Determining yield of forage crops using the Canopeo® mobile phone app

José M. JÁUREGUI[1,2*], Fernando G. DELBINO[2], María I. BRANCE BONVINI[2] and Gonzalo BERHONGARAY[2,3]
[1]*Gentos S.A., Dardo Rocha 3194, Martínez (Bs. As.), Argentina*
[2]*Facultad de Ciencias Agrarias (UNL), Kreder 2805, Esperanza (3080), Santa Fe, Argentina*
[3]*CONICET, Depto Ciencias del Ambiente, Facultad de Ciencias Agrarias (UNL), Kreder 2805, Esperanza (3080), Santa Fe, Argentina*
*Corresponding author: josemartinjauregui@gmail.com

Abstract
One of the biggest challenges in pastoral systems is accurately determining forage availability. Destructive sampling is the most accurate method to use but it is very time-consuming, so non-destructive methods are usually preferred. This study compared data on the percentage of green canopy cover (%GCC) obtained using a recently developed image-analysis mobile phone app (Canopeo®) with crop biomass, light interception and NDVI measurements. Data were obtained for a range of crop species from two dryland experiments of lucerne (E1) and winter forage crops (E2). Linear and quadratic regression models were constructed to evaluate the data obtained using Canopeo® to estimate biomass accumulation, light interception and NDVI. For lucerne, positive linear relationships were found between %GCC and biomass (0.77 and 0.79 for Spring + Summer and Autumn + Winter, respectively; $P<0.05$), and between %GCC and light interception ($R^2=0.83$; $P<0.05$). For winter forage crops, there was a linear relationship between biomass and %GCC ($R^2=0.81$; $P<0.05$), and a linear relationship between %GCC and light interception ($R^2=83$; $P<0.05$). NDVI data obtained using the GreenSeeker® crop sensing system was linearly related to %GCC data from Canopeo® in both experiments ($R^2=0.84$ in E1 and $R^2=0.93$ in E2; $P<0.05$). The Canopeo® app proved to be a fast and reliable method to estimate biomass accumulation and light interception of forage crops in this study and has potential wider applications. However, it does not distinguish between crops and weeds.

Keywords: canopy cover, forage availability, Android app, forage measurement

Introduction
One of the biggest challenges to farmers in pastoral systems is the ability to accurately determine pasture availability. This information is crucial to properly develop feed budgets and can have a profound impact on the profitability of pasture-based systems (Beukes et al. 2019). Destructive sampling is the most accurate method to determine pasture availability. However, this method is very time-consuming and may require numerous samples to obtain reliable pasture estimates (Brummer et al. 1994) and capture spatial heterogeneity of the swards. Non-destructive methods to determine forage availability are usually preferred because, even when less precise, many measurements can be made in a short period of time. Such methods include visual assessment (Haydock & Shaw 1975; Stockdale 1984), canopy height (Harmoney et al. 1997), rising plate meter (Earle & McGowan 1979) and sward sticks (Sanderson et al. 2001; Mills et al. 2016), among others. There has also been a growing interest in using satellite-derived products to estimate pasture biomass (Edirisinghe et al. 2011; Porter et al. 2014; Barrachina et al. 2015; Cicore et al. 2016), particularly to gain a better understanding of spatial heterogeneity within and among swards. In such cases, the use of a Normalised Difference Vegetation Index (NDVI) and/or other spectral indexes have proven to be able to estimate, with moderate ability, (R^2 between 0.5 and 0.8) both pasture cover and availability (Grigera et al. 2007; Fava et al. 2009). Canopy cover (CC) is another indirect method for monitoring forage productivity, in both grasses and legumes (Harmoney et al. 1997). However, until recently, the only way of measuring %CC was by using line quantum sensors (e.g. LI-190SA® [LI-COR Inc., USA], AccuPAR® [Meter Group Inc. USA], SunScan® [Delta-T Devices, UK]), which were expensive and had little portability. Such restrictions made this method unaffordable, and thus prohibitive to be used by farmers as a management tool. In addition, some authors reported that measurements should be taken close to noon in order to collect consistent data (Epiphanio & Huete 1995; Rahman et al. 2015), which limited the timing to conduct the task.

Canopeo® is a mobile phone application developed at Oklahoma State University (Patrignani & Ochsner 2015) that works both on Android (Google®) and iOS (Apple®) phones. Canopeo® is an image analysis tool which uses colour values in the red–green–blue (RGB) system to determine the percentage of Green Canopy Cover (%GCC). The app analyses and classifies all pixels in the image according to ratios of R/G, B/G,

ISSN 2463-2872 (Print) ISSN 2463-2880 (Online) https://doi.org/10.33584/jnzg.2019.81.385

and the excess green index (2G-RB), and then reports the average percentage of green canopy cover (%GCC) of the image. Compared with other software packages, Canopeo® uses an automatic colour threshold classification, which dramatically reduces the processing time of each picture compared to manual methods (Xiong et al. 2019). The user can preview images and then adjust the noise-reduction threshold to better represent reality. Data from Patrignani and Ochsner (2015) indicated that up to 90% of pixels which were classified as green in corn (*Zea mays* L.), forage sorghum [*Sorghum bicolor* (L.) Moench], bermuda grass [*Cynodon dactylon* (L.) Pers.], and switchgrass (*Panicum virgatum* L.) were indeed green. This evidence indicates that there is potential for Canopeo® to be used as a tool to determine biomass, light interception and NDVI of forage crops provided that a proper calibration is made. Pastoral farming requires fast, reliable and "farmer-friendly" methods to determine pasture availability, as this is crucial to increase farm profitability. In fact, according to a Delphi survey with 25 NZ top pasture management specialists, the #1 characteristic that a pasture measurement technology must have is that it should be easy to use by farmers (Eastwood & Dela Rue 2017). The objective of this work was to explore the viability of using Canopeo® as a tool to determine total aerial biomass, NDVI and light interception (%) of lucerne (*Medicago sativa* L.) and of five winter annual forage crops.

Materials and Methods

Two rainfed experiments were established in Esperanza, Argentina (-31°27', -60°55'). Experiment 1 (E1) consisted of a lucerne pasture established in August 2017. Plots were conventionally ploughed and were hand sown in 0.2-m spaced rows at a rate of 15 kg of bare seed per hectare. Plot size was 5 x 10 m and sowing depth was 1 cm. The experiment was a complete randomised block design with four replicates. Treatments consisted of three lucerne genotypes (autumn dormancy ratings 10 [experimental cv], 9 [cv Gitana] and 6 [cv 620]). Plant growth was measured during the establishment year (Aug 2017 – Jul 2018). Weeds were removed by hand and using a hoe. Measurement details are reported in Table 1.

Experiment 2 (E2) was sown as a fully randomised design with three replicates and five treatments and was established in late May 2018. Plots were conventionally ploughed and sprayed with glyphosate at a rate of 4 litres/ha (0.54 kg/litre). Afterwards, crops were sown with a commercial driller in 0.175-m spaced rows. Plot size was 3.3 × 120 m and sowing depth was 3 cm. Treatments consisted of different winter forage crops sown at the following densities: common oats (*Avena sativa* L.) (100 kg/ha), wheat (*Triticum aestivum* L.) (25 kg/ha), barley (*Hordeum vulgare* L.) (25 kg/ha), bristle or black oats (*Avena strigosa* L.) (100 kg/ha), and Italian ryegrass (*Lolium multiflorum* L.) (25 kg/ha).

In both experiments, three images per plot were taken prior to cutting using a mobile phone with the

Table 1 Details of measurements taken at different dates for Experiments 1 and 2.

Experiment	Date	Destructive aerial biomass sampling	NDVI (GS)	Canopeo®	Light interception
	08/11/2017	x	x	x	-
	01/12/2017	x	-	x	x
	15/12/2017	x	x	x	x
	09/01/2018	-	x	-	-
	26/01/2018	x	-	x	x
	09/03/2018	x	-	x	x
1	17/04/2018	x	x	-	x
	27/04/2018	x	x	x	x
	02/06/2018	-	x	x	x
	21/06/2018	-	x	x	x
	29/06/2018	x	x	x	x
	31/07/2018	x	x	x	x
	16/08/2018	x	x	x	x
	06/08/2018	x	x	x	x
2	23/08/2018	x	x	x	x
	18/09/2018	x	x	x	x

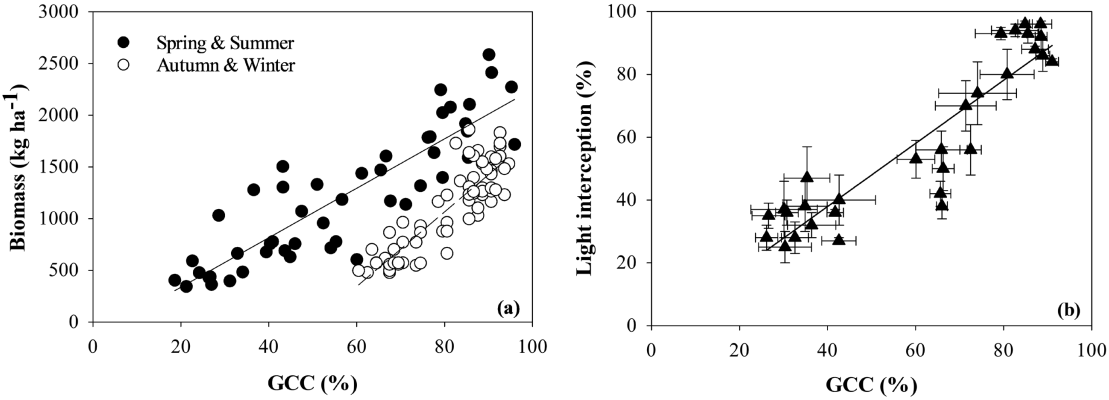

Figure 1 **(a)** Biomass accumulation (kg/ha) and (b) light interception of lucerne crops growing in Esperanza, Argentina (-31°27', -60°55') as related to green canopy cover (GCC %) measured using the Canopeo® app. Horizontal and vertical bars in **(b)** represent the standard error of the mean (mean of 3 replicates per plot). No error bars are presented in (a) as each point is an individual measurement.

Canopeo® app installed. The mobile phone was held ~1 m above the canopy and pictures were taken straight down between 11 am and 2 pm on clear days. Single-lens mobile-phone cameras were used in the experiment (focal length equivalence ~26 mm). Three NDVI measurements using a GreenSeeker® crop sensing system (Trimble, CA, USA) were also taken on those same spots. The GreenSeeker® device is a handheld active optical sensor that emits its own light and then measures the reflected light to calculate NDVI. Light interception was measured using a line quantum sensor (LI-190SA®; Li-Cor, NE, USA) by making one measurement above and four measurements below the canopy per plot on the same spots where images and NDVI measurements were made. Light interception measurements were made between 11 am and 2 pm. On the same spots where images were taken, crop aerial biomass (i.e. accumulated biomass above ground level) was determined by cutting a 0.5-m^2 and a 1.5-m^2 area (one sample per plot) for E1 and E2, respectively. Whole samples were forced-oven dried (65°C) until constant weight (48–72 h).

Statistical analyses

Linear and quadratic regression models were constructed to determine the capability of the Canopeo® app to predict biomass accumulation and light interception of crops. The correlation between %GCC and NDVI determined using GreenSeeker® was also evaluated. Models were evaluated using t-test analysis (α=0.05) and their goodness of fit (R^2).

Results

In Experiment 1 there were no differences (P>0.05) among lucerne genotypes for either biomass accumulation or light interception so the data for all three genotypes were combined. Biomass accumulation was linearly related to %GCC. However, regressions differed (P<0.05) between seasons. Thus, data were grouped into spring + summer (1 September–28 February) and autumn + winter (1 March– 30 August), and the overall goodness of fit (R^2) for biomass vs %GCC was found to be 0.77 (y = -135.3 + 24.1x, P<0.05) and 0.79 (y = -1813.5 + 36.2x, P<0.05), respectively (Figure 1a). There was also a linear relationship (y = -0.02 + 0.01x, R^2=0.83, P<0.05) between light interception and %GCC (Figure 1b). In this case, no differences (P>0.05) were detected between seasons.

In Experiment 2, biomass data required a Log transformation to normalise residuals and homogenise variances. After the log transformation, the overall goodness of fit for log biomass vs GCC % was 0.81 across all five species examined (Figure 2a) (y=1.84 + 0.0169x, P<0.05). Light interception was effectively predicted by Canopeo® using the whole dataset (Figure 2b; y = -0.113 + 1.15x; R^2=0.83, P<0.05). No differences (P>0.05) were found among species for either biomass or light interception.

Percentage of green canopy cover values obtained using the Canopeo® app were also tested against NDVI values generated using GreenSeeker®. In both experiments, there was a strong positive linear association between NDVI and %GCC (R^2=0.84 [y = 0.23 + 0.64x]) and R^2=0.93 [y = 0.15 + 0.7x], for E1 [Figure 3a] and E2 [Figure 3b], respectively). There were no differences (P>0.05) between the slopes of any of the annual crops nor the lucerne genotypes. However, the slope of lucerne crops was different (P<0.05) to that of winter annual crops.

Discussion

The Canopeo® app was developed to measure fractional green canopy cover but data from this app efficiently predicted biomass of both lucerne and the

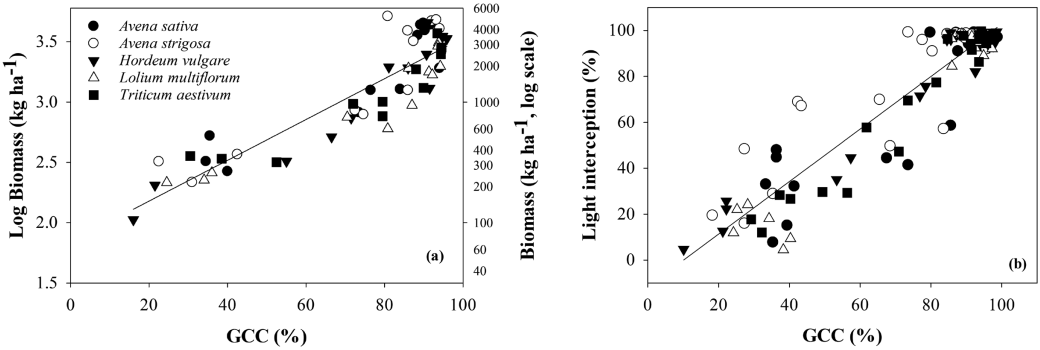

Figure 2 **(a)** Biomass accumulation (log transformed; kg/ha) and **(b)** light interception of winter annual crops growing in Esperanza, Argentina (-31°27', -60°55') as related to green canopy cover (%GCC) measured with Canopeo®.

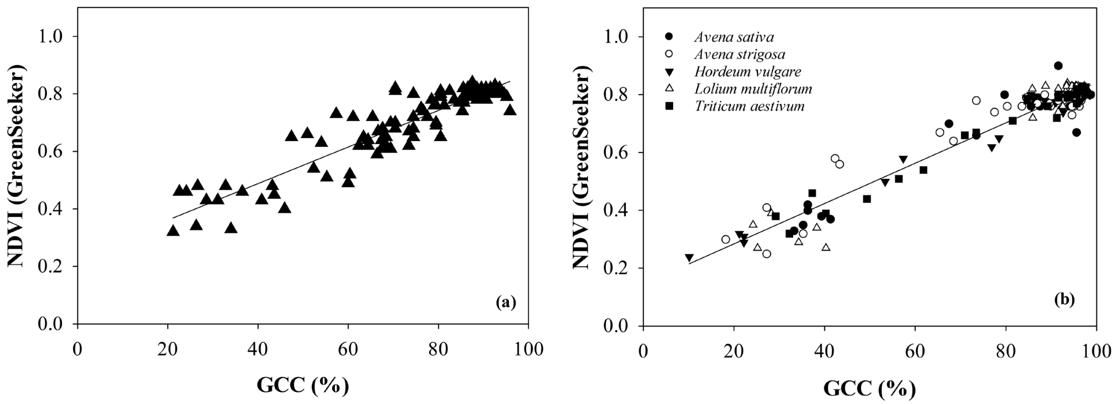

Figure 3 NDVI obtained using Greenseeker® of **(a)** lucerne crops and **(b)** winter annual forage crops growing in Esperanza, Argentina (-31°27', -60°55') as related to percentage of green canopy cover (GCC) measured using the Canopeo® app.

five winter forage crops evaluated in this experiment. In Experiment 1, however, data required specific seasonal calibrations to properly predict biomass. At similar %GCC, there was more (P<0.05) biomass in Spring + Summer than Autumn + Winter (Fig 1a). This is possibly due to differences in the structure of plants. As photoperiod increases (Spring + Summer), there is a higher partition of biomass to shoots, and when photoperiod decreases (Winter + Autumn) partitioning to roots increases, with the effect being particularly evident during the establishment year (Jáuregui et al. 2019). Similar results were reported by Mills et al. (2016), where the relationship between ruler height and biomass in lucerne crops required seasonal calibrations.

In Experiment 2, the large increase in biomass when %GCC rose above 80% (Figure 2a) was also evidence of differences in plant structure. This may have been related to increasing amounts of grass shoots and inflorescences as the plants entered their reproductive stage. There is ample evidence that most spectral indices saturate at high biomass (Sellers 1985; Mutanga & Skidmore 2004), and %GCC (related to the excess green index) seems to follow this same rule. This is possibly why little association between GCC % and biomass was observed when biomass data exceeded 2000 kg/ha. This would be an important issue to address, as farmers need to be able to determine biomass above that threshold, particularly during spring when growth rates are at their peak. Combining other indices into the analysis could help determine biomass when %GCC saturates. In particular, vegetation indices based on wavelengths located in the red edge region of the spectrum have been found to perform best at estimating biomass at high canopy densities (Mutanga & Skidmore 2004). However, such indices must be calculated after acquiring images with spectroradiometers (Li et al. 2017), hyper or multispectral cameras (Aasen et al. 2014) or satellites (Edirisinghe et al. 2012), which makes these alternatives more complex and less available to farmers. Alternatively, combining sward height with vegetation indices has been proposed as a simple way to overcome these limitations and better acquire the canopy structure and estimate biomass (Fricke & Wachendorf 2013; Baxter et al. 2017).

Notably, Canopeo® already incorporates a tag where the crop's height can be added to each picture that is taken. In a near future, the app could include an algorithm to combine both a spectral index and height, increasing its ability to estimate biomass when GCC is above 80%. In addition, the app also geo-locates every picture which could be used to provide maps of pasture availability to farmers in future updates.

One important limitation of both the Canopeo® app and GreenSeeker® is that neither method can differentiate crops and weeds. This means that weeds need to be removed prior to data acquisition when calibrating the device.

Conclusions and practical implications

Data obtained using a readily available mobile phone app (Canopeo®) was used to estimate biomass accumulation and light interception of forage crops. Good correlations were obtained in this study but further evaluation is required to assess the accuracy of this approach in a wider range of settings. This app could be used by farmers and farm advisors to frequently estimate pre- and post-grazing biomass of several winter annual forage crops and lucerne once calibration and use parameters are standardised. It could also be used by scientists to estimate light interception in remote areas or when more expensive equipment is not readily available. Canopeo® also showed a strong association with NDVI, indicating the correlation of a visual index (%GCC) and a spectral index. This might indicate the potential of the GreenSeeker® device to be used to estimate forage crops' biomass. An important limitation of this approach is that both Canopeo® app and the GreenSeeker® device cannot differentiate between crops and weeds. Future updates of the app should consider including height + GCC in a combined algorithm, and also mapping capabilities. Further calibration for other pastures and forage crops is required.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the collaboration of Sebastián Ballanti, Matías Bosio, Belén Iglesias, Tatiana Landucci, Rodrigo Merki, Leonardo Colomba and Ricardo Batistuta who helped sow the experiments and with the field work. The authors also wish to thank two anonymous reviewers for their insightful comments which helped improve this manuscript. This research was partially funded by Universidad Nacional del Litoral (CAI+D ORIENTADO 006.022.000 and PEIS 643662) and Gentos S.A.

REFERENCES

Aasen H, Bendig J, Bolten A, Bennertz S, Willkomm M, Bareth G. 2014. Introduction and preliminary results of a calibration for full-frame hyperspectral cameras to monitor agricultural crops with UAVs. Copernicus GmbH. Pp. 1-8.

Barrachina M, Cristóbal J, Tulla A. 2015. Estimating above-ground biomass on mountain meadows and pastures through remote sensing. *International Journal of Applied Earth Observation and Geoinformation 38*: 184-192.

Baxter LL, West CP, Brown CP, Green PE. 2017. Comparing nondestructive sampling techniques for predicting forage mass in alfalfa–tall wheatgrass pasture. *Agronomy Journal 109*: 2097-2106.

Beukes P, McCarthy S, Wims C, Gregorini P, Romera A. 2019. Regular estimates of herbage mass can improve profitability of pasture-based dairy systems. *Animal Production Science 59*: 359-367.

Brummer JE, Nichols JT, Engel RK, Eskridge KM. 1994. Efficiency of different quadrat sizes and shapes for sampling standing crop. *Journal of Range Management*: 84-89.

Cicore P, Serrano J, Shahidian S, Sousa A, Costa JL, da Silva JRM. 2016. Assessment of the spatial variability in tall wheatgrass forage using LANDSAT 8 satellite imagery to delineate potential management zones. *Environmental Monitoring and Assessment 188*: 513.

Earle D, McGowan A. 1979. Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture 19*: 337-343.

Eastwood C, Dela Rue B. 2017. Identification of operational performance attributes for pasture measuring devices. *Journal of New Zealand Grasslands 79*: 211-216.

Edirisinghe A, Hill M, Donald G, Hyder M. 2011. Quantitative mapping of pasture biomass using satellite imagery. *International Journal of Remote Sensing 32*: 2699-2724.

Edirisinghe A, Clark D, Waugh D. 2012. Spatio-temporal modelling of biomass of intensively grazed perennial dairy pastures using multispectral remote sensing. *International Journal of Applied Earth Observation and Geoinformation 16*: 5-16.

Epiphanio JCN, Huete AR. 1995. Dependence of NDVI and SAVI on sun/sensor geometry and its effect on fAPAR relationships in alfalfa. *Remote Sensing of Environment 51*: 351-360.

Fava F, Colombo R, Bocchi S, Meroni M, Sitzia M, Fois N, Zucca C. 2009. Identification of hyperspectral vegetation indices for Mediterranean pasture characterization. *International Journal of Applied Earth Observation and Geoinformation 11*: 233-243.

Fricke T, Wachendorf M. 2013. Combining ultrasonic sward height and spectral signatures to assess the biomass of legume–grass swards. *Computers and Electronics in Agriculture 99*: 236-247.

Grigera G, Oesterheld M, Pacín F. 2007. Monitoring forage production for farmers' decision making. *Agricultural Systems 94*: 637-648.

Harmoney KR, Moore KJ, George JR, Brummer EC, Russell JR. 1997. Determination of pasture biomass using four indirect methods. *Agronomy Journal 89*: 665-672.

Haydock K, Shaw N. 1975. The comparative yield method for estimating dry matter yield of pasture. *Animal Production Science 15*: 663-670.

Jáuregui JM, Mills A, Black DB, Wigley K, Ridgway HJ, Moot DJ. 2019. Yield components of lucerne were affected by sowing dates and inoculation treatments. *European Journal of Agronomy 103*: 1-12.

Li G, Wang C, Feng M, Yang W, Li F, Feng R. 2017. Hyperspectral prediction of leaf area index of winter wheat in irrigated and rainfed fields. *PLOS ONE 12*: e0183338.

Mills A, Smith M, Moot D. 2016. Relationships between dry matter yield and height of rotationally grazed dryland lucerne. *Journal of New Zealand Grasslands 78*: 185-196.

Mutanga O, Skidmore AK. 2004. Narrow band vegetation indices overcome the saturation problem in biomass estimation. *International Journal of Remote Sensing 25*: 3999-4014.

Patrignani A, Ochsner TE. 2015. Canopeo: A powerful new tool for measuring fractional green canopy cover. *Agronomy Journal 107*: 2312-2320.

Porter TF, Chen C, Long JA, Lawrence RL, Sowell BF. 2014. Estimating biomass on CRP pastureland: A comparison of remote sensing techniques. *Biomass and Bioenergy 66*: 268-274.

Rahman M, Lamb D, Stanley J. 2015. The impact of solar illumination angle when using active optical sensing of NDVI to infer fAPAR in a pasture canopy. *Agricultural and Forest Meteorology 202*: 39-43.

Sanderson MA, Rotz CA, Fultz SW, Rayburn EB. 2001. Estimating forage mass with a commercial capacitance meter, rising plate meter, and pasture ruler. *Agronomy Journal 93*: 1281-1286.

Sellers PJ. 1985. Canopy reflectance, photosynthesis and transpiration. *International Journal of Remote Sensing 6*: 1335-1372.

Stockdale C. 1984. Evaluation of techniques for estimating the yield of irrigated pastures intensively grazed by dairy cows. 1. Visual assessment. *Australian Journal of Experimental Agriculture 24*: 300-304.

Xiong Y, West C, Brown C, Green P. 2019. Digital image analysis of Old World bluestem cover to estimate canopy development. *Agronomy Journal 111*: 1247-1253.