Dry matter assessment in maize grains by NIR diode array spectrometer on combine harvesters

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Introduction

Modern near infrared (NIR) diode array (DA) spectrometers are highly suitable for screening plant breeders' germplasm by means of real time measurements on experimental harvesters in the field. By way of automated sampling and whole grain/seed analysis in the field—rather than in the lab—the duration and costs of a comprehensive quality assessment scheme may be reduced dramatically. Characteristically, already the first reported use of NIR measurements being conducted directly on a specialised harvester for field trials[1] took place in a plant breeding application. Along these lines we have developed a concept termed "NIRS Harvest Line" which is being realised step by step in field trial harvesters together with J. Haldrup a/s from Denmark, a producer of such specialised machinery. In addition to presenting the setting up and calibration of NIRS Harvest Line forage harvesters in another paper of these Proceedings,[2] we here provide information on the state of the art reached with an NIR DA installation on a combine plot harvester and its use for dry matter assessment of maize grains during harvesting breeding trials.

Materials and methods

Grain maize field trials and samples

In 2001, the trials FAL-Field (*n* = 137 plots) and KWS-Field (*n* = 47 plots) were available for our NIRS Harvest Line experiments. Additionally, 1600 maize grain samples (KWS-Lab) were measured on a stand-alone NIR module in the lab. In 2002, 18 KWS trials (*n* = 7565 plots) were measured on two separate harvesters.

NIRS Harvest Line

The original combine plot harvester by J. Haldrup A/S is designed for testing yield of grain crops such as cereals, oilseeds, grain legumes and grain maize in small field plots. In the special NIRS Harvest Line version a module for automatic sample presentation and actual measurement of grain NIR reflectance takes in the total mass of grains upon leaving the shaker. It is then transported pneumatically into a feeder from which the sample is gradually released and passed on a conveyor belt underneath an integrated InGaAs DA spectrometer Corona (Carl Zeiss). White referencing and dark current measurement is carried out automatically by tilting of the spectrometer in the direction of a dark chamber and a ceramic reflectance standard. Data collection is initiated by the driver of the harvester via touch-screen PC by means of the software Harvest Manager (Haldrup) which interacts with the NIR data collection software Cora (Carl Zeiss). Spectral artefacts (background spectra) were eliminated from the NIR data files with filters developed using the Cora add-on software Mask Factory (Carl Zeiss). Calibration was performed at the computing office using Winisi II software (Infrasoft International). Regression analysis between NIR spectral data and conventional dry matter data was carried out using the modified partial least square (MPLS) analysis. Also, an outlier elimination routine served for the elimination of samples with atypically high residuals between actual and predicted DM values and/or atypical spectra identified by extreme global H values. Statistical performance of the calibration in cross validation was characterised by the standard error of cross validation (*SECV*) and the proportion of explained variation in cross validation (1-*VR*).

Set-up of calibration/ validation experiment

In 2001, subsets of the data obtained from FAL-Field and KWS-Field were merged with a subset of the 1600 data resulting from KWS-Lab obtained on the stand-alone module. From this data set of the 2001 harvest an initial calibration for DM% was developed. The remaining samples from 2001 served for an initial validation. When the data of the field based NIR measurements in 2002 became available, the initial calibration from 2001 was extended by a subset of data from 4 KWS subtrials of the 2002 harvest to form the final calibration set (total $n = 565$). Final validation was performed on 5048 samples of 14 KWS trials of the 2002 harvest which were not represented in the final calibration set.

On line sample temperature measurement

Grain temperature was monitored by means of a non-contact infrared temperature sensor (CI by Raytek Corporation) during passage of each sample on the conveyor belt inside the NIR module.

Dry matter assessment

Dry matter content (DM%) was determined conventionally by assessing weight loss of intact maize seeds after drying at 105°C for 36 h in labs located near the respective field experiments.

Laboratory NIR

In addition to an NIR module for the harvester-based collection of diffuse reflectance spectra of whole grains passing on a conveyor belt underneath the DA spectrometer, an analogous stand alone module for the lab was constructed. It permitted NIR measurement of grains on a large sample cup spinning at slow motion underneath the DA spectrometer Corona 45 NIR at the same distance as in the conveyor belt module. It was also controlled by Cora software (Carl Zeiss Jena GmbH).

Results and discussion

The NIRS Harvest Line concept in trials with grain crops

The basic considerations in rationalising the assessment of quality in trials with grain crops are the same as those for forage crops. Here also, it is of paramount importance to save costs and yet maintain high experimental precision in both yield and quality assessments. Consequently, our NIRS Harvest Line concept when implemented on a combine harvester also follows the same basic rules, i.e.:

- Shorten the process (minimize the delay between harvesting and analysis)
- Avoid manual sampling (minimize sampling errors through automatic sampling)
- Minimise physical sample preparation (whole grain analysis; avoid drying and grinding)
- Maximise spectrometric sampling (fast continuous scanning of large sample surfaces)
- Use short wavelength NIR (maximise effective path length at low absorptivity)

Continuous sample presentation and spectral filtering

The sample presentation system as part of the NIR module of our harvester was designed to ensure the continuous collection of information of grain characteristics. And indeed, practical experience over both harvest years demonstrated that the unloading of the freshly threshed maize grains onto the conveyor belt and their presentation to the measuring head of the NIR DA spectrometer proceeded without complications. Unlike chopped forage with its poor flow characteristics maize grains flow well and evenly. A time sequence analysis of the spectral information collected in one typical, single maize plot demonstrated that once the maize grains started to pass through the sample presentation position of the NIR module, steady data were collected till the flow of sample material had come to an end (Figure 1).

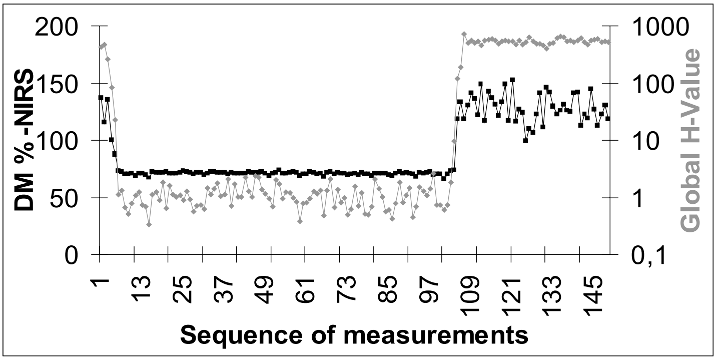

Figure 1. Time sequence of NIR predicted DM% and global H - value of one single field plot derived from the unfiltered spectra of maize grains shown in Figure 2.

The time sequence analysis was based on NIR predicted DM% and distance measures (global *H* statistic) derived from a typical, representative multi-file containing the raw spectra collected within one plot. Spectra collected before and after actual grain passage showed a generally elevated level of apparent absorption indicative of “background” characteristics (Figure 2) and were discarded from the multi-file by means of a suitable filter generated by using the Mask Factory software. This made up for the original lack of synchrony between grain passage and data collection and ensured a considerably higher spectrometric sampling intensity than is conventionally achieved.

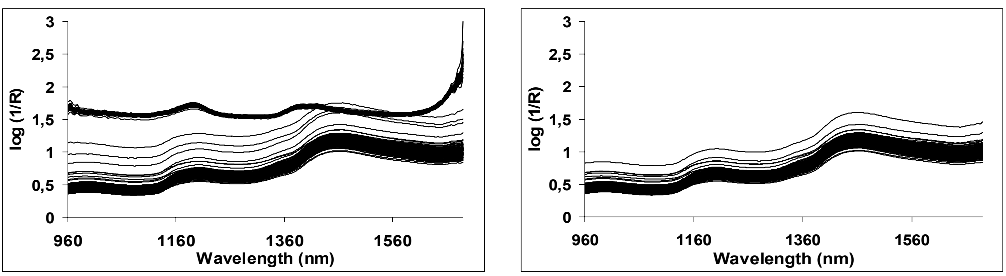

Figure 2. Unfiltered multi-file containing raw spectra collected within one single maize grain plot (left); filtered multi-file containing only typical maize grain spectra of the same plot (right).

Calibration and field performance in 2001/2002

The field experiments started in 2001 on a small scale, providing NIR data of less than 200 plots collected during grain harvesting at two different stations (KWS and FAL). So comparable data on maize grains obtained under lab conditions (KWS-Lab) were considered as an appropriate extension of the field data. Samples from the three sources were selected and joined for initial calibration. The remaining samples were treated separately in a first validation exercise. Validation of the initial equation for DM% in sample sets grouped according to source resulted in *SEP*s of 1.6, 1.1 and 0.6 DM% for FAL-Field, KWS-Field and KWS-Lab. As the same NIR equation had been used in all three validation sets, the observed differences mainly appeared to be a result of the particular precision of the underlying reference data.

For the prediction of the field based NIR measurements of the second harvest year the initial calibration of the previous year was extended by adding selected samples from specific subtrials of the 2002 harvest. So finally, a calibration set of 565 samples each was formed, the respective equation calculated und used in validation. Prediction of DM% in the unfiltered NIR spectra lead to a highly sloped relationship between predicted and actual DM% and a totally unsatisfactory error of prediction (Figure 3). While in the unfiltered data only about one quarter of the variation in DM% was explained by the NIR predictions, filtering of the spectra lead a much improved situation in which about three quarters of the variation were explained.

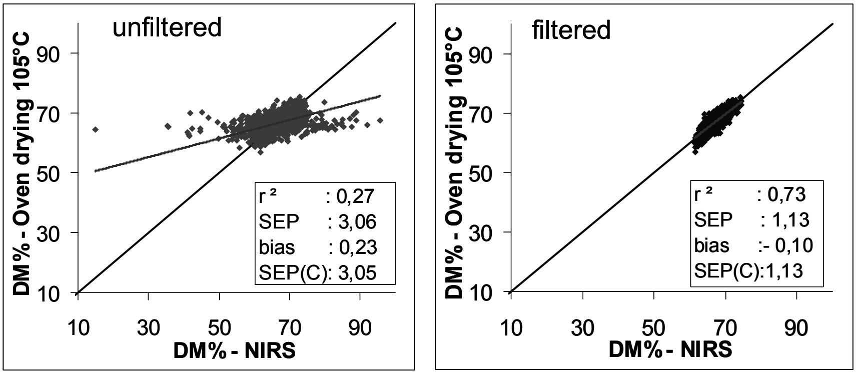

Figure 3. Validation of DM% prediction in maize grain based on unfiltered (left) and filtered (right) NIR-spectral data of 5048 breeder's plots in 14 North-West European trials.

Two facts seem worthy of consideration. In terms of NIR measurements, two NIR modules installed on two different combine harvesters had provided the spectral data and no effort had been undertaken to standardize the spectrometers. In terms of reference method, several of the 14 field trials which were the source of the data were located at different sites in North-West Europe. At each site slight differences in oven drying practice may be assumed to have negatively influenced the overall precision of the reference data. When considering these aspects, the standard error of prediction (*SEP*) of 1.13% achieved here seemed very satisfactory. Further results supported this view. Generally, the average correlation between field replicates of the same cultivar increased from 0.78 for DM% by oven drying to 0.92 for DM% by NIRS Harvest Line. This was associated with a coefficient of variation of 1.5% and 0.6% for DM% by reference and NIR, respectively. These and other statistical parameters demonstrated that the performance of experimental hybrids and cultivars in the trials could be assessed more precisely by NIR-based data than by the actual reference method. Yet, further efforts in the harmonisation of NIR instruments and reference methods might even lead to further improvements in the true and apparent error of DM% assessment by the NIRS Harvest Line method.

Effect of sample temperature

The ambient temperature during the maize grain harvest in North-West Europe fluctuates quite widely. This affects the temperature of the maize grains at the point of NIR measurement on the plot harvester. Our temperature measurements during three sequential harvest days in October 2002 confirm that during harvesting the grain temperature followed that of the ambient air and ranged from 5°C to 17°C.

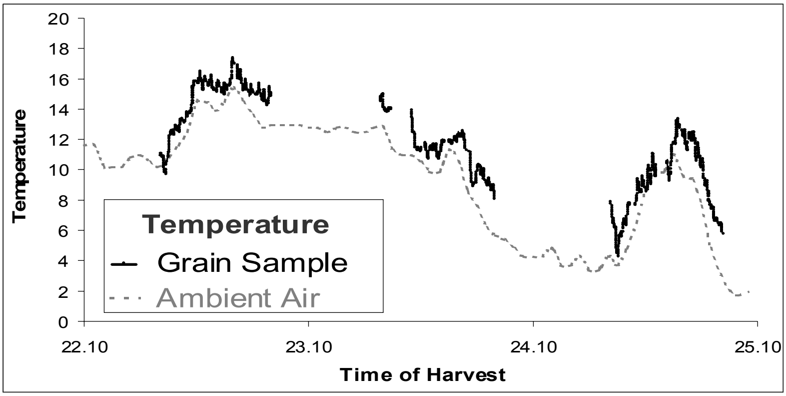

Figure 4. Ambient temperature and temperature of maize grain samples (moving average) on the combine harvesterat the point of NIR measurement during three sequential days of harvesting

The NIR-spectra collected during the whole course of maize grain harvest exhibited considerable OH-band shifts as induced by changes in temperature. A calibration/validation experiment formed from selected samples collected at defined temperatures showed that a calibration based on samples of a constant sample temperature class would result in NIRS equations which were bound to produce biased DM% predictions. For every 1°C deviation from the temperature of the calibration set a calculated systematic error between 0.1 and 0.15 DM% was found. Such an effect is easily avoidable by representation of all possible sample temperatures in the calibration set and will help to ensure NIRS Harvest Line calibrations which are robust towards variations in sample temperature.

Conclusions

Due to the uncomplicated flow characteristics of maize grains in comparison to forage more rapid progress has been achieved in setting up a pilot system for the *on line* quality assessment of grains as compared to forages in plot trials.[2] Within 18 months after the first test runs, a procedure was established which—during the short time of maize grain harvest in 2002—behaved mechanically robust enough to permit a throughput of about 4000 field plots on each of two commercial plot harvester equipped with a conveyor belt sample presentation underneath an InGaAs diode array spectrometer. In terms of the quality of the data produced it yielded more reliable data than the conventional oven drying method for assessing DM% and *vice versa* grain moisture. As is the case with *on line* forage analysis, the lack of synchronisation of presenting the actual grain sample and collecting spectra from it needs to be compensated by filtering of spectral data. And similarly, the calibration samples must implicitly include sample temperature as an important safeguard against possible temperature induced systematic errors in predicting grain DM%.

The ease of merging stationary lab scale NIR data with field based NIR data in this study raises the question whether DA spectrometers in future may be implemented for the dual purpose of field as well as lab applications, depending on availability. A logical consequence of such a dual purpose use would be the need to set up the respective calibrations from field and lab NIR data

Whatever the particular direction of the future development, certainly the demand among public and private institutions for intensifying the development of NIRS Harvest Line applications is strong. So the idea to form a collaborative network to support managers of field trials when starting to use this technology seems attractive. If this can be put into action, a large scale expansion of the NIRS Harvest line concept in field trial work to other crops, constituents and combine harvesters may follow. It remains to be seen whether from such a starting point NIR sensors will find their way into combine harvesters for the farming community.[3]

Acknowledgements

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References

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2. C. Paul and C. Pfitzner, in *Near Infrared Spectroscopy: Proceedings of 11th International Conference,* Ed by A.M.C. Davies and Ana Garrido-Varo. NIR Publications, Chichester, UK (2003)
3. Ongoing results of public R & D work along these lines were presented by Lars Thylen (Swedish Inst. Agric. & Environ. Engineering Uppsala / Sweden) and Jens Rademacher (University of Kiel / Germany) on April 1 2003 at an Occasional Symposium at the Federal Agricultural Research Centre at Braunschweig / Germany