Site specific calibration of a crop model by assimilation of remote sensing data : a tool for diagnosis and recommendation in precision agriculture

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Abstract

Crop models are key tools for helping in decision making in the frame of precision agriculture. However they need a site specific calibration in order to give coherent spatial representation of crop and soil state variables that can be used to make diagnosis and allow recommendations. This paper shows how to perform such a calibration, using the assimilation of external information on crop status obtained from remote sensing images. The improvement in model simulation was evaluated through the improvement in the final yield map estimation.

Keywords : Crop model, assimilation, remote sensing, agronomic recommendation

Introduction

Measurement techniques, interpretation models, and information management tools, have progressed in such a way that it is now possible to envisage taking into account field heterogeneity in crop management. The objective can be either a uniform or spatially variable application. It is necessary to build up tools for decision making using soil and climatic data to enable adapted recommendations for applications.

Crop models are particularly useful in the design of such tools. When provided with relevant climatic, soil and crop data, they allow dynamic simulation of the behaviour of the soil-plant system. Subsequently, they can give dynamic diagnostic information about soil and crop conditions. They allow simulation of their development under different scenarios of operation management and/or climate, thereby providing information for decision making.

Assuming that the models are used within their validity domain, they should meet two specific conditions in order to be applicable in such a methodology. On the one hand, the models should properly describe the processes affected by the operation for which recommendations are expected (for instance the processes linked to nitrogen cycle in the soil and the plant in the case of recommendation in nitrogen fertilisation). On the other hand, they should be able to reproduce the effects of the spatial variability of soil and/or crop conditions at large scale. For this aspect, it is expected: i) to have the set of parameters of the model functions corresponding to each existing situation; ii) to be able to describe the input variables of the model with a spatial resolution

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compatible with the objectives. This last condition can be met by using data assimilation techniques on remote sensing data acquired during the crop cycle (Guérif & Duke, 1998).

Using radiative transfer model inversion, remote sensors in the solar domain give access to canopy state variables such as leaf area index, and leaf chlorophyll content (Moulin et al. 2003). These estimates are available continuously over the entire set of fields, with a spatial resolution of 1 – 10 m, and a given temporal resolution, both related to the platform used (tractor, airplane, satellite). Using optimisation procedures, these canopy state variables allow re-estimation of parameter values and/or input variables and to force the model to simulate as well as possible the ”observed values”.

These methods have been applied in a project dedicated mainly to the development of a tool for de1cision making for nitrogen application to winter wheat. The principles and the first results of the method are presented here for one field cultivated with winter wheat.

The objective of this paper was to illustrate how data assimilation acquired during the crop cycle led to a better spatial processing of the model; the evaluation of the method was performed by comparing simulated spatially distributed yields to the observed yield map.

Material and methods

Experimental data

The experimental trial (Guérif et al. 2001) was made on two 10 ha fields cultivated alternatively with winter wheat and sugar beet during the first 2 years of experiment (2000-2001). The results presented here refer to one of those fields.

A high resolution soil survey was performed (100 samplings over 10 ha, from 0 to 1.50m depth), recording horizon type, stone content, rooting impedance depth and leading to the definition of 51 soil units. Local pedotransfer functions were defined which allowed each type of soil to be related to specific properties (bulk density and water retention at various soil potential). The 0-30cm layer was sampled on a regular grid (36mx36m) and standard physico-chemical analyses were performed. Soil sampling was performed on the grid at different dates (sowing, mid February, and harvest) and for each 30 cm layer, from 0 to 1.50m depth. Soil water and nitrogen contents were measured and interpolated by kriging (Mary et al, 2001). These data provided initial input values at sowing for the model, and validation data for the two other dates.

At several dates between early April and late June, remote sensing measurements were performed with a 2m resolution over the field with a CASI spectrometer mounted on an airplane. These measurements enabled estimation, by inversion of the model Prosail (Moulin et al., 2003), of values of leaf area index (LAI) and leaf chlorophyll content (Cab). These values have been corrected by calibration with data obtained on the ground at the time of the flight. SPOT data

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were also acquired but not used here. At harvest, a yield monitor operated by the farmer was used to produce yield maps.

The crop model.

The STICS-winter wheat model (Brisson et al., 1998) was used in its latest version (V5.0). Its sensitivity to the expression of the variability of soil characteristics has been checked (Houlès et al., 2002). Its ability to properly reproduce the effect of nitrogen fertilisation has been verified. An empirical function was introduced which simulates the leaf chlorophyll content as a function of the nitrogen amount in the canopy. This is based on the data obtained by Houlès et al. (2001).

Spatial resolution of the working units

We defined squared grid units of 20m x 20m. Soil data (permanent and non-permanent) and crop state data (LAI, Cab) were collected into a GIS. The intersection of the 20m x 20m grid with different information layers allowed to characterise the different soil grid units and to derive the necessary input variables for running the crop model.

The method used for remote sensing data assimilation

A simplex type method has been used which allowed re-estimation of some parameters or input variables of the model. The method minimises a distance criterion between the values estimated by the model and the values “observed” by remote sensing.

Parameters and variables to be re-estimated were chosen according to two criteria. One refered to the probable spatial variability due to soil characteristics, cultivation technique effects and soil - plant interactions. The other one refered to their importance shown by the sensitivity analysis of the model (Ruget et al., 2002). Three variables were outlined. The potential maximum depth of rooting (this is a key variable in the water and nitrogen absorption process and has been assessed during the soil survey) ; loss of nitrogen due to volatilisation of the fertiliser and the depth of the soil layer which is concerned by organic matter mineralisation.

Results

Direct simulation, without assimilation, led to a similar overestimation of LAI (Fig. 1, a1). Moreover, the simulated values of LAI for each date expresses very little spatial variability and a poor correlation with the observed LAI. The global bias was less for the chlorophyll content (Fig. 1, a2), but we still notice the incapacity to reproduce spatial variability and the lack of correlation between observed and simulated data. As a consequence of LAI overestimation, the simulated yield was also overestimated (Fig.1 a3).

Different stra[…] parameters:
V = fertiliser […].R. + depth

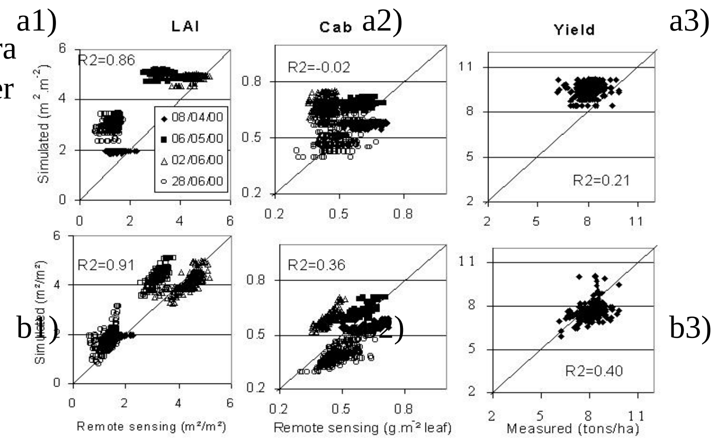


Figure 1. Simulation results a) with the model alone and b) after LAI and Cab data assimilation for 4 dates 1) simulated LAI, 2) simulated Cab, 3) simulated final yield

of mineralisation of the organic matter. Table 1 shows the efficiency of the different strategies to reduce the RMSE and the RRMSE. The results (LAI, Cab, & final yield) obtained with the different strategies are compared to the simulations with the model alone.

		Model alone	Model with assimilation		
		(a)	V (b)	V,R (c)	V,R,P (d)
LAI	RMSE ($m^2.m^{-2}$)	0.133	0.069	0.071	0.070
	RRMSE (%)	51.2	26.7	27.1	26.9
Cab	RMSE ($g.m^{-2}$)	0.015	0.011	00.11	0.011
	RRMSE (%)	27.7	19.8	19.9	19.8
Yield	RMSE (T/ha)	1.6	0.83	0.79	0.85
	RRMSE (%)	19.1	10.2	9.7	10.4

Table 1. Performance of direct simulation as compared with assimilation of LAI and Cab data

The 3 strategies appeared to be rather similar. The VR strategy allowed reduction of the yield errors from 19.1 to 9.7%. Figure 1 (b1,b2,b3) shows how the variability simulation had been improved as well as for the LAI, Cab and yield with the VR strategy.

The spatial display of the "rooting impedance depth" parameter suggested the interest of the method to estimate the spatial distribution of some of the unknown soil characteristics (Figure 2). In our case, we can compare this map with the one surveyed by the pedologist and outline the mismatches, which should be then validated. The map of simulated yields (Figure 3) shows that the assimilation has allowed better fitting of the range of simulated yields to that of the measured ones. Moreover, it allowed incorporation into the simulation of the spatial variability, which was existing in the images, obtained by remote sensing.

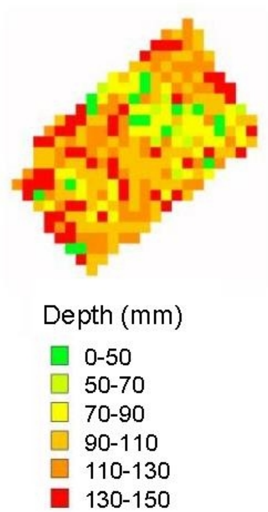
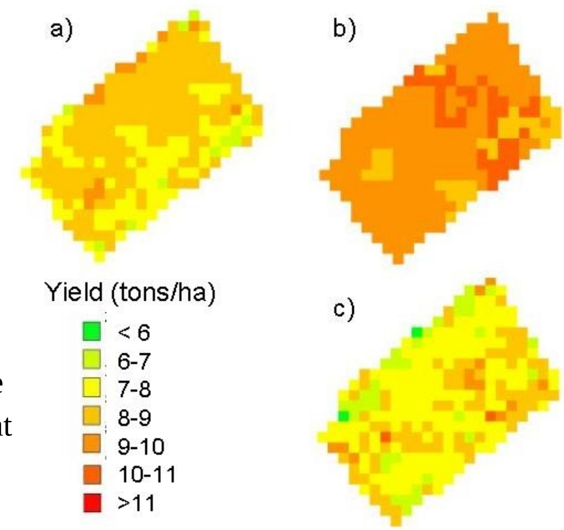


Figure 2. Ma[p] ... ng impe- dance depth" ... egy VP.



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Discussion

These first results showed the potential of the method in attaining a site adjusted simulation of the crop status. The performance of the method depends a lot on the number of data to be assimilated and their distribution along the crop season (Guérif & Duke, 1998). In our case the results should have been improved by images acquired earlier during the crop establishment. Apart from the soil-linked parameters that we tried to estimate, a global re-estimation of more specific plant parameters should be undertaken in a previous step.

This type of method is applicable to the assimilation (or inversion) of any information acquired during the cropping season: measure of the water content by electric resistivity, remote sensing data at different wavelengths, automated measure of yield. The assessment of the field permanent characteristics, in the case where they are unknown, could be performed by inversion of "collections" of yield map, using a model such as STICS, which allows simulation of crop rotations.

Conclusion

The combined use of the assimilation of data acquired during the crop growth, and of spatially distributed data obtained by an exhaustive characterisation (by geophysics or remote sensing) or by interpolation with geostatistics, allows relevant localised simulations of the plant and soil state variables. This spatial distribution is the first step of a method to develop nitrogen fertilisation recommendations. The next step of this method will consist of simulating fertiliser application and climatic scenarios, and finding the optimum of a cost function built on both production (yield, quality) and environmental variables relative to nitrogen losses.

References

Brisson et al, 1998. STICS: a generic model for the simulation of crops and their water and nitrogen balance. I. Theory and parameterisation applied to wheat and corn. Agronomie, **18**: 311-346.

Guérif M., Duke C., 1998. Calibration of the SUCROS emergence and early growth module for sugar beet using optical remote sensing data assimilation. Eur. J. Agron, **9**,127-136.

Guérif M. et al, 2001. Designing a field experiment for assessing soil and crop spatial variability and defining site-specific management strategies. In : Proceedings 3rd European Conference on Precision Agriculture, June 2001, Montpellier (FRA).

Houlès V, Guérif M., Mary B., Machet J.M., Moulin S., 2001. Do crop characteristics available from remote sensing allow to determine crop nitrogen status ? In: Proceedings 3rd European Conference on Precision Agriculture, Montpellier (FRA), June 2001, 917-922.

Houlès V., Nicoullaud B., Beaudoin N., Mary B., 2002. Sensitivity of a crop model to pedotransfer functions at the field scale. Proceedings VII Congress of the European Society for agronomy , Cordoba (Spain), 15-18 july 2002, 631-632.

Mary B., Beaudoin N., Machet J.M., Bruchou C., Aries F., 2001. Characterization and analysis of soil variability within two agricultural fields : the case of water and mineral N profiles. In : Proceedings 3rd European Conference on Precision Agriculture, June 2001, Montpellier (FRA), 431-436.

Moulin S., Zurita Milla R, Guérif M., Houlès V., and Baret F., 2003. Comparison of the performances of 3 remote sensing sensors and two methods for the retrieval of biophysical variables on a wheat field. In this issue.

Ruget, F., Brisson, N.,Delécolle, R., Faivre, R., 2002. Sensitivity analysis of a crop simulation model, STICS, in order to choose the main parameters to be estimated. Agronomie, **22** (2), 133-158.

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