Modelling

« Virtual plant » models

To better understand the development of a leaf disease or growing conditions of a wheat crop, scientists are now making use of virtual plants. These sophisticated models simulate the interaction of a plant's behaviour and variations in its environment.

By measuring the geometry of annual crops, we see that the cessation of tiller production is linked to the perception of the light reflected by the other plants.

Crop models allow one to understand and simulate the growth of cultivated plants. They give rise to numerous applications: predictions of growth stage, crop management, diagnosis of an earlier cropping disorder.
However these tools have certain limitations. For example they were developed for uniform and unchanging environments *(figure 1)* and thus represent interaction with the environment in a very simplified way.
They do not take account of plant morphology or the differences between plants within the crop.

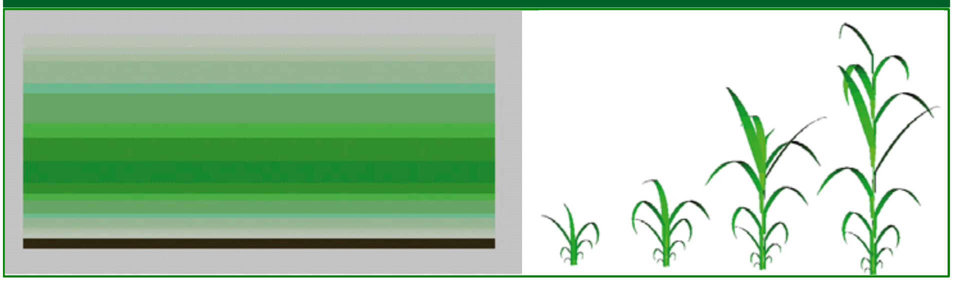
Simulating feedback loops

However, the environment and the resources available to a plant vary according to the way its neighbours modify the physical environment, notably by removing the available resources. To avoid these limitations, approaches known as « virtual plants » have developed, which help us to understand plant behaviour.

With this approach, the plant stand is seen as a collection of plants, each of which interacts with the environment which it perceives. These complex approaches bring together models simulating plant behaviour and the physical exchanges within the crop canopy, and make it possible to simulate the environment (radiation, temperature, soil moisture) perceived by each of the plant organs.

With these approaches, it becomes possible to represent the plant stand as a population of individual plants which develop in parallel.

Visual difference between a crop model and a virtual plant model *(fig. 1)*



Whilst a crop model is generalised and based on the canopy (left), the virtual plant approach is specific to the plant (right, here simulated by the Adel-maize model). A crop model reconstructs a continuous environment (in layers) whereas 3D technology makes it possible to take account of the micro climate on the scale of the organs

The architecture of a wheat crop arises from the emission of tillers and differs from one variety to another, which can influence the development of diseases.

Being immobile, plants adapt to their environment by means of strong plasticity, conferred by their modular organisation. To a certain extent, plants can be seen as a set of organs functioning in parallel. Each evolves according to the environment in which it finds itself. The environment of a plant is characterised by global variables (daylength, gravity) and by local variables, distributed over the architecture of each plant, (light, temperature, humidity, nutrient concentrations etc.). These variables change constantly over the course of time, notably according to the development of neighbouring plants, their shade, and that of the plant itself (self-shading, phototropism). Each plant perceives, responds to, and in its turn modifies the physical environment which surrounds it and its neighbours. For example the leaf nitrogen content is adjusted to the radiation perceived by the leaf, and the most brightly illuminated leaves are the most efficient for photosynthesis.

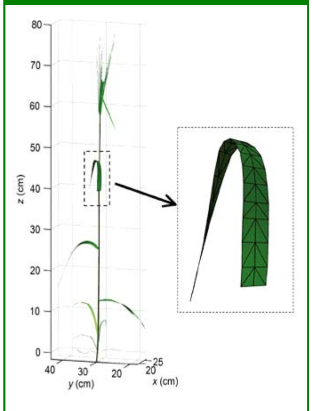
The orientation and growth of leaves, stems and roots also varies according to the temperature, rainfall and irradiance.

« Virtual plant » models simulate the consequences for a plant's behaviour of variations in its environment.

The plant can adapt its strategy for resource capture according to its local environment.

The « virtual plant » approach makes a major contribution here: to explicitly simulate these «feedback loops».

Digitisation of a barley tiller in 3D – the plant organs are represented by groups of points connected by triangles *(fig. 2)*



Here a barley stem is simulated with the model developed by T. Dornbusch at the University of Halle (Germany).

Calculating the perceived light

These approaches require a knowledge and description of four elements: the establishment of the canopy architecture, the relation between organs, and the physical environment and geometry of the organs. For example, for wheat, the rate of establishment of the canopy can be described simply with a variable called the phyllochron, which corresponds to the temperature sum required between the appearance of two successive leaves on the main stem of the plant. Tiller production, root extension and leaf appearance also follow the same rule. Another example on wheat: the relation (length, for example) of one leaf to another are stable: it is enough to know the size of certain leaves in order to know that of all of them, making it possible to simply describe the sizes of the leaves of a given stem or of successive tillers from a small number of measurements *(figure 2)*. INRA scientists have thus developed the Adel-maize and Adel-wheat models.

The possible applications of these approaches are numerous. Recently, on wheat, they have shown that the cessation of tiller production is linked largely to the perception of the light reflected by the other plants: this perception enables the plant to anticipate the competition from its neighbours, even before the competition begins: it avoids producing a large number of tillers which then would not survive. Similarly the virtual plant approaches, by their capacity to describe the establishment of the architecture, could make it possible to extrapolate the daily evolution of the leaf area index from a few well-targeted measurements (some leaf dimensions at key stages, for example). Collaboration between INRA (National institute of agronomical research) and ARVALIS – Institut du vegetal on this subject is just about to begin. On sugar beet, ITB (technical institute for sugar-beet) has been working for 3 years on the architecture model Greenlab, developed by groups from the Ecole Centrale Paris, INRA and CIRAD.

Sugar beet in 3D *(fig. 3)*

The Greenlab-sugar beet model is used to « trace » the transfers of sugars within the plant.

Variety and sowing density affect the Septoria incidence in fields.

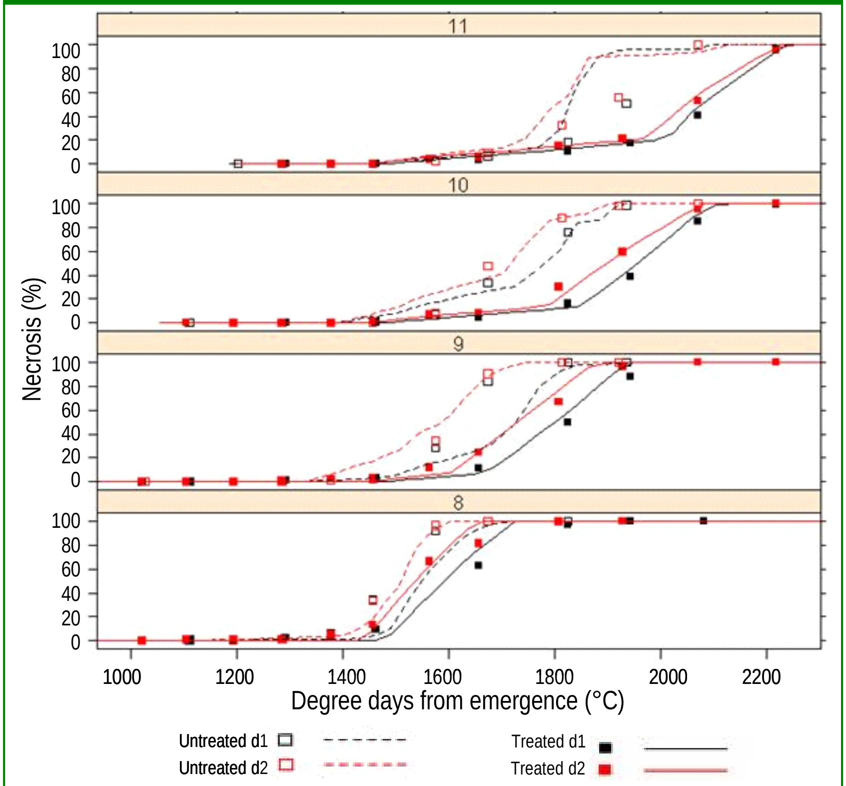
In Greenlab-sugar beet, the plant is seen as a group of organs: a root organ made up of a taproot and foliar organs whose development and growth are staggered over time *(figure 3)*.

Unlike classical crop models, the response to a stress does not affect the whole leaf compartment, but only the organs which have suffered this stress, and this is the whole point of the architectural approach.

A better knowledge of the interaction between a plant canopy and its environment can help us to refine models of the development of diseases or insects.

The model is used to « trace » the transfers of sugar within the plant and to understand how these are modified under stress.

Comparison of data simulated with Septo3D and observed on a trial carried out at La Minière (78) in 2005-2006 *(fi g. 4)*



The curves represent the simulated data. The points are for the observed data.

Interactions with diseases

Another field of application concerns crop diseases. Some of these diseases have cycles which interact strongly with the plant canopy. This is notably the case with Septoria on wheat: the upper leaves of the plant are infected following the transport by rain splash of spores present on the lower leaves. The penetration of the raindrops towards the base of the canopy where the symptoms are found, and the proportion of splashes reaching the upper leaves depend on the crop architecture.

Eventually we hope to understand why, under certain conditions, practices such as the choice of sowing density can bring about a reduction in the disease. This approach could also help to identify certain varietal architectures which deter the disease. Hence INRA has developed the model Septo3D by coupling a simulation model of Septoria with the Adel-wheat model. Early work with this model shows a potential interest in identifying the architectural traits which most influence the disease. It is being followed up by collaboration between ARVALIS - Institut du végétal and INRA to validate the model *(figure 4)*, financed through a national project (Casdar n° 6128) project as part of the Mixed Technology Unit PIVERT.

By taking account of the complex processes and including environmental stresses, the virtual plant approach expands the application domain of these models. The work involved envisages numerous applications to better understand tillering and hence yield elaboration and sensitivity to lodging, to define the factors in the development of a disease or study the effect of stress.

To find out more, visit: http://www.egc.grignon.inra.fr/pages-fr/ressources/texte-web-andrieu.Pdf

David GOUACHE
d.gouache@arvalisinstitutduvegetal.fr

Bruno ANDRIEU (INRA)
Bruno.Andrieu@grignon.inra.fr

Fabienne MAUPAS (ITB)
fabienne.maupas@itbfr.org

From Perspectives Agricoles n° 353 Feb.. 2009