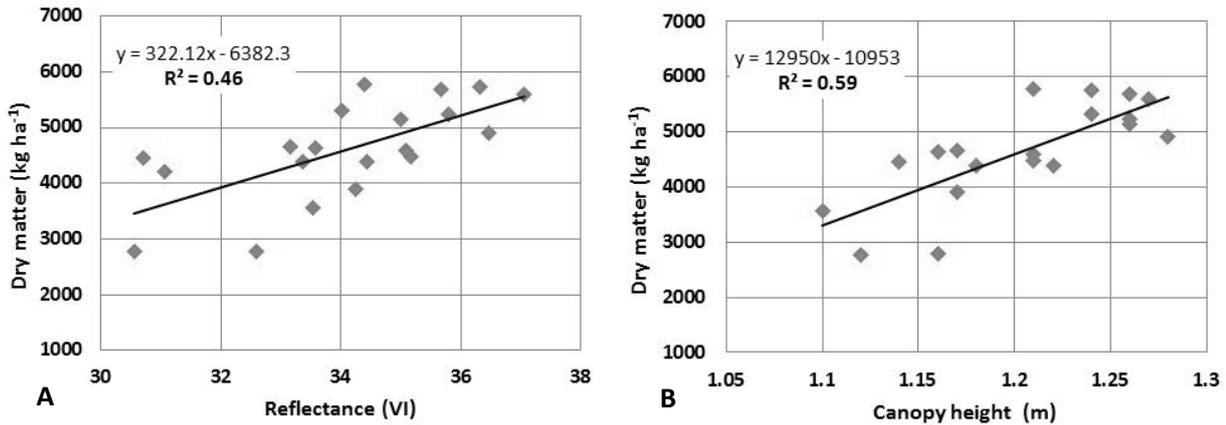


Figure 13 - Reflectance readings (A) and canopy height (B) related to dry biomass on field 2.

In this second area where the canopy height was higher and dry biomass were close to 6000 kg ha^{-1} , about 1500 kg ha^{-1} more dry matter compared to field 1, the ability of the sensors relating to biomass showed opposite behavior, being the canopy height measured by ultrasonic sensor the best relation to biomass. This result matches those from Portz et al. (2012) which observed that the reflectance sensor starts the saturation phenomenon of its signal when the crop reaches stalk heights above 0.6 m.

The graphs of Figures 14 and 15 show the relation of reflectance and canopy height with nitrogen uptake (concentration of N in the biomass, Lab. analysis from the sample points) for field 1 and field 2.

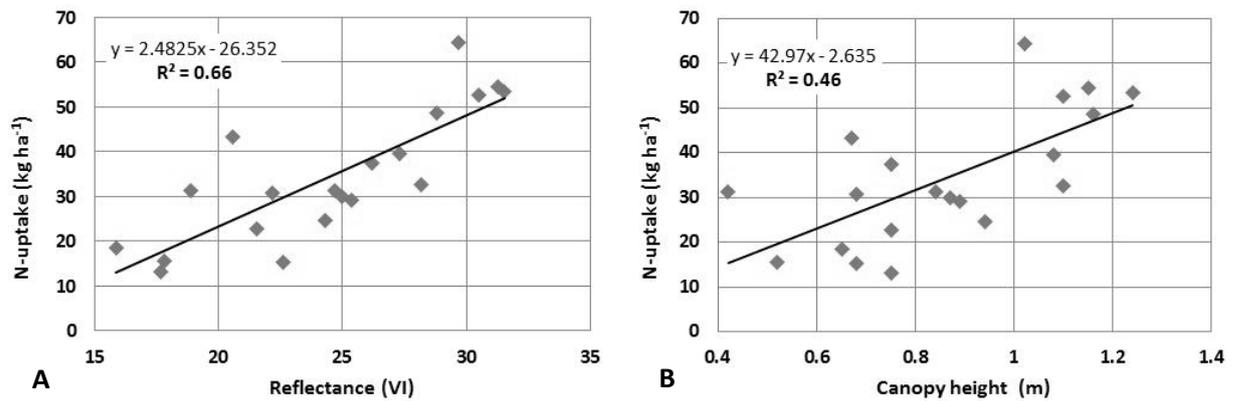


Figure 14 - Reflectance readings (A) and canopy height (B) related to nitrogen uptake on field 1.

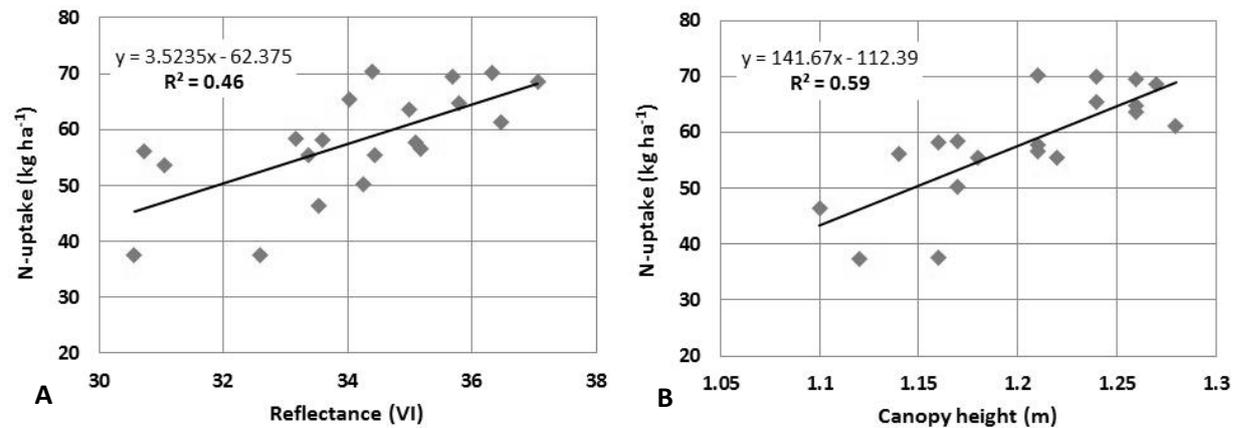


Figure 15 - Reflectance readings (A) and canopy height (B) related to nitrogen uptake on field 2.

Aiming nitrogen fertilization, nitrogen uptake is what really matters and on both, field 1 and field 2 (Figures 14 and 15) the relations of sugarcane nitrogen uptake with reflectance and canopy height measured by the sensor systems followed the behavior of biomass, with the same type of adjustment equations and almost equal coefficients of determination. Similarly, nitrogen uptake had broader values on field 1 (15 to 50 kg ha⁻¹), and higher and most concentrated on field 2 (45 and 70 kg ha⁻¹). These results corroborate with Freeman et al. (2007) findings in maize where optical reflectance and plant height are able to predict biomass and N-uptake.

The combined use of a reflectance sensor and a height sensor can increase the accuracy of the diagnostic from the nitrogen nutrition variability found in areas cultivated with sugarcane, especially when the crop is in advanced stage of development, above 0.6 m stalk height. More studies have to be done aiming to investigate the relationship of biomass and N-uptake measured over the sugarcane

canopy. Distance sensors should be tested on measuring sugarcane canopy against biomass and N-uptake.

4.4 Conclusions

The sugarcane stalk height presented high correlation with biomass and nitrogen uptake and should be considered as a possible data to be used to estimate biomass and nitrogen uptake especially above 0.6 m crop stalk height.

Sugarcane canopy reflectance sensor data relate to ultrasonic sensor readings on the same parameters, being possible to use ultrasonic sensors to identify the variability present in the areas. Both, reflectance sensor and ultrasonic sensor relate to crop biomass and nitrogen uptake being possible to estimate these crop parameters with the sensors data.

The reflectance sensor showed better performance at lower sugarcane canopies where the height amplitude was lower. In the other hand the ultrasonic canopy height sensor was superior in more developed crop, showing that the sensor systems are complementary.

References

AMARAL, L.R.; MOLIN, J.P. Sensor óptico no auxílio à recomendação de adubação nitrogenada em cana-de-açúcar. **Pesquisa Agropecuária Brasileira**, Brasília, v. 16, n. 1, p. 1633–1642, 2011.

_____. The effectiveness of three vegetation indices obtained from a canopy sensor in identifying sugarcane response to nitrogen. **Agronomy Journal**, Madison, v. 106, n. 1, p. 273–280, 2014.

AZIZ, S.A.; STEWARD, B.L.; BIRRELL, S.J.; KASPAR, T.C.; SHRESTHA D.S. **Ultrasonic sensing for corn plant canopy characterization**. St. Joseph: ASAE, 2004. (ASAE Paper No. 041120).

DWORAK, V.; SELBECK, J.; EHLERT, D. Ranging sensors for vehicle-based measurement of crop stand and orchard parameters: a review. **Transactions of the ASABE**, St. Joseph, v.54, n.4, p.1497-1510, 2011.

DILLEWIJN, C. VAN. **Botany of sugarcane**. Waltham: Chronica Botanica. 371 p. 1952.

FREEMAN, K.W., ARNALL, D.B., MULLEN, R.W., GIRMA, K., MARTIN, K.L., TEAL, R.K. AND RAUN, W.R. By-plant prediction of corn forage biomass and nitrogen uptake at various stages using remote sensing and plant height measures. **Agronomy Journal**, Madison, 99(2): 530-536. 2007.

FRICKE, T.; RICHTER, F.; WACHENDORF, M. Assessment of forage mass from grassland swards by height measurement using an ultrasonic sensor. **Computers and Electronics in Agriculture**, Amsterdam, v. 79, p. 142–152, 2011.

JASPER, J., REUSCH, S. AND LINK, A. Active sensing of the N status of wheat using optimized wavelength combination – impact of seed rate, variety and growth stage. In: EUROPEAN CONFERENCE ON PRECISION AGRICULTURE, 7., 2009, Wageningen. **Precision agriculture' 09: proceedings...** Wageningen, 2009. p. 23-30.

LOFTON, J.; TUBANA, B.S.; KANKE, Y.; TEBOH, J.; VIATOR, H. Predicting sugarcane response to nitrogen using a canopy reflectance-based response index value. **Agronomy Journal**, Madison, v. 104, n. 1, p. 106–113, 2012.

MUTANGA, O.; SKIDMORE, A.K. Narrow band vegetation indices overcome the saturation problem in biomass estimation. **International Journal of Remote Sensing**, Amsterdam, v. 25, n. 19, p. 3999-4014, Oct. 2004.

O'SULLIVAN J A. Evaluation of a Polaroid ultrasonic proximity transducer. **Journal of Agricultural Engineering Research**, Wageningen, v. 34, p. 63–73, 1986.

PORTZ, G. **Obtenção de algoritmo agrônomo para sensor foto ativo de refletância vegetal visando à aplicação da adubação nitrogenada na cultura da cana-de-açúcar.** 2011. 120 p. Dissertação (Mestrado em Máquinas Agrícolas) – Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo, Piracicaba, 2011.

PORTZ, G.; MOLIN, J.P.; JASPER, J. Active crop sensor to detect variability of nitrogen supply and biomass on sugarcane fields. **Precision Agriculture**, Dordrecht, v. 13, n. 1, p. 33–44, 2012.

PORTZ, G.; AMARAL, L.R.; MOLIN, J.P.; JASPER, J. Optimun sugarcane growth stage for canopy reflectance sensor to predict biomass and nitrogen uptake. In: INTERNATIONAL CONFERENCE ON PRECISION AGRICULTURE, 11., 2012, Indianápolis. **Proceedings...** Monticello: ISPA, 2012. CD-ROM.

REUSCH, S. Use of ultrasonic transducers for on-line biomass estimation In winter wheat. In: EUROPEAN CONFERENCE ON PRECISION AGRICULTURE, 7., 2009, Wageningen. **JIA2009 book of abstracts...** Wageningen: Wageningen Academic Publ., 2009. p. 169–175.

SHIBAYAMA, M.; AKIYAMA, T.; MUNAKATA, K. A portable field ultrasonic sensor for crop canopy characterization. **Remote Sensing of Environment**, Waltham, v. 18, n. 3, p. 269-279, 1985.

SHIRATSUCHI, L.S.; FERGUSON, R.B.; ADAMCHUK, V.I.; SHANAHAN, J.F.; SLATER, G.P. Integration of ultrasonic and active canopy sensors to estimate the in-season nitrogen content for corn. In: NORTH CENTRAL EXTENSION-INDUSTRY SOIL FERTILITY CONFERENCE, 39., 2009, Des Moines. **Proceedings...** Norcross: International Plant Nutrition Institute. 2009.

SOLIE, J.B.; RAUN, W.R.; STONE, M.L. Submeter spatial variability of selected soil and Bermuda grass production variables. **Soil Science Society of America Journal**, Madison, v. 63, n. 6, p. 1724-1733, Nov./Dec. 1999.

SUI, R.; THOMASSON, J.A. Ground-based sensing system for cotton nitrogen status determination. **Transactions of the ASABE**, St. Joseph, v. 49, p. 1983-1991, 2006.

SUI, R.; WILKERSON, J.B.; WILHELM, L.R.; TOMPKINS, F.D. A microcomputer-based morphometer for bush-type plants. **Computer and Electronics in Agriculture**, Amsterdam, v. 4, n. 1, p. 43-58, 1989.

5 ULTRASONIC PROXIMITY AND OPTICAL REFLECTANCE SENSING OF CROP CANOPY TO ESTIMATE SUGARCANE GROWTH INDICATORS

Abstract

The use of crop canopy optical reflectance sensors in sugarcane is being studied; however, the approach of real-time measurements of plant height provide another possibility for estimating the spatial variability of biomass and nitrogen uptake by the crop during the in-season fertilization period. An ultrasonic proximity sensor system was deployed to measure crop canopy height. The data were combined with commercially available canopy optical reflectance measurements to characterize spatial variability of crop growth in four commercial areas of southeast Brazil (over sandy soil and clayey soil) during three different growing stages (0.3-0.5 m, 0.5-0.7 m and 0.7-0.9 m of stalk height) over two seasons (dry and wet). After sensor mapping by the two sensor approaches, ten points in each field were defined to determine plant biomass and N-uptake through manual sampling and traditional measurements. Through the data analysis, a pixel by pixel comparison was performed to relate the interpolated maps obtained using different sensor systems. The ten points in each field were used to relate the actual biomass and N-uptake with the sensor data and compare them by coefficient of determination and standard errors and define the best approach in each situation according multivariable statistics. It was shown that both sensors correlate with biomass and nitrogen uptake. Canopy reflectance sensing produced a better assessment of crop growth at the earlier growth stage whereas the ultrasonic sensor resulted in more accurate predictions at the later growing stages and it is season dependent and the optical sensor is grow stage dependent. The integrations of both systems improve the predictions of biomass and N-uptake if the sensor fertilization approach is based to split the fertilization during the initial few months of the sugarcane season.

Keywords: Ultrasonic sensor, canopy height, plant reflectance, biomass, N-uptake.

5.1 Introduction

Sugarcane (*Saccharum spp.*) is the most important crop of sugar and ethanol production in tropical and subtropical regions. As with most grass species, nitrogen (N) is one of the major inputs on this crop; nevertheless, there is no reliable and inexpensive soil analyses procedure to determine N availability *in situ* during the growing season on tropical soils. To manage nitrogen fertilization according to local

needs, canopy reflectance sensors are already being intensively studied and results show that they can provide the status of biomass and N nutrition of sugarcane in real-time (AMARAL et al., 2012; PORTZ et al., 2012; LOFTON et al., 2012). However, these sensors can exhibit signal saturation when the sugarcane crop is above 0.6 m of stalk height, where increasing biomass does not reflect an adequate increase of the sensor optical vegetation index (VI) later in the season (PORTZ et al., 2012), when there is still room to conduct in-season nitrogen fertilization in some cases.

As an alternative, measuring crop canopy by using ultrasonic proximity sensors is not a new approach. During the 1980's Shibayama et al. (1985) used such a sensor for crop canopy characterization, and Sui et al. (1989) developed a measurement system using ultrasonic ranging modules to provide cumulative plant volume, plant width and height for a variety of bush-type plants, such as cotton and soybean. Later, ultrasonic proximity sensors were used simultaneously with crop canopy reflectance sensors. Scotford and Miller (2003) concluded that ultrasonic sensors proved to be useful for monitoring winter wheat growth beyond GS 30, whereas optical (NDVI) measurements were useful for monitoring winter wheat up to GS 31 (before the point of stalk elongation). Also Scotford and Miller (2004), exploring the possibilities of these devices, conclude that ultrasonic sensors could be used to determine the optimum level of inputs such as fertilizers, fungicides and growth regulators at a given stage of crop development and to account for variations within a field. This evidence suggests that by combining these two measurements, the crop can be monitored throughout the entire growing season.

Sui and Thomasson (2006) combined plant reflectance sensors and ultrasound sensors to determine the status of nitrogen in cotton and showed that the spectral information and ultrasonic plant height had significant correlation with the nitrogen contained in the cotton leaves. Shrestha et al. (2002), investigating ultrasonic sensor estimates of maize plant height in a lab environment, were able to show that the estimated height correlated with the manually measured height. While working with an optical reflectance sensor on maize, Freeman et al. (2007) also took measurements of plant height and concluded that plant height alone was a good predictor of plant biomass at all stages of sampled growth. Similarly, work conducted by Shiratsuchi et al. (2009) showed that correlations between height, biomass and nitrogen were observed in maize, suggesting the integration of plant reflectance

sensor and ultrasound measurements of plant height to estimate crop nitrogen uptake during the entire growing season.

Sudduth et al. (2010), comparing optical canopy sensors, found that GreenSeeker and Crop Circle ACS-210 are more affected by variations in maize height than by SPAD readings and leaf N contents. Also Sharma & Franzen (2013), using these same optical sensors, found that in the high clayey and medium textured soils at the V6 stage, maize height improved the relationship between INSEY (in season estimate of yield) and yield often enough to suggest that incorporating maize height into an algorithm for yield prediction would strengthen yield prediction, and thus improve N rate decisions.

According to Gebbers and Adamchuk (2010), on a revision over precision agriculture technologies, ultrasonic proximity sensing is still in the research stage. So it can be a new promise approach in well-developed canopies as sugarcane to access crop biomass as showed Portz et al. (2012), observing that sugarcane stalk height measured manually correlated with the crop biomass and N-uptake. This means that crop canopy height can provide complementary information or it can be considered an alternative to optical reflectance sensing when estimating crop biomass and N-uptake late in the sugarcane season. Based on that the objective of this project was to compare canopy reflectance and ultrasonic crop height sensing when predicting sugarcane biomass and N-uptake in real-time until late possible sugarcane fertilization stages.

5.2 Materials and methods

The study involved four commercial fields located around the São Martinho Sugar Mill (21°19'11"S, 48°07'23"W), in the state of São Paulo, Brazil, two on sandy (12 ha and 18 ha) and two on clayey (16 ha and 10 ha) soils. The fields were mechanically green harvested (with no burn) during mid-season (dry period, August), and late season (wet period, November) (Table 1) and were scanned three times after, when the crop was at 0.3 m to 0.5 m, at 0.5 m to 0.7 m and at 0.7 m to 0.9 m of field average stalk height.

Table 1 - Studied fields information and variables.

Field	1	2	3	4
Size (ha)	12	16	18	10
Harvest	Aug (dry season)		Nov (wet season)	
Soil	sandy	clayey	sandy	clayey
Variety	CTC9	CTC7	CTC2	CTC2

Sugarcane stalk height (grow stage) to set each scanning time was defined as the field plants average stalk length from the soil to the insertion of the Top Visible Dewlap leaf (TVD) (DILLEWIJN, 1952) on the stalk (Figure 1). Field view of the three stages mapped and sampled can be seen at Figure 2 for row spacing of 1.5 m. At the first stage rows are open and ground still visible; at the second stage canopy starts to close but rows still visible; at third stage canopy covers the ground.

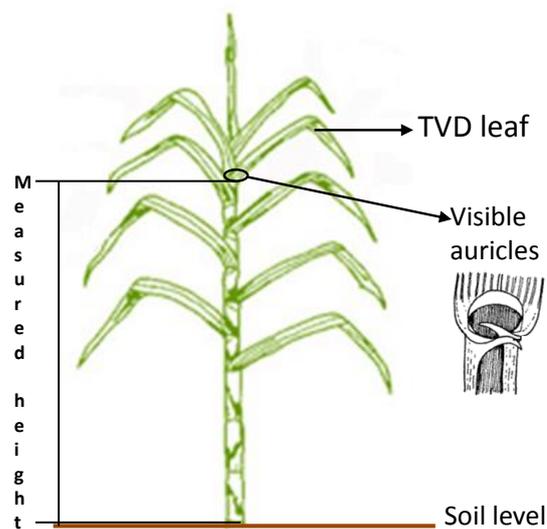


Figure 1 - Stalk height measurement for sampling stage definition



Figure 2 - Sugarcane view at first (A - 0.3-.05 m), second (B - 0.5-.07 m) and third (C - 0.7-.09 m) stages.

In each stage the fields were scanned simultaneously with a commercial crop canopy optical reflectance sensor (ORS) (N-Sensor[®] ALS, Yara International ASA, Duermen, Germany), and two ultrasonic position sensors (UPS) (Polaroid 6500, Minnetonka, Minnesota, USA). The N-Sensor ALS is comprised of a transmitter with a xenon flashlight, providing high intensity illumination between 650 and 1100 nm and a 10 Hz receiver with two photodiodes and interference filters of 730 and 760 nm in front of them measuring the proprietary defined vegetation index (Jasper et al., 2009). The two ultrasonic sensors were operated at a frequency of 49.4 kHz and connected to a data logger (CR 1000 Campbell Scientific, Logan, Utah, USA). All of the measurements were georeferenced using a L1P (carrier phase) Global Positioning System (GPS) receiver and a 1 Hz log file was created by synchronizing and aggregating all of the data. The sensors were mounted on top of a high clearance vehicle (Figure 3) that passed the field every 10 rows (15 m) at a travel speed between 3.3 and 4.2 m s⁻¹ (12 and 15 km h⁻¹) producing about 200 independent data points per hectare. Since the crop canopy reflectance sensor had an oblique view, three crop rows were sensed at a time on each side. Each ultrasonic system evaluated only one row, while being installed on a nadir view (Figure 3).

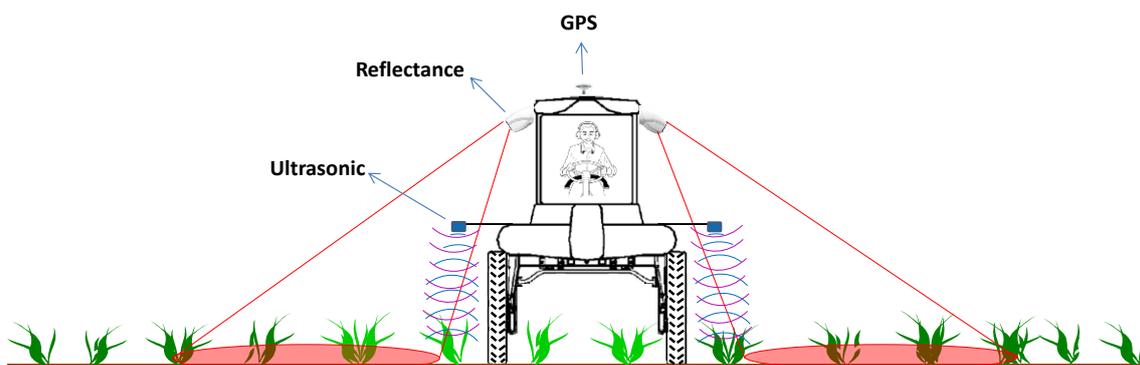


Figure 3 - Canopy sensors disposition on a high clearance vehicle.

Equation 1 was used to obtain the crop height from the ultrasonic distance sensors:

$$H = h - d \quad (1)$$

Where:

H – Plant height (soil level to canopy)

h – Installation height of the ultrasonic head to the soil level

d – Ultrasonic distance between sensor and crop canopy

The average of the recorded data from the left and right sensors were filtered, cutting off points outside the field boundaries and negative values; they were interpolated (inverse distance weighting) using a 5 x 5 m raster. A five-color legend (natural breaks) was applied for visual analysis. Ten validation locations were selected in each field (two per color class) to represent the entire range of sensor-based measurements for both systems. Each validation location (sample point) was located in the middle of a 5-m cell. In every case, destructive plant samples of the above ground biomass were taken by manually cutting a 1.5 m sub-plot consisting of three rows (4.5 m). The fresh matter samples were weighed in the field, sub-samples were taken, chopped and dried, after processed in the laboratory to measure total N content (Kjeldahl method) and, ultimately, the crop N-uptake estimated. Figure 4 illustrates the process.

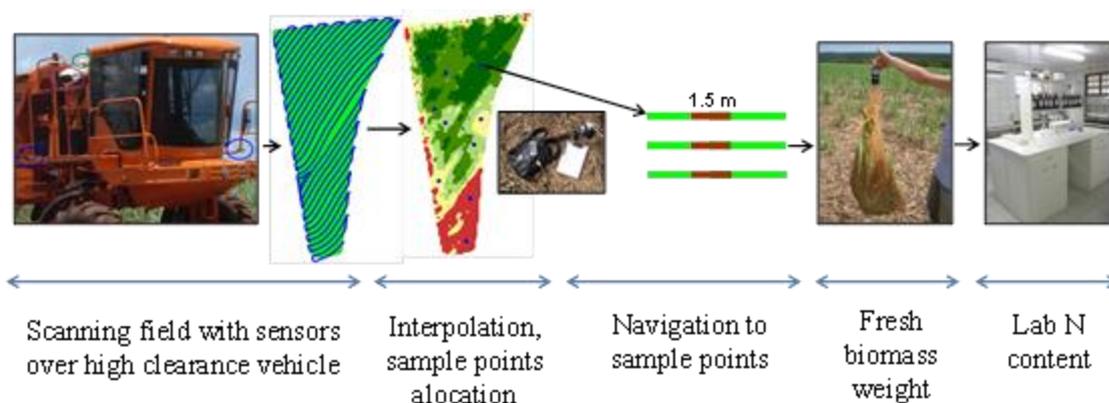


Figure 4 - Sampling process for each mapping time

The sensor-based data were compared using regression analysis applied to all of the interpolated pixels. Another set of linear regression analyses was conducted to relate the measured fresh matter and N-uptake of the sample points to the sensors measurements by analyzing coefficients of determination and standard errors of individual mappings and entire sampling season performance. Multivariable regressions were also performed to indicate the best model for each sensor on the different evaluated conditions.

5.3 Results and discussion

Interpolated data maps from the ORS and the UPS on the three measurements made on the sandy and clayey soil fields of the dry season are presented on Figure 5, and the same is presented on Figure 6 for the wet season areas. All of the maps illustrated the same spatial pattern showing that both sensor technologies are able to see the infield sugarcane crop variability. But as some differences between technologies exist, a single scale was used to better capture the sensibility of the sensors that contemplate values from the first to the third mapping.

It is possible to see that on the first mapping the ORS sensor was able to better classify the data showing on more detail the variability on the four studied fields. On the other hand, the URS sensor was able to see more variability on the third mapping event. Especially on the wet season the ORS showed less sensibility to the sugarcane on the third mapping event grouping most of the read values in a single map class.

On the second mapping event, over the dry season areas, the ORS and UPS sensors show similar results over clayey and sandy soils. On the other hand, during the wet season seems that the UPS was more sensible to the crop variation on the sandy soil and the ORS over the clayey soil area.

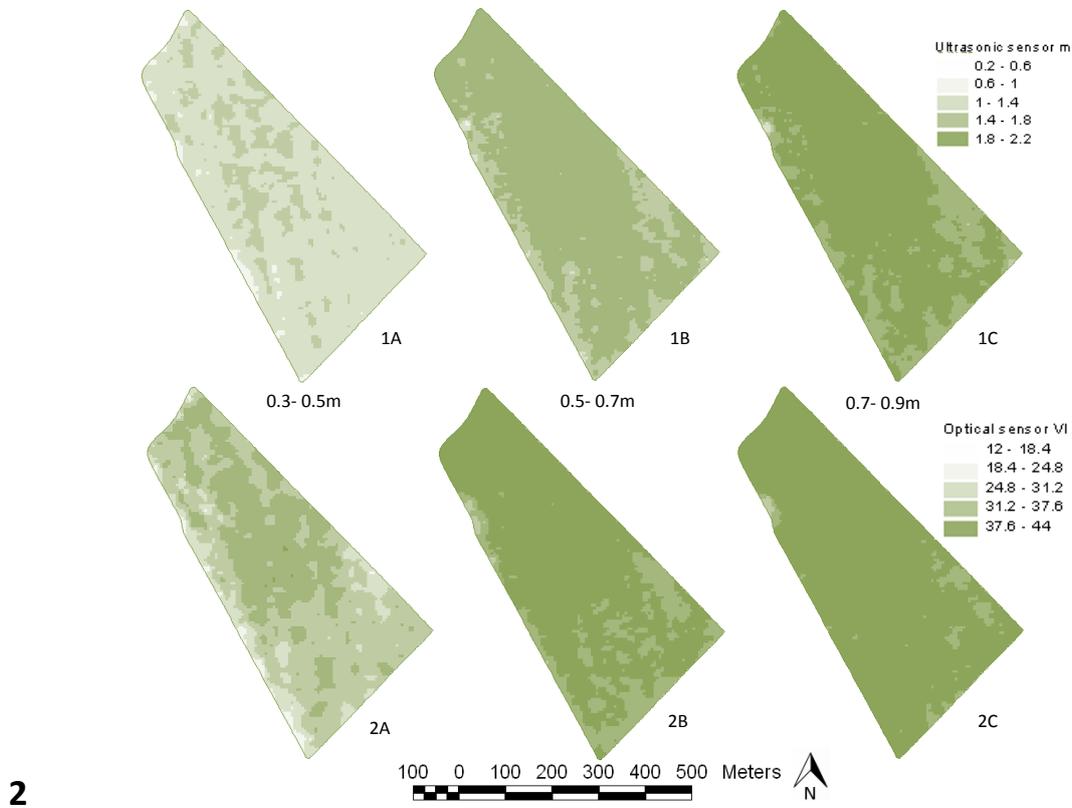
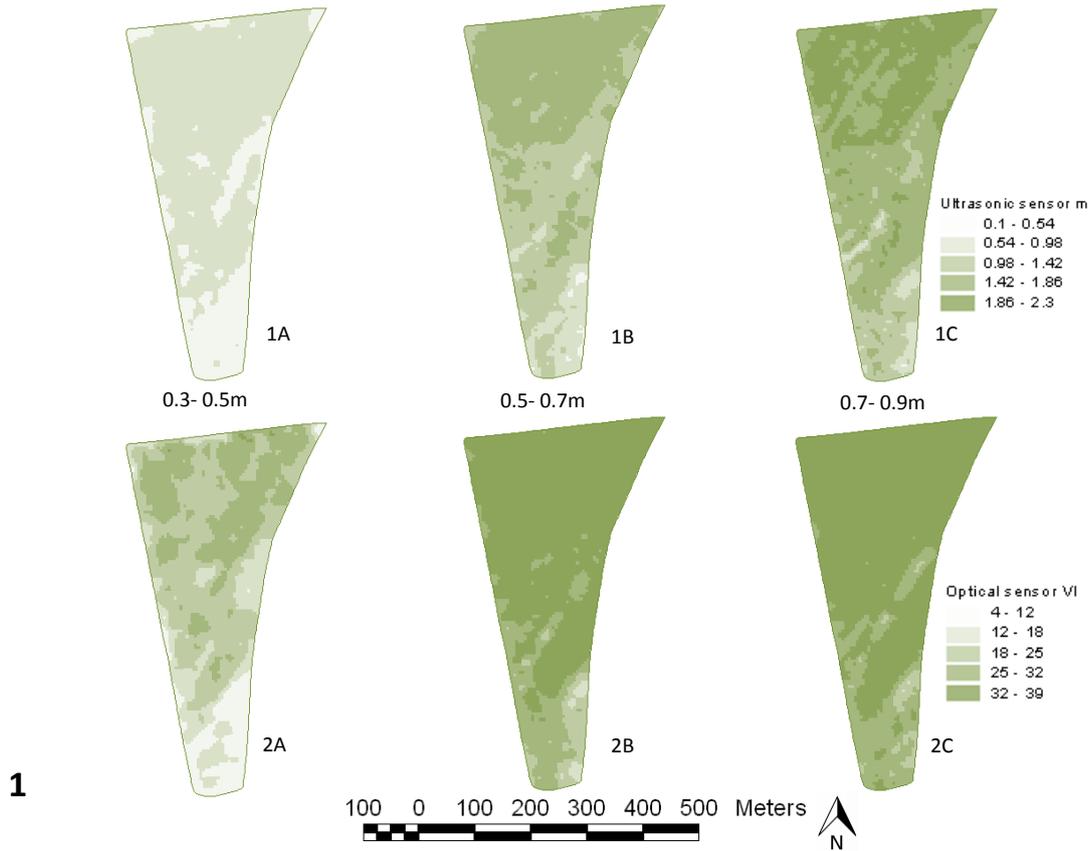


Figure 5 - Interpolated maps of crop canopy reflectance during the first (1A), second (1B) and third mapping (1C) and crop canopy height on first (2A), second (2B) and third (2C) mapping scanning during dry season (field 1 and field 2).

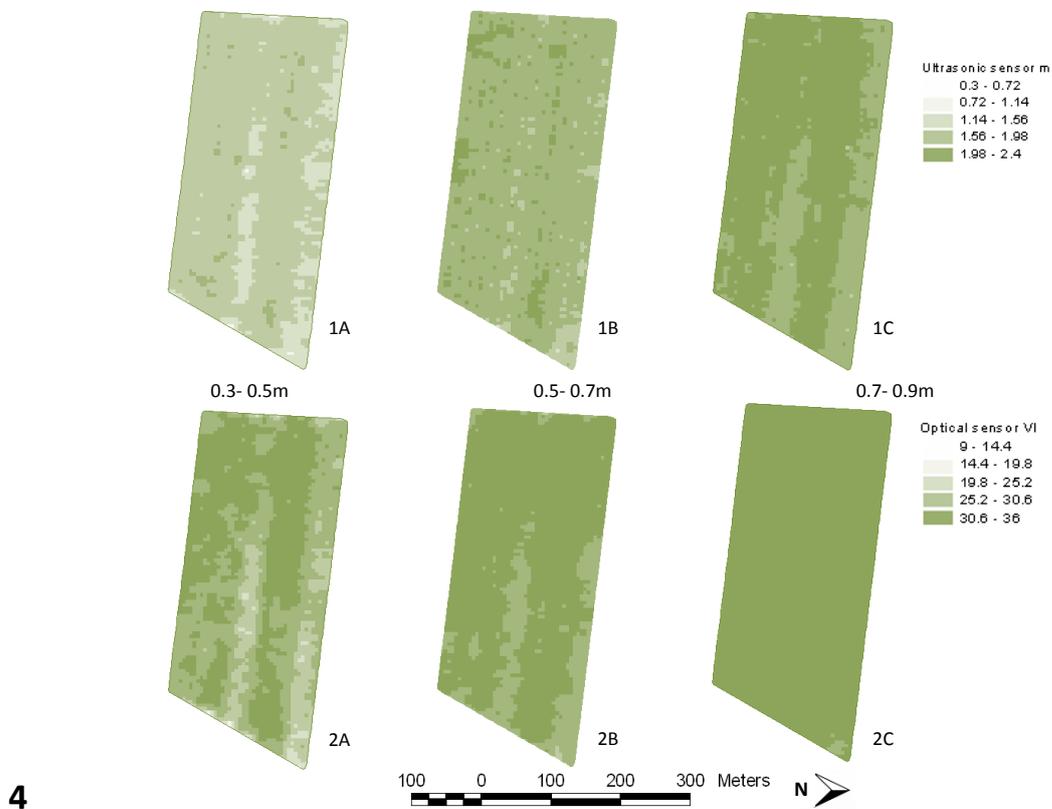
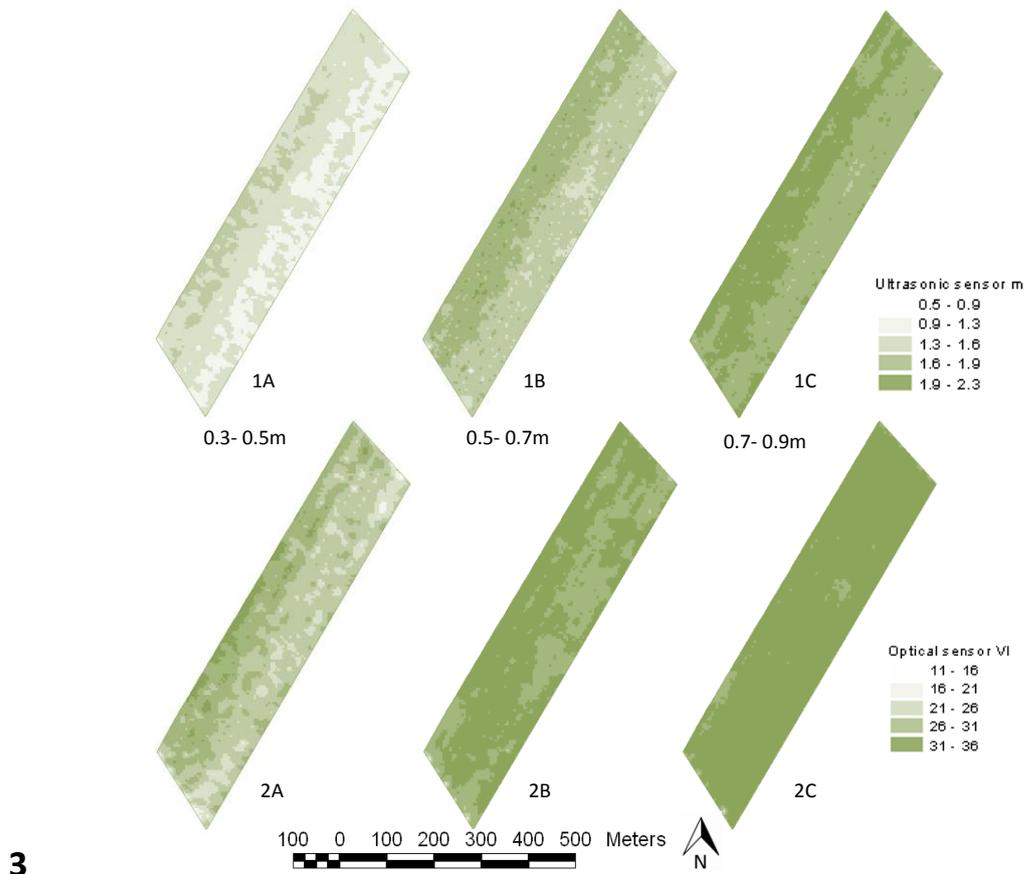


Figure 6 - Interpolated maps of crop canopy reflectance during the first (1A), second (1B) and third mapping (1C) and crop canopy height on first (2A), second (2B) and third (2C) mapping scanning during wet season (field 3 and field 4)

To better understand these map behaviors, a pixel by pixel correlation of the interpolated sensor maps between ORS and UPS systems was performed for each mapping event on the four studied fields (Figure 7).

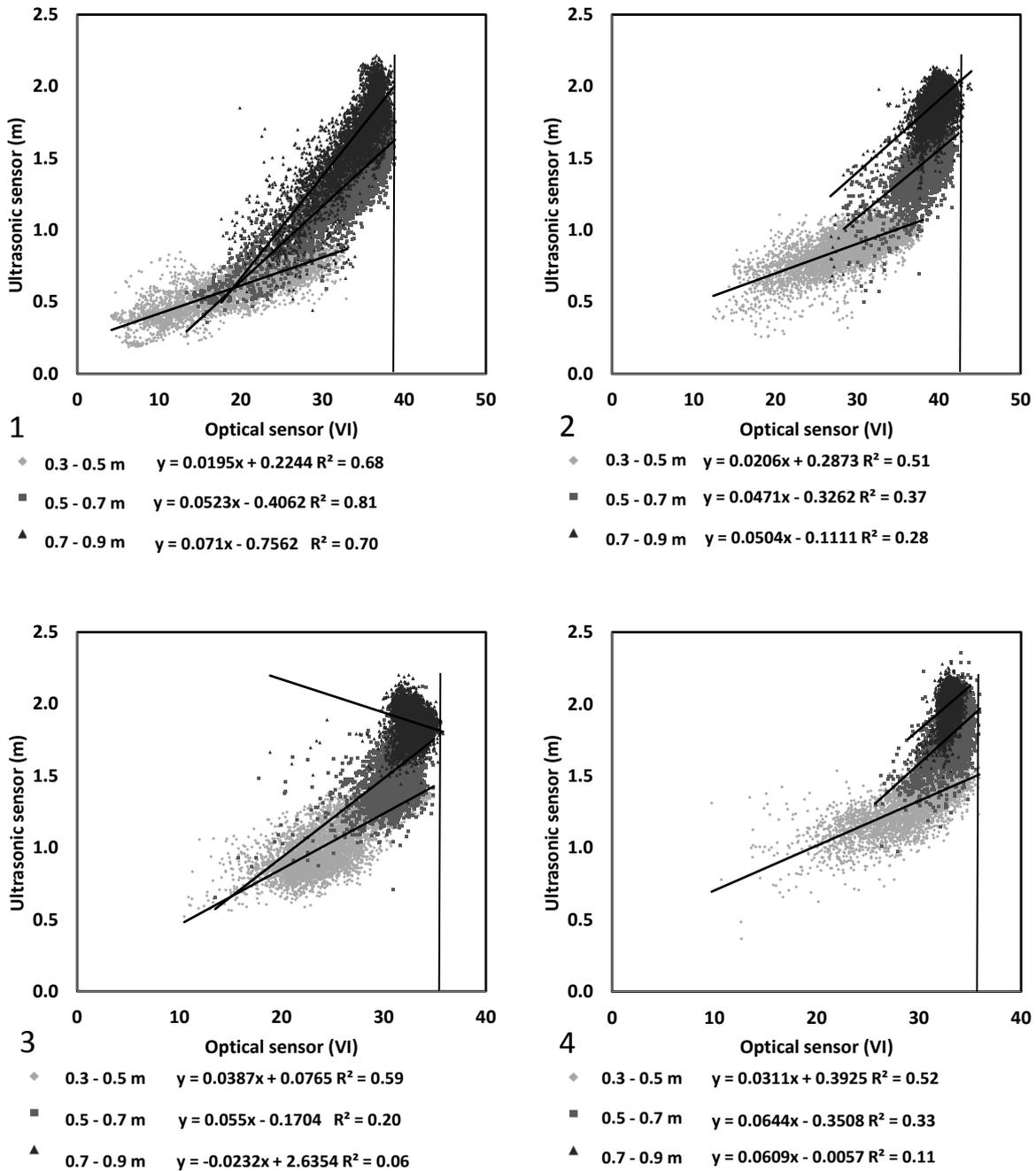


Figure 7 - Sensors signal pixel by pixel correlation of first, second and third scanning moments of the four studied fields

Following what could be seen on the interpolated maps, field number 1 (dry, sandy) presents the higher data range showing an uneven crop. On the other hand field number 4 (wet, clayey) presented the shorter data amplitude and showed the most uniform crop stand. Fields 2 and 3 had intermediate behaviors.

On the first mapping event (0.3 – 0.5 m) the ORS clearly had more data amplitude to characterize the crop compared to the UPS. But on the second evaluation (0.5 – 0.7 m) this behavior seems to equalize between sensors in a $\pm 45^\circ$ angle correlation line and finally on third and last evaluation (0.7 – 0.9 m) the UPS sensor seems to present more data amplitude. Also in the last measurement, the optical sensor seems to saturate its signal in parts of the field 3 as it shows no more correlation between sensors.

It is also possible to see that in certain point between 37 VI and 43 VI, depending on the field conditions, the optical sensor achieves an upper limit (line) and the scale of the ORS sensor reduces under 10 VI units on the last evaluation, except field 1 because of its large natural variability.

Summarizing, the range of measurements conducted by the ultrasonic sensor increased during the second scan indicating a strong sensor response to crop height and as consequence to biomass. On the other hand, the range of VI values has declined at this later growth stage indicating that the sensor was less capable of distinguishing crop performance in different parts of the field when compared to the earlier growing stage. This behavior can be explained by the fact that optical measurements primarily observe crop leaves and ultrasonic height assess the crop stalks. Thus, during the first scanning over a younger sugarcane crop, the leaves were more relevant to crop biomass and N uptake than the stalks. During the second and third scanning, the stalk was a bigger contributor to crop biomass leaving crop height measurements more responsive to spatially different crop performance.

Regards to validation from manual sampling data, field sampled fresh matter was related to the sub-samples of dry matter and respectively the dry matter N content to the nitrogen uptake on all the sampled points (Figure 8).

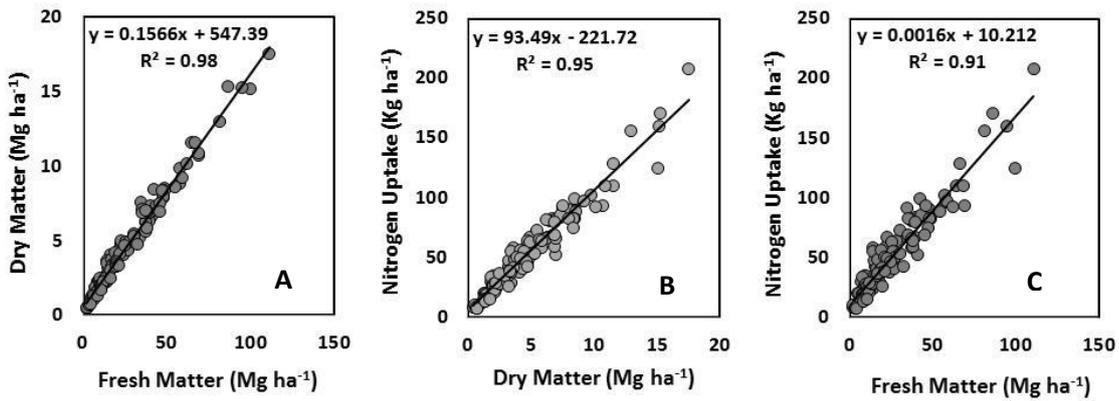
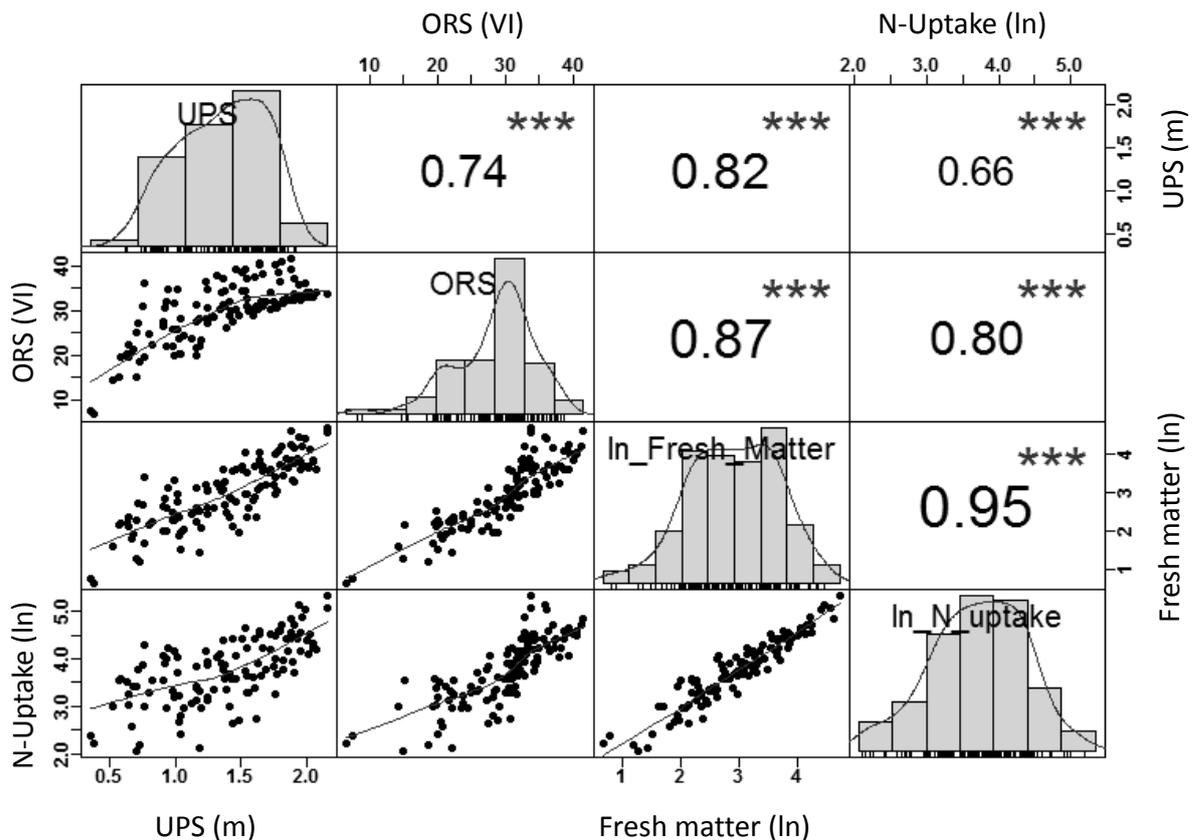


Figure 8 - Field sample points relation between dry and fresh matter (A), N and dry matter (B), and N uptake and fresh matter(C).

The three growth indicators are deeply related, showing high coefficient of determination, confirming that the data is reliable and that N-uptake is directly related to biomass, as it is the concentration of the nutrient in the dry samples multiplied by the amount of biomass. Using the above equations one parameter can be converted in to another, so further analyses will focus only on fresh biomass that can be easily measured in the field and converted to N-uptake that is the goal to drive variable rate application of nitrogen fertilizers. Figure 9 shows a matrix of Pearson correlation made on the statistical program R for the sample points between sensors with fresh matter and N-uptake with the data of all the investigated fields.



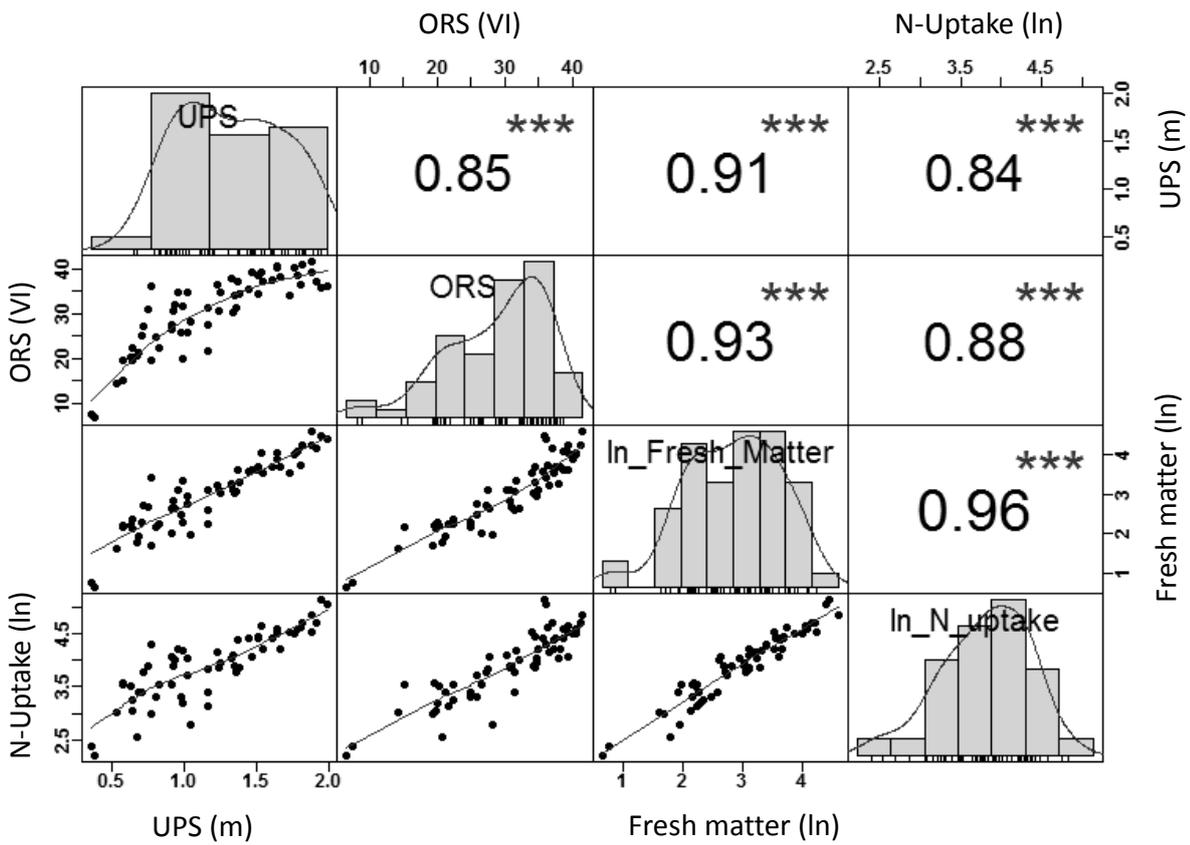
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 'ns' 1

Figure 9 - Sample points correlation matrix of all fields and stages for both sensors with fresh matter and N-uptake.

To satisfy the assumption of data normality, the values of fresh matter and N-uptake were transformed into natural logarithms and both sensor values lived as original.

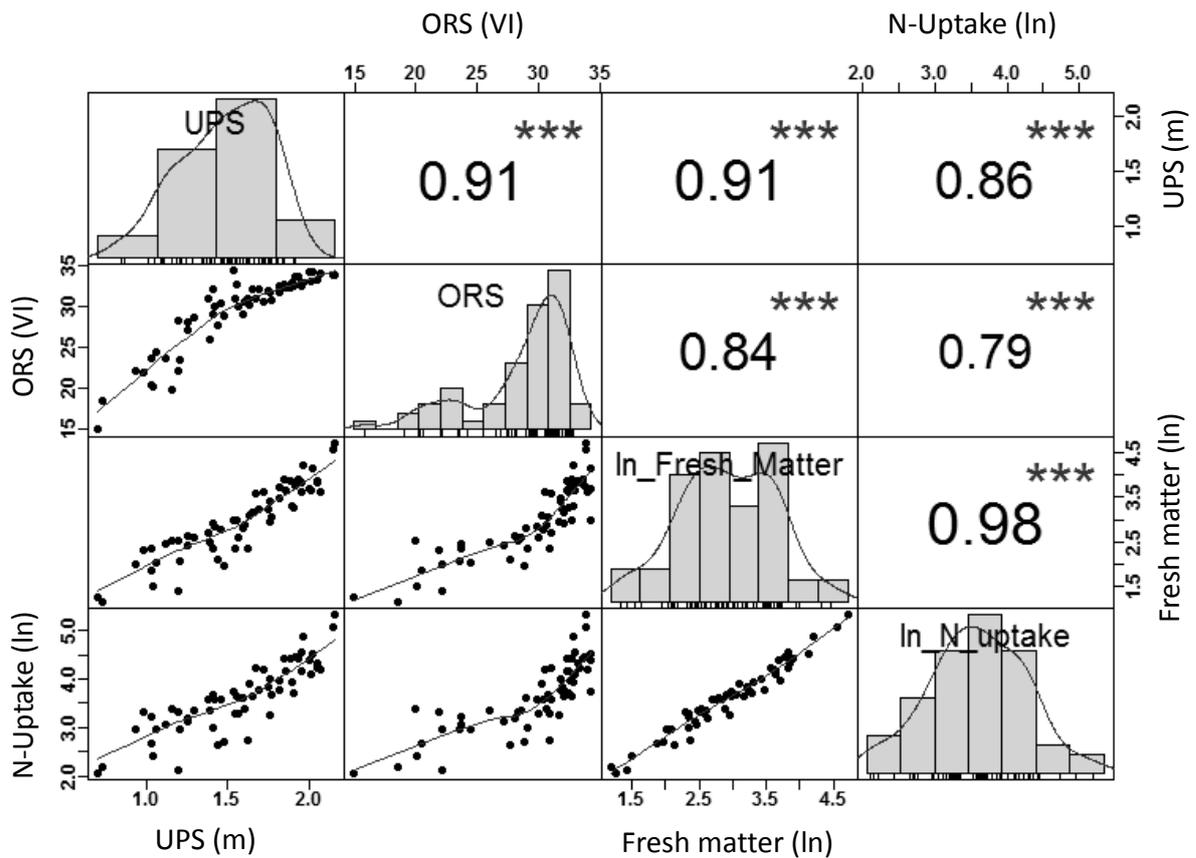
Analyzing all data combined, it is possible to see that both sensors are able to predict fresh matter and N-uptake with high statistical significance, being the ORS superior, especially on the prediction of N-uptake. But if this data is separated by dry and wet seasons this behavior changes (figures 10 and 11 respectively).

On the dry season, the ORS shows better correlation to fresh matter, and even better to N-uptake compared to the UPS. On the wet season the behavior is opposite and UPS was superior on the prediction of fresh matter and N-uptake compared to the ORS. This season independent analyze seems to be better as the correlation between sensors increases, also the accuracy of both sensor systems for fresh matter and N-uptake.



Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 'ns' 1

Figure 10 - Sample points correlation matrix of all fields and stages for both sensors with fresh matter and N-uptake on the dry season.



Signif. codes: 0 '****' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 'ns' 1

Figure 11 - Sample points correlation matrix of all fields and stages for both sensors with fresh matter and N-uptake on the wet season.

Analyzing R^2 and standard error of the sensors data on the three evaluated stages on all fields, different behaviors show of (Figure 12). Field 1 (dry season, sandy soil) had very heterogeneous crop height from north to south, so the UPS sensor was able to capture this variability well, but the ORS sensor also performed well as it presented no visible saturation.

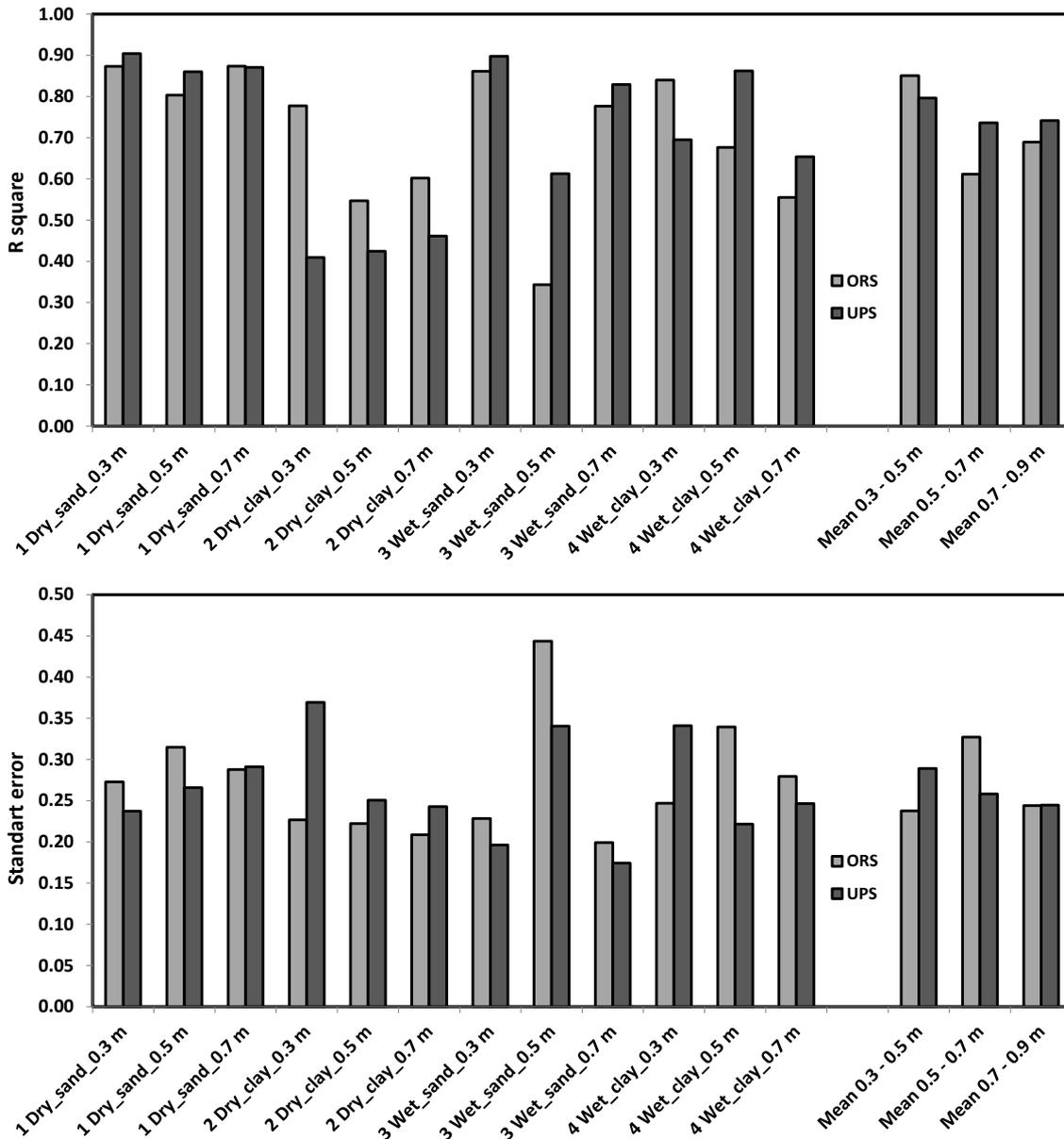


Figure 12 – R square and standard error of all mapping sample points regressions data of fresh matter for the ultrasonic and optical sensors and its mean on every growth stage.

Field 2 (dry season, clayey soil) presented a very homogenous crop, well sprouted and with no plant failures. Under these conditions the ORS sensor was more accurate, especially at the first evaluation when leaves dominate and stalks elongation is not representative. Field 3 (wet season, sandy soil) showed similar behavior for both sensor systems at the first evaluation, and advantage for the UPS sensor at the next two. Field 4 (wet season, clayey soil) showed best performance for the ORS sensor at the first evaluation and also an opposite behavior at the next two evaluations when the UPS sensor result was superior. Looking at the general average on every growth stage, the ORS had a better performance at the first

evaluation and the UPS sensor was superior at the next two evaluations when de sugarcane crop presented higher biomass related to stalks.

Besides that, at the sandy soils, where number of stalks (Appendix C) is usually lower and in-field variability higher, the UPS system performed better. On the clayey soil fields, at the dry season the ORS sensor showed superior results on the fresh matter prediction as it is better on achieving leaves and crop color. At the wet season the ORS showed superior values at the first evaluation and the UPS sensor at second and third. This can be explained by the fact that on clayey soils the number of shoots use to be greater at the beginning, providing superior leaves coverage detected better by the optical sensor and at the older stages stalks elongation seems to be more important, especially at the wet season when there is no water limitation for plant growth and internodes elongation. Figure 13 shows R^2 and standard error for both sensors by N-uptake on all the sampling situations.

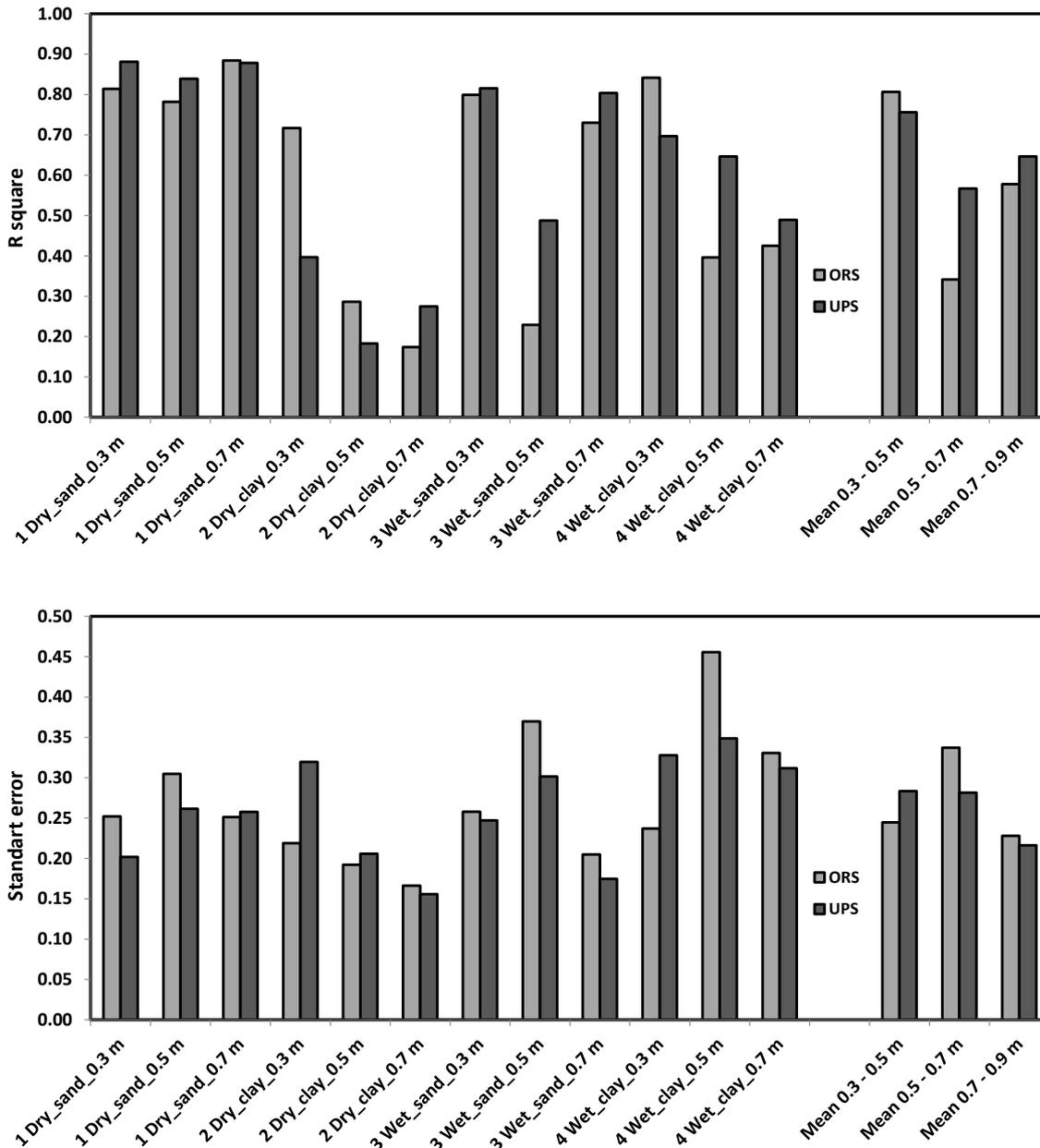


Figure 13 - R square and standard error of all mapping sample points regressions data of N-uptake for the ultrasonic and optical sensors and its mean on every growth stage.

Results related to N-uptake show the same behavior of fresh matter as it is the concentration of nitrogen (that have low variability) multiplied by the amount of biomass. But it seems that the difference on scale is intensified as the sensors performance can be differentiated a little easier. On the third evaluation of the second field the UPS sensor performed better than the ORS sensor for N-uptake reinforcing the assumption that in younger sugarcane the ORS system is superior and over more developed crop the UPS system performs better.

To better understand the sensors behavior in the different field situations a multiple linear regression analyses for fresh matter and N-uptake (table 2) was performed.

Table 2 - Summary of sensor performance indicators from multiple linear regressions.

Factor of influence	R ² (standard error in log of fresh matter)		
	UPS	ORS	UPS and ORS
No additional factors	0.67 (0.49)**	0.74 (0.41)	0.83 (0.33)
Growth stage (no interactions)	0.71 (0.46)**	0.84 (0.33)**	0.85 (0.32)**
Growth stage (complete model)	0.71 (0.46)	0.85 (0.33)*	0.89 (0.27)
Season (no interactions)	0.83 (0.35)**	0.74 (0.41)	0.86 (0.31)
Season (complete model)	0.83 (0.35)	0.77 (0.39)*	0.88 (0.29)
Growth stage and season (no interactions)	0.83 (0.35)	0.84 (0.34)	0.87 (0.31)
Growth stage and season (complete model)	0.83 (0.33)*	0.86 (0.30)	0.92 (0.25)
Factor of influence	R ² (standard error in log of N-uptake)		
	UPS	ORS	UPS and ORS
No additional factors	0.43 (0.52)**	0.62 (0.42)**	0.67 (0.38)
Growth stage (no interactions)	0.48 (0.50)**	0.68 (0.39)**	0.68 (0.39)
Growth stage (complete model)	0.52 (0.49)*	0.70 (0.38)*	0.81 (0.31)
Season (no interactions)	0.72 (0.37)**	0.64 (0.41)	0.74 (0.35)**
Season (complete model)	0.73 (0.36)**	0.69 (0.38)**	0.78 (0.33)
Growth stage and season (no interactions)	0.72 (0.37)	0.71 (0.38)**	0.74 (0.36)
Growth stage and season (complete model)	0.78 (0.34)*	0.77 (0.33)	0.87 (0.26)

** - every element of the model is significant at $\alpha=0.05$

* - the highest-order interaction is significant at $\alpha=0.05$

Analyzing the multiple linear regression indicators it can be seen that growth stage is the most important factor of influence for the ORS and season for the UPS. The combined sensor values were always equal or superior that a single sensor model to evaluate fresh matter and N-uptake. The union of both sensor systems shows superior results on predicting N-uptake on the investigated areas.

Figures 15 and 16 present the plotted correlations of fresh matter and N-uptake with both sensors by stage and season. Plotting the values it is clear to see that the UPS sensor had its values separated by season and the ORS sensor is more responsive to growth stage.

On the N-uptake linear regressions, the accuracy for both sensors is lower that by fresh matter, also the ORS sensor is superior than the UPS sensor on the growth stage models and the UPS is superior on the season models. The models representing the fusion of sensors data did not perform as well as by the fresh matter estimation on the individual models, but the average model was superior for the combination of both sensors.

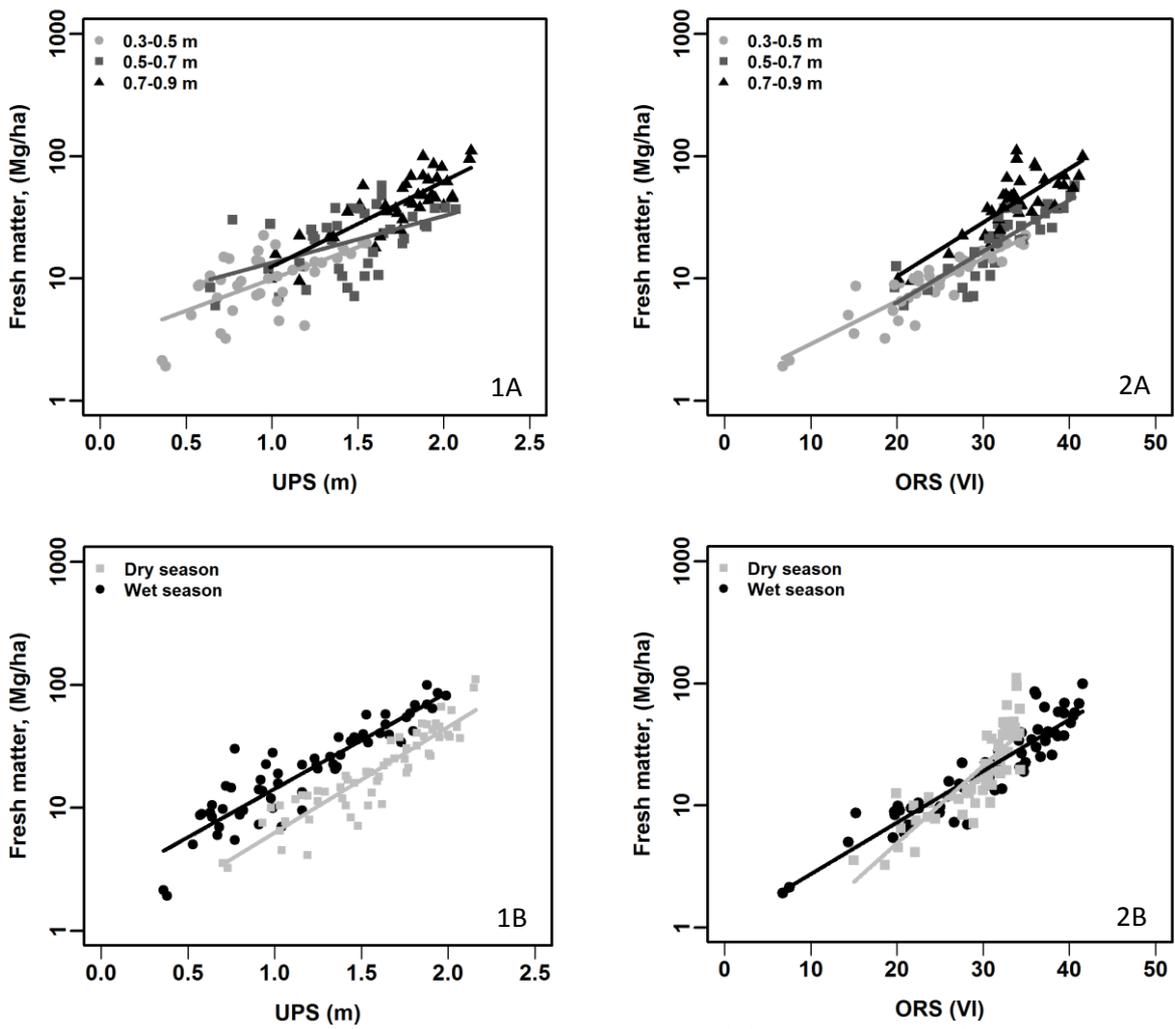


Figure 15 - Performance comparison of ultrasonic (1) and optical (2) with fresh matter regressions for all the fields sampled points by growth (A) stage and season (B).

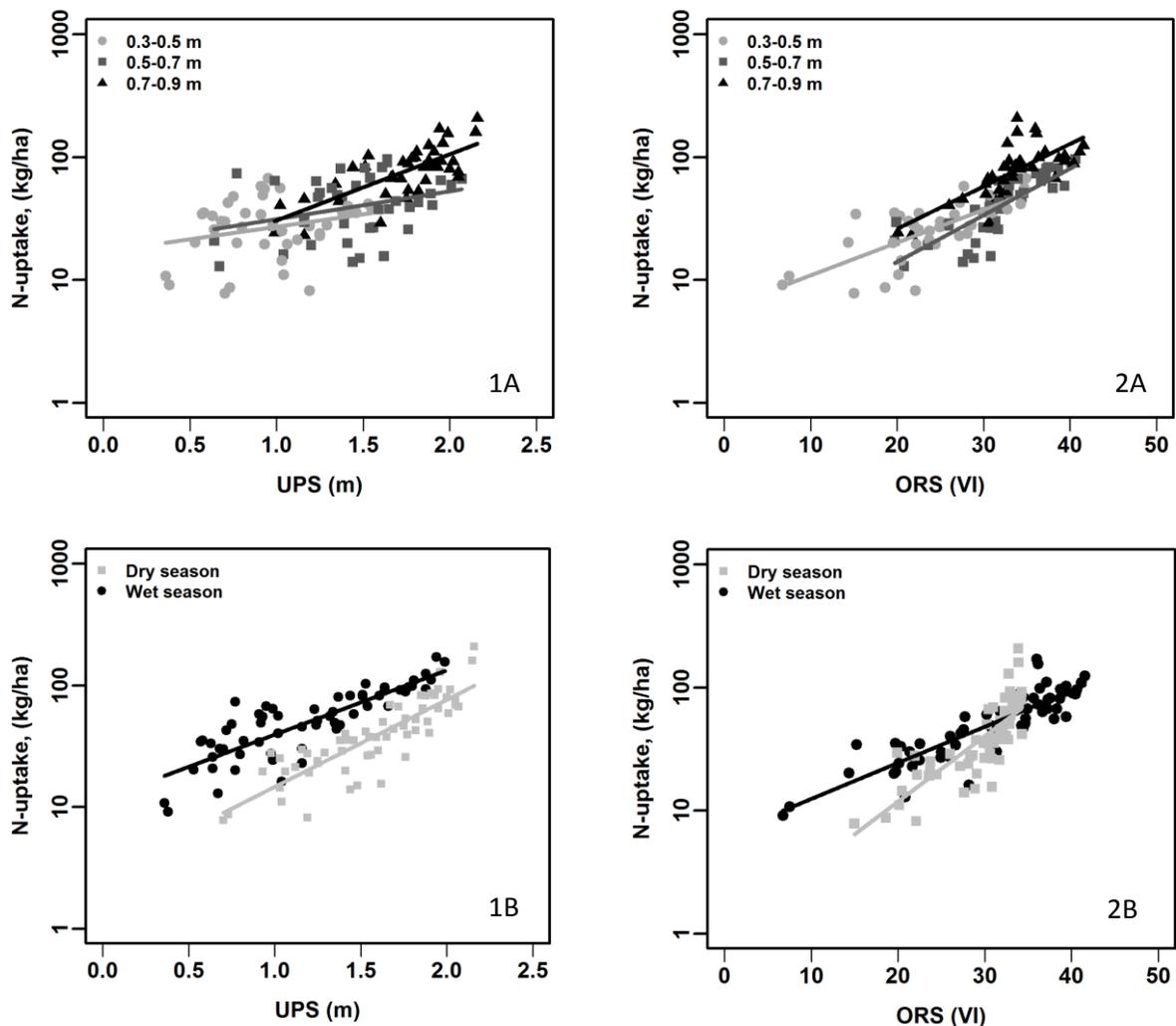


Figure 16 - Performance comparison of ultrasonic (1) and optical (2) with N-uptake regressions for all the fields sampled points by growth (A) stage and season (B).

5.4 Conclusions

The sensors data present consistent correlations when generating similar maps for canopy reflectance and canopy height on the four studied fields. Sampled biomass and N-uptake also correlate with both canopy reflectance and crop height sensor-based measurements.

Sugarcane at 0.3 - 0.5 m of stalk height can have better prediction of growth indicators by the optical sensor as it is more sensible to plant leaves. On crop above this stage the ultrasonic sensor is presented as an accurate alternative as it is more sensitive to stalk height, especially during the wet season. The fusion of both sensor systems is beneficial to predict sugarcane parameters on measurements from young shoots until late possible sugarcane fertilization stages.

References

AMARAL, L.R.; PORTZ, G.; ROSA, H.J.A.; MOLIN, J.P. Use of active crop canopy reflectance sensor for nitrogen sugarcane fertilization. In: INTERNATIONAL CONFERENCE ON PRECISION AGRICULTURE, 10., 2012, Indianapolis.

Proceedings... Monticello: ISPA, 2012. 1 CD-ROM.

DILLEWIJN, C. VAN. **Botany of sugarcane**. Waltham: Chronica Botanica. 371 p. 1952.

FREEMAN, K.W.; ARNALL, D.B.; MULLEN, R.W.; GIRMA, K.; MARTIN, K.L.; TEAL, R.K.; RAUN, W.R. By-plant prediction of corn forage biomass and nitrogen uptake at various stages using remote sensing and plant height measures. **Agronomy Journal**, Madison, v. 99, n. 2, p. 530-536, 2007.

GEBBERS, R.; ADAMCHUK, V.I. Precision agriculture and food security. **Science**, Washington, v. 327, n. 5967, p. 828-831, 2010.

JASPER, J., REUSCH, S. AND LINK, A. Active sensing of the N status of wheat using optimized wavelength combination – impact of seed rate, variety and growth stage. In: EUROPEAN CONFERENCE ON PRECISION AGRICULTURE, 7., 2009, Wageningen. **Precision agriculture '09: proceedings...** Wageningen, 2009. p. 23-30.

LOFTON, J.; TUBANA, B.S.; KANKE, Y.; TEBOH, J.; VIATOR, H. Predicting sugarcane response to nitrogen using a canopy reflectance-based response index value. **Agronomy Journal**, Madison, v. 104, n. 1, p. 106–113, 2012.

PORTZ, G.; AMARAL, L.R.; MOLIN, J.P. Measuring sugarcane height in complement to biomass sensor for nitrogen management. In: INTERNATIONAL CONFERENCE ON PRECISION AGRICULTURE, 10., 2012, Indianapolis. **Proceedings...**, Monticello: ISPA, 2012. 1 CD-ROM.

PORTZ, G.; MOLIN, J.P.; JASPER, J. Active crop sensor to detect variability of nitrogen supply and biomass on sugarcane fields. **Precision Agriculture**, Dordrecht, v. 13, n. 1, p. 33–44, 2012.

PORTZ, G.; AMARAL, L.R.; MOLIN, J.P.; JASPER, J. Optimum sugarcane growth stage for canopy reflectance sensor to predict biomass and nitrogen uptake. In: INTERNATIONAL CONFERENCE ON PRECISION AGRICULTURE, 10., 2012, Indianapolis. **Proceedings...** Monticello: ISPA, 2012. 1 CD-ROM.

SCOTFORD, I.M.; MILLER, P.C.H. Combination of spectral reflectance and ultrasonic sensing to monitor the growth of winter wheat. **Biosystems Engineering**, New York, v. 87, n. 1, p. 27-38, 60, 2003.

_____. Estimating tiller density and leaf area index of winter wheat using spectral reflectance and ultrasonic sensing techniques. **Biosystems Engineering**, New York, v. 89, p. 395–408. 2004.

SHARMA , L. K. AND FRANZEN, D. W. Use of corn height to improve the relationship between active optical sensor readings and yield estimates. **Precision Agriculture**, Dordrecht, v 15: 331–345. 2013.

SHIBAYAMA, M.; AKIYAMA, T.; MUNAKATA, K. A portable field ultrasonic sensor for crop canopy characterization. **Remote Sensing of Environment**, Waltham, v. 18, p. 269-279, 1985.

SHIRATSUCHI, L.S.; FERGUSON, R.B.; ADAMCHUK, V.I.; SHANAHAN, J.F.; SLATER, G.P. Integration of ultrasonic and active canopy sensors to estimate the in-season nitrogen content for corn. In: NORTH CENTRAL EXTENSION-INDUSTRY SOIL FERTILITY CONFERENCE, 39., 2009, Des Moines. **Proceedings...** Norcross: International Plant Nutrition Institute, 2009. p. 18-29.

SHRESTHA, D.S.; STEWARD, B.L.; BIRRELL, S.J.; KASPAR, T.C. **Plant height estimation using two sensing systems.** (ASAE Paper, 021197). ASAE Annual International Meeting, CD-ROM. ASAE, St. Joseph, MI. 2002.

SUDDUTH, K.A.; KITCHEN, N.R.; DRUMMOND, S.T. Comparison of three canopy reflectance sensors for variable-rate nitrogen application in corn. In INTERNATIONAL CONFERENCE ON PRECISION AGRICULTURE, 10., 2010. **Proceedings...** Denver: ISPA, 2010. 1 CD-ROM.

SUI, R.; THOMASSON, J.A. Ground-based sensing system for cotton nitrogen status determination. **Transactions of the ASABE**, St. Joseph, v. 49, p. 1983-1991, 2006.

SUI, R.; WILKERSON, J.B.; WILHELM, L.R.; TOMPKINS, F.D. A microcomputer-based morphometer for bush-type plants. **Computer and Electronics in Agriculture**, Amsterdam, v. 4, n. 1, p. 43-58, 1989.

6.0 OVERALL SUMMARY AND SUGGESTIONS FOR FUTURE WORKS

The main objective of this research work was to validate and develop real-time data collection systems of sugarcane parameters aiming N variable rate application strategies based on canopy sensors (Reflectance and Ultrasonic) considering the natural variability found on sugarcane commercial fields.

The first research was implemented to validate the previous calibration made for the Yara N-Sensor on the sugarcane crop (Portz et al., 2012), being the results identical to the previous acquired data, independent of crop year. The best correlations of sampled crop parameters and sensor predicted were found when the crop has stalk height between 0.3 m and 0.4 m of field average.

The second conducted research used the N-Sensor with de sugarcane acquired calibration to test real-time variable rate application of N using the negative and positive application rate approaches over strips located on soil and season distinct commercial fields. Results show that in three of the four tested situations, the positive approach was superior, indicating that the negative slope is better during the raining season over clayey soil, related to good crop growth conditions.

Manual measured sugarcane plant height acquired on the sample points from the reflectance sensor calibration, to correlated plant stalk height with biomass and N-uptake, was the main topic in the first phase of the third investigation. In a second phase an ultrasonic sensor system was assembled and mounted in a high clearance vehicle to scan sugarcane crop canopy fields. Biomass and N-uptake had high correlations with the plant stalk height, especially biomass. The ultrasonic system was able to scan the crop canopy and produce field maps very similar to those made by the canopy reflectance sensor for the same fields.

And the last investigation was dedicated to the comparison of the assembled ultrasonic sensor with commercial reflectance sensor by estimating the sugarcane crop parameters on sandy and clayey soil fields during the dry and wet growth seasons. Results show that the reflectance sensor was able to better predict biomass and N-uptake during the initial sugarcane growth stages (until 0.4 m of stalk height). In the other hand, the ultrasonic system could predict better the parameters after this stage because the reflectance sensor starts to suffer with saturation. So the sensor

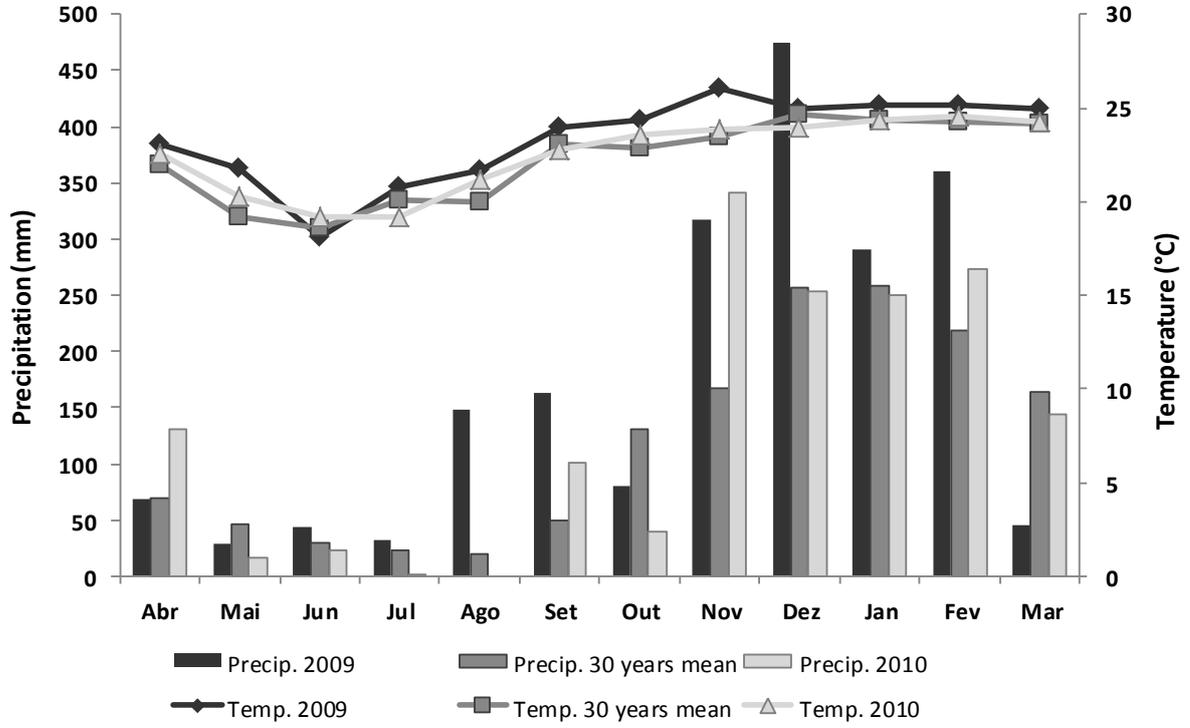
systems can be complementary when the intention is to apply the fertilization during an extended period of the initial sugarcane growing season.

For further development of the sugarcane canopy sensors approach, the “Big Data” concept have to be taken into account, as the stand alone information of canopy sensors in many cases is not in off to tell if the local low biomass sensed come from N deficiency, or are other local issues like other nutrients and/or physical problems affecting the crop and limiting yield. So, the use of additional layers of information (yield potential, soil type, soil electrical conductivity or an integrated information like management zones) can improve the system by preventing the sensor on over application of N fertilizer on areas were are known as low yield potential, making so a better use of the fertilizer by increasing NUE and helping the environment.

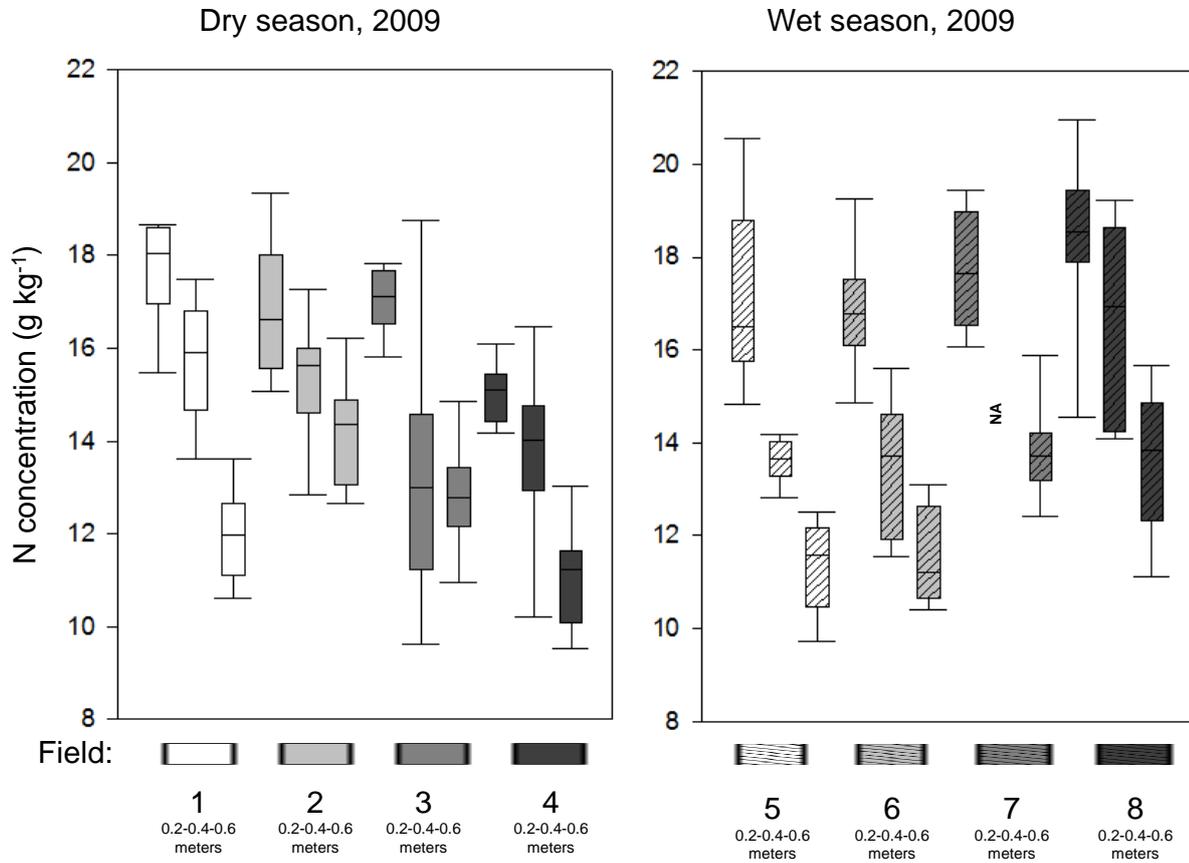
Another issue regarding the ultrasonic sensor that could be further researched is the fact that the system calculated its crop height by the difference from the distance of the sensor head to canopy surface from the actual sensor installation height in the machine. This approach was taken having in mind that canopy closes on late stages and hide soil level from the sensor signal, but in the other hand, on very young sugarcane (below 0.4 m of stalk height) where rows are still open, the height acquisition from the difference of the first and last wave signal return can be more accurate, and maybe the use of both approaches on an ultrasonic system could improve the accuracy of the technology through the entire sugarcane fertilization period.

APPENDICES

Appendix A - Precipitation and temperature for the years of 2009, 2010 and local average values from the last 30 years



Appendix B - N concentration on the plant samplings (0.2, 0.4 and 0.6 m of stalk height) on the eight studied fields during the two seasons of the first year



Appendix C - Number of stalks per hectare over the clayey and sandy soil fields sampled on the dry season of the year.

