Agricultural Water Management 164 (2016) 137–147

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Comparative performance of remote sensing methods in assessing wheat performance under Mediterranean conditions

Salima Yousfi[a], Nassim Kellas[b], Lila Saidi[b], Zahra Benlakehal[b], Lydia Chaou[b], Djamila Siad[b], Farid Herda[c], Mohamed Karrou[d], Omar Vergara[a], Adrian Gracia[a], José Luis Araus[a], Maria Dolores Serret[a,*]

[a] Unitat de Fisiologia Vegetal, Facultat de Biologia, Universitat de Barcelona, 08028 Barcelona, Spain
[b] Institut Technique des Grandes Cultures, 16016 Alger, Algeria
[c] Institut National de Recherche Agronomique d'Algérie, 16200 Alger, Algeria
[d] International Center for Agricultural Research in the Dry Areas (ICARDA), Egypt

ARTICLE INFO

Article history:
Received 24 April 2015
Received in revised form
11 September 2015
Accepted 18 September 2015

Keywords:
Canopy temperature
NDVI
RGB images
Stable carbon isotope composition
Wheat
Yield

ABSTRACT

Vegetation indices and canopy temperature are the most usual remote-sensing approaches to assess cereal performance under Mediterranean conditions. However wide differences exist in the costs of the different equipment deployed to measure vegetation indices (e.g. spectroradiometers versus conventional red/green/blue cameras) or canopy temperature (infrared thermometers versus thermal cameras). In this study we compared different methodological approaches measuring vegetation indices and canopy temperature in durum wheat (*Triticum turgidum* L. ssp. *durum* (Desf.) Husn.) and bread wheat (*Triticum aestivum* L.) under different water conditions. These two categories of indices were correlated against grain yield during two consecutive years and with total biomass as well as water status (evaluated as carbon isotope composition, $\delta^{13}C$, and stomatal conductance) and nitrogen status (nitrogen and chlorophyll content) of the flag leaf during the first year. For the two crop species, and regardless of the device used, vegetation indices (the green area and the greener area) obtained with conventional cameras and the normalized difference vegetation index (NDVI) measured with a spectroradiometer were significantly correlated with grain yield, $\delta^{13}C$ and stomatal conductance. Moreover, while canopy temperature measured with a thermal camera was better related to grain yield and $\delta^{13}C$ than when measured with a low cost device such as an infrared thermometer, the latter approach still performs reasonably well when assessing yield and water status. This study highlights the usefulness of low-cost approaches to assess crop growth and water status in wheat under Mediterranean conditions.

1. Introduction

Durum wheat followed by other cereal crops such as barley and bread wheat are the most cultivated crops in the south and east Mediterranean basin (http://www.fao.org/docrep/006/y4011e/y4011e04.htm), where drought is the main constraint limiting grain yield (Araus, 2004). Increasing productivity in these semiarid environments depends on the efficiency of crop management (Oweis et al., 2000) and breeding (Araus et al., 2002), where methodologies to monitor crop performance for agronomical purposes (such as for example precision agriculture, scheduling irrigation), yield prediction, or to assess phenotypic variability for breeding are bottlenecks to fully exploit these technological avenues (Reynolds et al., 1999; Araus et al., 2002, 2008). Such limitation is particularly evident for small-medium seed companies, national agricultural research institutions and most farmers from developing countries, where lack of resources may limit the adoption of new technologies that are frequently very fashionable but expensive (Araus et al., 2013). Given their versatility, remote sensing techniques at the canopy level have become valuable tools for precision agriculture and high throughput phenotyping (Montes et al., 2007; Seelan et al., 2003, 2007; Chapman, 2008; Araus and Cairns, 2014). For example, these techniques can help farmers to practice a more sustainable agriculture, minimizing risks of losing the harvest by providing (whenever is possible) the resources (e.g. water) needed to secure yield. In addition, prediction of grain yield via remote sensing has additional applications. Yield forecasts before harvest may also help to predict farmer's income.

* Corresponding author. Fax: +34 934112842.
E-mail address: dserret@ub.edu (M.D. Serret).

http://dx.doi.org/10.1016/j.agwat.2015.09.016

Remote sensing tools may also be useful to guide logistical planning, predicting, for example, local and regional trading fluxes or the planting area of a given crop for the next season.

The normalized difference vegetation index (NDVI) is one of the most well-known vegetation indices derived from optical remote sensing imagery. NDVI has been used extensively to estimate plant biomass (Prince, 1991; Hansen and Schjoerring, 2003; Babar et al., 2006; Teal et al., 2006; Marti et al., 2007; Inman et al., 2008), the leaf area index (Asrar et al., 1984), patterns of productivity (Goward and Dye, 1987), growth status and spatial density distribution (Purevdorj et al., 1998), nitrogen status (Wright et al., 2005) and yield in wheat and other cereals (Filella et al., 1995; Aparicio et al., 2000, 2002; Royo et al., 2003). Moreover, the leaf chlorophyll content measured with a portable chlorophyll meter, based on the light transmitted through the leaf, is already extensively used not only to assess nitrogen fertilization but also as a secondary trait in wheat breeding for Mediterranean conditions to assess, for example, senescence (Araus et al., 1997; Munns and James, 2003; Harris et al., 2007). Alternatively, the use of information derived from conventional digital RGB (red, green, blue) images to formulate canopy vegetation indices may represent an alternative from spectroradiometrical vegetation indices. Green area and greener area represent two indices derived from digital conventional images. The first parameter describes the amount of green biomass in the picture, while the second one excludes the more yellowish-green pixels. In fact, greener area is aimed at capturing active photosynthetic area and plant senescence (Casadesus et al., 2007). Such indices are formulated using open access (i.e. free) software (Casadesus et al., 2005; Casadesús and Villegas, 2014).

A particularly widely used method for detecting water stress-induced stomatal closure as a guide to irrigation scheduling or genotypic performance under drought is measuring the canopy temperature using either infrared thermometry (Idso et al., 1981) or thermography (Jones, 2004a,b). Canopy temperature can provide information on transpiration as the main contributor to reduced leaf temperature. Reynolds et al. (2007) have reported that canopy temperature is a relative measure of plant transpiration associated with water uptake from the soil. Given that a major role of transpiration is leaf cooling, canopy temperature and its depression relative to ambient air temperature is an indicator of the degree to which transpiration cools leaves under a demanding environmental load (Araus et al., 2008). Infrared thermometry, measured as canopy temperature or canopy temperature depression, has been proposed in crop management to enable scheduling of support irrigation (Inoue, 1990; Colaizzi et al., 2012) or assess spatial soil heterogeneity (Jia and Menenti, 2010). Additionally, thermal imaging (i.e. thermography) is a powerful alternative to measure plant temperature, including spatial temperature patterns associated with transpiration at the canopy level (Chaerle et al., 2007; Grant et al., 2007; Möller et al., 2007; Araus et al., 2008).

In addition, other physiological characteristics related to plant water status such as stomatal conductance and stable carbon isotope composition (δ^{13}C) are also often used for evaluating drought tolerance (Araus et al., 2008; Aminian et al., 2010). The natural ^{13}C abundance in plant matter provides time-integrated information of the effects of water stress on the photosynthetic carbon assimilation of C_3 species including wheat and on the water use efficiency of the plant (Farquhar and Richards, 1984; Condon and Richards, 1992). However, a limitation of this approach is again its price. Concerning stomatal conductance, which gives and instantaneous measurement of plant water status, the use of portable and relatively inexpensive porometers makes the measurement of individual leaves quite fast (less than one minute between consecutive leaves).

The objective of this study was to ground test the efficiency of different remote sensing methods in assessing the yield performance of wheat under a range of Mediterranean conditions while also considering the cost differences between methods. These methods may be useful for crop irrigation management and scheduling (Droogers et al., 2010), yield prediction (Panda et al., 2010) or even plant phenotyping (Deery et al., 2014). The two categories of methods used included the assessment of green biomass and water status. Within the first category, NDVI, measured with a portable spectroradiometer with an active sensor, together with leaf chlorophyll content assessed with a chlorophyll meter, were compared with several vegetation indices derived from conventional digital pictures. For the second category, canopy temperature was assessed using either infrared thermometry or thermography, which were compared. The study took place during two consecutive growing seasons. In the first season the different remote sensing parameters were measured at heading and grain filling and correlated against grain yield at harvest as well as against water status using alternative approaches (δ^{13}C and stomatal conductance of the flag leaf) as a reference. In the second season the performance of the most promising remote sensing approaches was validated. The final objective was to assess if these remote sensing techniques were good predictors of yield and if the low-cost alternatives (infrared thermometry and conventional images derived indices) for the two categories of methodologies could be used in a manner comparable to the more expensive technologies.

2. Materials and methods

2.1. Plant material and growing conditions

Field trials were conducted during two crop seasons (2012–2013 and 2013–2014) at Bouhmidi Pilot farm in the area of Khemis Miliana commune, approximately 230 km to the south west of Algiers (Algeria). This commune receives an average rainfall between 350 and 400 mm (Supplemental Table S1), with generally 79 days of rain, and it is characterized by clay soils. In the first crop season (2012–2013), five durum wheat (*Triticum turgidum* L. ssp. *durum* (Desf.) Husn.) and five bread wheat (*Triticum aestivum* L.) genotypes were planted on 6 December 2012. The durum wheat genotypes were Bousselam (drought resistant variety), GTA DUR (highly responsive variety to water regime), Amar 6, Megress, and Sersou (local varieties). The bread wheat genotypes were HD 1220 (local variety), Anza (widely adapted variety), Arz and Ain-Abid (modern varieties) and Maaouna (local variety). In the second crop season (2013–2014) four durum and four bread wheat genotypes were planted on 20 November 2013. Durum wheat genotypes were Bousselam, GTA DUR, Amar 6, and Semeto and the bread wheat genotypes were Arz, Ain-Abid, Maaouna and Wifak. For the two crop seasons plots were harvested with a sickle after physiological maturity and grain yield was estimated.

2.2. Vegetation indices

NDVI was determined with a portable spectroradiometer (GreenSeeker handheld crop sensor, Trimble, USA) and it is calculated using the following equation: (NIR – R)/(NIR + R), where R is the reflectance in the red band and NIR is the reflectance in the near-infrared band. The distance between the sensor and the plots was kept constant at around 50–60 cm above and perpendicular to the canopy. Additionally, one digital conventional picture was taken per plot, holding the camera about 80 cm above the plant canopy in a zenithal plane and focusing near the centre of each plot. Digital images were taken using a Nikon D40 digital camera. The zoom was set at a focal length of 18 mm; using FOV of 66° 43′ and 46° 51′ for the horizontal and vertical angles, respectively, representing an area of ≈ 0.73 m^2; the shutter speed was 1/125 and the aperture