Monitoring Wheat Protein Content On-Harvester: Australian Experiences

James Taylor[1], Brett Whelan[1], Lars Thylén[2], Mikael Gilbertsson[2] and James Hassall[3]

[1]*Australian Centre for Precision Agriculture*
McMillan Building A05, University of Sydney NSW 2006
j.taylor@agec.usyd.edu.au
[2] *Swedish Institute of Agricultural and Environmental Engineering (JTI)*
Box 7033, SE-750 07 Uppsala
[3] *"Kiewa", Gilgandra, NSW, Australia*

[This paper was first published in Precision Agriculture '05, Proceedings of the 5th European Conference on Precision Agriculture, ed. J.V. Stafford, Wageningen Academic Publishers. It is reproduced here with the permission of the editor. Please acknowledge the original source when referencing.]

Abstract

An on-harvester protein sensor has been tested for two seasons on a commercial combine harvester in Australia. Operators report that sensor and software were relatively easy to use especially since the model used is still a prototype set-up. Some problems with operation were noted and have been addressed for future commercial development. Output from the Zeltex NIT protein sensor was coherent and often strongly correlated to yield response, giving a good indication that the observed protein patterns are real. Absolute protein values however appeared suppressed and a new calibration curve for Australia has been developed for the Zeltex AccuHarvest® sensor.

Keywords: Real-time protein monitoring, Australia, nitrogen budget

Introduction

In Australia, protein content is an important consideration in grain sale price, particularly wheat varieties. A bonus/discount payment is made on a 0.1% sliding scale beyond the base rate for each grade. Knowledge of the variability in protein content prior to marketing could be used in many tactical ways to optimise farm gate returns. However, while the opportunity to raise profits does exist, the actual return to the grower is dependent on market forces (Long *et al.* 2002) and the cost/effort required for differential harvest, which may deter contract harvesters from the practice. Information on nitrogen use and removal, in conjunction with yield data, would also be useful in the strategic management of nitrogen fertiliser and the development of more accurate site-specific gross margin analysis. This may be of greater benefit to growers in the short term due to tangible savings in fertiliser cost, which may be upwards of 30% of production costs.

The potential benefits of protein maps, particularly for nitrogen management, have prompted a great deal of interest in the development of both on-the-go and remote-sensing based protein measurement in Australia, as well as North America (Long *et al.* 1998. For the 2001, 2003 and 2004 winter cropping seasons, the Australian Centre for

Precision Agriculture (ACPA), in conjunction with growers in Conservation Farmers Incorporated (CFI), has been collaborating with Zeltex and the Swedish Institute of Agricultural and Environmental Engineering (JTI) to test a prototype Near-Infrared Transmission (NIT) on-harvester grain protein and moisture sensor. This paper reports on some of our experiences with the sensor and the development of a calibration for Australian conditions.

Sensor Mounting and Operation

In Australia, grain tends to be harvested at a lower moisture content (generally <13%) to avoid post-harvest drying. Climatic conditions at harvest are generally dry and dusty with temperatures often above 40ºC. In 2001, dust and light contamination created problems with sensor operation. As a result very little useful data was recorded. The sampling system was subsequently redesigned to minimise dust and light contamination.

The sampling system has been designed to mount on the side of the clean grain elevator housing. Grain is sampled from the up elevator shaft and deposited into the down elevator shaft. The inlet and outlet are controlled by two trapdoors driven by windscreen wiper motors. The trapdoors close tightly to seal the chamber and avoid contamination in the sensor. Figure 1 illustrates the mounting and sampling mechanism. The trapdoors are activated by LED fill sensors at the top and bottom of the NIT sensor measurement chamber. When the top fill sensor is triggered the top door closes and the NIT sensing protocol is initiated. Once the NIT sensing is complete the bottom trapdoor opens to purge the NIT sensor of grain. The bottom trapdoor closes once the lower fill sensor is activated and the top trapdoor opens completing the cycle. If the cycle gets stuck at a particular stage for >30s, the sensor has an override function to open the bottom trapdoor and restart the cycle. In initial testing this option was not available and the sensor had to be manually restarted if it stopped functioning. The sensor takes a reading at approximately 12s intervals, which equates to 65-70 points/hectare at normal harvesting speeds. The actual NIT sensor is a 14-band Near Infrared Transmission whole grain analyser (Zeltex AccuHarvest®) operating 14 wavelengths between 893 and 1045nm.

The data from the sensor is currently being logged onto a laptop computer installed in the cabin of the harvester. The software is written in LabView. The software is easy to use and provides a graphical and numerical indication of how grain protein and moisture is varying over a 3-4 minute window. The growers had no problem interacting with the software and the only drawback was the current use of a laptop to log the data. The cabin environment in combine harvesters is not particular suited to laptops and a more robust, simpler data logger will be required for any commercial release.

At the time of writing the second full harvest of protein data has been collected with the Zeltex sensor. The same system has now been used for 2 Australian and 2 European harvests. For the 2004 harvest in Australia, the sensor was run at two locations over a period of 6 weeks. The sampling system that was used is an early prototype that has not been updated. As a result some hardware fatigue issues were identified from overuse that will be addressed in future models. In general, however, the system worked well and for the second year running a large amount of data has been collected. Both growers that operated the sensor had no problems apart from the hardware fatigue. Without having analysed, visualised and discussed the data from 2004, the information displayed in real-time on the software interface generally concurred with the growers' knowledge of the field.

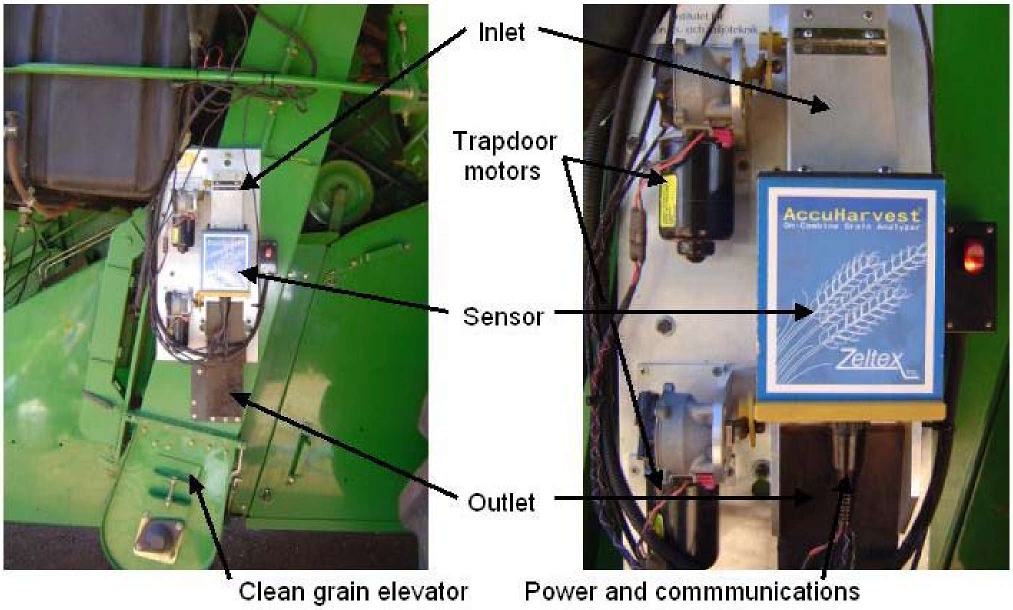

Figure 1: The sensor and sampling system mounted on the clean grain elevator (left) and a close-up of the sensor and sampling system (right)

Sensor Calibration

The Zeltex NIT sensor is currently calibrated using data from the Northern Hemisphere (North America and Europe). One of the aims of this study was to determine if the calibration is applicable to Australian conditions. The null hypothesis was that the calibration is the same for both Australian and Northern Hemisphere wheat production. This hypothesis was initially tested in the field and later in the laboratory.

Field Testing

For the field situation, two transects in a wheat field near Gilgandra, NSW, were used. As the combine harvester harvested the two transects, the Zeltex sensor was used to measure grain protein on-harvester. At the same time 15 samples were manually collected from the bubble-up auger near the top of the clean grain elevator. These samples were taken at approximately the same recording interval (12s) as the on-harvester protein sensor. The manually sampled grain was analysed using desktop NIT spectrophotometers at the Gilgandra silo and the Australian Bread Research Institute (BRI) using the FOSS Infratec 1229 (Global calibration No. WH000003). The mean protein values of the two transects from the different measurements are given in Table 1.

The comparison of the desktop results with the on-harvester sensor indicated that the on-harvester sensor was underestimating both grain protein and grain moisture content. The mean protein difference between the desktop sensors (at the Gilgandra Silo and BRI) and the Zeltex was 0.94%. The mean moisture difference was 0.62%. There may be some error in this approach as it was not possible to manually collect the same grain that was sampled by the Zeltex sensor. It is hypothesized that this underestimation is a bias from the use of the Northern Hemisphere calibration curve. To test this a laboratory experiment was conducted.

Table 1: Comparison of protein results from samples taken along two transects and analysed with three different NIT sensors. (NB. The Gilgandra silo and BRI sensors analysed the same grain samples. *The adjusted Zeltex response is discussed in the following section)

Sensor	**Transect**	**Protein % (σ)**	**Moisture % (σ)**
Silo	1	14.64 (0.58)	10.32 (0.13)
	2	14.50 (0.96)	9.58 (0.12)
BRI	1	14.70 (1.13)	10.30 (0.15)
	2	14.46 (0.62)	9.63 (0.16)
Zeltex	1	13.70 (1.11)	9.33 (0.26)
	2	13.57 (1.19)	9.35 (0.13)
Zeltex (adj)*	1	14.54(1.07)	10.39 (0.35)
	2	14.88 (0.72)	

<u>Laboratory Experiment</u>

The results from the field trial indicated that a new calibration would be required for Australian conditions. This was not unexpected given the different climate conditions, wheat varieties and moisture content at harvest in Australia. The new Australian calibration for the Zeltex sensor was derived using 99 Australian grain samples sourced from different regions of the Australian grain belt, including North-West NSW, the Riverine district on the NSW/Victoria border and the Yorke Penisula in South Australia.

The grain samples were analysed using the FOSS Infratec 1229 protein content under standard conditions (25ºC) at the Australian Bread Research Institute (BRI) at North Ryde, NSW. The FOSS Infratec 1229 analyses the grain at 2nm intervals between 850 and 1048nm. The spectra were extracted and a protein and moisture value determined using the standard calibration (WH000003) for Australian wheat developed for the FOSS Infratec 1229

The same samples were then run through the Zeltex sensor, mounted in a laboratory at the University of Sydney, at two temperatures, 25°C and 40°C. The two temperatures were selected as temperature has a known effect on NIT and it was desirable for the calibration to encompass the probable temperature ranges at harvest. The raw output from the sensor (14 wavelengths) was extracted. From this analysis 5 readings gave strange values and were discarded. This left 193 readings (from the 99 samples at two temperatures). A Multiple Linear Regression (MLR) was performed to predict the BRI protein % using the wavelength response from the Zeltex sensor. Similarly the moisture

% was also predicted. Alternative regression models, Multiple Stepwise Linear Regression (MSLR) and Partial Least Squares Regression (PLS) were also tried with no additional benefit.

Results and Discussion

The protein and moisture calibration resulting from the MLR is shown in Figure 2. The r^2 and standard error of prediction (SEP) are given on the graphs. The SEP value for protein is similar to those derived using the Northern Hemisphere data set (Thylén and Algerbo, 2001), however the moisture SEP is higher. This may be due to the lower moisture contents at harvest or the different grain varieties. The protein shows a strong 1:1 linear response over a large range of protein values (9-17%).

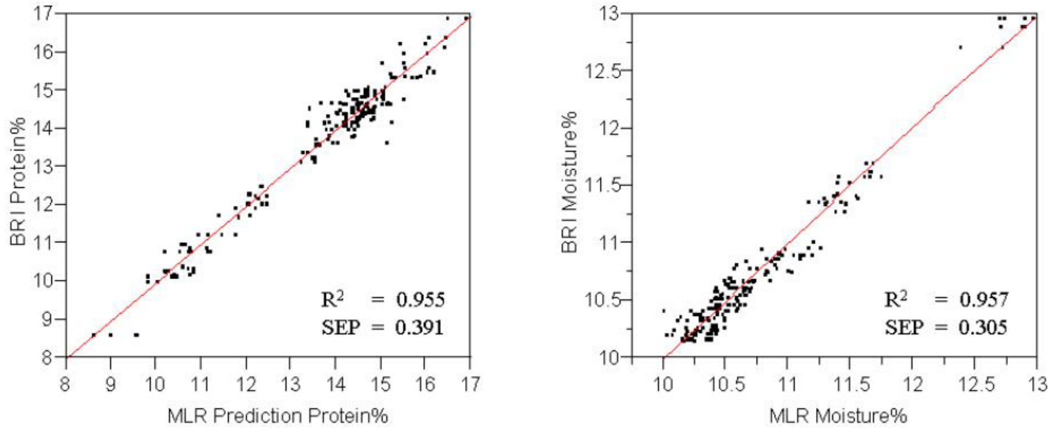

Figure 2: Plots of measured vs predicted protein (left) and moisture (right) using derived calibration equations.

For the general calibration curve the transect data from the within field transects was used. The transect data was excluded from the dataset and a new calibration curve derived (n=134). The new calibration curve was then applied to the transect data to predict protein and moisture for the transect data above. The mean results are shown in Table 1 (Zeltex adj.). After transformation the absolute mean difference in percent protein measurement between the standard laboratory measurements and the Zeltex instrument decreased from 0.94% to 0.14%. For moisture the absolute mean difference was slightly increased from 0.29% to 0.41%. The Australian calibration curve appears to be giving a better protein prediction than the Northern Hemisphere calibration for the data from these two transects.

For the 2004 harvest, field samples were again taken to help validate the accuracy of the protein sensor. These data were not analyzed at the time of this writing and cannot be presented here.

Nitrogen Budgeting.

One of the principal benefits of a protein monitor identified by Australian growers is the ability to better identify nitrogen use within fields and variably replenish nitrogen. The amount of nitrogen removed from a system is a function of the amount of grain (yield) and the amount of nitrogen in the grain. For Australian conditions the relationship between protein, yield and nitrogen removed in wheat has been quantified by Kelly *et. al*. (2003) as;

$$\text{N removal (Mg/ha)} = \text{Grain Yield (Mg/ha)} \bullet \text{Grain Protein (\%)} \bullet 1.75 \qquad (1)$$

The relationship in North America has also been quantified (see Long *et al.* 1998) but is not used here due to different varieties and growing conditions. Since both yield and protein data have been collected on-the-go the data can be interpolated (block kriged using local variograms) onto a common grid and the nitrogen removed from the cropping system calculated using Equation 1.

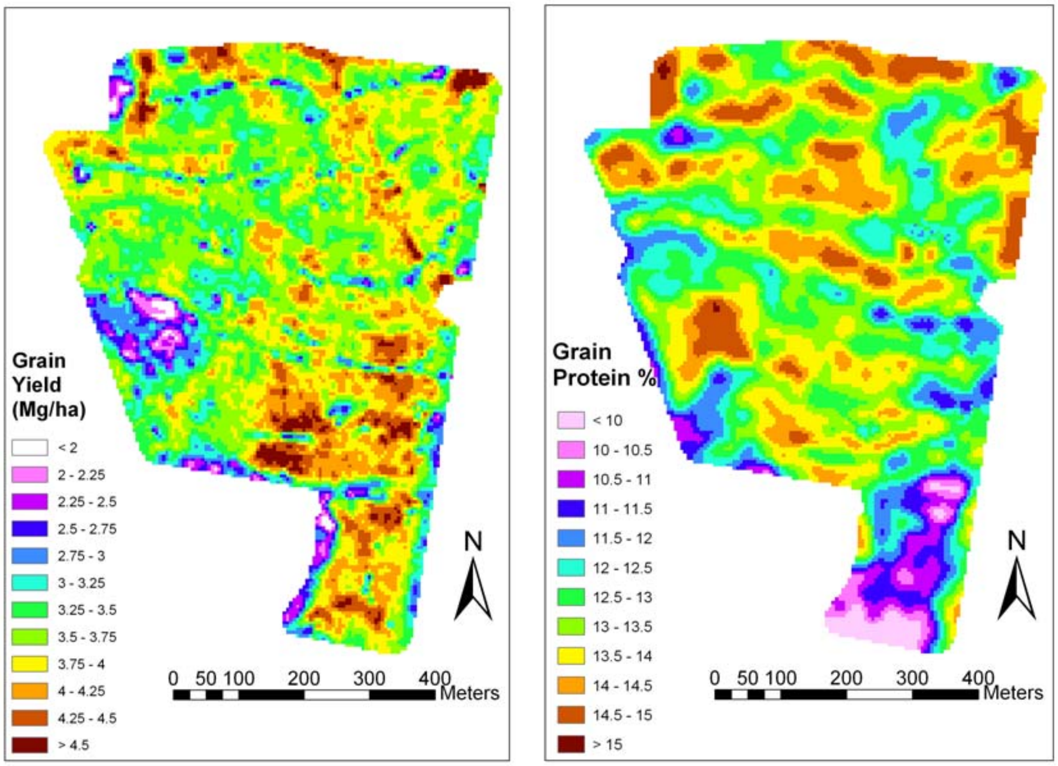

Figure 3: Interpolated maps of Grain Yield (Mg/ha) (left) and Grain Protein (%) right.

The interpolated grain yield and protein maps are shown in Figure 3. Both maps show similar spatial patterns with a negative response between grain and protein (highlighted by the boxed areas). This negative relationship is not unusual in Australia and generally reflects either insufficient nitrogen or soil moisture to achieve yield potential. The nitrogen removed map is shown in Figure 4.

As well as calculating the amount of nitrogen removed a site-specific nitrogen budget can be determined using Equation 2.

$$\text{N budget} = \text{N present} + \text{N input} - \text{N removed} \qquad (2)$$

This is similar to the approach of Long *et al.* (1998) except that the inherent soil nitrogen pre-sowing is considered. In Australia this is important as the variable rainfall means that crop failure is quite possible and in drought situations there may be a large amount of residual nitrogen stored in the soil. For Field 3, the pre-sowing soil nitrogen levels were only available as a field average of 60kgN/ha. A pre-sowing application of 80kg/ha Monoammonium phosphate (MAP) (12%N) was applied. The majority of the field, except for the panhandle in the southeast corner, was also top-dressed with 50kg/ha urea (46% N). This means that the majority of the field received 32.6kg N/ha (assuming an even distribution) and the panhandle received 9.6kg N/ha. The panhandle was not top dressed due to the spreader running out of fertiliser. The crop response to this missed application is clearly evident with grain protein suppressed in the panhandle although grain yield was not (Figure 3).

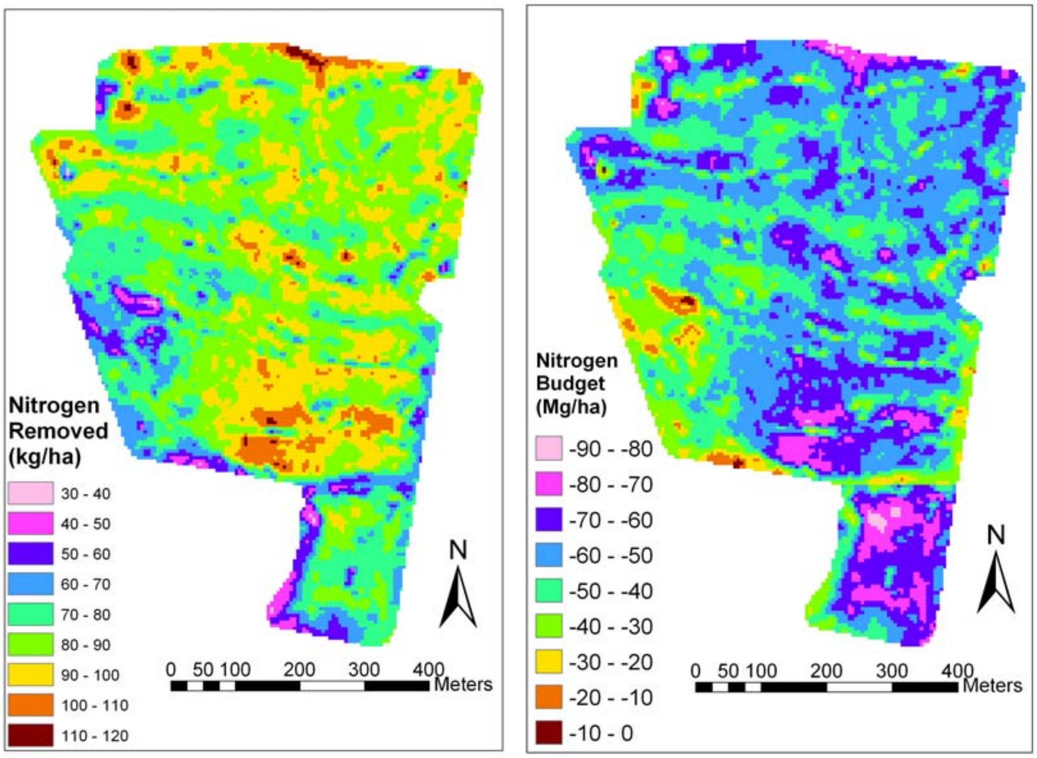

Figure 4: Map of Nitrogen removed (left) and the Nitrogen Budget (right) for Field 3 derived from the interpolated yield and protein maps (Figure 5)

Figure 4 shows a continuous nitrogen budget map for Field 3. In reality, field management, including fertiliser, is being managed at a zone level. To facilitate adoption the ACPA intends to develop a protocol to incorporate this information into management class response functions as proposed by Whelan *et al.* (2005). The nitrogen budget is currently limited by the use of a mean response for initial soil N. Without real-time soil N-sensors, it is an expensive soil sampling exercise to obtain an accurate map of soil available N prior to sowing. Management zones represent an approach that allows the grower to determine the mean zone 'N present' in a cost and time effective manner at a similar resolution to which management is being applied (Whelan et al. 2002).

While Equation 2 allows for the calculation of a nitrogen budget, the actual level of nitrogen applied will be dependent on the availability of soil moisture. Determining rainfall and soil moisture availability is difficult, however, in Southern Australia where top dressing (within season fertilising) is common, earlier season rainfall can be a strong indicator of total seasonal rainfall (Peter Stone, CSIRO Land and Water, *pers. comm.*)

Conclusions

The output from the protein sensor shows strong spatial patterns that are consistent with what the grower expects, observed yield variations and management decisions. Growers are enthused about the quality of data being generated by the sensor while combine operators are happy with the ease of performance of the sensor and data collection software on-harvester. There seems little reason from an engineering perspective not to commercially release a limited number of units for the next harvest.

Preliminary investigations into deriving an Australian based protein and moisture calibration curve appear to give better results, in Australian conditions, than the current global calibration curves. However further validation is needed over a wider distribution of grain samples. Accurate site-specific determination of protein content will provide growers with confidence in calculating site-specific or zonal nitrogen budgets as well as trying to determine the reasons for spatial patterns in their crop production.

Acknowledgements

The authors would like to acknowledge the assistance and in-kind support given to this project by Todd Rosenthal and the staff at Zeltex Inc. Maryland, USA.

References

Kelly, R., Strong, W., Jensen, T., Butler, D., Town, B. and Adams, M. 2003 Recurrence of yield and protein variation in the northern grains region. Proceedings of the 11th Australian Agronomy Conference, Australian Society of Agronomy, Geelong, February, 2003 (http://www.regional.org.au/au/asa/2003/c/15/kelly.htm)

Long, D.S., Carlson, G.R. & Engel, R.E. 1998 Grain protein mapping for precision manangement of dryland wheat. In P.C. Robert, R.H. Rust & W.E. Larson (eds) Precision Agriculture, Proceedings of the 4th International Conference on Precision Agriculture ASA/CSSA/SSSA, Madison, WI, USA pp787-796

Long, D.S., Carlson, G.R. & Engel, R.E. 2002 Gross value of spring wheat under precision nitrogen management as influenced by grain protein. In P.C. Robert, R.H. Rust & W.E. Larson (eds) Precision Agriculture, Proceedings of the 6th International Conference on Precision Agriculture, ASA/CSSA/SSSA, Madison, WI, USA, CD-ROM

Thylén, L. and Algerbo, P.A. 2001 Development of a protein sensor for combine harvesters. In G. Grenier & S. Blackmore (eds) ECPA 2001, Proceedings of the 3rd European Conference on Precision Agriculture, Montpellier, June, 2001, pp869-873

Whelan, B.M., Cupitt, J. & McBratney, A.B. 2002. Practical definition and interpretation of potential management zones in Australian dryland cropping. In P.C. Robert, R.H. Rust & W.E. Larson (eds) Precision Agriculture, Proceedings of the 6th International Conference on Precision Agriculture, ASA/CSSA/SSSA, Madison, Wisconsin, pp325-329

Whelan, B.M. and Taylor, J.A. 2005. Local response to inputs: advancing SSCM in Australia. In Proceedings of the 5th European Conference on Precision Agriculture. Ed J.V. Stafford, Wageningen Academic Publishers, The Netetherlands