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Canopy reflectance indices: A new tool for assessing durum wheat LAI and yield

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SUMMARY – The aim of this work was to study the potential of using canopy reflectance indices to provide accurate and non-destructive estimates of leaf area index (LAI) and grain yield in durum wheat (*Triticum turgidum* L. var. *durum*). Reflectance from the vegetation was measured at four growth stages, from booting to milk-grain, in twenty five genotypes under irrigated and rainfed conditions in Lleida (NE Spain). The vegetation indices SR, NDVI, SIPI and WI were calculated from durum wheat crop reflectance. LAI was measured at each sampling time, and grain yield was determined at maturity. Correlation coefficients between LAI and the spectral indices were lower under irrigated than under rainfed conditions. NDVI seemed to be the best index for the assessment of LAI, especially in the rainfed environment. Significant positive correlations of NDVI and SR with grain yield were observed when both trials were considered together. In contrast, the relationship of WI and SIPI with grain yield was negative. These results suggest that spectral vegetation indices may be useful tools for predicting changes in LAI and grain yield in environments or crop stages with LAI values <3.

Key words: Remote sensing, integrative physiological traits, durum wheat.

RESUME – *"Indices de réflectance du couvert végétal : Un nouvel outil pour l'évaluation de l'indice de superficie foliaire et rendement du blé dur". L'objectif de ce travail a été d'étudier la validité des indices de réflectance du couvert végétal, comme méthode non-destructive et précise, d'évaluation de l'indice de superficie foliaire (LAI) et du rendement en grains du blé dur (*Triticum turgidum *L. var.* durum*). La réflectance de la végétation de vingt-cinq génotypes différents a été mesurée, à 4 stades de croissance du blé et dans des conditions d'irrigation ou de non-irrigation, à Lleida (Nord-Est de l'Espagne). Les indices de végétation, SR, NDVI, SIPI et WI ont été calculés pour la culture de blé dur. La LAI a été mesurée à chaque prise d'échantillons. Les coefficients de corrélation entre la LAI et les indices spectraux ont été plus faibles pour la culture irriguée que pour la culture non-irriguée. NDVI semblait être le meilleur indice pour déterminer la LAI, surtout pour les cultures non-irriguées. Des corrélations positives significatives ont été observées entre NDVI et SR, pour le rendement en grains, lorsqu'on analysait les deux essais conjointement. Au contraire, la relation entre WI et SIPI était négative pour le rendement en grains. Les résultats précédents suggèrent que les indices spectraux de végétation peuvent être des outils utiles à la prédiction de changement dans la LAI et dans le rendement en grains dans des milieux ou des stades de culture qui possèdent une LAI inférieure à 3.*

Mots-clés : *Télédétection, caractères physiologiques, blé dur.*

Introduction

In the past, the classical empirical breeding approach has obtained only limited yield increases in areas affected by drought, such as Mediterranean environments (Ceccarelli and Grando, 1996), where durum wheat is one of the main cereal crops. The use of morpho-physiological traits as indirect selection criteria for grain yield (known as "analytical" breeding) is an alternative approach. The traits used as selection criteria must be highly heritable, easily and rapidly screened, and relatively inexpensive (Richards, 1982).

Remote sensing techniques, which are based on the measurement of the spectra reflected by crop canopies at different wavelengths, may become useful tools in the assessment of stress effects on crop growth and yield performance. These techniques allow the evaluation of integrative traits related to yield either over time (i.e. during the plant cycle) or at the organization level (e.g. whole plant, canopy) (Araus, 1996). Spectral reflectance indices, which are formulations based on simple operations between the reflectances at given wavelengths, are mainly used in the assessment of plant characteristics related to the total photosynthetic area of the canopy.

Our objective was to study the usefulness of different narrow-band spectral reflectance indices in assessing durum wheat yield and changes in LAI over time under irrigated and rainfed conditions.

Materials and methods

Field experiments were conducted in 1998 under irrigated and rainfed conditions in Lleida (north-east Spain). Twenty five durum wheat genotypes, covering a wide range of genetic variability, were sown at a seeding rate of 550 viable seeds/m^2 in an alpha-lattice design with 4 replicates. Plot size was 14.4 m^2. Field measurements were carried out at the following developmental stages: booting, inflorescence emergence, anthesis and milk-grain. For leaf area index (LAI) estimation, the plants contained in a 0.5 m row length were pulled up at random at each sampling time, from a central row at each plot. Five representative plants per plot were taken, and their green leaves were separated. The projected area of the leaves was measured using a leaf-area meter, and the LAI was calculated as N x LAP where N = number of plants/m^2, and LAP = leaf area/plant. Plots were mechanically harvested at ripening. Grain yield (kg/ha) was determined on a plot basis.

Canopy reflectance was detected with a narrow-bandwidth visible/near infrared portable field spectroradiometer. The instrument detects 512 continuous bands from 350 to 1050 nm wavelengths, covering the visible and near infrared portion of the spectrum. The measurements were made at midday, in cloudless conditions, and were taken with the sensor at a zenith angle of 60º and with the radiometer in a nadir orientation. Three spectral reflectance measurements were taken at each plot. Standard reflectance measurements were made frequently. Radiometric vegetation indices were calculated from the comparison between visible and near-infrared reflectance (Table 1). Least square means were obtained by the MIXED procedure of the SAS-STAT statistical package (SAS, 1987). Pearson correlation coefficients were used to study the relationship between radiometric indices and LAI and yield.

Table 1. Definition of the spectral vegetation indices used in this study

Index	Definition†
SR, simple ratio	(R_{900}/R_{680})
NDVI, normalized difference vegetation index	$(R_{900} - R_{680})/(R_{900} + R_{680})$
SIPI, structural independent pigment index	$(R_{445} - R_{800})/(R_{445} + R_{800})$
WI, water index	(R_{970}/R_{900})

†R_n = reflectance at the wavelength (nm) indicated by the subscription.

Results and discussion

The four vegetation indices studied (SR – simple ratio, NDVI – normalized difference vegetation index, SIPI – structural independent pigment index and WI – water index), as well as LAI and grain yield, were higher under irrigated than under rainfed conditions. When the 25 genotypes and the four growth stages were analysed together, significant ($p < 0.05$) relationships appeared between LAI and all the vegetation indices in each environment, these relationships being strongest under rainfed conditions. The relationship between SR and LAI was linear (Fig. 1a), but a high dispersion of the values was found for LAI values beyond 2.5. On the other hand, the relationship between NDVI and LAI was exponential, with NDVI values increasing rapidly until LAI values of around 3, when a plateau was attained (Fig. 1b). The exponential pattern of the relationship between NDVI and LAI is reported in other studies (Aparicio *et al.,* 2000). LAI was negatively correlated with SIPI and with WI, the coefficients of correlation being r = -0.66 and r = -0.90 for SIPI under irrigated and rainfed conditions respectively, and r = -0.21 and r = -0.66 for WI under irrigated and rainfed conditions respectively.

Yield was positively correlated ($p < 0.05$) with SR and NDVI measured at any of the growth stages studied when both environments were considered together. Correlation coefficients with yield were maximum for the spectral reflectance indices measured at milk-grain stage (r = 0.91 and r = 0.89, for SR and NDVI respectively). On the other hand, the relationships between grain yield and WI and SIPI were significantly negative, probably because both indices give an indirect indication of the degree of stress of the crop. The highest values for the correlation coefficients between yield and WI and SIPI were found at anthesis (r = -0.92 for WI and r = -0.88 for SIPI respectively). No significant correlations were found between grain yield and the spectral reflectance indices when independent analyses were carried out for each environment.

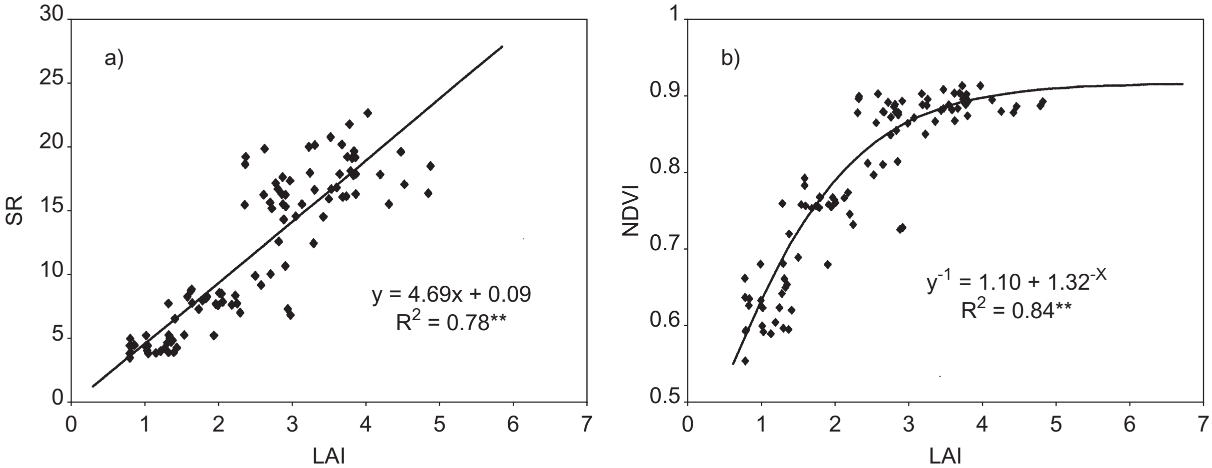

Fig. 1. Relationship between leaf area index (LAI) and a) simple ratio (SR), and b) normalized difference vegetation index (NDVI), under rainfed conditions. Data from the 25 durum wheat genotypes and the four growth stages are considered together.

Conclusions

Spectral vegetation indices seem to be useful tools for predicting changes in LAI and grain yield under Mediterranean conditions, especially for environments with low and medium yield potential, where LAI values are usually lower than 3.

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