Characterizing soil hydraulic properties from Sentinel 2 and STICS crop model

Lammoglia S.K.
UMR System
CIRAD/INRA/Supagro-Montpellier
Montpellier, France
karen.Lammoglia@cirad.fr

Chanzy A.
UMR EMMAH
INRA/Université D'Avignon
Avignon, FranceCountry
Andre.chanzy@inra.fr*
correponding author

Guerif M.
UMR EMMAH
INRA/Université D'Avignon
Avignon, France

Abstract: Soil Water storage Capacity (SWC) is an important quantity in the field of hydrology and agronomy, but SWC characterization using classic method is often impossible due to soil spatial variability. In this study we take profit of the new capacities offered by the Sentinel 2 mission, which allows characterizing relevant features in vegetation dynamic linked to stresses and particularly water stresses. In addition, yield map offers an additional source of information. Both yield and vegetation development are sensitive to several factors as the water supply, nitrogen supply, crop installation quality or pest. To isolate the influence of the water supply, and therefore access parameters involved in the SWC, it is necessary to invert a crop model able to simulate the observation together with the representation of most influencing factors. After a sensitivity analysis, we have developed an inversion procedure of the STICS crop model. The procedure was tested on non-irrigated durum wheat in a Mediterranean context in southeastern France. The approach was evaluated on heterogeneous field. Soil heterogeneities are well captured by the method, but some heterogeneities interpreted as soil heterogeneities might be artefacts induced by other factors. A multiyear analysis is then necessary to get the permanent features that are most likely linked to soil properties.

Keywords: soil hydraulic properties, remote sensing, crop model, yield map, inversion, Sentinel 2

I. INTRODUCTION

The characterization of soil hydraulic properties such as the soil water storage capacity (SWC) is essential in hydrology or agronomy to establish the soil water balance and thus represent the hydrological functioning of a territory and/or the dynamics of a crop. SWC spatial variability is often strong resulting from heterogeneity in texture and structure as well as soil depth. In situ measurement of SWC is expensive, destructive and cannot be considered over a large area as it requires very large sampling plans. Therefore, the characterization of SWC by non-destructive and implementable on large area is a means of addressing the mapping issue. Remote sensing is one of the possible approaches. It allows determining soil properties by inverting surface functioning models such as soil-vegetation-atmosphere transfer models or crop models. Remote sensing provides access to surface moisture, the evolution of which being determined by surface flows and water flows within the soil profile which are governed by soil hydraulic properties [1]. Remote sensing also provides access to canopy characteristics (evapotranspiration, leaf dynamics) reflecting the functioning of plant cover, which may be influenced by the availability of soil water[2, 3].

In this work we wish to take advantage of Sentinel 2 mission acquisitions whose short revisit time, its exhaustive spatial coverage and its high spatial resolution constitute a significant advance making it possible to closely monitor over time the dynamics of the vegetation cover and thus characteristics strongly involved in the water and carbon cycles such as the fraction of radiation absorbed by plants (FAPAR) or the foliar surface (LAI). In the case of field crops, yield maps are also interesting information as yield is an "integrator" of different stresses encountered throughout the plant cycle as water stresses. While water conditions have an impact on foliar development and yields, other factors such as cultivar, crop establishment quality, nutrient availability and plant health hazards are also likely to have an effect. The challenge is therefore to be able to separate these factors in order to extract the effect of water conditions and thus have access to SWC. For this purpose, the use of a culture model such as STICS [4] is necessary. Indeed, the model allows simulating the observed variables (LAI, FAPAR and yield) by taking into account the main factors (nitrogen supply, crop establishment, crop variety).

The purpose of this study is to develop a method to characterize SWC based on sentinel 2 images, yield map and the STICS model. The challenge is then to analyze how a model such as STICS, which involves a very large number of parameters, can be used in an operational context. This leads to define an inversion strategy that takes the main factors of variation into account.

II. MATERIAL AND METHODS

The study was conducted on durum wheat crops in the Avignon region (southeastern France). Durum wheat is non-irrigated and generally suffers from water stress at the end of the crop cycle. Soils of the region are alluvial soils with variations in texture and depth linked to the history of the river which deposited heterogeneous materials generating sharp soil variations. A set of 7 plots were monitored, 6 of which were cultivated by a farmer equipped with a yield monitoring device and 1 on the INRA research center. The study was conducted over the period 2016-2018, offering the possibility on some plots of having two years with a wheat crop.

Remote sensing data were acquired by sentinel 2 satellites. The images were processed by BOKU (Vienna, Austria) with the application of atmospheric corrections and the production of a cloud mask. The LAI and FAPAR were calculated using a neural network applied to the 2, 4 and 8[5] bands at the resolution of 10 m. Field observations were made in pits (3 to 5 pits per plot) where soil depth and texture were systematically observed. SWC was measured on 5 of the 7 plots. On the INRA plot, which has a high degree of soil depth heterogeneity, a geophysical campaign was carried out to characterize the electrical resistivity over 3 possible layer thicknesses.

The STICS crop model was used with the following assumptions:

- Most of the parameters are fixed to the default values given with the model distribution.
- The agricultural practices calendars are known
- The parameterization of the durum wheat was already established on independent data sets
- The quality of the crop implantation was simulated by playing on the sowing depth which may have an impact on plant density and emergence date and the sowing density.
- Variations in soil nitrogen supply were taken into account by tuning the initial nitrate content and the organic nitrogen content. Other mineral elements are not taken into account in STICS and therefore neglected in the study
- Soil moisture initialization was done at the beginning of September with levels are fixed according to the previous crop, mainly distinguishing between irrigated crops (canned tomatoes) and non-irrigated crops (wheat, sunflower).

Prior to the inversion method design, a sensitivity analysis was made using the Morris method[6] considering soil thickness, SWC in unit layer, sowing depth, sowing density, soil initialization (water and nitrogen) and organic nitrogen content. The inversion was done using the GLUE method [6] a Bayesian approach which allows exploring the parameter field within an a priori distribution.

III. Results

The sensitivity analysis highlights the role of the climatic year, which is not always favourable for characterizing soil properties. This is particularly the case in rainy years at the end of the wheat cycle. With the exception of the initialization of soil moisture, all the investigated parameters may have a significant influence on yield. It is therefore important to have an inversion method that can separate the effects of the different parameters.

With regard to foliar development (LAI, FAPAR), the relative influence of each factor varies over time. Thus, at the beginning of the cycle, the parameters used to simulate the quality of crop establishment are the only ones that have an influence. The influence of parameters related to SWC is mainly expressed at the end of the crop cycle with differentiation in the rate of LAI senescence and the crop yield. Over the rest of the cycle, all the parameters have an influence with nevertheless a relative importance of each parameter that changes according to the climatic years.

Soil thickness and SWC per unit layer both contribute to soil SWC. It has been shown that the value of the SWC is the main factor influencing the calculation of yield and leaf development, while the way in which the SWC is established is less important. Thus, we can limit the number of parameters to be calibrated by focusing either on the soil thickness or the SWC per unit horizon according to the a priori knowledge we have on the soil. Concerning the parameter used for the crop installation parameters, it has been shown that even if the effects of the two parameters are strongly correlated, there is an adding value in maintaining the estimation of both parameters. Finally, for the soil nitrogen effect, it has been established that the determination of the two parameters, the initial soil nitrogen and the soil organic nitrogen, is not necessary, the initial nitrogen content of the soil being sufficient to represent the influence of the soil with regard to nitrogen nutrition. The inversion procedure is therefore as follows

- sowing depth and sowing density are determined from data acquired before March 1
- The determination of the other parameters is made using the LAI or FAPAR values of the following period together with the yield

The evaluation of the results was carried out by directly comparing the inverted SWC with field measurements. Another evaluation was done by comparing the spatio-temporal patterns of the LAI/FAPAR and the yield simulated by STICS by applying the determined SWC to simulate crop development and yield during a different climatic year. Results have shown that when the soil has heterogeneities, these are well captured by the method. However, we also observed that some spatial structures that do not coincide with the reality in the ground. This might be due to the effect of factors such as phytosanitary problems, deficiencies in fertilizing elements not simulated by STICS or a factor that is not properly taken into account (moisture initialization). One way to limit the erroneous detection of spatial structures would be to accumulate the results over years in order to eliminate spatial structures that would only be detected over one year.

IV. Conclusions

This paper has shown that LAI or FAPAR time series combined with yield map on yield enable mapping of effective SWC feature when water stress affects the crops. However, other factors might affect foliar dynamic and yield that led to artefacts in SWC determination. Crop models offer a mean to consider part of those factors and it has been shown that the STICS model is able to represent the quality of the crop installation and the nitrogen supply together with constraints on water supply. This was possible in an operational context, where most of the model parameters were set to default parameters. Multi-year analysis might be a mean to limit residual artefacts generated by pest and plant health. The study also underlines the importance of having frequent image acquisition, as it allows capturing short-term features as the senescence rate which appears as an important proxy of the availability of water in the soil.

REFERENCES

[1] Wigneron, J.-P., A. Chanzy, J.-P. Calvet, A. Olioso and Y. Kerr (2002). "Modeling approaches to assimilating L band passive microwave observations over land surfaces." Journal of Geophysical Research 107(D14).

[2] Guérif, M., Houlès, V., Makowski, D., Lauvernet, C., 2006. Data assimilation and parameter estimation for precision agriculture using the crop model STICS. In: Wallach, D., Makowski, D., Jones, J.W. (Eds.), Working with Dynamic Crop Models. Elsevier.

[3] Sreelash K. et al. 2012, Parameter estimation of a two-horizon soil profile by combining crop canopy and surface soil moisture observations using GLUE, Journal of Hydrology, Volumes 456–457, Pages 57-67

[4] Brisson N, Gary C, Justes E, Roche R, Mary B, Ripoche D et al. 2003. European Journal of Agronomy, 18, 309-332.

[5] Weiss, M., Baret, F., Leroy, M., Hautecoeur, O., Bacour, C., Prevol, L., Bruguier, N.: Validation of neural net techniques to estimate canopy biophysical variables from remote sensing data, Agronomie-Sciences des Productions Vegetales et de l'Environnement, 22(6), 547-554, 2002.

[6] Morris M., 1991, Factorial sampling plans for preliminary computational experiments, technometrics, 33(2), pp 161-174

[7] Makowski, D., Wallach, D., Tremblay, M., 2002. Using a Bayesian approach to parameter estimation; comparison of the GLUE and MCMC methods. Agronomie 22, 191–203