Growth assessment of individual plants by an adapted remote sensing technique

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SUMMARY – The applicability of spectroradiometry to breeding programs could be enlarged if the method was adapted to measure individual plants in early generations of selection. In this study we evaluate the performance of a set-up consisting on a tube with reflecting walls and diffuse illumination for the case of assessing the growth rate of young durum wheat and barley plants from the Normalized Difference Vegetation Index (NDVI). The results showed a strong correlation between NDVI and plant fresh weight (r^2 = 0.98) and plant green area (r^2 = 0.95), specially for NDVI < 0.5. The resolution of the method allowed the quantification of the growth rate of a single plant in a weekly interval.

Key words: Breeding program, growth rate, leaf area, NDVI, RGR, spectroradiometry.

RESUME – *"Evaluation de la croissance de plantes individuelles par une technique adaptée de télédétection". La gamme de possibilités d'usage de la spectroradiométrie dans les programmes d'amélioration des végétaux pourrait être élargie si la méthode était adaptée à la mesure de plantes individuelles dans les états initiaux de la sélection. Dans ce travail nous évaluons la viabilité d'employer un tube aux parois réfléchissantes et de la lumière diffuse pour l'estimation de la croissance de plantes de blé dur et d'orge à travers le NDVI. Les résultats montrent une forte corrélation entre NDVI et le poids frais (r^2 = 0,98) et l'aire verte (r^2 = 0,95), spécialement pour NDVI < 0,5. La résolution de la méthode permet la quantification de la croissance d'une plante individuelle dans l'intervalle d'une semaine.*

Mots-clés : *Aire foliaire, amélioration génétique, croissance, spectroradiométrie, NDVI, RGR.*

Introduction

Ground level remote sensing techniques based on spectroradiometry are promising tools for the evaluation of crops at the plot level (Wiegand and Richardson, 1990; Daughtry *et al.,* 1992; Elliott and Regan, 1993; Araus, 1996; Aparicio *et al.,* 2000). Important factors determining yield, such as the amount of green biomass of a canopy, can be estimated by remote sensing techniques using spectroradiometric indices like the Normalized Difference Vegetation Index (NDVI). Additionally, spectroradiometry can supply information on the current physiological state of a crop and can be used for assessing the incidence of a range of stresses (Peñuelas, 1998).

However, the approach at the plot level may be less appropriate in a number of situations, such as in the case of isolated plants or for plants growing in pots, where considerable noise is introduced in the measured spectra due to variation in external factors like the colour of background or the geometry between sun, sample and sensor. An alternative for these cases may be the integration of a number of measurements at the leaf level, but this would require a large number of measurements covering the whole population of leaves (differing in age, position, etc.). The adaptation of spectroradiometry from the level of plot to the level of one single plant would cover the gap between the leaf and the canopy, by integrating the whole population of leaves in a single measurement while remaining unaffected by external factors. All the different kinds of assessment currently available at the canopy level could be applied to single plants provided that a method was developed for repetitive sampling of the spectra reflected by a single plant.

In the special case of breeding programs, adaptation of spectroradiometry to the level of individual plants could supply indirect selecting techniques appropriate for early generations of selection, where very large numbers of genotypes must be screened using a minimum of plants. Thus the genetic progress attained during the breeding process may be enhanced if genotypes could be routinely selected already at the individual plant level. A particular ability of spectroradiometry adapted to individual plants could be the non-destructive assessment of size of the same plant at different times, thus allowing the estimation of the particular growth rate of each individual plant.

The technical adaptation from the plot to the single plant would require limiting the field of view of the instrument to the area occupied by the plant being measured. In addition, contrasting with the plot level, some external factors such as light distribution and the characteristics of the background can be optimised by the design of the set-up, providing potentially more accurate estimates. Thus, a more homogeneous distribution of light may reduce the interference of the spatial structure of the plant. In laboratory conditions, the ideal set-up for sampling the reflectance of a whole plant would be a large integrating sphere, but this would result unpractical for field use with plants rooted in soil.

The purpose of this work was to evaluate the performance of a spectroradiometrical device based on the measurement of reflectance with the plant enclosed in a tube with diffuse illumination and reflecting walls. The method was tested in the assessment of total green area and biomass of single seedlings of durum wheat and barley.

Materials and methods

Plant material

Seedlings of durum wheat (*Triticum turgidum* L. var. *durum* cv. Mexa) and barley (*Hordeum vulgare* L. cv. Triumph) were cultivated in small pots, 5 cm diameter and 18 cm height, on a peat-based substrate with one plant per pot which was manually irrigated with a complete nutrient solution. Plants were sown the 29th September 1999 and stayed outdoors in the Experimental Fields of the University of Barcelona (45.8ºN, 4.25ºE).

Measurement of spectra

The plants to be measured were covered by a tube with reflecting walls and illuminated with a diffuse artificial light source (described below). The reflectance spectrum for each plant was calculated from the spectrum sampled with the plant inside the tube divided by the spectrum previously sampled in the tube without a plant.

The enclosing tube was 19 cm diameter and 65 cm long with its inner face coated with a highly reflecting aluminium foil. Before the plant was covered by the tube, a crushed aluminium foil was placed around the base of the plant so that it covered all the tube base and provided an homogeneous background. The inside of the tube was lightened by a diffuser ring placed at the top and illuminated from behind by an incorporated halogen lamp (OSRAM 35 W Decostar 51S). The spectra were sampled at the centre of the tube top by a Full Sky Irradiance Remote Cosine Receptor (from Analytical Spectral Devices, Inc., Boulder, Colorado, USA) which conveyed the sampled radiation across a fiberoptic towards a narrow-bandwidth visible/near infrared portable field spectroradiometer (FieldSpec UV/VNIR from Analytical Spectral Devices).

NDVI was calculated from the reflectance spectra as NDVI = $(R_{770} - R_{680}) / (R_{770} + R_{680})$, where R_{770} and R_{680} are the reflectances at 770 and 680 nm.

Assuming a linear relationship between NDVI and dry biomass, the Relative Growth Rate (RGR) for a single plant was estimated from two consecutive measurements of NDVI, as:

RGR = $[\mathrm{Ln}(NDVI_2) - \mathrm{Ln}(NDVI_1)] / (t_2 - t_1)$, where dry biomass terms of the classical definition (Evans, 1972) have been substituted by NDVI.

Experimental protocol

The reflectance of a same set of five durum wheat and five barley plants were measured 10, 17, 24, 31 and 42 days after sowing. In addition, for each day of measurements, the reflectance of other 3 durum wheat and 3 barley plants were also measured and later sampled for biomass and leaf area. The fresh weight and leaf area of these plants were measured by balance and scanner respectively.

Results and discussion

The reflectance spectra measured inside the described set-up dramatically changed as a result of plant growth. The major changes consisted on a progressive deepening of the reflectance at the Photosynthetically Active Radiation (PAR) region and a much smaller decrease in the reflectance of the Near Infrared Radiation (NIR).

NDVI showed a very strong correlation with plant fresh weight (r^2 = 0.98) and plant green area (r^2 = 0.95). These relationships were independent of the species (Fig. 1) in spite of the fact that durum wheat and barley showed marked differences in growing rates and leaf erectness, suggesting a good stability of the method over a range of variation in shape and spatial distribution of leaves.

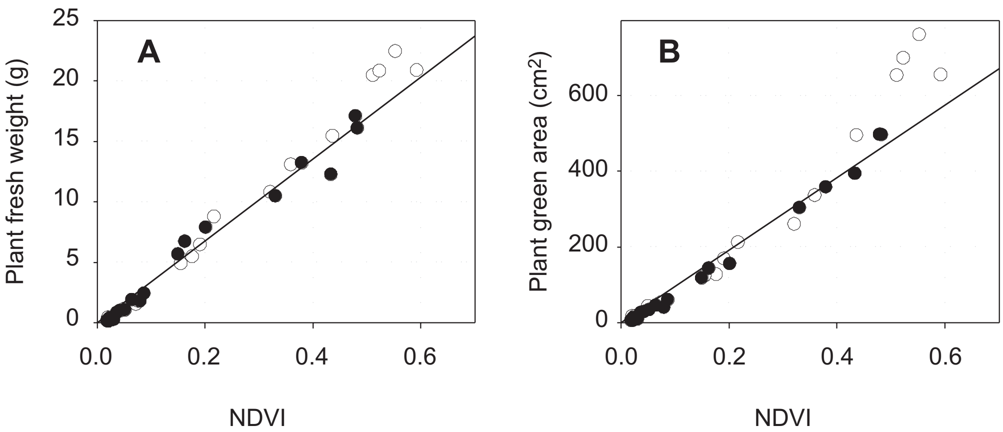

Fig. 1. Relationship between NDVI and (A) plant fresh weight and (B) plant green area. Closed symbols are durum wheat; open symbols are barley.

The sensitivity of the method was better for NDVI values below 0.5. For higher values, NDVI became less sensitive to further increases in plant green area. This saturation of the relationship between NDVI and crop parameters related with leaf area is well known in remote sensing of canopies (e.g. Sellers, 1987; Aparicio *et al.,* 2000). The Green Area Index inside the tube (green area divided by tube section) was around 2.5 for the plants showing signs of saturation, which lies in the range of saturation of NDVI described for canopies (Sellers, 1987). This indicates that, in the case of a plant enclosed in a tube, the size of the plant at which the relationship become saturated depends on the diameter of the tube. Therefore the appropriate diameter should be chosen as a compromise between maximum sensitivity during the period analysed, without being saturated at the largest growing stages analysed.

The linear relationship between NDVI and plant size allows the estimation of the RGR based on two consecutive measurements of NDVI on the same plant. In our case, the evolution of RGR during the course of the experiment could be compared between durum wheat and barley seedlings, showing a distinct trend for each species (Fig. 2). Barley presented a higher RGR at the initial samplings, which was in accordance with the commonly observed higher early vigour of barley than wheat (López-Castañeda *et al.,* 1995).

The described method could be appropriate for the characterisation of the growing strategies of different genotypes or for assessing their sensitivity to some environmental factors. The advantage of this method is that the required data can be obtained by fast and non-destructive measurements on a reduced number of plants; indeed the same plants all along the period of measurements. This contrasts with the large number of plants and tedious work required by a classical growth analysis, where different plants must to be sampled each time. Further information of each individual plant may be obtained by using other indices besides NDVI.

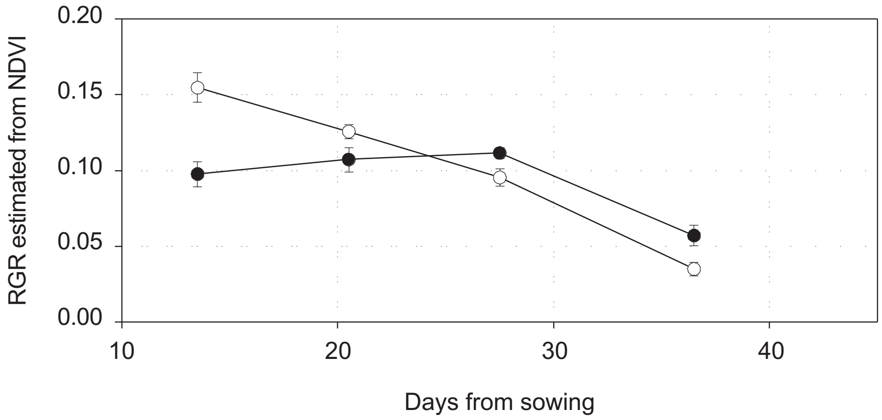

Fig. 2. Comparison of the pattern of changes with time of the Relative Growth Rate (RGR) in durum wheat and barley obtained by spectroradiometrical measurement of individual seedlings. Closed symbols are durum wheat; open symbols are barley. Error bars are standard error of the mean for 5 replicates. The same seedlings were measured through all the studied period.

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References

Aparicio, N., Villegas, D., Casadesús, J., Araus, J.L. and Royo, C. (2000). Spectral reflectance indices for assessing durum wheat biomass, green area, and yield under Mediterranean conditions. *Agron. J.,* 91 (in press).

Araus, J.L. (1996). Integrative physiological criteria associated with yield potential. In: *Increasing Yield Potential in Wheat: Breaking the Barriers,* Reynolds, M.P., Rajaram, S. and McNab, A. (eds). CIMMYT, México, pp. 150-167.

Daughtry, C.S.T., Gallo, K.P., Goward, S.N., Prince, S.D. and Kustas, W.P. (1992). Spectral estimates of absorbed radiation and phytomass production in corn and soybean canopies. *Remote Sens. Environ.,* 39: 141-152.

Elliott, G.A. and Regan, K.L. (1993). Use of reflectance measurements to estimate early cereal biomass production on sandplain soils. *Australian Journal of Experimental Agriculture,* 33: 179-183.

Evans, G.C. (1972). *The Quantitative Analysis of Plant Growth*. Blackwell Scientific Publications, Oxford.

López-Castañeda, C., Richards, R.A. and Farquhar, G.D. (1995). Variation in early vigor between wheat and barley. *Crop Science*, 35: 472-479.

Peñuelas, J. (1998). Visible and near-infrared reflectance techniques for diagnosing plant physiological status. *Trends in Plant Science*, 3: 151-156.

Sellers, P.J. (1987). Canopy reflectance, photosynthesis, and transpiration. II. The role of biophysics in the linearity of their interdependence. *Remote Sens. Environ.*, 21:143-183.

Wiegand, C.L. and Richardson, A.J. (1990). Use of spectral vegetation indices to infer leaf area, evapotranspiration and yield. I. Rationale. *Agronomy Journal*, 82: 623-629.