Simple and spatialize approach to optimize irrigation water and wheat yield in the semi-arid areas

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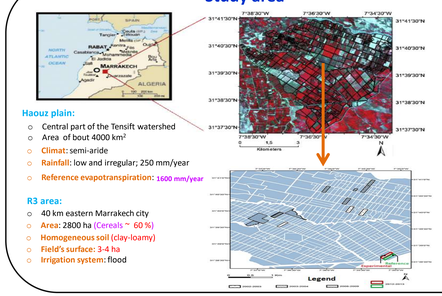
Abstract

Population growth and the associated increase in demand for food have led to an urgent need for efficient agricultural production monitoring systems. Furthermore, southern Mediterranean, water shortage is likely to be one of the main pressing problems, resulting from combined effects of alterations in the hydrological cycle, anticipated under climate change, and of the increase in water demands, especially for agriculture.
The objective of this study is to develop a simple and spatial approach, based on remote sensing data, to optimize water irrigation and cereal production (dry matter DM and grain yield GY) in the semi-arid areas. The proposed method is based on the three efficiencies model of Monteith (1972). It consists of converting of solar radiation to the DM by the climate (ε_c), interception (ε_i) and conversion (ε_{conv}) efficiencies. The proposed method combines the maximum of both ε_i and ε_{conv} (noted ε_{imax} and $\varepsilon_{convmax}$) into a single parameter denoted ε_{max}, calculated as a function of cumulated growing degree day (CGDD). Also, the stress coefficient K_s, which affects the conversion of the absorbed solar radiation to the biomass, was derived from the surface temperature or the FAO-56 water balance at the root zone. In addition, the expression of K_s has been improved to optimize water irrigation amount and cereal production. It has been shown that the value 0.7 of Ks is considered as a suitable threshold for triggering irrigation in semi-arid areas. Otherwise, the developed method proposes a variable Harvest Index coefficient (HI) for partitioning the dry matter developed, between straw and grain. Since the ear apparition, the evolution of HI is derived from CGDD whereas, the final harvest Index (HI_0) is estimated from the maximal value of Normalized Difference Vegetation Index (NDVI)). The developed model has been calibrated and validated on both semi-arid regions (Haouz in Morocco and Kairouan in Tunisia). The obtained results showed a good agreement between observed and estimated DM and GY values. Average values of R^2 and RMSE are about 0.98 and 0.35 t/ha for DM and 0.98 and 0.19 t/ha for GY, respectively.

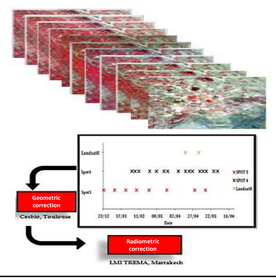
Materials and methods

Study area

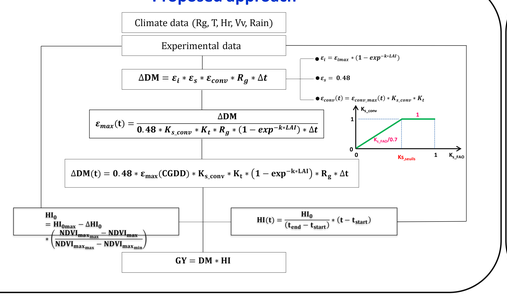


Experimental data

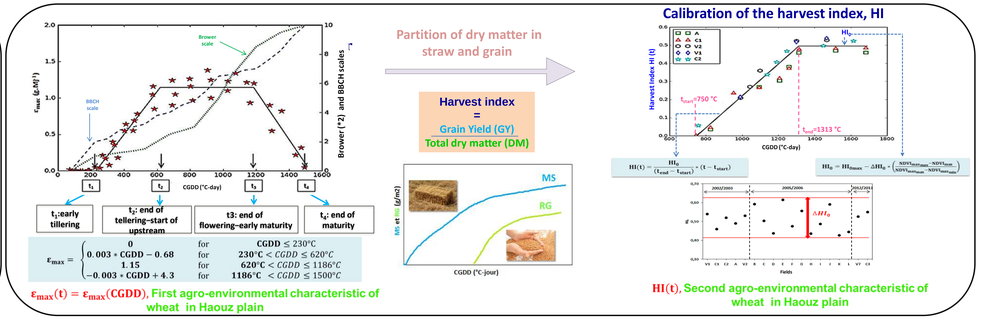
Remote sensing data



Proposed approach



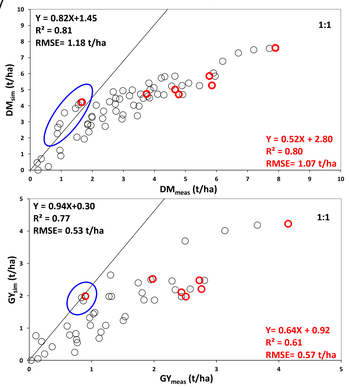
Calibration of the developed yield estimation method



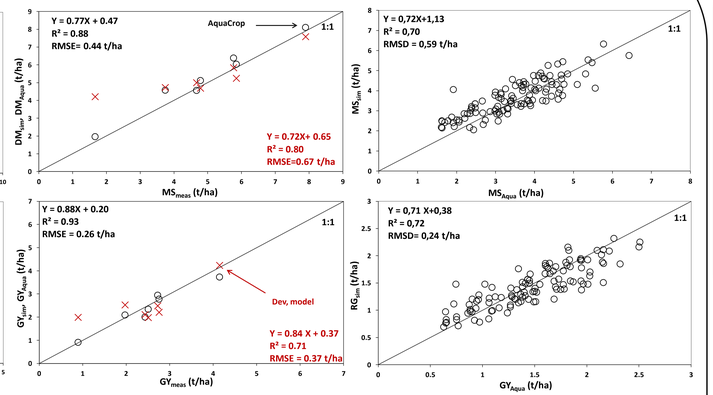
Validation of the developed yield estimation method

Haouz plain, R3 area (Morocco)

Validation at the field scale, *field observations*



Validation at the field scale, Comparison with AquaCrop model



❑ The obtained results show a good consistency between the simulated and observed yields for the dynamic (black circles) and final (red circles) for both DM and GY. The correlation coefficients are close to 1 and the RMSE values are low with comparison to the average observed yields. The encircled values are due to the wild oat developed in one field during the 2002/2003 season.

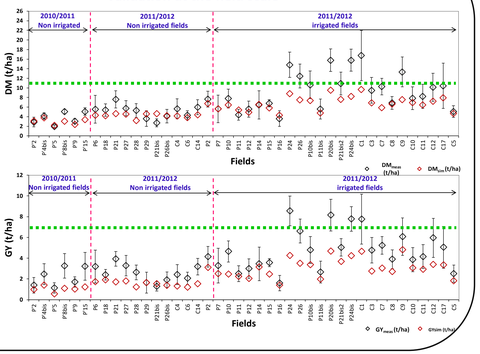
❑ The performance of the proposed model was tested against the AquaCrop model (more complex). The first comparison was made to retrieve the final yields (DM and GY) observed on 7 fields. Despite its simplicity, the statistical performances (R^2, RMSE and regression line) of the developed model are close to those of the AquaCrop model. The second comparison was made on 112 fields for which the observed yields are not available but we have the necessary data to implement both models. Here also, the performance of our simple method is very encouraging.

❑ In addition, the proposed approach was compared to a very simple NDVI-based relationship. The results obtained show that the developed method retrieved well the observed grain yield values along the wheat seasons. This stability is very interesting by comparison to the NDVI-based relationship known by its instability from year to year and from site to another.

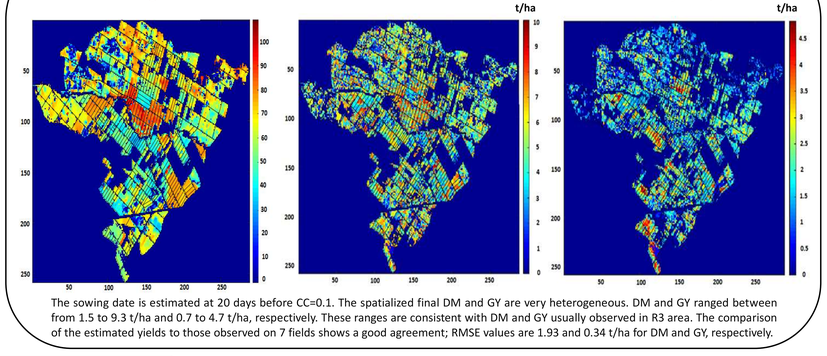
Kairouan plain (Tunisia)

For the Kairouan plain, the developed model is used without local calibration. Despite this, the proposed model shows a good accuracy to reproduce the final yields of dry matter (DM) and grain (GY) mainly for DM less than 11 t/ha and less than 7 t/ha for GY, respectively. However, there is an underestimation for a high yields. This could should be corrected by a local calibration which can be imposed by NDVI saturation, although we estimate that some observed yield values are above the maximum values obtained in the region.

Validation at the field scale



Model spatialization, R3 zone



The sowing date is estimated at 20 days before CC=0.1. The spatialized final DM and GY are very heterogeneous. DM and GY ranged between from 1.5 to 9.3 t/ha and 0.7 to 4.7 t/ha, respectively. These ranges are consistent with DM and GY usually observed in R3 area. The comparison of the estimated yields to those observed on 7 fields shows a good agreement; RMSE values are 1.93 and 0.34 t/ha for DM and GY, respectively.

Conclusion

As conclusion of this work:
- The proposed approach is simple and spatialize; the interception and conversion coefficients are calculated by combining meteorological data, sum of temperature, Leaf Area Index (LAI) and a threshold stress coefficient for starting irrigation ($K_{s,threshold}$).

- The test of this approach showed good performance:
• At the filed scale, in Morocco and Tunisia, RMSE values low than 0.98 t/ha and 0.35 t/ha for DM and GY, respectively.
• At the regional scale (R3 zone, 2800 ha) RMSE values are about 1.18 and 0.54 t/ha for DM and GY, respectively.
• The accuracy of the simple proposed approach is consistent with the performance of AquaCrop model (relatively more complex).

Acknowledgements

This work was conducted within the frame of the International Joint Laboratory TREMA (http://trema.ucam.ac.ma/). The authors wish to thank the projects: REC (grant agreement no: 645642), the ANR AMETHYST project (ANR-12-TMED-0006-01), the SAGESSE project (Projets Prioritaires de Recherche PPR - Type B) and ERANETMED03-62 CHAAMS.