

Quality assessment of wheat and forage using diode array NIR instrument on the harvester

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Introduction

Near infrared reflectance spectroscopy is a well known technique as far as the analysis of cereals and forages are concerned^{1,2}. The recent development of diode array instruments allow on site measurements and opens the field of embedded NIR (directly mounted on a harvesting machine).

The first aim of this study is to evaluate the performances of embedded NIR for the quality assessment of wheat on the combine harvester as the grain flows. A second aim is to evaluate the forage quality on the harvesting machine. Some work was already presented earlier or by other authors. They are mainly dealing with "on the harvester analysis" of cereals^{3,4,5}, silage maize^{6,7} or forages⁸. NIR is investigated in a context of precision agriculture to have a real time measurement of the crop quality and to link these figures to the position of the harvester (Global positioning System) in order to built maps of the field. These maps, like the protein one, could then be used to adapt the nitrogen fertilisation scheme. For breeding companies having thousands of experimental plots each year on several location, the embedded NIR can drastically reduced time-consuming treatments and analyses as well as investments (oven, ...).

Materials and methods

NIR measurements and data treatment

All the NIR measurements were performed with an InGaAs diode array spectrometer (Zeiss-Corona 45, 950-1700,2 nm). The spectra were acquired using the Cora v1.84 software (Zeiss-Germany). Calibrations were derived from the Grams V6.00 software (Galactic-USA) and the WinIsi software v1.5 (Foss-Infrasoft international-USA).

Grain measurement devices

Before measuring on the combine harvester itself, two laboratory devices were designed in order to exploit small amount (static device) or bigger amount (dynamic device) of wheat samples with known reference values (figure 1). These devices were very useful to initiate the spectral database and to include a broad spectral variability (year effect, temperature effect, suitable ranges in concentrations, ...). The laboratory dynamic device was then adapted to a Deutz-Fahr Topliner combine harvester. Getting a suitable flow of grains into the by-pass mounted on the combine

appeared to be the most difficult part of the work. The design was heavily modified several times to get a similar flow as the one obtained on the laboratory dynamic device.



Figure 1. Experimental devices for the laboratory measurements (static and dynamic).

Forage measurement device

An experimental forage harvester (Haldrup, Denmark), was equipped at the rear with a transverse conveyor belt. The chopped forage is flattened on the conveyor belt straight under the spectrometer (figure 2).



Figure 2. Conveyor belt mounted at the rear of a forage harvester under the diode array spectrometer.

Results and discussion

Wheat measurements

A first wheat database was developed on the basis of the spectra acquired with the laboratory static and dynamic devices. The principal component analysis showed a clear difference between the spectra acquired in the lab on the spectra acquired on the combine harvester. It was even possible to distinguish between the spectra obtained with the static and the dynamic devices as well as those obtained on the harvester.

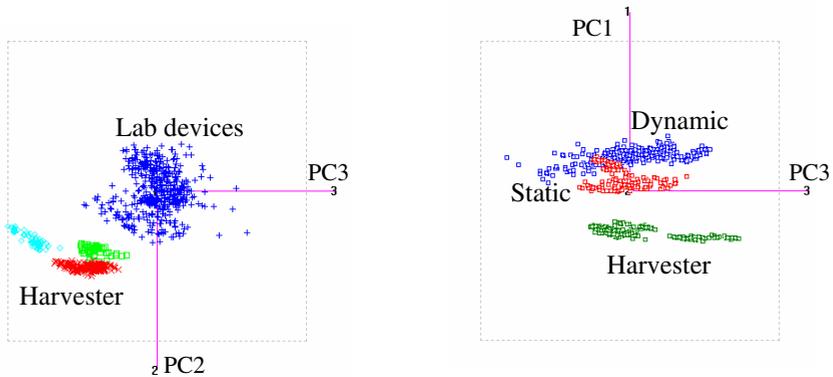


Figure 3. Principal component projections of the spectra acquired with the laboratory devices (static or dynamic) and from the harvester.

Finally, the spectra obtained from two out of the three investigated fields and measured on the harvester were added to the initial database and the spectra from the third field were used as a validation set. The data base is made off 375 samples measured with the dynamic device (year 2000 and 2001), 95 with the laboratory static device (year 2001) and 95 obtained on the harvester (year 2002). All the samples were measured on a Foss-Tecator 1241 spectrometer equipped with the specific gravity device; protein and moisture contents were derived from ANN calibrations. Table 1 shows a summary of the values used to calibrate the embedded spectrometer. The data includes a broad variation for each constituents and came from different years, different varieties and origins. Table 2 shows the data of the validation set that is only covering the variability of one field harvested in 2002.

Table 1. Wheat : summary of the values used to calibrate the embedded NIR

(n=565)		Units	Mean	SD	Min	Max
Moisture	MOI	%	14.6	1.77	10.3	22.1
Protein	MPT	% DM	12.3	1.12	9.0	16.5
Specific gravity	SG	kg/hl	76.2	3.72	65.3	85.4

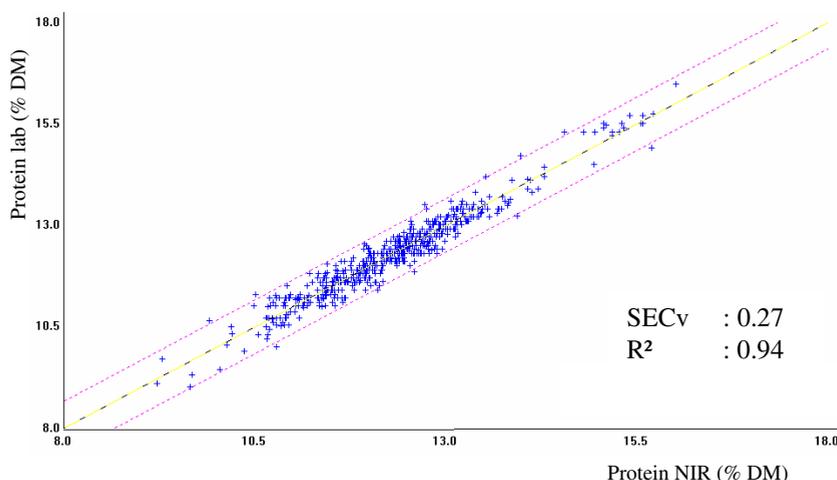
Table 2. Wheat : characteristics of the validation set (18 samples, twelve replicates).

Parameter (n=18 * 12 repl)		Units	Mean	SD	Min	Max
Moisture	MOI	%	14.7	0.32	14.2	15.3
Protein	MPT	% DM	12.0	0.68	10.8	12.7
Specific gravity	SG	kg/hl	78.8	1.07	75.8	80.6

The predicted values obtained with an Artificial Neural Network calibration (Foss-Tecator 1241 instrument) were used to calibrate the embedded Zeiss diode array spectrometer. The variability of the validation set made of samples from one field is rather restricted (table 2). The performances of the best calibration models are given in table 3. As an example, the protein calibration is illustrated in figure 4).

Table 3. Wheat : calibrations models developed for the embedded NIR.

	Units	SEC	R ² c	SECv	R ² cv
MOI	%	0.16	0.99	0.19	0.99
MPT	% DM	0.25	0.94	0.27	0.94
SG	Kg/hl	1.22	0.89	1.33	0.87

**Figure 4. Wheat : calibration developed for the determination of protein with the embedded NIR.**

The variation of the field used as independent validation set is so restricted that the standard error of validation observed for protein (SEV = 0.32) is about half the variation observed in that particular field (SD = 0.68). Lots of spectra were measured on that given field and predicted with

the equations. The pair and odd measurements were separated so that each predicted value could be compared to the next measurement. The SED observed between two consecutive protein measurements was 0.21 % DM.

Fresh forage

The fresh forage spectral data were collected using the described experimental design (Figure 5).

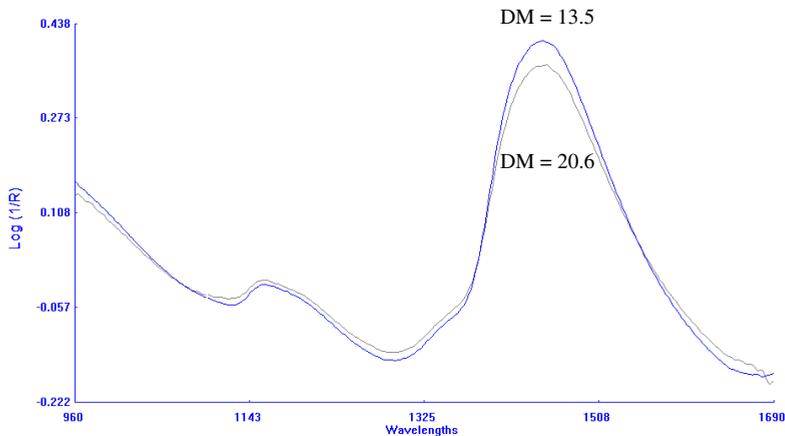


Figure 5.: Spectra of fresh forages (Dry matter = 13.5 and 20.6 %) collected with the Zeiss Corona mounted on a forage harvester.

A fresh forage data base was created in order to include a large spectral variability including the types of forage (Italian Ray grass, Westerwold Ray grass, Festulolium), the harvest year (2001-2002), the cuts (late and early cuts). On the principal components projections, it was possible to distinguish between forage samples of different harvest years or cuts.

During the experiments, samples were collected for the oven dry matter determination. After drying and grinding first with a Retch hammer mill SM100 (Retsch, Haan-Germany) and then with a cyclotec mill (Foss-Tecator, Sweden), the samples were then measured in the reflectance mode (FOSS-NIRSystems 6500) and predicted using the available calibrations (table 4). The predicted values derived from the laboratory instrument were then used to calibrate the embedded NIR. The best calibration models are given in table 5. From SD/SEC values observed, it is possible to make a three group classification for dry matter. For the other constituents under investigation, the SEC or SEC_v values should be improved to enables quantitative determinations.

Table 4. Dry forage calibrations on the laboratory instrument (Foss-NIRSystems 6500).

Constituent	n	Mean	SD	SEC	R ² c	SECV	R ² cv	SD/SEC
MPT	2765	14.77	5.90	0.848	0.979	0.861	0.979	6.96
CEL	2494	26.66	5.41	1.330	0.940	1.346	0.938	4.07
NDF	1299	48.62	7.19	1.944	0.927	1.992	0.923	3.70
ADF	865	27.40	4.85	1.282	0.930	1.327	0.925	3.78
SS	1015	11.41	8.20	1.326	0.974	1.361	0.972	6.18
OMD	1598	77.09	10.18	2.198	0.953	2.247	0.951	4.63

Table 5. Calibrations developed for the embedded NIR (Zeiss Corona).

Constituent	n	Mean	SD	SEC	R ² c	SECV	R ² cv	SD/SEC
DM	731	20.09	2.845	0.987	0.880	1.014	0.873	2.88
MPT	722	13.82	2.117	1.109	0.726	1.149	0.705	1.91
CEL	720	25.61	2.156	0.943	0.809	0.979	0.794	2.29
NDF	711	51.38	3.089	1.443	0.782	1.539	0.752	2.14
ADF	713	29.66	2.011	0.996	0.755	1.034	0.736	1.94
SS	714	13.95	4.843	1.945	0.839	2.019	0.826	2.49
OMD	713	79.01	5.165	2.295	0.803	2.460	0.773	2.25

n= number of samples, SD = standard deviation, SEC = standard error of calibration, R²c = determination coefficient calibration, SECV= standard error of cross validation, R²cv = determination coefficient cross-validation, DM = dry matter, MPT = total protein, CEL = cellulose, NDF = Neutral detergent fibre, ADF = acid detergent fibre, SS= soluble sugar, OMD = Organic matter digestibility.

Conclusions and further prospects

Wheat experiment

- Using a laboratory experimental device simulating the combine harvester is probably the best way to bring spectral variations in the data base (temperature, instruments, samples) and to use samples with known reference values.
- Laboratory NIR or NIT can be used to calibrate the embedded instrument.
- Technically, the most difficult part is the conception of the by-pass for the measurement.
- The robustness of the models should be further improved.
- The within field variation in this experiment was too narrow to evaluate the interest of NIR in a context of precision agriculture.
- The transferability between different NIR instruments on different combines should be further investigated.
- Linking the GPS position of the harvester to the NIR predictions remains a difficult task

Fresh forage experiment

- Again, all the variation sources have to be integrated in the data base (temperature, instruments, samples).
- Laboratory NIR or NIT instruments can be used to calibrate the embedded device.
- By itself, the measurement of the dry matter gives important information for plant breeding companies.
- More work is required to improve the calibration results and the robustness.
- A true validation with real laboratory values is required.

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