Do crop characteristics available from remote sensing allow to determine crop nitrogen status

V. Houlès, Bruno Mary, J.M. Machet, Martine Guerif, Sophie Moulin

DO CROP CHARACTERISTICS AVAILABLE FROM REMOTE SENSING ALLOW TO DETERMINE CROP NITROGEN STATUS ?

V. HOULÈS, B. MARY, J.M. MACHET
I.N.R.A. Unité d'Agronomie de Laon, rue Fernand Christ, Laon cedex, France
E-mail : houles@laon.inra.fr

M. GUÉRIF, S. MOULIN
I.N.R.A. Unité de Bioclimatologie, Site Agroparc, Avignon cedex 9, France
E-mail : mog@avignon.inra.fr

ABSTRACT

A promising way to optimise nitrogen fertilisation is to use the data provided by remote sensing. The two main crop characteristics assessable from remote sensing and useful to carry through this objective are : 1) the Leaf Area Index (LAI) and 2) the leaf chlorophyll content estimated on leaf area basis (CHL_{La}). The aim of our present work, based on a field trial conducted on soft wheat at six nitrogen levels (Guérif *et al.* this volume), was to determine whether these two variables allow to evaluate the nitrogen nutrition status of a crop. At first, we tried to calculate the Nitrogen Nutrition Index (NNI) from the value of CHL_{La} and LAI. We described several different relations. Some of them need parameters depending on time to account for the influence of the crop stage. The best result leads to an estimation of NNI with an RMSE of 0.12.

The assessment of NNI can be improved using the integrated variable $LAI \times CHL_{La}$ to estimate its numerator and LAI to estimate the denominator. The product variable $LAI \times CHL_{La}$ represent the amount of chlorophyll contained by leaves of the canopy and is better determined by remote sensing. This way conduct to an estimation of NNI with an RMSE value of 0.10.

Another measurement campaign in 2001 and further data treatments should allow to improve the precision of these relationships.

INTRODUCTION

Precision agriculture's goal of matching nitrogen supply with crop requirements at any point in a field requires spatial information on the nitrogen status of the crop. Some operational methods (e. g. JUBIL®, Hydro N-Tester) have been developed at a field level but their implementation at a within-field level with a high spatial resolution is not conceivable.

Remote sensing techniques allow to determine biological and physical properties of a canopy with an interesting spatial and temporal resolution. The nitrogen status of a crop can notably be deduced by this way. The first approaches consisted in trying to establish a direct relationship between reflectance and nitrogen status (Bausch & Duke 1996, Peñuelas *et al.* 1994). The results are encouraging on the leaf scale but on the canopy scale there might be a confusing effect. Considering nitrogen has not a direct effect on reflectance (Baret & Fourty 1997), it seems to be more appropriate to determine the variables which directly influence reflectance, and which are themselves linked to the nitrogen status of the crop, that is to say leaf chlorophyll content (CHL_{La}) and leaf area index (LAI) (Guérif *et al.* 1996). It is important to note that the product $CHL_{La} \times LAI$ is better assessed than the values of these individual variables (Baret *et al.* 1996).

A reference index has been defined (Lemaire & Gastal 1997) in order to determine the nitrogen status of the crop by comparing its real nitrogen content (N_r) and a critical nitrogen content (N_c). The latter is determined by the dilution curve and is a function of the aerial biomass (W).

$$INN = \frac{N_r \ (\mathrm{g.100g^{-1}})}{N_c \ (\mathrm{g.100g^{-1}})} \quad with \quad N_c = 5.35 \cdot W^{-0.442} \qquad [1]$$

This index has already been linked to CHL_{La} determined by remote sensing among several varieties. The relationship is parameterised by the stage of the crop (Gate 2000).
The aim of this study was to determine different ways to calculate NNI from CHL_{La} and LAI and to evaluate their reliability.

MATERIAL AND METHODS

Field trial

A field trial was conducted near Laon (north of France) on winter wheat (*Triticum aestivum* L.), Shango variety (Guérif *et al.*, this volume). Five nitrogen levels were used, from 0 to 300 kg $N.ha^{-1}$ after the last treatment. 60 kg $N.ha^{-1}$ were supplied at five dates, each of them differentiating a new treatment (March 6, March 20, April 11, May 5, May 24). Table 1 shows how the different treatments were set up :

	Nitrogen supplies				
Treatments	March 6	March 20	April 11	May 5	May 24
0 N	0	0	0	0	0
60 N	60	60	60	60	60
120 N	60	120	120	120	120
180 N	60	120	180	180	180
300 N	60	120	180	240	300

Table 1 : Total amount of nitrogen brought to each treatment vs date

Sampling and chemical analysis

Four sampling were realised in April and May 2000. The surface sampled was 0.85m² at each date. A subsample of plants was divided into shoots, leaves and ears. Leaves area measurements were made using a LICOR® LI-3000A and LI-3050A. The dry weight of each organ was evaluated so as their total nitrogen content using the Dumas method. This method is based on a complete combustion of a sample. The chlorophyll content of leaves was measured by pigment extraction with N,N-Dimethylformamid (DMF) and concentration measurement with a spectrophotometer.

Data treatment

Leaves nitrogen and chlorophyll contents (N_L and CHL_{La}, $g.m^{-2}$) and crop LAI ($m^{-2}.m^{-2}$), aerial and leaves dry mass (W and W_L, $g.m^{-2}$), crop real nitrogen content (N_r) and NNI were determined on the base of the values measured destructively as described above.
Three different methods were developed to estimate NNI from CHL_{La} and LAI :

1) The direct relationship between NNI and CHL_{La} : NNI = f(CHL_{La}) ;
2) The relationship : NNI = f(CHL_{La} ; LAI), estimating the numerator of NNI with CHL_{La} and the denominator with LAI ;
3) The relationship : NNI = f(CHL_{La}×LAI ; LAI), estimating the numerator by the CHL_{La}×LAI product, the denominator still estimated from LAI.

The accuracy of the different relationships was compare using their Root Mean Square Error (RMSE).

RESULTS

Physiological responses

Figure 1 presents the evolutions of a) CHL_{La}, b) LAI, c) W and d) NNI *versus* julian days. The kinetic of NNI shows that the different N treatments have effectively been differentiated. The dry mass (W) distinguishes the different N treatments worse than the three others variables even if at the last sampling date the dry mass of the 300N treatment is twice the dry mass of the 0N. Moreover it seems that LAI becomes different between two newly differentiated treatments only after more than two weeks : CHL_{La} and NNI react more quickly. This signifies indices like CHL_{La} or NNI are better to diagnose rapidly a N deficiency than indices such LAI or W.

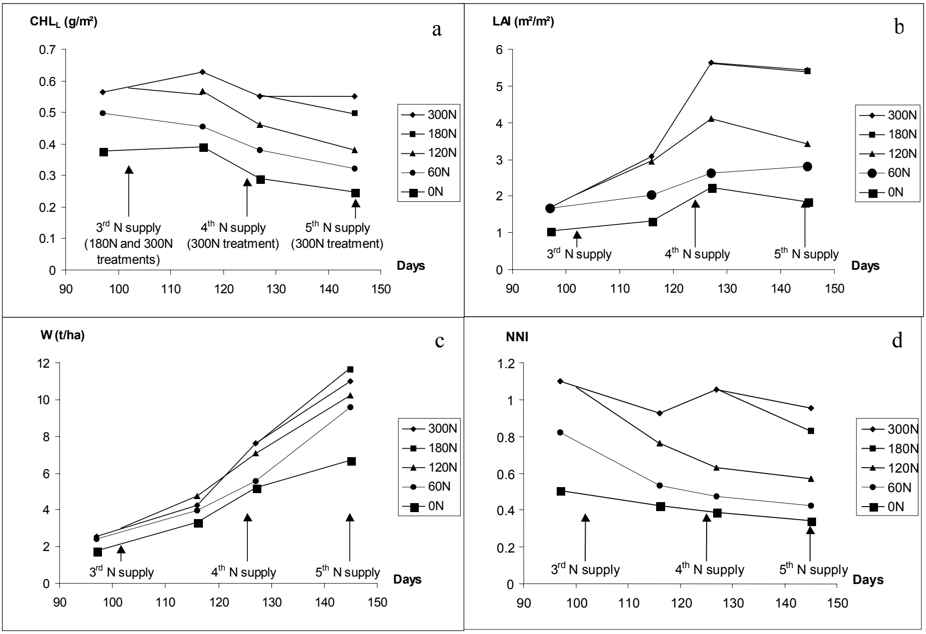
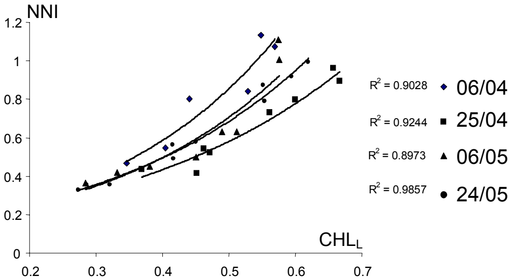


Figure 1 : Evolution of different crop variables.

Direct relationship between NNI and CHL

Fig. 2 suggests that NNI is an exponential function of CHL_{La} for a given date. Indeed, it seems that there is a saturation of NNI for high values of CHL_{La}. On the other hand, this relations are not the same for each date. The relationship : NNI = a. $\exp^{b.CHL}$ was parameterised with this points and the result gave an RMSE value of 0.12 (Fig. 3). When parameterising each relation date by date with the sum of degree-days since emergence (Σ(°C.day)), no significant improvement occurred.

According to the fact that a nitrogen shortage begin when NNI=0.9 and that nitrogen nutrition is optimum when NNI=1.0, it seems reasonable to say that we have to predict NNI with a precision of at least 0.5. So, this way of determination has to be improved.



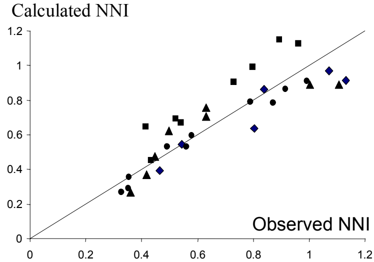


Fig. 2 : Evolution of NNI vs CHL_{La}.

Fig. 3 : Comparison between observed and calculated NNI evaluated directly from CHL_{La}.

Relationship between CHL_{La}, LAI and NNI

We tried to calculate NNI from CHL_{La} and LAI by the following way :

$$NNI = \frac{N_r}{N_c} = \frac{f(CHL_{La})}{5.35 \cdot [g(LAI)]^{-0.442}} \qquad [2]$$

The numerator can be assessed by several different means :

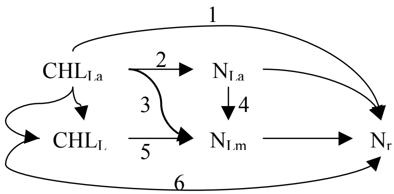


Fig. 4 : Different ways to determine N_r from CHL_{La}.

CHL_{La} : leaves chlor. content on an area basis ($g.m^{-2}$)
CHL_{Lm} : leaves chlor. content on a mass basis ($g.g^{-1}$)
N_{La} : leaves nitrogen content on an area basis ($g.m^{-2}$)
N_{Lm} : leaves nitrogen content on a mass basis ($g.g^{-1}$)
N_r : crop nitrogen content on a mass basis (NNI numerator) ($g.g^{-1}$)

All these tracks give similar results (relative RMSE from 21.6 to 24.8%). The best one is the number 3.

The aerial dry weight (W) was assessed from LAI. Fig. 5 shows that we can represent this relationship as follow :
W = a. ln(LAI) + b.

This relation was parameterised using Σ(°C.day). The resulting RMSE on W was 0.6 t/ha (10%).

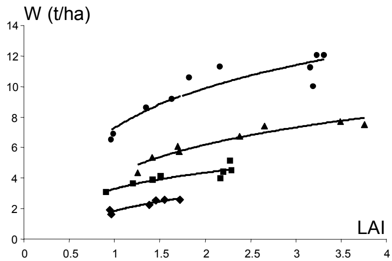


Fig. 5 : Evolution of aerial dry weight vs LAI.

Equation [2] using these results allowed to estimate NNI with RMSE=0.15, that is to say worse than the direct relation NNI = f(CHL_{La}). This illustrates the fact that less there are intermediate relations, better is the result.

Relationship between CHL_{La}×LAI, LAI and NNI

An other way to deduce NNI was attempted. Considering that the product variable CHL_{La}×LAI is better assessed than the CHL_{La} and LAI variables individually by the means of remote sensing, we tried to deduced NNI from this product variable :

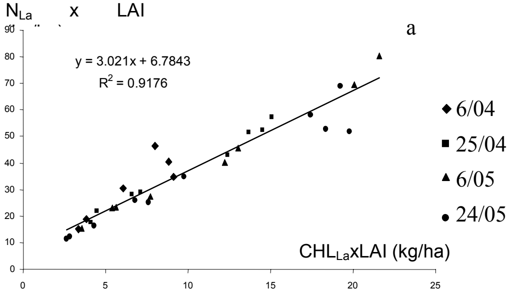
$$NNI = \frac{N_r}{N_c} = \frac{N_r \times W}{N_c \times W} = \frac{Total\ amount\ of\ N\ in\ the\ crop}{5.35 \cdot W^{1-0.442}} \qquad [3]$$

The numerator can be estimated from the product CHL_{La}×LAI which is the total amount of chlorophyll contained in all the leaves of the crop. The best results for the relation N_r×W = f(CHL_{La}×LAI) is obtained using as intermediary the amount of nitrogen contained in the leaves : N_{La}×LAI (leaves nitrogen content on an area basis multiplied by LAI) :

$$N_r \times W = f(N_{La} \times LAI) = fog(CHL_{La} \times LAI) \qquad [4]$$

The first relation, N_{La} × LAI = g(CHL_{La} × LAI) is quite stable with time, which is encouraging (Fig. 6-a).

The second relationship (Fig. 6-b) can be parameterised by Σ(°C.day). It could also have been parameterised by the stage of the culture because the change of the relation is certainly mainly related to the evolution of the ration stem on leaf.



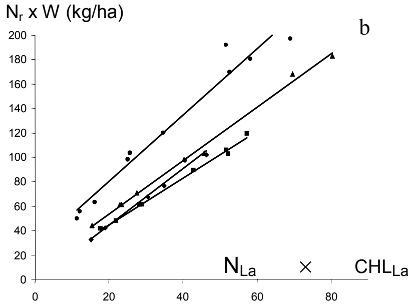


Fig. 6-a : Amount of nitrogen in leaves vs amount of chlorophyll in leaves

Fig. 6-b : Amount of nitrogen in crop vs amount of nitrogen in leaves

Using these relationships and equation [3], the numerator of NNI is obtained with RMSE=9.1% and NNI with RMSE=0.10 (Fig. 7) :

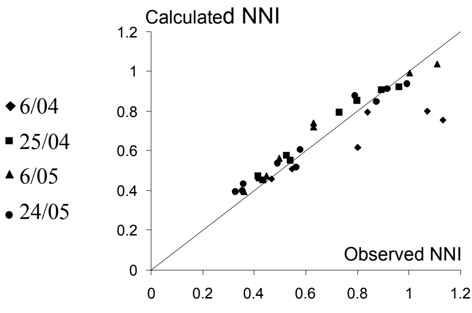


Figure 7 : Calculated NNI using equation [3]vs observed NNI

The RMSE on NNI of the different relationships described above are summarised in the following table :

Relation	RMSE on NNI	RMSE on numerator	RMSE on denominator
Direct relation NNI = f(CHL_{La})	0.12		
NNI = f(CHL_{La},LAI) (equation [2], way 3 for the numerator)	0.15	21.6%	0.6 t/ha (10%)
NNI = f(CHL_{La}×LAI,LAI) (equation [3])	0.10	9.1%	0.6 t/ha (10%)

Table 2 : Comparison of RMSE obtained for the different relationships.

CONCLUSION

All the relationships presented above have to be improved if we want to estimate properly the nitrogen status of a crop from remote sensing data by the way of NNI, with an RMSE of at least 0.5. In particular, the relationships should be parameterised with the crop stages instead of Σ(°C.day) alone. We can also think to parameterise these relationships by NNI itself. Thus, the determination on NNI would be done in two steps : at first with the relationships not parameterised with NNI and then with the relationships parameterised by NNI using the first calculated NNI as input. However that may be, equation [3] is the most promising one because it is based on a value well assessed by remote sensing, it is less parameterised (more robust) than equation [2] and give the best result.

During the year 2001, another campaign of experimentation should allow to obtain larger and more complete data which ought to improve significantly the relationships. They are indeed due to be introduced in a crop growth model to adapt it to remote sensing.

REFERENCES

Baret, F., Fourty, Th. (1997) Radiometric Estimates of Nitrogren Status of Leaves. *Diagnosis of the Nitrogen Status in Crops, Chapter 12, G. Lemaire (ed) © Springer-Verlag Berlin Heidelberg 1997.*

Baret, F., Tchamitchian, M., Sohbi, Y. (1996) Inversion de modèles : quelques exemples dans le domaine de la télédétection. *Actes de l'Ecole-Chercheurs INRA en Bioclimatologie Département de Bioclimatologie INRA F78850 thiverval-Grignon (ed), Tome 2 81-108.*

Bausch, W.C., Duke, H.R., (1996) Remote Sensing of Plant Nitrogen Status in Corn. *American Society of Agricultural Engineers, VOL. **39(5)** 1869-1875.*

Gate, Ph. (2000) La prise de décision face à la variabilité – exemples d'applications sur les céréales à partir de la télédétection. *Actes du colloque UMR Cemagref-ENESAD, Dijon (France), 29-30 mai 2000. © Educagri Editions, BP 87999, F21079 DIJON Cedex.*

Guérif, M., Lagouarde, J.P. and Nicolas, H. (1996) Variables de fonctionnement des couverts végétaux issues des données de télédétection dans les domaines optiques et infra-rouge thermique. *Actes de l'Ecole-Chercheurs INRA en Bioclimatologie Département de Bioclimatologie INRA F78850 Thiverval-Grignon (ed), Tome 2 81-108.*

Lemaire, G. and Gastal, F. (1997) N Uptake and Distribution in Plant Canopies. *Diagnosis of the Nitrogen Status in Crops, Chapter 12, G. Lemaire (ed) © Springer-Verlag Berlin Heidelberg 1997.*

Peñuelas, J., Gamon, J.A., Fredeen, A.L., Merino, J. and Field, C.B. (1994) Reflectance Indices Associated with Physiological Changes in Nitrogen- and Water-Limited Sunflower Leaves. *Remote Sensing Environnement, **48:**135-146.*