Determination of bare soil and its seasonal variation using image analysis

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ABSTRACT

Bare soil is of outstanding interest as an indicator of land degradation because it is strongly related with water erosion, particularly in low-vegetated areas as those typical of the Mediterranean rangelands. In areas with high livestock densities, erosion can ultimately get to a partial or total soil loss, particularly at the beginning of the rainy season, when the surface cover is reduced after the dry summer period. Therefore, it is necessary to develop accurate methods allowing the quantification of soil exposed areas and their temporal dynamics. The main goal of this work is the determination of bare soil surfaces using aerial orthophotomaps and the analysis of the changes resulting from the analysis and classification of images corresponding to two contrasting seasons (summer and spring). The study area located in Monroy, Cáceres province, Spain, is a privately owned farm 1,024 hectares in size, and is grazed by sheep and pigs. It correspond to a representative area of the wooded rangelands (dehesas) characteristics of the south-western part of Iberian Peninsula

Keywords: Bare soil, Erosion, Soil degradation, Image analysis, Livestock.

INTRODUCTION

In Mediterranean type climates, the seasonal variation of rainfall produces differences in vegetation cover and, hence, in the amount of bare soil. During the dry summer, pasture cover may be reduced, especially in combination with grazing domestic animals, leading to bare areas of varying extension and form. The reduction of biomass and soil cover due to grazing causes a decrease in rainfall interception, increasing bare soil surface and, consequently, less protection against raindrops impact on the soil surface. Indirectly, the reduction of biomass, and the consequent reduction of soil organic matter, provokes soil degradation (Imeson, 1998). The existence of long drought periods coupled with the period of autumn rains, characteristic of Mediterranean climate, are likely to cause important amounts of soil matter losses. Therefore, in grazing systems the dominant types of degradation are physical and biological.

Quantifying bare soil surface and its temporal dynamics by field work can be a highly demanding activity in terms of both time, and economic costs. For coarser spatial scales and low needs of detailed information, using satellite image analysis can be a good strategy. Nevertheless, satellite images overestimates or underestimates bare areas at the plot level. Using aerial photographs of high spatial resolution supply better soil surfer information while lacking the spectral information of the satellite images.

Modern techniques of orthophotomap image analysis and statistical procedures help in avoiding some of the lacks of visual aerial photograph interpretation, leading to the possibility of accurately quantifying some of the surface properties, particularly those as bare soil surface areas, easily identifiable in terms of their visual spectral properties.

The main goal of this work is the quantification of bare soil areas and its temporal (interseasonal) dynamics at a fine spatial resolution. The study area is a farm located in a woody rangeland (dehesa) in SW Spain, covering a surface area of 1,024 hectares, grazed by sheep and pigs and under Mediterranean climate conditions.

METHODS

Material

The whole work was carried out on the basis of two orthorrectified aerial photograph: One in 0.4 m pixel size, dated on July 2002 taken *ex profeso* and another of 0.5 metres pixel size (digitally resampled to 0.4 m) dated on April 2006 taken from SIGPAC project (Geographical Information System of Agricultural Plots from Spanish Ministry of Environment).

Unsupervised classification

For the determination of bare soil areas, unsupervised classification techniques were applied to the abovementioned orthophotomaps using both RGB bands and a calculated brightness band component. Unsupervised classification uses only data from the pixel image spectral characteristics, performed by assigning classes to series of homogenous pixel groups called clusters. The first step in an unsupervised classification is the creation of clusters using a multivariate technique for grouping based on ISODATA (Iterative Self-Organizing Data Analysis Technique) algorithm, which consists in assigning each pixel to a centroid, minimizing the residual variance and separating the images into homogenous classes. The creation of clusters is not based on any spatial feature, just in the pixel values (individual pixel value, mean, variance and covariance between bands and within each band). ISODATA algorithm builds clusters as follows: determine the mean centres of each class in the image histogram, assign all the pixels to the nearest class, compute the new mean centres of each class, rearrange the class mean centres on the basis of the control parameters specified by the user, back to assign all the pixels of the image to the nearest centroid and re-iterate until no changes are produced. The selection of centroids and the allocation of pixels to them are made by k-means clustering algorithm. The resulting classified image is composed according to maximum likelihood of each pixel of belonging to the created classes. Due to its spectral characteristics (high values of RGB and brightness digital levels), bare soil pixels were always classified according to the statistical properties of the last class in all the classifications performed. A number of 42 classifications were performed using different band combinations for each image (RGB, brightness and RGB+brightness) and different settings of the k-means algorithm from 2 to 15 predefined classes. The better classifications for each band combination were afterward selected on the premise of maximizing the minimum statistical distance among classes and reclassified into two classes, covered and uncovered (bare soil) surfaces.

Validation of the results

To validate the results a number of 1000 random points were generated over the image and their cover characteristics thoroughly checked on the screen based on the prior knowledge of the study area characteristics. Statistical algorithms used for measuring the classification accuracy were contingency matrices, and area under ROC (Receiving Operating Characteristic) curves.

RESULTS AND DISCUSSION

Best results were obtained from a combination of the RGB+brightness component of the images, classifying them to first obtain the optimum number of classes (k) and afterwards carrying out a reclassification process in order to obtain two final classes as described in methods. For spring 2006 the optimum number of classes was 6, being 5 in the case of summer 2002. The validation procedure showed high accuracy levels: 93.4 % for the spring image and 93.1 % for the summer one (Table 1). The Area Under the Curve (AUC) from the ROC validation technique amounted to 0.94 and 0.91 for spring and summer respectively (Table 2). 10.7 % of the study area was estimated as bare soil in summer and 84.3 % in spring. 81.2 % of the farm surface was permanently covered, and a 3.8 % was always bare. Approximately 15% of the surface changed from covered to bare or vice versa (Figure 1). Useful information can also be gathered from the characteristics of exposed areas, such as density of animal paths and piospheres.

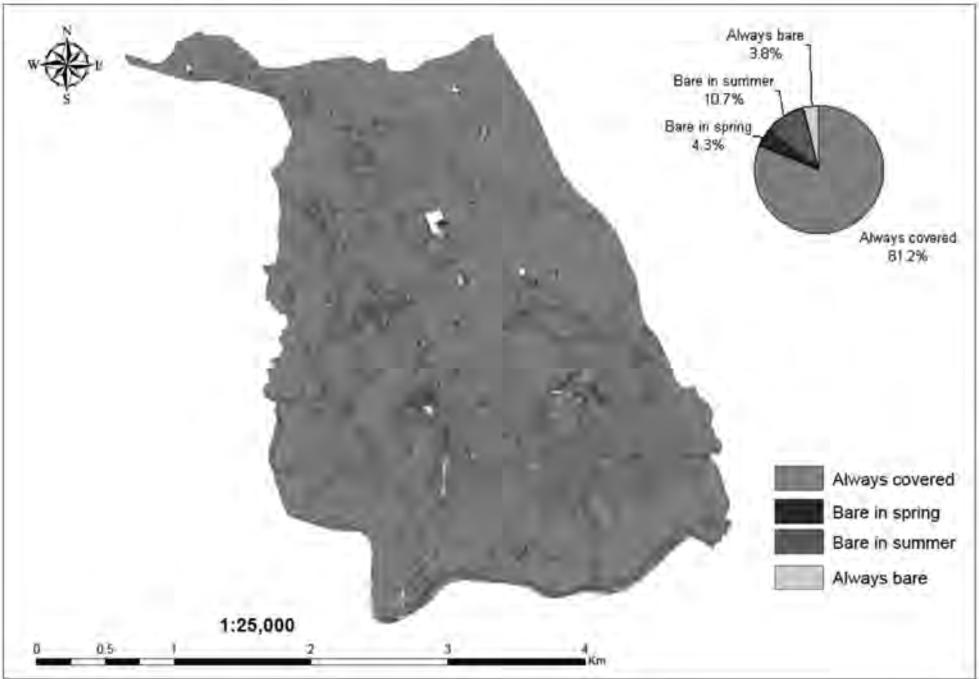

Figure 1. Bare soil and its seasonal variation.

Table 1. Percentage of accuracy of unsupervised classifications using 1000 field work random validation points. RGB: RGB Image; BR: Brightness component of the RGB Image; RGB + BR: Combination of RGB Image with its brightness component; BS: Bare soil; CS: Covered soil; T: Total.

Number of classes (k)	2002									2006								
	RGB			BR			RGB + BR			RGB			BR			RGB + BR		
	BS	CS	T	BS	CS	T	BS	CS	T	BS	CS	T	BS	CS	T	BS	CS	T
2	99.4	47.4	56.5	99.4	47.4	56.5	99.4	47.9	56.9	100	35.1	41.6	100	33.1	39.8	100	34.7	41.2
3	98.9	70.5	75.5	98.9	69.8	74.9	98.9	65.3	71.2	99.0	57.3	61.5	100	56.4	60.8	99.0	57.0	61.2
4	95.4	85.7	87.4	96.6	84.4	86.5	96.6	82.3	85.0	99.0	79.7	81.6	99.0	78.6	80.6	99.0	79.6	81.5
5	88.6	93.8	92.9	91.4	93.0	92.8	91.4	94.9	93.1	98.0	87.4	88.5	98.0	86.1	87.3	98.0	87.2	88.3
6	82.9	97.7	95.1	83.4	96.8	94.5	83.4	97.2	94.7	94.0	93.8	93.8	95.0	92.8	93.0	95.0	93.2	93.4
7	75.4	99.1	95.0	78.9	98.5	95.1	78.9	98.2	94.8	89.0	97.1	96.3	89.0	96.7	95.9	89.0	97.0	96.2
8	70.3	99.4	94.3	76.0	99.3	95.2	76.0	99.3	94.8	79.0	99.2	97.2	79.0	98.8	96.8	79.0	99.1	97.1
9	66.3	99.9	94.0	72.0	99.8	94.9	72.0	99.5	94.2	68.0	99.6	96.4	69.0	99.1	96.1	68.0	99.4	96.3
10	62.3	99.9	93.3	69.7	99.8	94.5	69.7	99.9	93.9	64.0	99.8	96.2	60.0	99.6	95.6	62.0	99.7	95.9
11	57.1	99.9	92.4	66.3	99.9	94.0	66.3	99.9	92.8	58.0	99.8	95.6	59.0	99.6	95.5	59.0	99.8	95.7
12	57.1	99.9	92.4	64.0	99.9	93.6	64.0	99.9	92.5	58.0	99.8	95.6	57.0	99.7	95.4	57.0	99.8	95.5
13	57.1	99.9	92.4	61.7	99.9	93.2	61.7	99.9	92.2	55.0	98.8	95.4	56.0	99.8	95.4	56.0	100	95.6
14	55.4	99.9	92.1	59.4	99.9	92.8	59.4	99.9	92.2	54.0	100	95.4	55.0	99.9	95.4	55.0	100	95.5
15	55.4	99.9	92.1	59.4	99.9	92.8	59.4	99.9	91.8	53.0	100	95.3	51.0	100	95.1	53.0	100	95.3

Table 2. Area Under the ROC Curve (AUC). RGB: RGB Image; BR: Brightness component of the RGB Image; RGB + BR: Combination of RGB Image with its brightness component; BS: Bare soil; CS: Covered soil; T: Total.

Number of classes (k)	2002			2006		
	RGB	BR	RGB + BR	RGB	BR	RGB + BR
2	0.734	0.734	0.737	0.676	0.666	0.673
3	0.847	0.843	0.821	0.782	0.782	0.780
4	0.906	0.905	0.900	0.893	0.888	0.893
5	0.912	0.923	0.913	0.927	0.921	0.926
6	0.903	0.901	0.900	0.939	0.939	0.941
7	0.873	0.887	0.885	0.931	0.928	0.930
8	0.848	0.876	0.865	0.891	0.889	0.891
9	0.831	0.859	0.843	0.838	0.841	0.837
10	0.811	0.847	0.828	0.819	0.798	0.808
11	0.785	0.831	0.797	0.789	0.793	0.794
12	0.785	0.819	0.788	0.789	0.783	0.784
13	0.785	0.808	0.779	0.774	0.779	0.780
14	0.777	0.797	0.779	0.770	0.774	0.775
15	0.777	0.797	0.768	0.765	0.755	0.765

CONCLUSIONS

A surface of 10.7 % of the total farm was bare in summer mainly due to grazing by livestock, and 4.3 % was bare in spring also due to other human activities. Permanently uncovered areas were also animal paths, tracks and areas around ponds.
The method is efficient in terms of bare soil determination, with more than 90 % of success in the classes assigned. Unsupervised classification methods are appropriate for bare soil surface quantification in the study area and are particularly relevant by avoiding time and economic consuming labours when selecting supervised areas for training purposes.

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