Farmstar-Rapeseed: a decision support system for rapeseed nitrogen fertilization based on satellite data

Luc Champolivier[1], Thierry Fourty[2], Hervé Poilvé[2], Grégoire Sigel[2], Julien Charbonnaud[3], Etienne Pilorgé[1]

[1] Cetiom, Centre de Grignon, B.P. 4, 78850 Thiverval-Grignon France. Email: champolivier@cetiom.fr; pilorge@cetiom.fr
[2] Infoterra France, 31 avenue des Cosmonautes, Z.I. Le Palays, 31402 Toulouse Cedex, France
Email: thierry.fourty@infoterra-global.com
[2] Cetiom, 270 Avenue de la Pomme de Pin, B.P. 90635, 45166 Olivet Cedex France. Email: charbonnaud@cetiom.fr

Abstract

Farmstar -Rapeseed is a decision support system developed in France by Infoterra France and Cetiom, based on satellite data to estimate the optimum economical amount of nitrogen (N) fertilizer for a winter rapeseed crop in each field and in each point of the field. The fertilization rate is calculated using a simplified previsional N balance method fitted to the rapeseed crop. This method takes into account several parameters including the N amount in the whole plants at the beginning and at the end of the winter which can be very variable for this crop (about 30 to 200 kgN/ha). This N amount in the whole plants is difficult to measure for the farmers. Cetiom has developed a method to estimate it from the fresh matter weight of aerial part (FMW) which is easier to measure in the field. Nevertheless, only few farmers weigh their rapeseed plants. A model has been developed to estimate the FMW from satellite data at the field scale. For this purpose, a radiative transfer model is used to derive from the reflectance the Leaf Area Index (LAI). This information is later transformed in FMW by a specific relationship depending on the architecture of the plants, the spacing between seedling rows and the mass per area unit of the leaf limbs. All the Farmstar-Rapeseed products are based on this relationship. For each campaign, a network of fields managed by Cetiom is used to weigh the FMW in order to monitor the quality of the relationship. Farmstar-Rapeseed has been marketed during the last 4 years. In 2006, Farmstar-Rapeseed made it possible to advise producers on 80 000 ha of rapeseed crop in France and to improve the way they manage the N fertilization at the field scale. This represents a much higher penetration level than any other decision support system for rapeseed N fertilization developed in the past. Another interest of this method is that being based on satellite data, thus in coordinates system, it allows to modulate the N fertilizer amount inside the field, depending on the crop heterogeneity.

Key words: nitrogen, fertilization, decision support system, remote sensing, satellite

Introduction

In France, the decision support system used to manage the winter rapeseed mineral nitrogen (N) fertilization in spring at the field scale is based on the simplified previsional N balance method (Comifer, 1996 ; Reau and al., 1995). Its principle is to equilibrate the foreseeable N requirement of the crop and the quantity of nitrogen available for the crop in the soil. It amounts to solve the following equation:

$$F = (b \times Y) + Rf - Nh - Rh - M$$, where:

- F is the rate of nitrogen coming from the mineral fertilizer amount (kg N/ha) ;
- b is the N requirement of the crop : total N content of the crop (aerial + root parts) in kg/ha per t of harvested seeds ;
- Y is the yield goal (in t/ha for seeds at 9 % of moisture and 2 % of impurity);
- Rf is the N mineral content of the soil (kgN/ha) at harvest;
- Rh is the N mineral content of the soil (kg N/ha) at the time of the growth recovery at the end of winter;
- Nh is the total N content of the crop (aerial + root parts) (kg N/ha) at the end of winter;
- M is the net N mineralization (kgN/ha) in the soil between the end of the winter and the harvest (coming from the humus, previous crop residues and possible amounts of organic products …).

The total N content of the plants is often neglected in other crops, but it cannot be the case for the rapeseed because it varies frequently from 50 to 100 kg N/ha, but can spread from 20 to more than 150 kg N/ha, depending on the seedling date, the climate during the autumn and winter period, the water and N availability… Consequently, the total N content of the crop is variable over the years and between fields and even inside each field.

One of the characteristics of the rapeseed crop is that it may lose a more or less big part of its leaves during winter after frost periods. The greater the total N content in the plant, the more the leaves fall. This loss of leaves can represent more than 50 kg N/ha. The N contained in these fallen leaves is rapidly mineralized in the soil. It is considered that about 50% of the N content of these fallen leaves are absorbed again by the rapeseed crop during the following of its growth. In these situations of strong leaf losses this N amount is taken into account in the calculation of the N fertilizer rate, by considering as income data of the equation for Nh, the mean of the total N contents at the beginning (before the first frost period) and at the end of the winter.

The total N content of the crop at the beginning and at the end of winter are the more variable parameters of the equation. This is why it is recommended to measure them in the fields. However, in practice, the farmers cannot carry out this measurement which requires to dry the plants and to determine the N content (% of dry matter) in a laboratory. Cetiom studies show that the fresh matter weight of rapeseed aerial part (FMW) is well correlated with the total N content (aerial + root parts). The total N content (Nh) can be estimated with the following equation: Nh (kg N/ha) = FMW (kg/m²) x C, C varying from 65 to 75 depending on the region. This estimation method (FMW weighing on some m²) of the total N content is recommended to farmers. Nevertheless, it often remains too constraining. The spatial variability at the field scale raises also a problem: to take it well into account would require to make a lot of FMW measurement in the different areas of the field and to calculate the N fertilizer rate specific to each area. Most often, the farmers measure the FMW in the homogeneous area of the field which represent its greater part, then only one N fertilizer rate is calculated and applied to the whole field.

In order to release the farmers from making these measurements in their fields, and to be able to modulate the N fertilizer rate inside the field, depending on the total N content heterogeneity, Infoterra France and Cetiom have developed a model in order to estimate the rapeseed FMW at the field scale, using remote sensing data from satellites.

Material and methods

The first step assumed by Infoterra France is the retrieval of the Green Leaf Area Index (GLAI) of the crop canopy from satellite reflectance data using a Crop Canopy Reflectance Model (CCRM). After the initial pre-processing that provides geo-corrected and radiometrically corrected data (radiance data), the core part of the processing is the “biophysical processing”, i.e. the generation of biophysical information (GLAI) from the remote sensed data. It is based on a reflectance modeling approach, and implements the coupling of a crop canopy reflectance model with an atmospheric model. The crop canopy reflectance model is a SAIL + PROSPECT model. PROSPECT is a generic model of the leaf transmittance /reflectance (Jacquemoud & Baret, 1990), and SAIL computes the overall crop canopy reflectance using the leaf properties and global parameters to describe the canopy structure (Verhoef, 1984). The model applied for atmospheric correction is MODTRAN. Using this overall vegetation/atmosphere model, fast inversion and map generation techniques are applied so to be compatible with the constraints of operational production (Jacquemoud et al., 1999; Fourty & Baret, 1997).

The crop canopy reflectance model incorporates a number of parameters. Some of these parameters are not accessible by remote sensing: they must be set according to crop characteristics. We focused on a major biophysical variable that provides key information for a number of end-products: the GLAI that quantifies the green foliage development as the area of green leaves per unit area (m^2 m^{-2}). The GLAI is a notion classically used in remote sensing and an input variable to the SAIL model. The calculated GLAI is then converted into fresh matter weight of aerial part (FMW). At the end of the winter, the GLAI estimated at the beginning of the winter is also taken into account in the calculation. Cetiom is very much involved in building relationship between GLAI and FMW of the crop at the beginning and end of the winter.

A large part of the initial work should have consisted in validating the GLAI information that could be retrieved from remote sensing with the same quantities measured on the ground through direct or indirect measurements. Considering the difficulty to measure the Nh in a lot of fields, it has been chosen to use the transformed variable FMW in order to validate the model. Each year since 2003, Cetiom has carried out measurements of FMW in fields chosen in order to represent diversified crop situations (soil, climate, cropping system) in several regions in France. These measurements took place at the beginning and end of winter, at variable dates depending on the region (for example in the Centre region, between 15th November and 5th December at the beginning of winter and between 20th January and 10th February at the end of winter). At each period and in each field, these measurements were carried out on 4 small zones of 1 m² each. These 4 zones were located within a sampling area of about 150 m², in a great homogeneous part of the field. The sampling area was located with a GPS receiver, in order to compare the ground measurement data and the remote sensing data. One of the difficulties of this work was that for each field, the ground measurement data and the remote sensing data were never acquired the same day. It was then necessary to build a model in order to transform the GLAI estimated by remote sensing method the day the image was acquired from satellite into the GLAI estimated the day of ground measurement, by taking into account leaf losses due to the frost periods.

Results and discussion

There is a relation between the FMW estimated from ground measurement and from remote sensing measurement, either at the beginning and at the end of winter, as shown in figure 1 (2005). Despite the error terms cumulated in its calibration, this relation is sufficient to build a decision support system for rapeseed N fertilization at spring, using satellite imagery: Farmstar-Rapeseed. The error terms are : i) the FMW estimation with remote sensing method, ii) the ground estimation of FMW on 4 m² of soil, iii) the difference between the spatial scales of ground measurement (4 m²) and satellite measurement (pixels of about 400 m²).

In practice, the agricultural cooperatives conclude an agreement with Infoterra France and propose the Farmstar-Rapeseed service to farmers. Farmers provide to Infoterra France the location of the fields they want to follow with Farmstar-Rapeseed, their goal yields, and simple information in order to characterize the soil types and the crop management systems.

Each field must have a minimal surface of 4 ha, to contain a sufficient number of pixels and allow a reliable estimation of the FMW. Each field must be homogeneous in term of cultural practices. The cost of subscription depends on the surface.

For each field, farmers receive by mail maps of the FMW at the beginning and at the end of winter and a map representing the total N fertilization rate to apply in spring (figure 2). Statistic data are associated to these maps. They describe the variability of the FMW and of the N fertilization rate in each field. The median N rate advised for the whole field is indicated in the document for the farmers who cannot or do not want to modulate the N fertilization rate in the field. This rate allows to satisfy the median requirement of the field.

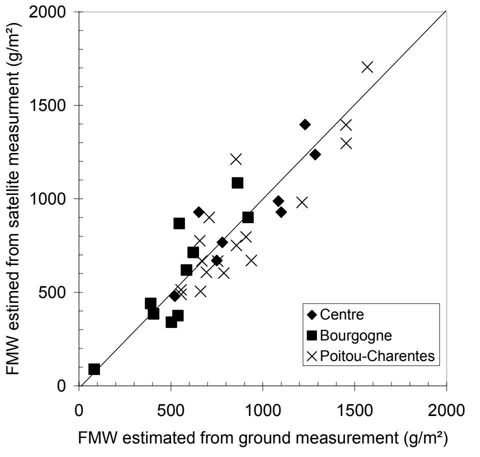
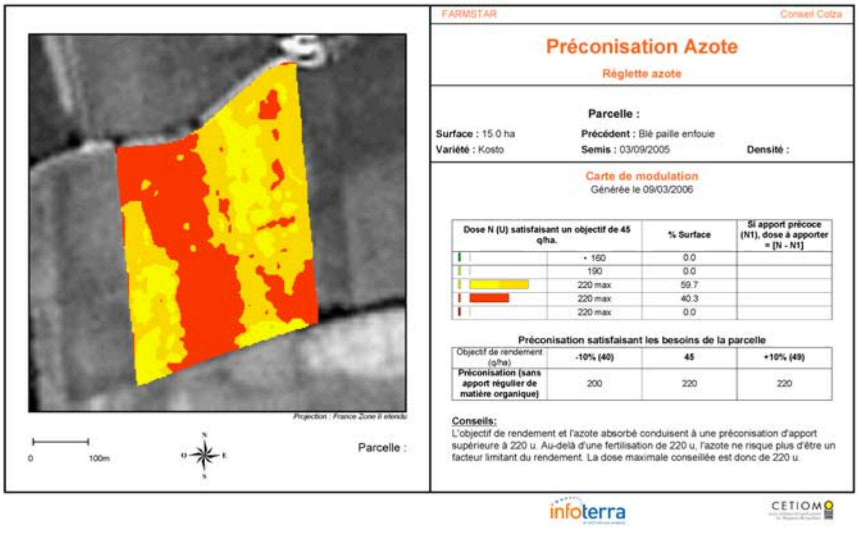


Figure 1: Relation between FMW of aerial part at the beginning of the winter estimated from ground and satellite measurement.

On the other hand, if they want to, farmers can modulate the N fertilization rate, either manually from the paper map, or automatically if they have a GPS receiver and a fertilizer spreader with variable rate technology, by buying the numeric file. This latest method allows them to modulate the N fertilization rate pixel by pixel.

At the beginning, there were also discussions on whether the spatial resolution of SPOT data (20 m to 10 m depending on SPOT generation) would be appropriate for the agriculture application. The actual finding after the first campaigns was that this resolution is fully sufficient for this usage, users have even more information than they can actually handle, however they are sensitive to a correct image location and a perfect delineation of the field boundaries.



FARMSTAR Conseil Colza

Préconisation Azote

Réglette azote

Parcelle :

Surface : 15.0 ha Précédent : Blé paille enfouie

Variété : Kosto Semis : 03/09/2005 Densité :

Carte de modulation

Générée le 09/03/2006

Dose N (U) satisfaisant un objectif de 45 q/ha.		% Surface	Si apport précoce (N1), dose à apporter = [N - N1]
	• 160	0.0	
	190	0.0	
	220 max	59.7	
	220 max	40.3	
	220 max	0.0	

Préconisation satisfaisant les besoins de la parcelle

Objectif de rendement (q/ha)	-10% (40)	45	+10% (49)
Préconisation (sans apport régulier de matière organique)	200	220	220

Conseils:
L'objectif de rendement et l'azote absorbé conduisent à une préconisation d'apport supérieure à 220 u. Au-delà d'une fertilisation de 220 u, l'azote ne risque plus d'être un facteur limitant du rendement. La dose maximale conseillée est donc de 220 u.

Parcelle :

0 100m

infoterra CETIOM

Figure 2 : Example of document sent to farmers : N fertilization rate advice

The areas concerned by the decision support system Farmstar-Rapeseed are in constant progression since its marketing. It represented about 80,000 ha in 2006, including about 2,000 ha with an automatically modulation of the N rate inside the field.

The better adjustment of the N fertilization rate to the requirement of the crop thanks to Farmstar-Rapeseed allows the farmers to reduce their fertilizer expenses, to make use of cultural practices which are more respectful for the environment, while optimizing the oil content of the harvested seeds (the oil content decreases if the N fertilization excess increases). These effects are all the stronger that they use the modulation of the N rate in the field.

Each year since the beginning of Farmstar-Rapeseed, a validation of the FMW estimations was carried out in a plot network in which ground measurements have also been realized. The goal is to be able to avoid such a validation soon. The results obtained in the crop year 2006 allowed us to identify some ways of progress in order to achieve that. It concerns particularly the improvement of the prevision model of GLAI evolution in winter, and the better taking into account of the row spacing effect in the radiative transfer model (in France, row spacings vary between 12 to 80 cm).

Conclusion

Farmstar-Rapeseed is a decision support system which is well-adapted to farmers' requirement : it is precise enough, it allows to avoid field measurements, and it accounts for the variability in the field. It will be further developed over the next years to improve the models which make it up and simplify relationships with farmers (next year, it will be possible to deliver results by internet).

Cetiom and Infoterra are now studying the possibilities to extend the use of the remote sensing from satellite to others applications on rapeseed crop, particularly the yield prevision.

References

COMIFER. 1996. Calcul de la fertilisation azotée des cultures annuelles (Methods to assess the optimum N fertilizer application rate). Guide méthodologique pour l'établissement des prescriptions locales, p.25.

Fourty, T., Baret, F. 1997. Vegetation water and dry matter contents estimated from top of the atmosphere reflectance data: a simulation study. Remote Sensing of Environment 61, p.34-45.

Jacquemoud, S., Bacour, C., Poilvé H., Frangi JP. 1999. Comparison of Four Radiative Transfer Models to Simulate Plant Canopies Reflectance – Direct and Inverse Mode. Remote Sensing of Environment, 2000.

Jacquemoud, S., Baret, F. 1990. PROSPECT: A model of leaf optical properties spectra. Remote Sensing of Environment 34,p.75-91.

Reau R., Sauzet G., Wagner D., 1995. A prévisionnal nitrogen balance method for winter rapessed spring fertilization.

Verhoef, W. 1984. Light scattering by leaf layers with application to canopy reflectance modeling: the SAIL model. Remote Sensing of Environment 16, p.125-141.