2003 BELTWIDE COTTON CONFERENCES, NASHVILLE, TN – JANUARY 6-10

DEVELOPMENT OF COMMON LANGUAGE TO ALLOW TECHNICAL EXCHANGE AMONG CROP MODELS USERS

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Abstract

The variability of options, points of view and requirements attached to the choice of one of the numerous available tools for crop management, leads to difficulties in technical exchanges among model users. Difficulties arise from the choice of the output and from the different representations of mechanisms adopted by the different users. The approach currently being explored by the CIRAD Cotton Program is to develop new interfaces consistent with user representation as output of the complex crop model COTONS. To illustrate this approach, an example is presented showing soil representation involved in the water balance. Tensiometers were chosen to represent the grower's point of view to schedule crop water requirements. Modeller's point of view is a two compartment representation as adopted in many models compared to a 2D soil representation as in COTONS. By definition, an interface does not change the way phenomena are simulated, but how the output is presented. In that sense, no modification was done to the water balance processes such as evapotranspiration, root growth rate, runoff and percolation that are all simulated by COTONS. The task was then limited to calculate the fraction of available soil water content (FTSW) as proposed by Sinclair and Ludlow (1986) in accordance to the cell and the layer soil representations and to propose an empirical method to link the modelling output to the observed soil water depletion. To deal with this problem, it was proposed to consider a minimum weight of root per cell as limit of the effective rooting depth (ERD). While FTSW is widely used in modelling to quantify soil and plant water status (Sadras and Milroy, 1996), the output water stress index proposed by COTONS (WSTRS) depends on mean cell water potential during the day, the average daily air temperature and the net radiation. As a result of the work being done, comparisons revealed little difference between FTSW calculated in accordance to the 2 compartments and soil cell representations. Differences between water stress indices were however shown in South France climate conditions between WSTRS and FTSW as radiation and air temperature started to limit plant transpiration later in the season.

Introduction

In the past several years, models have been developed for most industrial crops such as CERES-Maize and CORNF for corn (Jones and Kinery, 1986 ; Stapper and Arkin, 1980), GLYCIM and SOYGRO for soybean (Acock and Trent, 1991 ; Hoogenboom *et al.*, 1992), PNUTGRO for peanut (Boote *et al.*, 1989), and GOSSYM and COTONS for cotton (Baker *et al.*, 1983; Jallas, 1998). Most of these tools are detailed physiologically based models that simulate the physiological phenomena at the process level. Despite their interest in crop management, the experience of the authors at CIRAD's research community, shows that except within the teams where these models were developed, they are little used by other scientists and growers. In parallel to complex plant models, simple models have been developed and utilized successfully for examining regional yield potential and production risks. A simple and robust crop model for soybean was developed by Sinclair (1986) using crop phenomenological and crop physiological frameworks. This modelling approach has been generalized and used on other crop such as sorghum (Hammer and Muchow, 1991), maize (Muchow *et al.*, 1990) peanut (Hammer *et al.*, 1995) and is planed to be developed on cotton by CIRAD. A third family of decision support systems is based on field observations of soil or plant status. Measures of soil depletion (Devitt, 1983) or crop canopy temperature (Idso, 1981) to schedule water supply, plant mapping as proposed by COTMAN ™ (Cochran *et al.*, 1998) for N and regulators supplies, are examples of this family of tools.

The variability of options, points of view and requirements attached to the choice of one of the numerous available tools for crop management, leads to difficulties in technical exchanges among model users. The main reason behind Hammer *et al.* (1995) to develop a simple peanut model while PNUTGRO already exists, is to create a tool that is easy to interpret and use. Hammer's *et al.* assertion underlies that the coincidence between developers and users representation of mechanisms is a way to face technical exchanges problems. From this experience, a hypothesis can be formulated that appropriate outputs must be referred to users representation of the different determinants that lead to a result. The approach currently being explored by the CIRAD Cotton Program is to develop new interfaces consistent with users representation as output of the complex crop model COTONS.

To illustrate this approach, an example is presented showing soil representation involved in the water balance. Tensiometers were chosen to represent the grower's point of view to schedule crop water requirements. The soil is considered as a reservoir characterized by a volume and a water content in which water content measurements and experience about soil characteristics allow the water management access. The reference simple model used is the one developed by Lecoeur and Sinclair's (1996) that considers the soil as an horizontal layer which depth is limited by the effective root depth (ERD) and water content defined by the fraction of available soil water content (FTSW) as proposed by Sinclair and Ludlow (1986). In that representation, the roots, water and nitrogen distributions are supposed to be isotropic within the layer and FTSW is the water stress index considered as suggested by Ritchie (1981).

COTONS uses the same 2D soil representation of GOSSYM (Boone *et al.*, 1995). The soil is divided in cells that exchange water and contains growing absorbing roots. This representation allows an anisotropic distribution of roots, water and nitrogen within the profile which is required to treat spatial distribution problems such as competition, root disease or localized soil compaction. However, the evaluation of the available water to the plant become more difficult to figure out than and that the water stress index used as output becomes a combination of the soil water status, the air temperature and the net radiation. This paper describes the development of a common interface to allow sharing water stress index outputs according to grower's layer and cell soil representations.

Material and Methods

COTONS' Soil Representation and Water Stress Indicator

COTONS uses RHIZOS soil and water module (Boone *et al.*, 1995) to simulate water and nutrient budget in row crops and between two rows. It divides the profile into cells and computes the water budget for each cell (figure 1). Water can flow in and out every cell based on water potential. RHIZOS does not have an infiltration function and uses the curve number method to simulate runoff and infiltration. It simulated the saturated flow based on the bucket gravitational flow concept and unsaturated flow based on an analytical solution to Richard's equation. COTONS also simulates root growth, root distribution and water and nutrient uptake based on some empirical functions.

Plant Water Stress

COTONS evaluates plant water stress as:

$$\text{WSTRS} = (-2.5 / (\text{soilWaterPot} - 1.6)) + (0.0005 * \text{soilWaterPot} * \text{tempDay}) - (0.001 * \text{netRadiation})$$

FTSW Output Evaluation

By definition, an interface does not change the way phenomena are simulated, but only the output. In that sense, no modification was done to the water balance variables such as evapotranspiration, root growth rate, runoff and percolation that are all simulated by COTONS. The task was then limited to calculate FTSW in accordance to the cell and the layer soil representations and to propose an empirical method to link the modelling output to the observed soil water depletion.

FTSW is the ratio of the actual transpirable soil water to the total transpirable soil water (TTSW) explored by roots. As discussed by Sadras and Milroy (1996), the higher and the lower limits of soil available water vary depending on species and soil properties. Within the range of soils usually of interest to cotton production and in accordance to usual representation of growers, TTSW is assumed to be the difference between the soil water content at field capacity and permanent wilting point. In that case, FTSW is calculated as:

$$\text{FTSW}_t = \frac{(\text{SWS}_t - \text{SWS}_{pw})}{\text{TTSW}_t}$$

where FTSW_t is the fraction of transpirable soil water for Day t, SWSt is the soil water storage for Day t, SWS_{pw} is the soil water storage at permanent wilting point and TTSW_t is the total transpirable soil water for Day t.

Soil Cell Rrepresentation

Some ambiguity exists in representing the volume of soil to take in account as COTONS considers capillary flows between cells. COTONS water stress index considers the mean water potential of all cells containing "capable of uptake" roots (CU roots). In accordance with that option, FTSW_{cell} was calculated on a soil volume corresponding to the sum of all cells containing CU roots whatever their dry mass is.

Soil Layer Representation

The option was to simulate a soil water status in a soil layer using COTONS. Reference soil representation is that of Lecoeur and Sinclair (1996). The soil is considered as a reservoir with two compartments, whose relative sizes vary in time with root growth. The first compartment, explored by the roots, contains the available water reserve for plants. This compartment is supplied by rainfall and irrigation. Water loss from this compartment is due to deep percolation and evapotranspiration as calculated by COTONS. Deep percolation occurs when the amount of water received in a compartment exceeds that of its reserve, which corresponds to its field capacity. The soil in the second compartment is supplied by the percolation from the first compartment and water loss due to deep percolation.

The depth of the first compartment, which changes at the expense of the second compartment, is determined by the ERD i.e. the depth of the layer of soil in which the plant is able to access the available soil water (Lacape *et al.*, 1998). Sadras and Milroy (1996) discussed the ERD variation in relation with growth and ontogeny is a key variation of PAW (Ritchie, 1981) among authors. In COTONS, water uptake from each cell is a function of CU roots dry mass per cell. It appeared then consistent with the ERD notion to introduce a minimum CU roots mass value per cell above which the presence of root is considered as being effective. ERD could be defined then as being the progression of the deepest cell containing the minimum CU root mass value.

The link to the field observations was done using an empirical estimation of root presence revealed by tensiometric measurement in the soil. Root activity results in increasing soil water potential at the different depth where tensiometers are placed. A threshold value of 15 cb is assumed to correspond to root colonization of the concerned depth. Empirical approaches of ERD consisted then of the progressive depth of passing over the threshold value of 15 cb as roots grow deeper.

Field Reference

The field reference runs came from Montpellier CIRAD Research Station (South of France). The climate is north Mediterranean, characterized by a short season with average day temperatures less than 20°C starting from early September, as shown on figure 2 for 2002 conditions. The simulations used corresponds to 2002 weather conditions under a deep loamy soil. Variety DES 119 is conducted under a moderate water deficit throughout the season, on bare soil and without any application of crop regulators. No N deficit was observed nor detected by the simulation.

The reference observed data provided from 11 experimental plots corresponding to 1996 and 1997 at two field locations but more or less the same soil type and water regime compared to 2002. Observations consisted of bi-weekly tensiometric readings with a set of 3 Watermark (Irrometer and co.™) installed at 30, 60 and 90 cm depth.

Results

ERD Consideration

To illustrate the method, an output was generated for the CU root mass contained in the cells vertically located under the crop row. Figure 3 shows the CU roots mass evolution within the concerned cells as a function of thermal time, at different soil depth (every 20 cm) for a 2002 moderate water deficit conditions. After a rapid growth phase, mass per cell decreases to reach a plateau till the end of the simulation. For the example shown, the maximum UC root density is observed in the 40 upper soil cm. The level of the different plateaus decreases drastically under 60 cm depth. For the deepest cells, maximum CU root mass are respectively, 0.0326 and 0.0035 mg for 1 and 1.2 m. Under this condition, the adoption of a minimum CU root mass value of 0.2 mg results in a maximum ERD value slightly superior to 1 m.

Different ERD curves can be obtained in relation to the different minimum CU mass per cell tested. Figure 4 shows the ERD obtained with minimum CU root mass per cell of 0, 0.1, 0.2 and 0.3 mg, as a function of thermal time. Stresses occurring during the growing cycle resulted in growth delays that did not much affect the general linear shape of the ERD curves. This result is consistent with Dardanelli *et al.* (1997) observations for other plant species. Increasing minimum CU mass values resulted in delaying ERD curves in time and a reduction of the maximum ERD but does not affect the slopes. Figure 4 also show the 11 observed values of root presence detected using the tensiometric empirical method. Obtained for the same soil and plant variety, results show a range of variability that decrease respectively from 160 CDD at 30 cm to 100 CDD at 90 cm. Precision of the method do not allow a determination of the impact of the location and year on ERD evolution. However, despite the lack of precision, the observation of the relative position of the different ERD curves in reference to observed data allows the determination of a suitable value of CU minimum root mass per cell which appears to be 0.2 mg for the example shown.

Water Stress Index Consideration

While FTSW is widely used in modelling to quantify soil and plant water status (Sadras and Milroy, 1996), the output water stress index proposed by COTONS (WSTRS) depends on mean cell water potential during the day, the average daily air temperature and the net radiation. The first question that arises is about the difference between both options. Comparison between WSTRS and $FTSW_{cell}$ (cell soil model) is shown on figure 5 for the 2002 simulation example. Evolution of both indices as a function of thermal time show the same general trend until 1050 CDD. However, WSTRS presents higher instability compared to FTSW, only soil water status related. After 1050 CDD, COTONS shows that low thermal and radiation conditions (see figure 2) reduce the sensibility of cotton plants to soil water deficit.

Other questions that arise are related to the difference between $FTSW_{cell}$ and $FTSW_{2c}$ from cell and layer soil representations, respectively. Figure 5 shows the evolution in thermal time of $FTSW_{cell}$ and $FTSW_{2c}$ as affected by a minimum CU root mass of 0.2 mg. In accordance to ERD empirical observations, the reduction of soil volume considered in the calculation of $FTSW_{2c}$ slightly emphasises the water stress in comparison to $FTSW_{cell}$ and even WSTRS until 720 CDD. After the time corresponding to the complete colonization of the layer by CU roots, there is no difference between $FTSW_{cell}$ and $FTSW_{2c}$.

Conclusion

There is no need to insist on the importance of technical communication for mutual enrichment of the different actors of agriculture development. However, the diversity of representations and concepts at the basis of the numerous existing tools induce a problem for technical exchanges among those actors. Experience presented in this paper to address this issue shows that the development of appropriate interfaces for common output could be a solution. The contribution of the complex model COTONS to FTSW consideration according to grower's observation and simple soil representation is an example of the interest of the method and the same work is being done on the "nodes above white flower" concept (NAWF). Similarly, this work will hope to allow communications concerning other mechanisms simulated by COTONS or other models that could be of interest to improve technical exchange. Expected too, is the diversification of reference data sets that could be used to calibrate the crop models.

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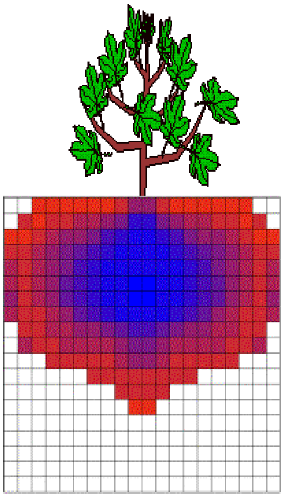

Figure 1. Soil representation of CU roots in COTONS.

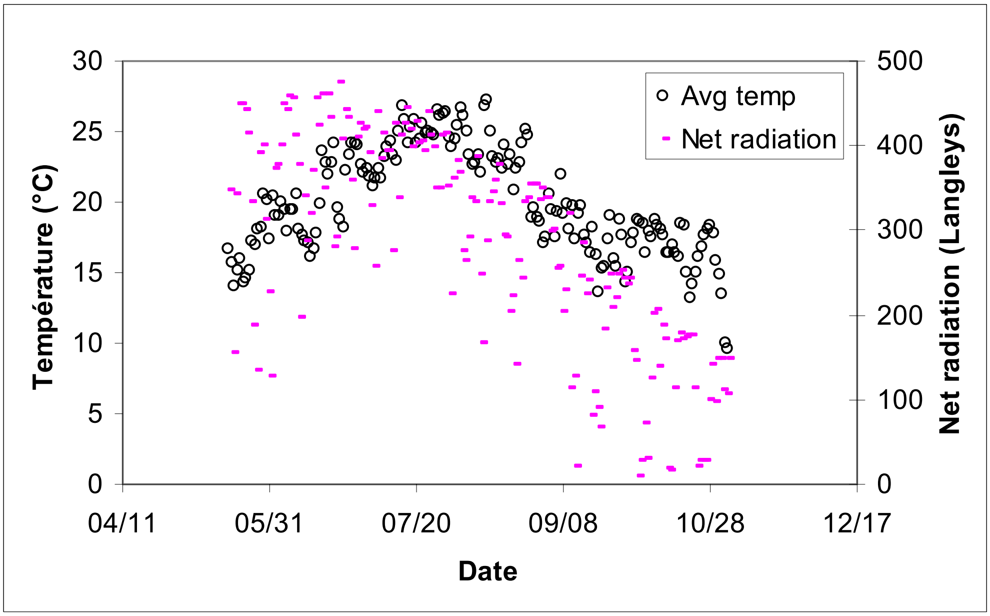

Figure 2. Temperature and solar radiation data, Montpellier (France) 2002.

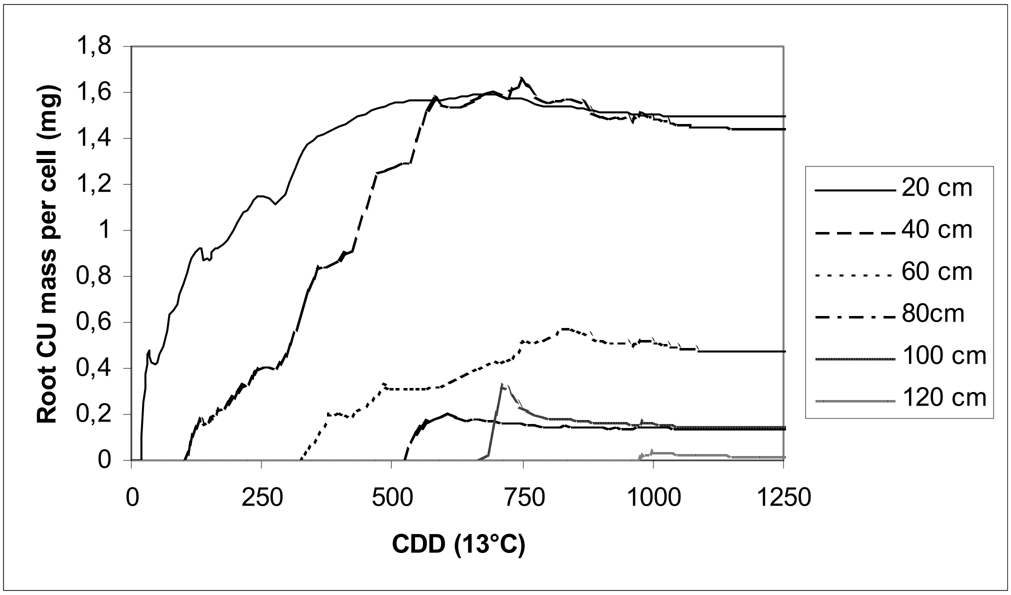

Figure 3. Mass of roots capable of uptake located below a plant at different depths in the soil.

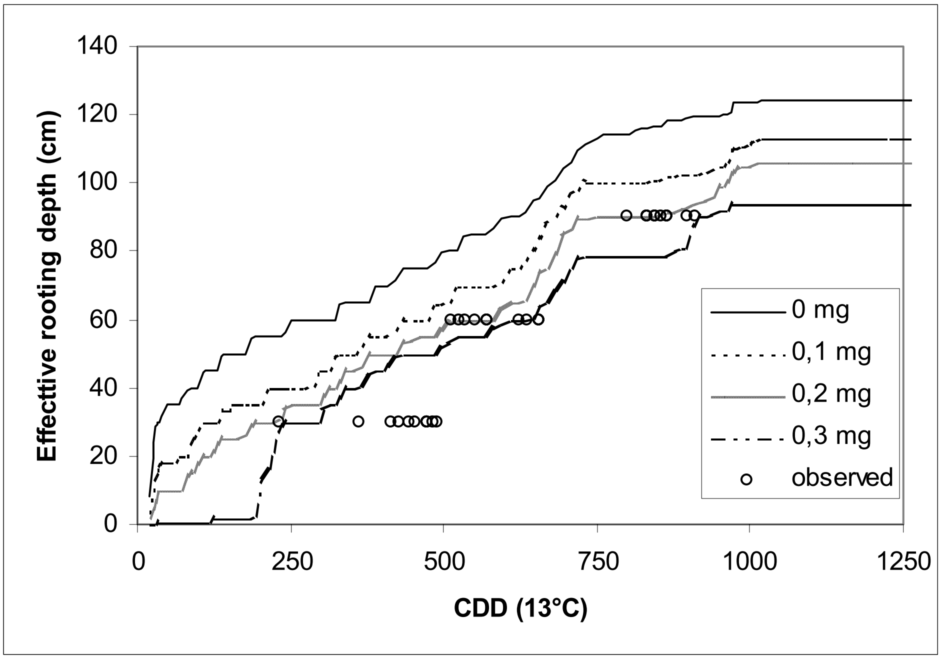

Figure 4. ERD for various critical effective CU root mass simulated by Cotons and observed values of root activity measured by tensiometers.

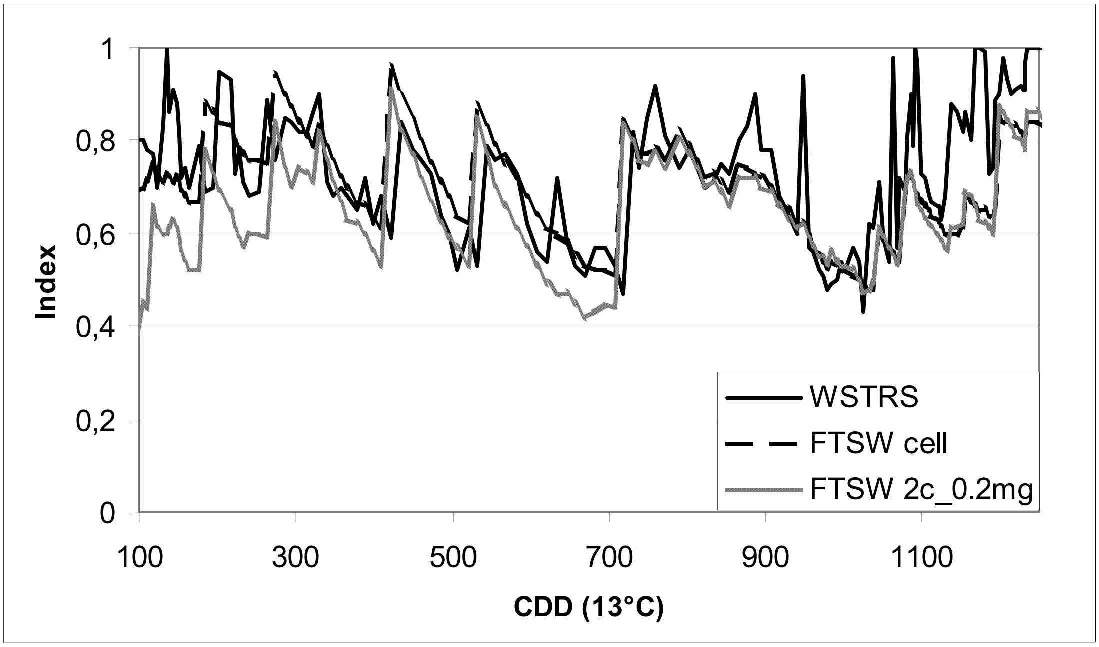

Figure 5. Water stress indices comparison.