Evaluation of the temporal dynamics of spectral indices and their relationship with biophysical variables on wheat for the purpose of yield estimation

Andres G. Berger [1]
Deborah Gaso [1]
Veronica S. Ciganda [1]
Alvaro Otero [2]

[1] INIA La Estanzuela
Ruta 50 km 11, 70000 Colonia, Uruguay
aberger@inia.org.uy, vciganda@inia.org.uy, dgaso@inia.org.uy

[2] INIA Salto Grande
Camino al terrible, Salto, Uruguay
aotero@inia.org.uy

Abstract. Early crop yield estimation is extremely relevant to assist on management decisions and to plan harvest logistics and commercialization. The purpose of this study is to evaluate the ability of widely reported spectral indices to estimate leaf area index (LAI) and total above ground biomass (DW) through the season, and their capacity to provide useful information for crop yield estimation. Particular emphasis is placed in identifying indices that can estimate the biophysical parameters of crops that accumulate large amounts of DW and LAI. The study site located in the south west of Uruguay was planted with wheat cultivar Biointa1006. From emergence until maturity the site was imaged approximately every 15-20 days with a UAV carrying a multispectral camera with channels in the green, red and NIR regions. Three indices were estimated, NDVI, NDVIgreen, CIgreen. Approximately at the same date of the flight sampling points were visited, DW and LAI were measured. The evolution of indices resembled the evolution of LAI and DW accumulation. CI_green was the index that discriminated better differences in LAI at zadoks 4.7, while NDVI showed a diminished ability to reflect increments in LAI after zadoks 3.0. Results suggest that there is a trade off among indices, between indices that show a tight relationship to biophysical variables but loose sensitivity at larger LAI or DW, and those that maintain sensitivity but present more error. Further analysis is necessary to confirm these hypotheses and evaluate different methods of yield estimation based on remote sensing and biophysical models combined.

Palavras-chave: remote sensing, UAV, yield estimation, wheat, leaf area, aboveground biomass

1. Introduction

Early crop yield estimation is extremely relevant to policy makers, farmers and consultants that use it to plan harvest logistics and commercialization. It is also, when done at the field scale, extremely relevant for management and for the identification of low yielding areas within a field, in which targeted actions usually have the highest profit and impact in increasing mean yield. In this case, high resolution images obtained from UAV provide both the temporal and spatial resolution necessary, and are increasingly being used by farmers and service providers. Among the most notable challenges for the use of this technology are: i) image calibration; ii) the relationship of biophysical variables with remote sensing estimates; and iii) the interpretation and incorporation of biophysical parameters into models used for yield estimation and decision making (Lelong et al. 2008). The present work focuses mainly on the last two points.

It is common practice for yield estimation to combine remote sensing with models of different degree of complexity (Laguette, Vidal and Vossen, 1995; Moriondo et al. 2007; Patel et al. 2006; Wang and Lin, 2005). Thus the precision of yield estimation methods is usually directly linked to the precision of remote sensing in estimating biophysical variables related to yield or yield directly. NDVI has been widely used for this purpose (Moriondo et al. 2007), but there are other indices that have been reported to better relate to biomass, leaf area index or yield (Gitelson, 2012). Examples of those are the ones that include spectral bands in the red edge region, or in the green region.

The purpose of this study is to evaluate the ability of widely reported spectral indices to estimate leaf area index and biomass through the season, with particular emphasis in identifying indices that can estimate the biophysical parameters of crops that accumulate large amounts of biomass and leaf area.

2. Materials and methods

The study site was located at 33°34’44S latitude and 58°10’06W longitude in the south west of Uruguay. The site has been managed with continuous no-till agriculture with standard management practices, and a crop rotation that typically includes a winter cereal (wheat or barley) and a summer crop (soybean or maize). Wheat cultivar Biointa1006 was planted on 23 May and emerged 7 June 2012. From emergence until maturity the site was imaged approximately every 15-20 days with a UAV (ADP-Aerovision) flying at an altitude of 600m, carrying a multispectral camera (miniMCA, Tetracam Inc.). Images were taken around solar noon on cloud free days. The camera has six spectral channels, from which three were selected for this study: green (546-556 nm FWHM), red (657-667 nm FWHM), NIR (826-836 nm FWHM).

Within the site 13 sampling points were selected, based on prior knowledge of the location of low and high yielding areas, in an attempt to have representative samples of the different regions that could possibly be observed within that field. Each sampling point was visited at approximately the same date of the flight, and total above ground biomass (DW, Kg ha^{-1}) samples were collected at three locations within a 10m distance from the sampling point. Also in the same locations, leaf area index (LAI, m^2 m^{-2}) and fractional ground cover was measured with a ceptometer (AccuPAR, Decagon Devices).

Three indices were estimated for each image, NDVI, NDVIgreen, CIgreen, according to equations 1, 2 and 3 and the values of each index corresponding to each sampling point was extracted in order to construct a time series for each sampling point that could be correlated to the biophysical parameters measured in the destructive samplings.

$$NDVI = (NIR-Red)/(NIR+Red) \quad (1)$$

$$NDVIgreen = (NIR-Green)/(NIR+Green) \quad (2)$$

$$CIgreen= (NIR/Green)-1 \quad (3)$$

This data will be used to both calibrate the general relationships between indices and biophysical parameters, and to feed into crop models that will simulate the growth of the crop during the growing season. The models selected are Safi (Duchemin et al. 2008) and Gecros (Yin and vanLaar, 2005). Safi is a simple model that follows the accumulation of biomass and leaf area and estimates biomass accumulation using radiation use efficiency. Gecros on the other hand is a fully developed dynamic crop model, which simulates all components of the soil-plant-atmosphere continuum in a mechanistic way. Gecros has the disadvantage that it is more sensitive to initial conditions than Safi, but has the advantage that simulates all factors involved in yield determination, and thus can presumably better simulate the grain filling period of wheat. They represent a simple and a complex approach towards the assimilation of remotely sensed data into a crop model for the purpose of yield estimation.

3. Results and discussion

The site was imaged from planting until booting, on 9/7, 20/7, 13/8, 22/8, 12/9, 1/10 which corresponded with the zadoks growth stage of Z1.0 (emergence), Z 1.3 (three leaves), Z 2.2 (two tillers), Z 3.0 (start of stem elongation), Z 3.3 (three nodes), Z 4.7 (booting) respectively. Figure 1 shows sample images for selected dates. Productivity within different parts of the field was extremely variable, as shown on images and measurements at sampling points.

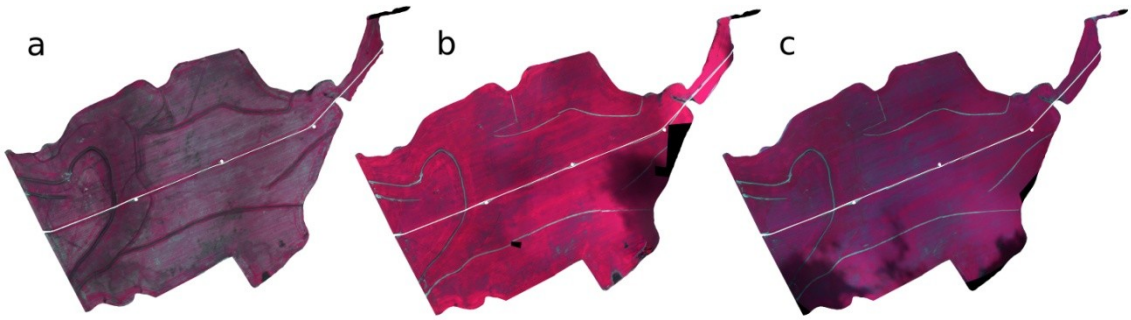


Figure 1. Sample false color images collected at Zadoks 2.2 (a), Zadoks 3.3 (b) and Zadoks 4.7 (c).

The evolution of indices resembled the evolution of leaf area index (LAI) and total above ground biomass accumulation (DW), with exponential increments early in the season and a plateau as the crop reached anthesis time (Figure 2). CI_green was the index that discriminated better differences in biomass at Z4.7, while NDVI showed a diminished ability to reflect increments in biomass and LAI after Z3.0, which approximately corresponded to LAI of 2, in agreement with previous studies (Gitelson, 2012). This behavior can also be seen

on figure 3 and 4, where NDVI plateaus at LAI between 2-3 and DW between 2000-3000 kg ha^{-1}.

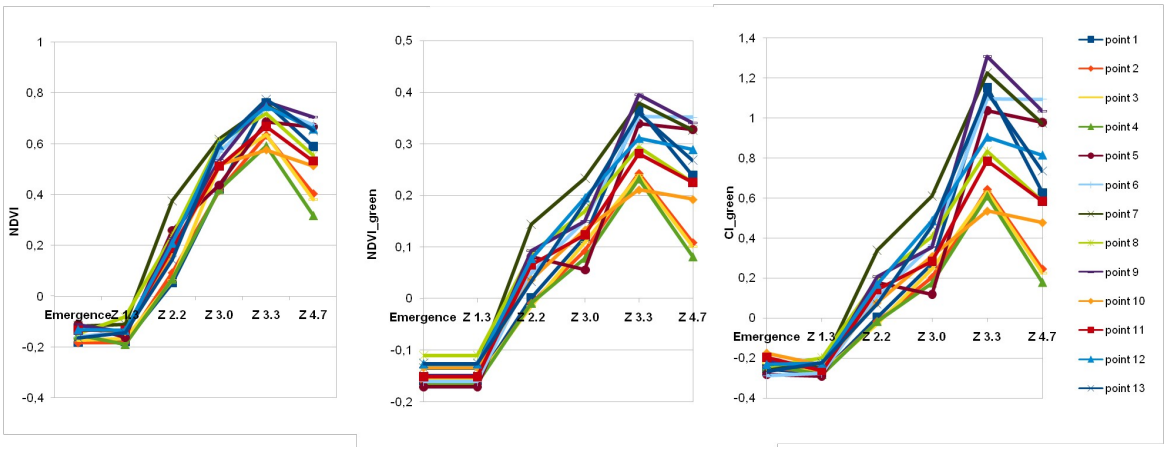


Figure 2. Temporal evolution of selected spectral indices through the growing season.

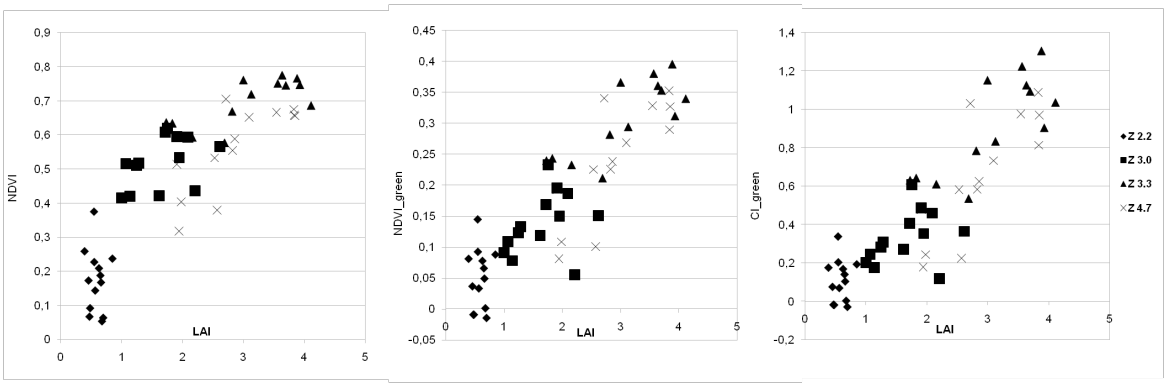


Figure 3. Changes in NDVI, NDVI_green and CI_green at different growth stages as a function of leaf area index (LAI)

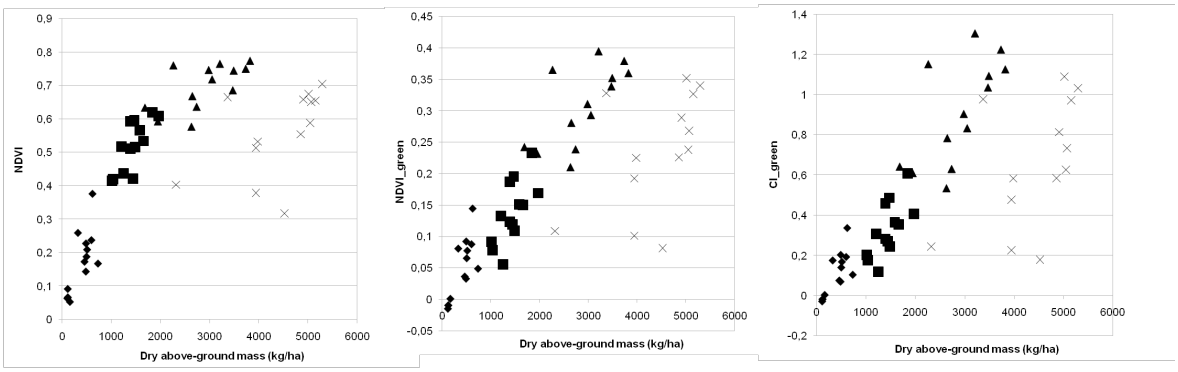


Figure 4. Changes in NDVI, NDVI_green and CI_green at different growth stages as a function of total above-ground mass.

Both NDVI_green and CI_green are sensitive beyond the limits where NDVI plateau, however the dispersion showed by these indices is significant, and comparably larger than the dispersion showed by NDVI at low LAI and DW levels. Also it is noticeable that the dispersion observed for DW is significantly larger than the dispersion observed for LAI,

suggesting that it is more difficult to estimate DW than LAI. That is likely related to the accumulation of DW in non-leaf components (spike and stem), which start to increase from Z3.0 until anthesis, and becomes the only fraction accumulating DW after anthesis.

4. Conclusions

Results suggest that there seems to be a trade off among indices, between indices that show a tight relationship to biophysical variables but loose sensitivity at larger LAI or DW, and those that maintain sensitivity but present more error. In the context of yield estimation, on one hand, it appears that methods based on NDVI will have a significant amount of error, unless they are combined to a model to project through the growing season LAI and DW estimates based on NDVI early in the season. On the other hand, methods based on CI_green, will be more accurate, even if the index is used to estimate LAI or DW late in the growing season. Further analysis and data from the site yet to be collected, is necessary to confirm these hypotheses and evaluate different methods of yield estimation based on remote sensing and biophysical models combined.

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