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# Assimilating leaf area index time series into a simple crop growth model to estimate effective rooting depth and soybean yield

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**Abstract.** Soil water holding capacity is the main determinant of soybean yields in rainfed agriculture in the pampas region. Estimating water holding capacity is challenging, and the capacity to measure it over large areas is limited. The main goal of this work is in advancing in methods to estimate maximum effective root activity depth (RDMAX) as a proxy for water holding capacity based on inverse modeling of crop growth, relying on the assumption that it is the main factor accounting for variations in crop growth. For that purpose we used a simple model developed by Campbell and Diaz (1988). The model was inverted to estimate RDMAX, using TOA NDVI time series (Landsat 7 ETM+ and Landsat 8 OLI) as input while holding other parameters describing the site and crop fixed (i.e. planting, emergence and maturity dates, and dry matter water ratio). The model was also modified to estimate grain yield, assuming linear increase in harvest index and senescence driven by nitrogen remobilization from the above ground biomass. The model was tested at five fields where soybean was grown for six growing seasons. RDMAX was calibrated obtaining an estimate of RDMAX for each year and each pixel within a field independently. Comparison across years and sites suggest that general patterns are estimated correctly, in particular in normal years (not too wet, not too dry). The use of a simple model with few parameters to adjust proved useful in achieving sufficiently reliable and robust estimates of final RDMAX and grain yield.

**Palavras-chave:** remote sensing, soil water holding capacity, root depth, sensoriamento remoto.

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## 1. Introduction

Soil water holding capacity (WHC) is the main determinant of soybean yields in rainfed agriculture in our region. Estimating WHC is challenging, and the capacity to measure it over large areas is limited. Remote sensing tools offer the opportunity to overcome some of these challenges. The main goal of this work is in advancing in methods to estimate WHC or maximum effective root activity depth (RDMAX) based on inverse modeling of crop growth, relying on the assumption that it is the main factor accounting for variations in crop growth.

## 2. Materials and methods

We used a simple model of crop growth and soil water balance developed by Campbell and Diaz (1988). The model was inverted to estimate maximum rooting depth, using leaf area index time series as input while other parameters describing the site and crop remained fixed (i.e. planting, emergence, flowering and maturity dates and soil parameters). Among all parameters related to WHC and plant available water, we selected to calibrate RDMAX because it is the parameter that accounts for the majority of the variation in plant available water. RDMAX is the maximum of an exponentially decaying root density function that in the model, defines how water extraction is distributed within the soil profile, therefore it could be understood as the maximum effective root activity depth for the growing crop.

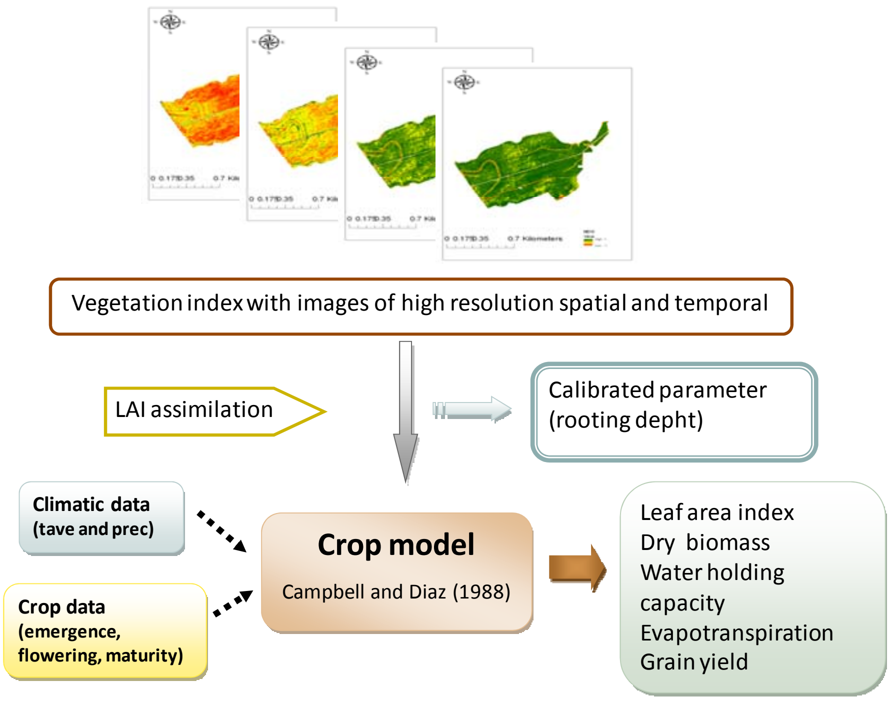


Figure 1. Conceptual scheme of data assimilation of leaf area index from high resolution images into a simple crop model.

The model was also modified to estimate grain yield, assuming linear increase in harvest index and senescence driven by nitrogen remobilization from the above ground biomass (Sinclair and Amir, 1992). The allometric relationship used to estimate the increase in leaf area index through above ground biomass, was adjusted with field data collected during 2011-

2015. With the same data also functions to estimate leaf area index from NDVI and above ground dry mater from leaf area index were derived.

Five agricultural fields in Uruguay were selected based on cropping history and data availability (Landsat path-row 225-83). These sites had soybean in all years during six growing seasons, and complementary information about the crop was available (planting date, cultivar, R5 date, physiological maturity, and grain yield). The closest weather station was used to obtain rainfall, maximum and minimum air temperatures.

For each field, we selected cloud free Landsat 7 ETM+ and Landsat 8 OLI images when available, generating a time series of 5 to 7 images during the growing season. Using TOA NDVI from these images the model was run (inverted) for each pixel individually, yielding an estimate of the parameter RDMAX and also an estimate of grain yield for the pixel. Estimates for each pixel are independent from neighboring pixels and depended only on the evolution of the NDVI time series, and the fit of the model to them, considering the evolution of soil water balance and crop growth. We did not gap-fill the SLC-off gaps; therefore there was some missing data in the images producing bands of outliers in the output.

## 3. Results and discussion

The model adequately simulates the evolution of LAI, potential evapotranspiration, actual evapotranspiration, aboveground dry matter and grain yield (data not shown) when run in forward mode. After calibration of key parameters determining growth and yield, the model was inverted against the image time series yielding estimates of RDMAX and grain yield (Figure 2 and 3, one site shown as example).

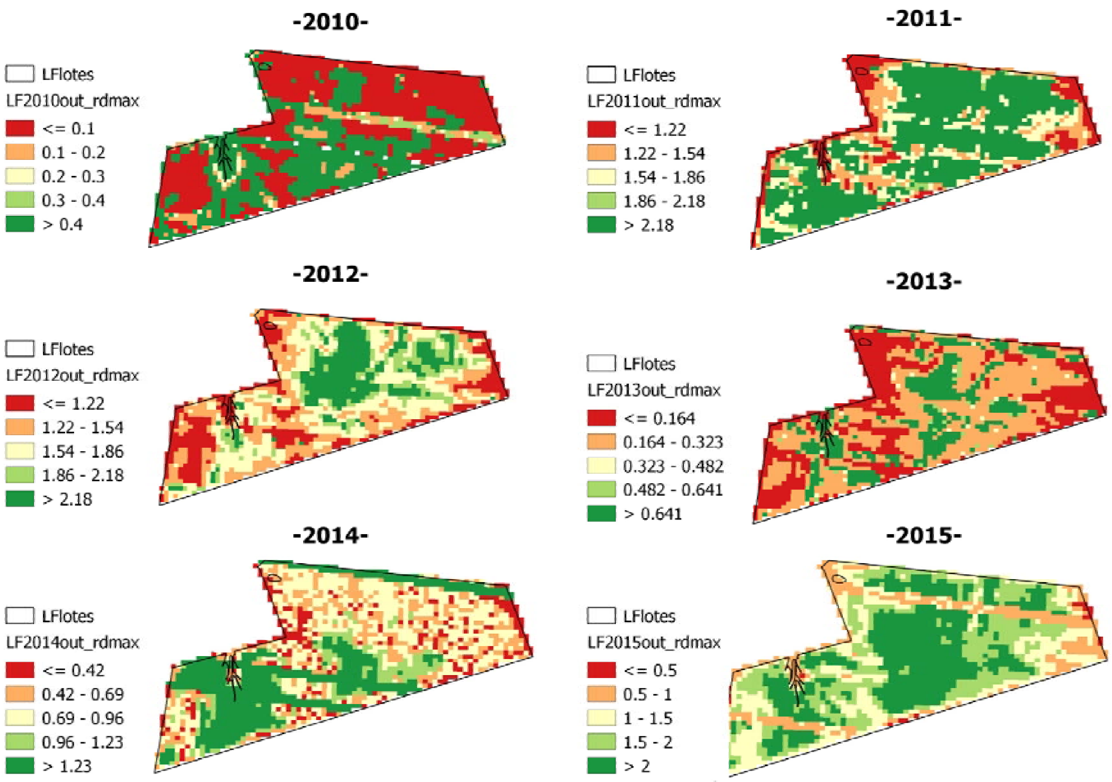


Figure 2. Estimates of RDMAX in meters for LF site across years.

Estimates of RDMAX for the site LF varied across years in range, but in general when comparing them, the patterns of RDMAX were maintained across the field. Only in two years

(2010 and 2013) the observed values for RDMAX were constrained within a narrow range (0-0.6m) probably associated with a poor fit of the model due to small number of images (2010) and conditions of high rainfall (2013) where the crop even with a small RDMAX (in the model) was able to grow successfully. On the contrary, in the other years, the patches with large and small values of RDMAX are repeated and appear in the same areas of the field. These areas correspond to areas where the large observed leaf area was only possible if deep root exploration occurred and areas where shallow root exploration was enough to maintain and grow the observed amount of leaf area. The same behavior is also observed when comparing the values of RDMAX across years (average for all sites) (Figure 3), dry years like 2011 and 2015 present larger values of RDMAX, while wet years show smaller RDMAX values.

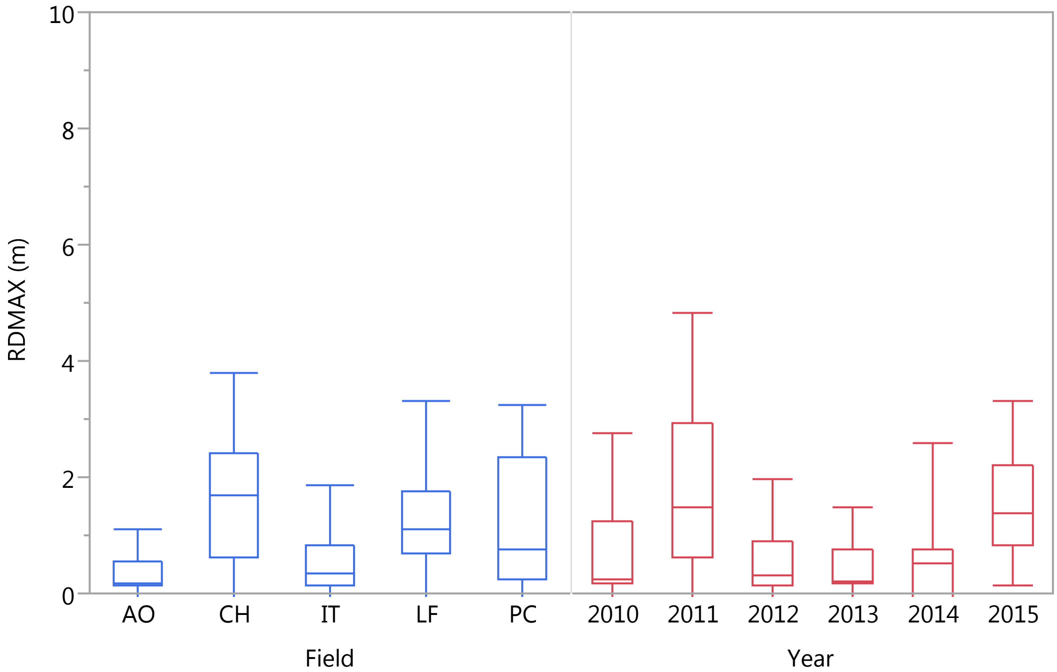


Figure 3. Estimated RDMAX for all sites and years of simulation.

Not surprisingly grain yield followed closely the observed patterns of RDMAX (Figure 4). Simulation of deeper soil exploration was clearly associated with larger accumulation of leaf area, biomass and higher yields.

Clear differences in RDMAX are found across sites, suggesting shallower depths in AO and IT compared to the rest.

RDMAX seems to be a good choice of parameter to estimate among the ones we tested, because the inversion is stable, and fitted parameters vary within a range similar to the expected values for the soils present at the sites.

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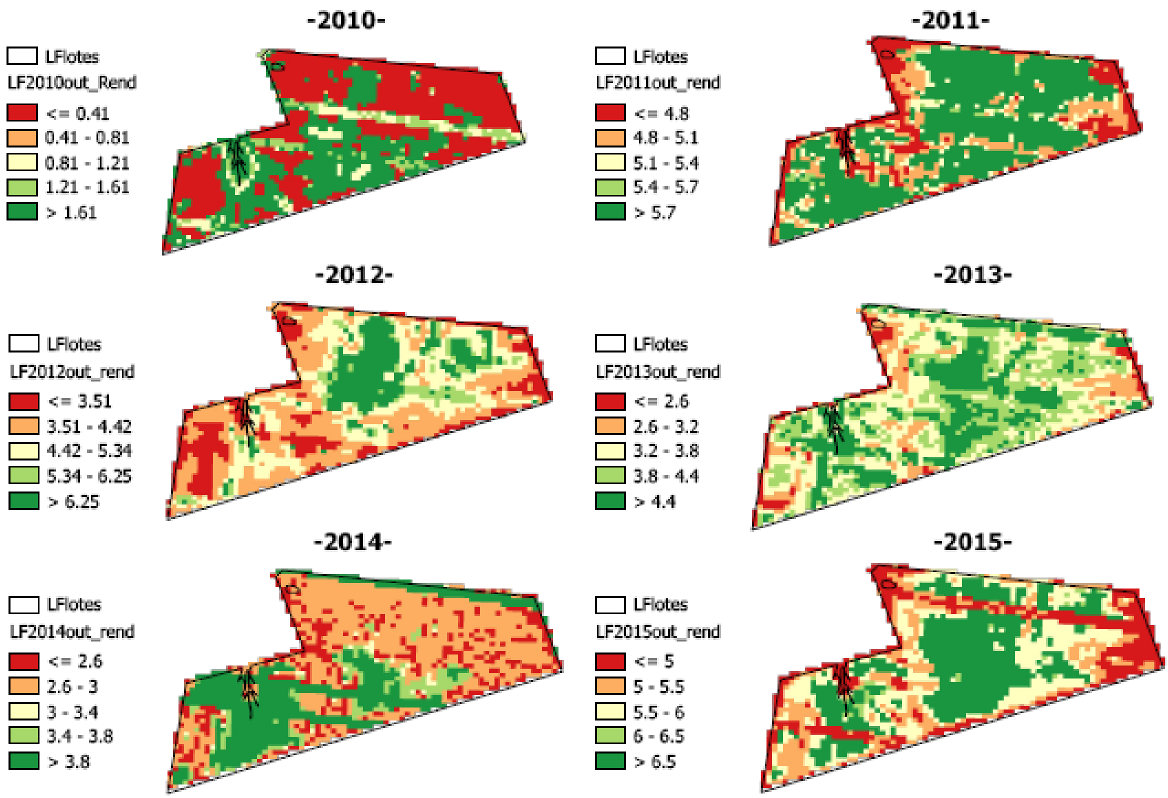


Figure 4. Estimates of grain yield (kg $ha^{-1}$) for LF site across years.

## 4. Conclusions

The use of a simple model with few parameters to adjust proved useful in achieving sufficiently reliable and robust estimates of grain yield and maximum effective root activity depth.

The assimilation of data from high resolution multispectral images into crop models is a powerful tool to estimate pre-harvest grain yield and to separate regions within the field differing in yield potential.

## Acknoledgements

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