PREDICTION OF A WHEAT CROP YIELD MAP BY USING POST-ANTHESIS RADIOMETRICAL DATA

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ABSTRACT

Because yield maps provide only synthetic information on the whole crop cycle, it appears necessary to supplement them with more analytical tools enabling to explain the spatial variations in measured yield and to make diagnosis. Here we tested two candidate methods: simulation modelling and radiometric mapping of green leaf area index (GLAI) after anthesis, on a 15-ha wheat-cropped field with marked soil and topographic heterogeneity under a temperate climate.
When aggregated over the major soil units within the field, GLAI maps and modelling could mimic their overall effects on yield. However, they both were poor predictor of short-range (10 m) yield variability, even when the model was re-initialized with the GLAI data measured after anthesis. Possible reasons include sampling and spatial joint biases, and that GLAI should be taken several times during grain filling.

INTRODUCTION

Although crop models were not designed to simulate within-field variability, several authors used them in site-specific agriculture simulation attempts (Boone et al, 1997 ; Sadler et al, 2000). As they pointed out, making crop diagnosis and yield predictions with such models requires to improve model sensitivity to soil and micro-climate characteristics, and the capacity of models to make use of crop status indicators.
Thus, the objective of this paper was to evaluate the benefits of using GLAI data (obtained shortly after anthesis) to the CERES-Wheat model in order to improve its site-specific prediction of final yields.
With this objective in mind, we mapped the leaf area index of a wheat crop on an heterogeneous 15ha field with a radiometrical georeferenced measurement system mounted on a tractor.
The estimated leaf area data were then considered as resulting from a multi-site experiment and were used as independent driving variables in a wheat simulation model (CERES-Wheat). The model was parameterized from geo-referenced soil functional characteristics (texture, water

availability, etc..), and run on a regular 30 m resolution grid.

MATERIALS AND METHODS

Experimental setup

A field experiment was conducted with wheat in 1999-2000 at the Experimental Farm of Institut National Agronomique Paris-Grignon, Thiverval-Grignon, France (48.9 N, 1.9 E). The initial aim of the experiment was to study different factors acting on take-all disease (Gaeumannomyces graminis var tritici). In order to obtain crops with a range of variability, two sowing dates, two cultivars and two sowing densities were interposed. Details of crop management are given in a companion paper (Boissard et al., 2001).
The field is 15 ha in size, and comprises three main soil units: a flat plateau made up of calcareous loamy soil, a sloping zone of shallow sandy calcareous soil, and a lowland with a thick loamy soil (colluvium). Within-field soil variability was characterised by sampling cores along a regular square grid with a resolution of about 40 m (King, 1976). Cores were taken with a hand auger until the parent material was reached, with a maximum depth of 120 cm. They were sliced according to their pedological characteristics, and half of the sub-samples were randomly taken to the laboratory for analysis of their basic physical and chemical properties (particle-size distribution, C and N content, pH). Table 1 lists some summary statistics for the 178 cores taken.

TABLE 1. Statistics of soil properties within the experimental field, in the form: mean [standard deviation]

Properties	Soil		
	Bottom of slope	Mid-slope	Edge of plateau
Percent Clay	21.4 [2.1]	21.0 [1.7]	22.3 [4.6]
Percent Sand	54.9 [2.2]	55.3 [2.7]	50.2 [3.9]
Depth to parent material (cm)	91 [27]	69 [34]	55 [20]
Plant Available Water (mm)	19 [6]	14 [8]	11 [8]

Green leaf area index (GLAI) and yield mappings

Crop GLAI was mapped from radiometric data provided by on board sensors mounted on a tractor (Boissard et al., 2001). Red to near infra red ratios were taken across 4 m wide strips along the tractor's direction. Because the cross distance between wheel tracks was 6 m, portions of the field were not sampled. The GLAI map used in this paper was taken on June, 8th (crop development stage 70; Zadoks et al, 1974)
Final crop yields were mapped by a CLAAS combine harvester (6 m cutting width) rigged with Quantimeter metering hardware, a portable on-board ACT computer integrating the Racal DGPS and the CLAAS LEM modules. Point GLAI and yield data were also averaged every 5 m along the tractors' direction.
Prior to simulation modelling, a linear model was built to relate yield to GLAI and other factors (soil unit, gravel content, slope of terrain, and crop treatement). The analysis of co-variance was done with the GLM procedure of the SAS package (SAS Institute).

Site-specific simulation

Model description

CERES-Wheat (Ritchie and Otter, 1985) is a dynamic, daily-time step model simulating the cycles of water, carbon and nitrogen in soil-crop systems. It comprises sub-models for the major processes at stake. A physical module simulates the transfer of heat, water and nitrate down the soil profile, as well as soil evaporation, plant water uptake and transpiration in relation to climatic demand. Next, a microbiological module simulates the turnover of organic carbon and nitrogen along with the nitrification and denitrification processes. Lastly, plant growth and development is driven by air temperature and incoming radiation, as modulated by water and N availability to the roots in the soil profile.

Parameterization and running

CERES-Wheat was run on each of the soil profiles sampled in the field, at the centre of the regular square grid. For the various horizons within the profiles, soil physical and micro-biological parameters were estimated from the basic properties given in Table 1, using a standard procedure (Gabrielle et al., 2001). Soil depth was corrected (reduced) when materials characterized by a very low water holding capacity occurred in the profile. These materials include layers of coarse sandy soil or compact chalk. The necessary weather data were taken from a weather station located less than 1-km from the field, and each simulated point was assigned with the appropriate management techniques (cultivar, sowing date and density).
The linkage between the CERES executable and the GIS software package ArcView 3 (ESRI) was done in a similar fashion as described in Engel et al. (1997) Comparison between CERES-simulated and observed data was made through spatial joints between simulation points and the centres of the rectangles in which GLAI and yield data were obtained. The joint was made with the point to point procedure under ArcView. In a second set of runs, CERES was re-initialized after anthesis by substituting the simulated GLAI with the radiometric GLAI data taken at that time. Specific leaf weight and leaf nitrogen content were assumed constant in this re-initialization.

RESULTS

CERES managed to capture the differences between the three soil units (Figures 1 and 2, Table 2), although the point agreement between predicted and harvested yields was rather poor. The coefficient of determination of the regression between the yields simulated at the 178 soil sampling locations and the joint harvested yields was only 2%. Thus, the model could not explain short-range variations at the 30 m spatial resolution imposed here. Also, the model under-estimated final yield by a factor of 2, and was therefore crudely calibrated by extending the last soil layer by 60 cm.
Besides, when the model was re-initialized with the radiometric GLAI data obtained after anthesis, yield predictions did not improve at all, since the model achieved the same R^2 as without the GLAI data. This was due to its lack of sensitivity to green LAI after anthesis, a time at which grain filling was half completed and essentially limited by water stress. This low influence of GLAI on yield also appeared in the experimental data, since the introduction of this co-variable in the linear model of yield only increased its R^2 from 41 to 51% (Table 3).

Table 2: Comparison of simulated and measured yields for the three pedological zones. Statistics are given in the form: mean [standard deviation] *degrees of freedom*

Soil zone	Edge of plateau	Mid-slope	Bottom of slope
Simulated yields	5.23 [1.99]	5.47 [2.02]	6.61 [0.98]

	50	*50*	*48*
Observed yields	5.94 [1.16] *50*	5.97 [0.63] *50*	6.77 [1.21] *48*

Table 3: Analysis of co-variance table for the linear model of yield. Factors include: GLAI, soil unit (SOIL), treatment (TREAT), slope index (SLOPE) and topsoil gravel content (GRAV).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	35	704.37	20.12	55.95	0.0001
Error	1883	677.34	0.36		
Corrected Total	1918	1381.71			
	DF	Type III SS	Mean Square	F Value	Pr > F
GLAI	1	112.77	112.77	313.51	0.0001
SOIL	2	3.76	1.88	5.23	0.0054
TREAT	7	13.65	1.95	5.42	0.0001
SLOPE	1	0.85	0.85	2.35	0.1252
SLOPE*TREAT	7	9.84	1.41	3.91	0.0003
GRAV	1	0.32	0.32	0.89	0.3460
GRAV*TREAT	7	12.32	1.76	4.89	0.0001
GLAI*TREAT	7	21.56	3.08	8.56	0.0001
GLAI*SOIL	2	2.49	1.24	3.46	0.0316

DISCUSSION-CONCLUSION

This preliminary work on the linkage between crop models and geo-positioned information in the field was designed to assess the potential benefits of associating the two techniques. At that point, it shows that crop models should be adapted to simulate within-field variability, since CERES only captured it at the level of soil units. However, the model provided correct order of magnitudes for the yield variances, which is an encouraging result compared to previous work pointing out that CERES lacked some sensitivity to soil factors (Sadler et al., 2000). On the other hand, CERES under-estimated the average yield, implying that some calibration should be undertaken. A likely reason for that bias is the assumption that some soil horizons could not supply crops with any water, which yielded rather low values for plant available water. Further experimental is therefore warranted and planned to characterize the water holding capacity of the soil profiles involved.

Although we focused here on the scale of soil units rather than elementary sampling cells, it is worth analysing the discrepancies between point model predictions and harvested yield. These might be due to a lack of precision on the position of soil cores (which were taken long before the development of differential GPS techniques) as well as on the estimates given by the yield sensor. Also, yield and GLAI data were aggregated over 6 m strips of different widths (6 m and 4 m, resp.), and not exactly overlapping. Thus, small-scale (less than 5 m) variations in soil or crop status would cause some noise in the relationships of GLAI or modelled outputs to observed yields. On a larger scale (10 m), more heterogeneity was induced by the 8 different agronomic treatments received by the crop, and applied along strips parallel to the sampling strips visible on Figure 1. Other sources of variation include the effect of the slope, which influences crop interception of radiation and the relationship of the red to near-infra-red ratio to GLAI (Boissard et al., 2001). Lastly, some limiting factors might have occurred between June, 8th and harvest (e.g., water stress or take-all damages). Thus, GLAI should also be monitored during this period, as well as before anthesis since earlier sampling would be more

efficient at correcting the crop model. Multi-date collection of radiometric GLAI should therefore be favoured in future experiments.
Regarding the integration of GLAI maps into the model, better improvement might be expected with assimilation techniques in which the model would be inverted so as to fit the GLAI data.

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FIGURES

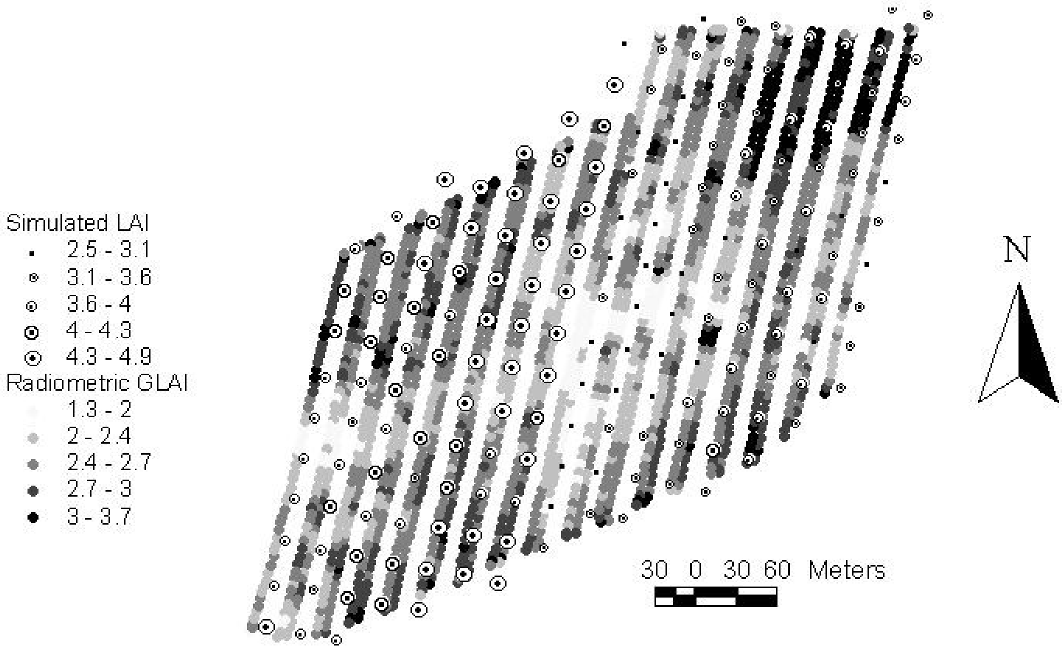

FIGURE 1: Map of radiometric GLAI values (closed dots) overlaid with point simulations of LAI on June, 8th (open circles). Some points fall outside the measured strips since portions of the field were not covered.

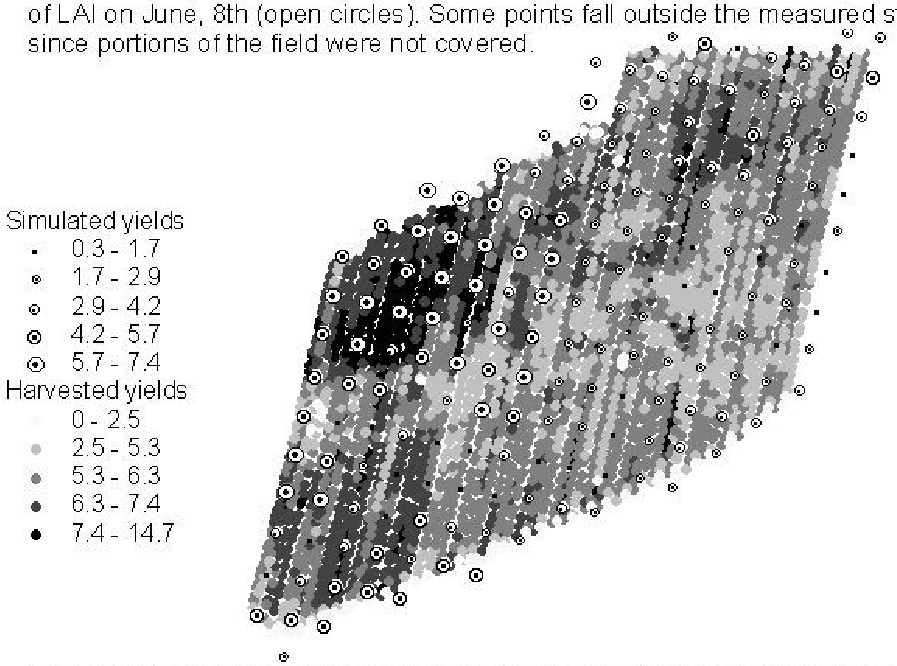

FIGURE 2: Map of combine-harvested yields (closed dots) overlaid with simulated yield data along the square soil sampling grid (open circles).