Turf color measurement with conventional digital cameras.

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Abstract

Conventional digital cameras are low cost devices that could have a generalized use in a number of agricultural applications. However, its performance as a measuring device has been limited by the fact that most commercial cameras self-adjust to the scene's lighting conditions and many of them do some image processing operations too. Therefore, the resulting image depends on the camera behaviour, which varies between camera models and even between pictures taken with the same camera under different background or lighting conditions.

In order to facilitate the use of unspecific conventional digital cameras for the assessment of color and other traits of vegetative crops, we have developed a protocol for picture acquisition in the field and its later processing once downloaded to a PC. This protocol is based on the inclusion of a reference of known color in a corner of the field of view of each picture. Later, the image processing software automatically finds the reference and corrects the color of the image.

Here we compare the color of a range of turf surfaces measured by radiometrical methods and by digital imaging. The results show the need for image color correction in order to get comparable results with scenes of different luminance and when using different devices. Nevertheless, without color correction Hue appears as a relatively robust parameter, even when comparing images obtained by different cameras.

Key words: Digital imaging, image processing, turf.

1 Introduction

Conventional digital cameras can be viewed as a poor relative of the digital cameras used in remote sensing and photogrammetry. Nevertheless, their ubiquity and ease of use make them a promising tool for field data acquisition in many areas. Their limited features from a spectrometry point of view may be compensated by their widespread availability by potential users.

One of its applications is the assessment of the vegetative state of crops. While a number of spectrorradiometrical indices can be used in remote sensing for the estimation of green biomass, Chlorophyll or related concepts (Wiegand et al. 1991), most of them need other spectral bands than those available in conventional digital images, which are limited to red, green and blue (RGB). However, some parameters based on RGB can be used as surrogates of known remote sensing indices, at least in some specific domains. For example, a ratio green to red has been shown highly correlated with NDVI in wheat senescent canopies (Adamsen et al. 1999), and the hue component of color has been found a suitable parameter for assessing turfgrass quality (Karcher and Richardson, 2003).

However, for a widespread use of conventional digital cameras in field data acquisition, it would be convenient to provide robust protocols that minimized the effects of lighting conditions, scene's background and specific features of the camera. Some practical problems for color measurement based on conventional digital cameras arise with the self-adjustments and image processing operations that take place in the camera itself, which vary between traders and models. Practically all commercial cameras self-adjust their sensitivity to a given scene and many of them also incorporate some kind of image processing operations in order to “improve” the quality of the image. These features use to work behind the scenes, without control by the user, and that would cause the same object appear in different colors depending on the combination of lighting conditions, scene’s background, camera model, etc.

In this context, we have evaluated a protocol for field image acquisition and later processing in a PC, which pretends to compensate the “uncontrolled” self-adjustments and image processing operations that take place in the camera. The protocol is based on the inclusion on each picture of a reference object whose color has previously been characterized by other methods. Once the images have been downloaded to a PC, the image processing software automatically finds the reference object and corrects the color of the overall image in such way that the reference object appears with its actual color.

This contribution evaluates the protocol with turf, where a set of 156 turf plots were measured radiometrically and by digital photography at different seasons of the year. Also, a selected set of turf plots was measured by different cameras and compared.

2 Material and Methods

This trial consisted of two parts, one intended to compare turf color measurement by a digital camera to the color measurement of the same samples by a portable spectrorradiometer. The other part intended to evaluate the comparability of turf color measurements made with different commercial digital cameras.

Both parts were conducted on an experimental field from Semillas Fitó. S.A. located in northwest of Spain (Cabrera de Mar, Barcelona, Spain), at about 4 Km from the Mediterranean Sea. The field contained 156 (2 x 1.5 m) plots of turf composed by cultivars and mixes of different turf species, among which *Lolium perenne* (L), *Festuca arundinacea* (Schibn.), *Festuca rubra* (L.), *Poa Pratensis* (L.), *Cynodon dactylon* (L.), *Paspalum vaginatum* (L), *Pennisetum* sp and *Agrostis* sp. The turf was sown in May 2004, and its irrigation, fertilization and other maintenance activities were conducted as usual for turf in the Mediterranean area.

The comparison of photographic vs. radiometrical color measurement consisted on the parallel measurement of the whole set of 156 turf plots by the two methods in three dates, August 2004, October 2004 and March 2005. All measurements were collected in sunny days between 2h before and 2h after solar noon.

For the radiometrical measurements we used a narrow band-width portable spectrorradiometer USB2000 from Ocean Optics, connected to a foreoptic with a field of view of 15º held at 1.2 m from the ground, which recorded the reflectance spectra in the range 350 to 1000 nm. The measurements were referred to periodic reflectance measurements taken from a plate of 15 cm diameter painted with WRC-680 Diffuse White Reflectance Coating, from Labsphere.

From the reflectance spectra we calculated the *Tristimulus values* CIEXYZ, which are the starting point for converting to different color spaces and represent the assumed stimulation of the three color receptors of the human eye. The calculation of CIEXYZ from the reflectance spectra was based on Ohno (2000) and used the *CIE 1964 supplementary standard colorimetric observer* specified in ISO/CIE 10527:Colorimetric Observers, and a Standard Illuminant D65, specified in ISO 10526:1999/CIE S005/E-1998: CIE Standard Illuminants for Colorimetry. The Intensity, Hue and Saturation (IHS) for each spectrum was calculated from the CIEXYZ values by the methods implemented in the Java Advanced Imaging (JAI) package, from Sun Microsystems, and based on Seul et al. (2000). Similarly, the RGB coordinates were calculated for the sRGB color space defined by Stokes et al. (1996), from the CIEXYZ values using the methods implemented in the JAI package.

The protocol for image acquisition in the field consisted of taking zenithal pictures of the turf plots with the camera held at 1.2 m from the ground, after placing a reference panel over the turf surface close to a corner of the scene. The photographer was facing south in order to avoid shading the scene. The reference panel was a disk of PVC, with a grey circle of 75 mm diameter inside of a black circle of 100 mm diameter. The grey circle was painted with plastic paint and polished to reduce glare. Its color was measured at full sunlight with the described spectrorradiometer, which reported the RGB coordinates {90,93,107}. The digital camera was a FUJI FinePix 6900, which was kept to its default settings and stored 1280 x 960 pixel images in JPG format.

Once in the PC, the images were processed by a custom made program based on the JAI package. This program analyses automatically all the image files found in the directory indicated by the user. For each image the program searches the reference panel, measures the average RGB of its grey circle and calculates the appropriate coefficients for each band that restores the actual color of the grey circle. Then, the color of the whole image is recalculated using those coefficients. The average color of the whole image excluding the reference panel is calculated in RGB coordinates. Then, Intensity, Hue and Saturation (IHS) and CIEXYZ coordinates are calculated from the average RGB, based on Seul et al. (2000) whose formulae are already implemented in the JAI package.

The second part of the trial consisted on using 6 different conventional digital cameras for capturing the same set of 15 turf plots, which were selected from the above mentioned 156 plots. The pictures were obtained on clear sunny conditions in April 2005, with few minutes of difference between the cameras. The protocol for image acquisition and processing was the same as described before. The set of cameras consisted of FUJI FinePix 6900, Canon PowerShot A75, Casio QV-R62, Kodak EasyShare CX7220, Ricoh Caplio R1 and Inovix DC-400. All the cameras were used with their default settings.

3 Results and Discussion

The dates of image acquisition corresponded respectively to summer, autumn and winter Mediterranean conditions, allowing the expression of different seasonal behaviour of the diverse turf species. In summer, some difference in color presumably related with heat sensitivity could be appreciated, while in autumn all plots were intensely green and in winter all C4 species were dry due to winter dormancy. The overall set of images covered what can be assumed a complete range of possible turf colors.

It must be noted that several turf plots showed a heterogeneous appearance that in some cases was due to the mix of turf species with different seasonal behaviour, while in other cases was due to poor germination. The heterogeneity may disturb the relationship between radiometrical measurements and digital image measurements because the effect of spatial heterogeneity can be different in both methods, and also because the sampled area by both devices was not exactly the same. Nevertheless those plots have not been rejected from the analysis because we consider that some plots with heterogeneous cover would be found in most real case applications of the method.

3.1. Data from spectra

The amount of radiation in the visible region –400 to 700 nm- reflected by the turf surface was around 5% of the incident radiation in the same region, as illustrated in Fig.1. The state of the vegetation determined the reflectance spectra and hence the relative intensities of red, green and blue captured by the camera. The general trend is that vigorous plots have a lower reflectance in the blue and red regions of the spectra due to the absorption of radiation by Chlorophyll. If turf losses Chlorophyll for some reason such as summer heat damage or for winter dormancy, then the reflectance at the overall visible region increases, specially in the red region. Then, vigorous turf surfaces are darker and digital cameras tend to compensate it by increasing the luminosity of the image as compared with brighter dry turf surfaces, where cameras do the opposite.

The intensity reflected by the turf plots is a small and variable fraction of the incident intensity, and digital cameras try to optimise the available 255 levels for each primary color in an independent way for each picture. The consequence is that the actual intensity corresponding to a given band level varies from picture to picture and this may affect the robustness of color measurement based on digital images.

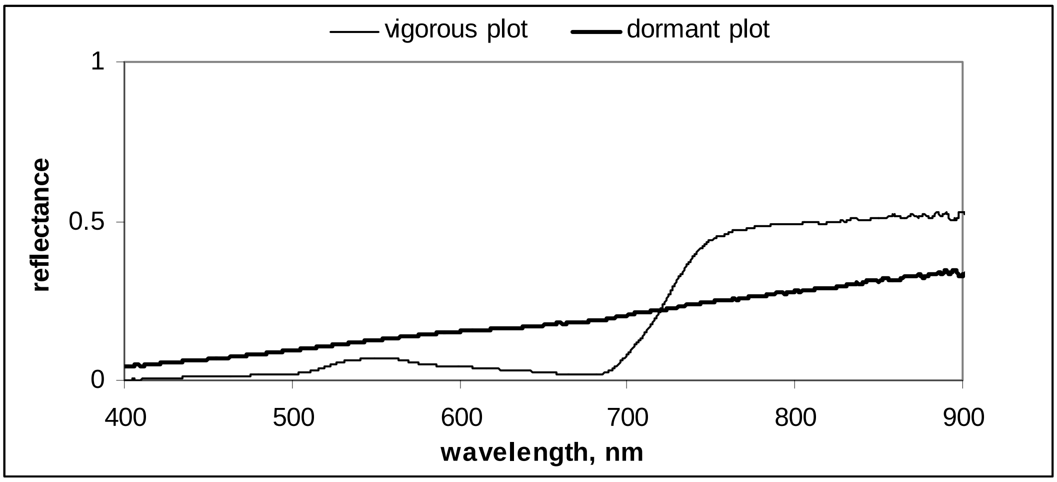

Figure 1. Example of the reflectance spectra by two contrasted turf plots; a vigorous intensely green plot and a completely dry plot due to winter dormancy. Note the different level of reflectance in the overall visible region.

The widely used radiometrical index NDVI quantify the spectral changes related with vegetation based on reflectances in red and near infrared. As conventional digital cameras do not record the latter band we need a surrogate of NDVI based on the red, green and blue bands or on any color parameter derived from them. In this sense we have analysed the relationship between NDVI and some color parameters calculated from the same reflectance spectra in search for possible candidates (Table 1).

The results show a high correlation between NDVI and both RGB and CIEXYZ coordinates, especially with R and CIE-X (Table 1). In the case of Hue we also found a strong relationship to NDVI though it is not linear in the whole range, as is illustrated in Fig.2.

Table 1. R-square values of the linear regression between NDVI and some color parameters calculated from the same spectra.

R	G	B	CIE-X	CIE-Y	CIE-Z	I	H	S
0.87	0.74	0.73	0.91	0.87	0.84	0.83	0.79	0.04

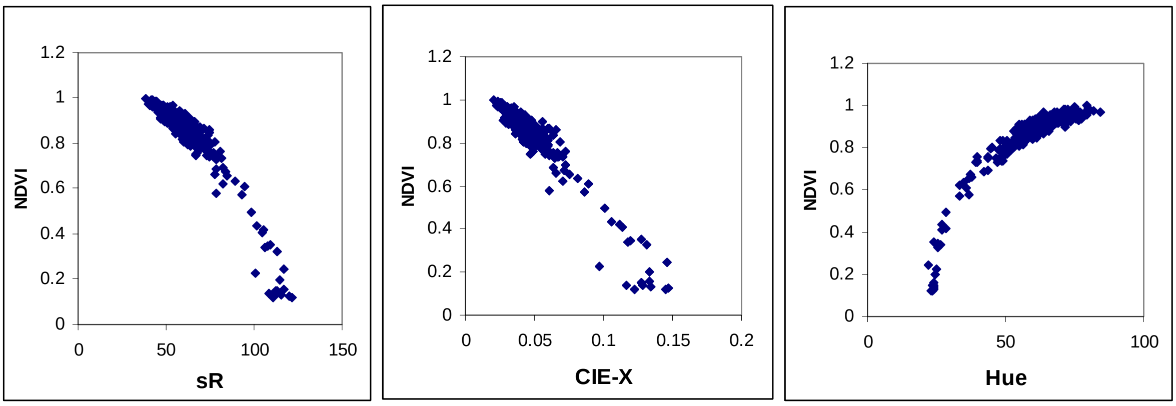

Figure 2. Relationship between NDVI and different color parameters calculated from the same spectra.

3.2. Corrected and uncorrected pictures vs. spectra.

In order to analyse the robustness of diverse color parameters, we compared the values calculated from the reflectance spectra with those calculated from the average pixel of each picture. The results show a poor correlation between the same parameters calculated in these two ways. Neither the RGB nor the CIEXYZ coordinates of the average pixel, nor its brightness and saturation fit with its equivalent value calculated from the spectra (Table 2). On the other hand, the Hue component does show an acceptable fit, which indicates the robustness of Hue and confirms its suitability as indicator of the state of the vegetation. However, Hue is only one component of the IHS color space, and hence it is not enough for a full description of a color.

Table 2. R-square values of the linear regression between color parameters calculated from reflectance spectra and those calculated from the average pixel of each picture. The first line corresponds to the digital images before color correction and the second line to the same images after color correction.

	R	G	B	CIE-X	CIE-Y	CIE-Z	I	H	S
pict	0.46	0.00	0.37	0.15	0.01	0.23	0.21	0.73	0.56
pict-cc	0.73	0.66	0.77	0.83	0.79	0.84	0.74	0.59	0.51

The relationship between the color calculated from the spectra and the color calculated from the digital image improves when the image color is corrected based on a panel of known color included in the scene (Fig. 3). The fit between spectra and picture measurements becomes particularly good for CIEXYZ coordinates. This means that an acceptable description of the color can be recovered with color correction. On the other hand, the color correction reduces the fit for Hue. This might be due to the fact that the color correction algorithm used here was chosen for restoring in a simple way the RGB coordinates, which might alter the Hue in a non linear maner.

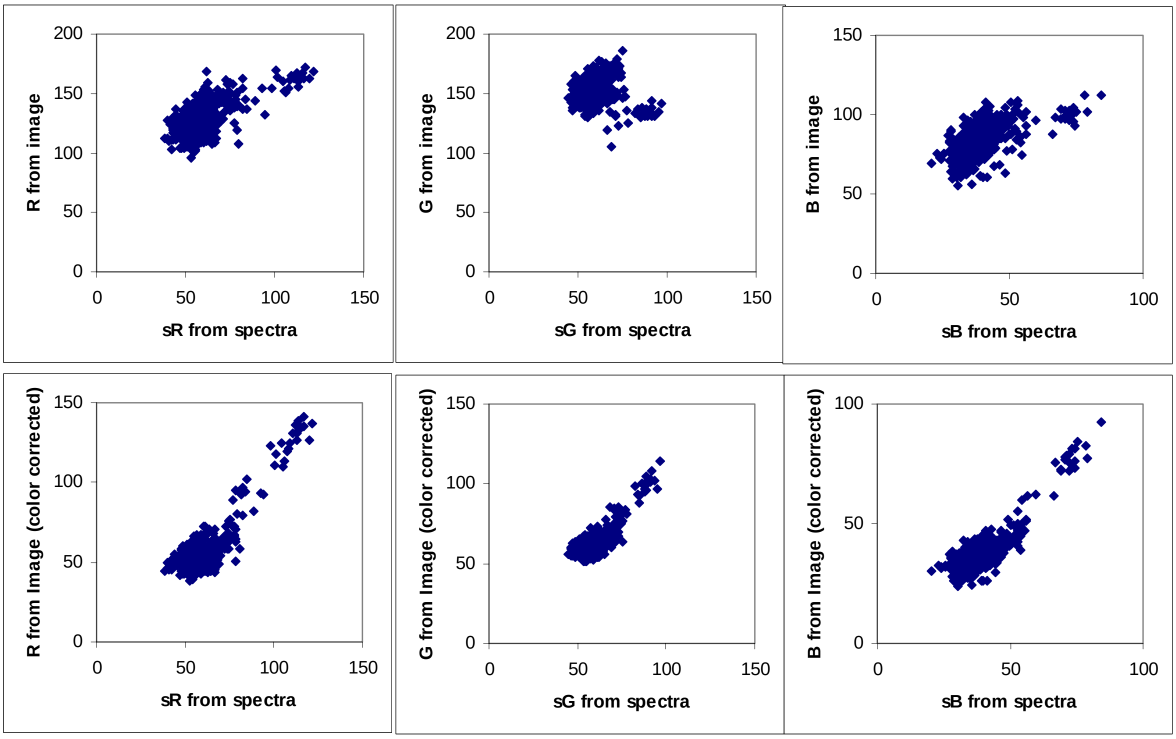

Figure 3. Relationship between the RGB color coordinates calculated from the reflectance spectra and those of the average pixel in the digital image before (upper panels) and after (lower panels) color correction of the image.

3.3. NDVI vs corrected and uncorrected color.

Returning to the suitability of the diverse color parameters as indicators of the state of vegetation, the case is completely different if the image color has or has not been corrected. For non color-corrected pictures, the relationship between NDVI and either RGB or CIEXYZ of the average pixel is unacceptably low (Table 3). Only Hue stands as a possible surrogate for NDVI. On the other hand, once the color of pictures has been corrected, RGB and specially CIEXYZ show high correlations with NDVI, which emphasize them as appropriate data for deriving information about the state of vegetation.

Table 3. R-square values of the linear regression between NDVI and the color of the average pixel. In the first row the color of the average pixel was calculated without color correction. In the second row it was calculated after the image color had been corrected.

	R	G	B	CIE-X	CIE-Y	CIE-Z	I	H	S
pict	0.34	0.11	0.13	0.07	0.00	0.08	0.09	0.79	0.08
pict_cc	0.76	0.66	0.70	0.81	0.78	0.78	0.75	0.63	0.03

3.4. Color parameters measured by different cameras.

We analysed the robustness of the color assessment of the same set of turf plots obtained by different cameras. The set of turf plots used for the comparison covered a wide diversity of turf colors while each plot presented a homogeneous cover. The pictures were obtained in mid April, coinciding with large contrasts between species, as dormant species were still inactive whilst perennial species were vigorously growing.

The results show some differences between cameras for the RGB and CIEXYZ coordinates of the average pixel, while Hue and saturation seem acceptably stable among cameras (Fig.4 and Fig.5). After color correction of the image, the stability of RGB and CIEXYZ is drastically increased (Fig. 4, lower panels) (Table4).

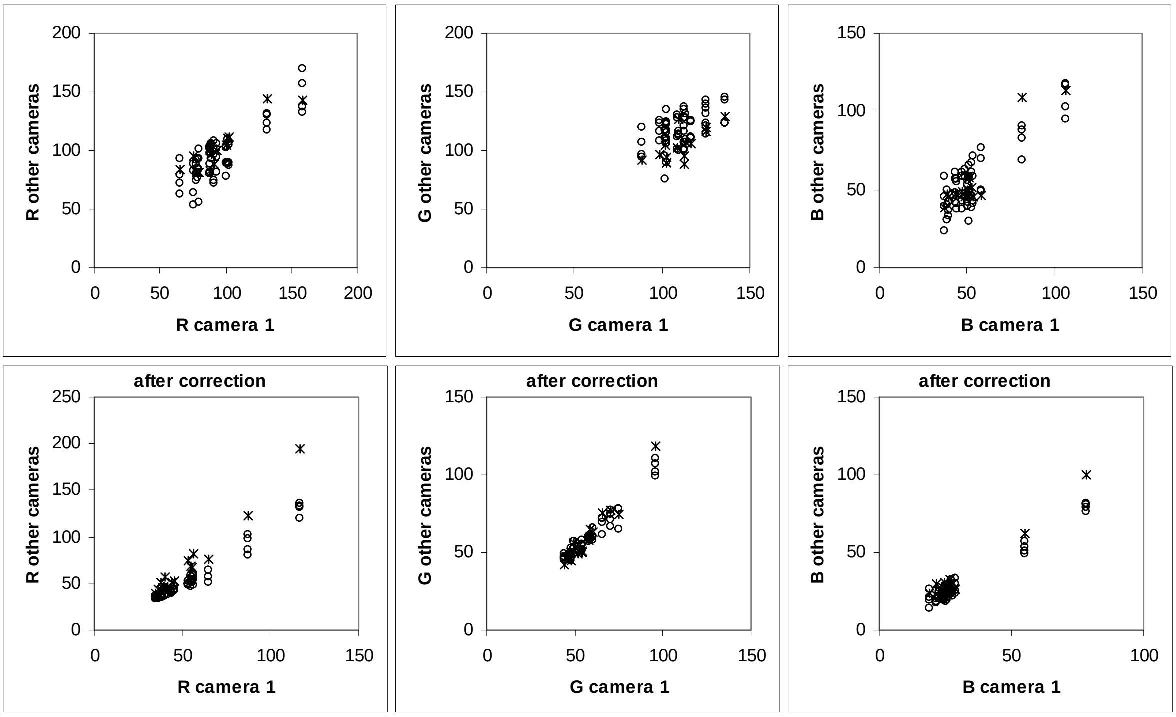

Figure 4. Relationship between the RGB coordinates of the average pixel measured by the first camera – Fuji FinePix6900- and those measured by the other 5 cameras, before color correction (upper panels) or after color correction (lower panels). The symbol asterisk represents the lowest rank camera, which showed a different response than the other cameras, represented by open circles.

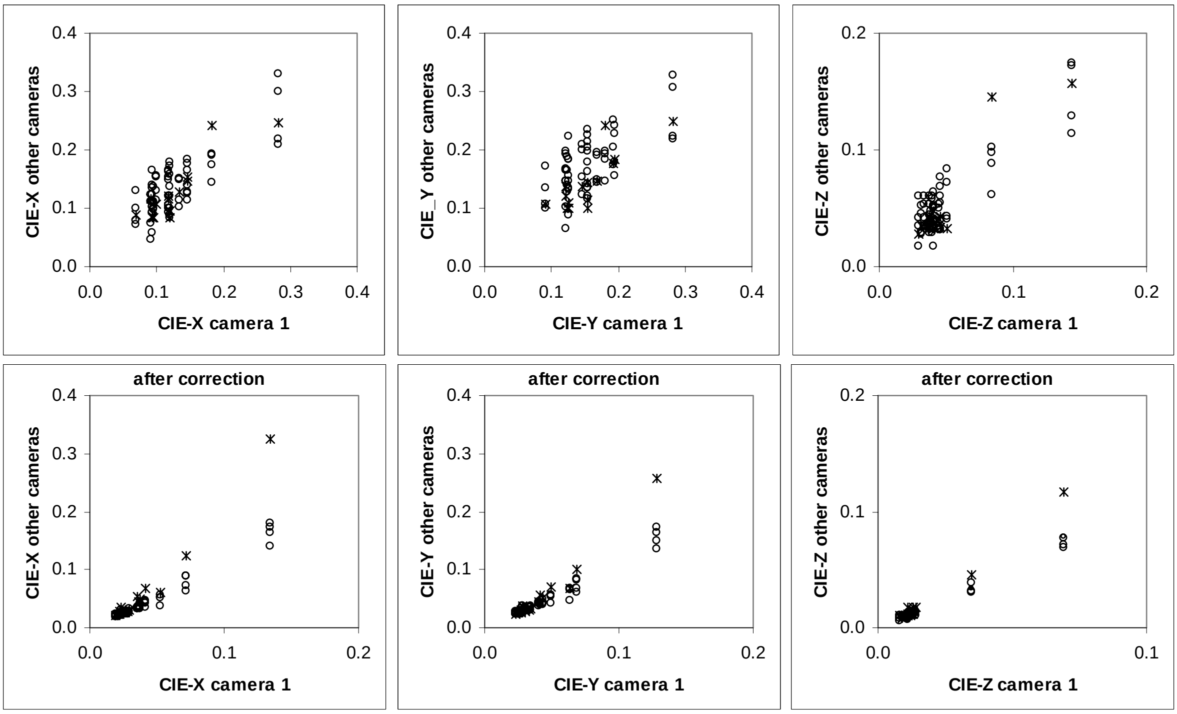

Figure 5. Relationship between the CIEXYZ coordinates of the average pixel measured by the first camera –Fuji FinePix6900- and those measured by the other 5 cameras, before color correction (upper panels) or after color correction (lower panels). The asterisk symbol represents the lowest rank camera, which showed a different response than the other cameras, represented by open circles.

Once corrected the color measured by 5 of the 6 cameras showed comparable values. The camera that departed from the others was the cheapest, lowest quality one, Inovix DC400. In the pictures obtained with this camera the grey circle of the reference panel appeared with bands of different color, probably due to either poor intensity resolution of the sensor or to unoptimal digitalisation. All other cameras showed the reference circle with a smooth grey circle where no bands could visually be appreciated. The similarity of the response of all other cameras, after color correction is remarkable.

Table 4. R-square values of the linear regression between color parameters obtained by the reference camera and those obtained by the set of all other commercial cameras on the same turf plots. The first row is before color correction, including all cameras. The second row is after color correction, including all cameras. The third row is after color correction and excluding the lowest rank camera.

	R	G	B	CIE_X	CIE_Y	CIE_Z	I	H	S
pict	0.73	0.28	0.77	0.65	0.44	0.77	0.61	0.79	0.81
pict-CC	0.87	0.93	0.94	0.83	0.88	0.92	0.92	0.76	0.76
pict-CC*	0.96	0.94	0.96	0.96	0.96	0.98	0.97	0.98	0.74

4 Conclusions

The RGB and CIEXYZ coordinates of the colors in images acquired by conventional digital cameras are unstable values which vary depending on the luminance of the scene and among different cameras, possibly due to the self-adjustments and optimizations made by the camera for each individual picture. However the Hue of the average pixel is an acceptable robust parameter when comparing scenes and also for comparing cameras, which points to that color parameter as a suitable surrogate for NDVI, though the relationship between Hue and NDVI is not linear.

CIEXYZ and RGB coordinates of the average pixel, specially CIEX and R, can also be used for assessing the state of the vegetation but in this case, the color of the picture must be corrected in order to compare scenes of different luminance and also for comparing images obtained by different cameras.

The described protocol for picture acquisition and color correction allows the comparison of color measurements obtained from diferent scenes and by different cameras. This confirms conventional digital cameras as a suitable tool for field data acquisition in the context of turf, and possibly of other crops.

5 References

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