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Coupling Sentinel-2 images and STICS crop model to map soil hydraulic properties

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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. This study aims 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.

Material and Methods

The study was conducted on durum wheat crops in the Avignon region (South-Eastern France). A set of 7 plots was monitored, 6 of which were cultivated by a farmer equipped with a yield monitoring device and 1 on the INRA research centre. Remote sensing data were acquired by sentinel 2 satellites. The LAI and FAPAR were calculated using a neural network applied to the 2, 4 and 8 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. The parameterization of the soil moisture initialization in STICS model was set up at the beginning of September depending on the previous crop. Prior to the inversion method design, a sensitivity analysis was made using the Morris method 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 a Bayesian approach, which allows exploring the parameter field within an *a priori* distribution.

Results

The influence of each investigated factor on foliar development varies over time. The crop establishment parameters are more influential at the beginning of the crop cycle. The influence of parameters related to SWC is mainly expressed at the end of the crop cycle with a difference 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 change according to the climatic years. All the investigated parameters had a significant effect on the annual yield. It is therefore important to have an inversion method that can separate the effects of the different parameters. 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, 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, 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 is sufficient to represent the influence of the soil with regard to nitrogen nutrition. Comparing the inverted SWC to field measurements, we showed that the SWC was well characterized, in particular, when the soil has strong heterogeneities. Some spatial structures that do not coincide with the reality in the ground. This might be because STICS model do not simulate crop diseases or deficiencies in fertilizing elements. To limit the detection of those erroneous spatial structures, we simulated crop development in a different climatic year using the determined SWC.

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Conclusions

This study showed that the inverse use of the STICS model with time series of Leaf Area Index (LAI) retrieved from remote sensing enable mapping the soil water storage capacity (SWC), in particular in water stress conditions. 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 the STICS model is particularly 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 diseases. The study also underlines the importance of having high frequency Sentinel-2 images, as it allows capturing short feature as the senescence rate, which appears as an important proxy of the availability of water in the soil.

Keywords: crop model, remote sensing, soil water storage capacity, Sentinel-2.