economical way to achieve a better description of the agronomic parameters of a pasture. However, such indices should be considered with some attention in case of heterogeneous pastures constituted by species with low decomposition rate (see also Gianelle *et al.*, 2003)

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Integrating proximal sensing techniques in the prediction of agronomic characteristics of pastures

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Summary

Remote sensing techniques have been proposed and developed to extend at regional level local measurements of biomass, LAI and nitrogen in agronomic crops. At present, only few data are available for natural grassland ecosystems. In order to improve the correlation between data collected at different investigation scales, the use of a close network of quick field measurements of canopy spectral reflectance to calibrate airborne and satellite data has been proposed for agronomic crops. This paper aims to extend the above technique to heterogeneous alpine grasslands. In the canopy of an alpine grassland located at 2 000 m a.s.l. and referring to a typical *Nardetum alpigenum* association, reflectance data were collected with a portable spectroradiometer. Measurements were carried out on several geo-referred locations and repeated at two-week intervals during the entire vegetative period. Biomass, LAI and nitrogen content of the forage were also measured. Subsequently, the possibility to integrate proximal sensing data with different canopy parameters was investigated. Correlations obtained between the Normalized Differential Vegetation Index (NDVI), phytomass, biomass and LAI are discussed, together with relations between nitrogen content, PSSRa and PSNDa indices.

Keywords: spectral reflectance, vegetation indices, alpine pastures, agronomic parameters.

Introduction

The assessment of the production of a given mountain pasture is critical in determining its feeding capacity. Production is currently estimated by clipping and testing very few pasture samples, which brings about considerable uncertainty in the evaluation. Furthermore, summer grazing frequently implies a decrease in animal production, more or less severe according to the animal production level and distance of time from calving (Zemp *et al.*, 1989; Malossini *et al.*, 1992; Andrighetto *et al.*, 1996). As a result, total animal nutritional requirements may be not satisfied.

A more accurate assessment of both production and feeding capacity requires dense measurements of biomass availability and quality, instead of the current scattered ones. The use of a portable spectroradiometer may be helpful, as it allows relatively quick and cheap measurements and offers the additional possibility of extending local data at regional level by calibrating remote sensing data, thus increasing their reliability.

Spectral vegetation indices are widely used in remote sensing to monitor, at regional and continental scale, time- and space-wise variations of canopy structure, changes in Leaf Area Index (LAI), net primary production and forage quality (Clevers and van Leeuween, 1996, Myneni *et al.*, 1995, 1997).

Most vegetation indices combine information obtained in the red and near-infrared (NIR) bands. The red reflectance will decrease with vegetation cover increase, due to the strong chlorophyll absorption in the red band, while the reflectance in the NIR spectral region will generally increase.

NDVI is one of the most widely used vegetation indices, because it provides information on production, total leaf area and canopy architecture; it also compensates, at least in part, for changing illumination conditions, surface slope and viewpoint position (NOOA, 1990). NDVI is stable enough to permit meaningful comparisons of seasonal and inter-annual changes in vegetation growth and activity. Main disadvantages of this index are the signal saturation at increasing biomass or LAI values and its considerable sensitivity to background reflectance.

For the nitrogen biomass content, the Pigment Specific Simple Ratio (PSSRa) and the Pigment Specific Normalized Difference (PSNDa) can be used. PSSRa is the ratio of the reflectance at 676 nm to the one at 810 nm for chlorophyll *a*. PSNDa is the normalized index referring to the same wavelength of PSSRa for chlorophyll *a* (McNairn *et al.*, 2001).

At present, no extensive data sets of canopy reflectance collected on natural alpine grasslands are available. This work presents preliminary results on canopy reflectance related to an alpine pasture, aiming to integrate proximal sensing with different canopy parameters such as phytomass, LAI and nitrogen content.

Material and methods

The site investigated is characterized by the typical Central-East Alps climate, with long, cold winters and warm, wet summers. The mean annual temperature is 2.7°C and the annual rainfall is 1 100 mm, abundant in the summer.

"Malga Juribello" is a typical alpine mountain pasture. The pasture has an area of approximately 170 ha and is located between 1 820 and 2 230 m a.s.l.. The pasture is managed by the "Breeder Provincial Federation of Trento" and is grazed by 130 cattle. The grazing period lasts about 90 days, from June 15th to September 15th. The study was carried out on a less exploited pasture sector of 60 ha, where the vegetation is dominated by the primary *Nardetum alpigenum* association, typical of the siliceous sub-alpine belt. The pasture was grazed throughout the day and night by 30 cattle for a period of 50 days.

Grassland productivity and LAI have been studied using direct and indirect methods based on spectroradiometry techniques. The direct method involved clipping repeated at twenty-day intervals, in three 0.5 x 0.5 m homogeneous plots. The phytomass was first divided into biomass and necromass and then dried up h at 80 °C for 48. The total leaf area was determined using an optical scanner and the Image Tools software (UTHSCSA, University of Texas, USA). In the same plots, nadir canopy reflectance was measured before clipping with a portable spectroradiometer (FieldSpec Pro ASD), using a field of view of ten degrees. The NDVI index based on red and near infrared spectral region was calculated and correlated with phytomass and LAI. Moreover, the eLAI was determined at two-week intervals by an indirect, non-destructive technique involving the use of optical sensors (Li-cor LAI 2000, Lincoln, Nebraska, USA) and appropriate inverse models of radiative transfer.

The nitrogen content of the forage was determined with an elementary analyzer (Perkinelmer Series II CHNS/O Analyzer 2400) and data were correlated with chlorophyll indices PSNDa and PSSRa.

Results and discussion

The correlations between NDVI, phytomass ($r^2 = 0.70$), biomass ($r^2 = 0.37$) and necromass ($r^2 = 0.33$) are statistically significant ($P < 0.01$).

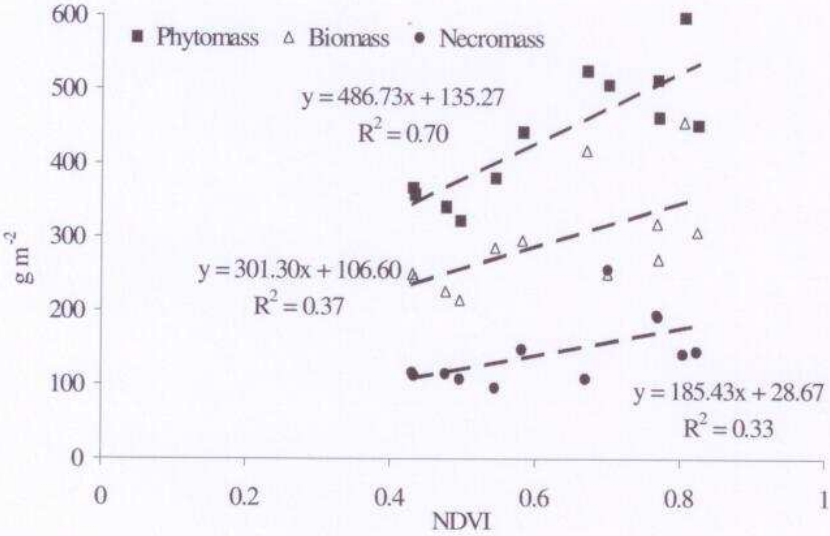

Figure 1. Relationship between NDVI, phytomass, biomass and necromass. Linear regressions are statistically significant (P<0.01).

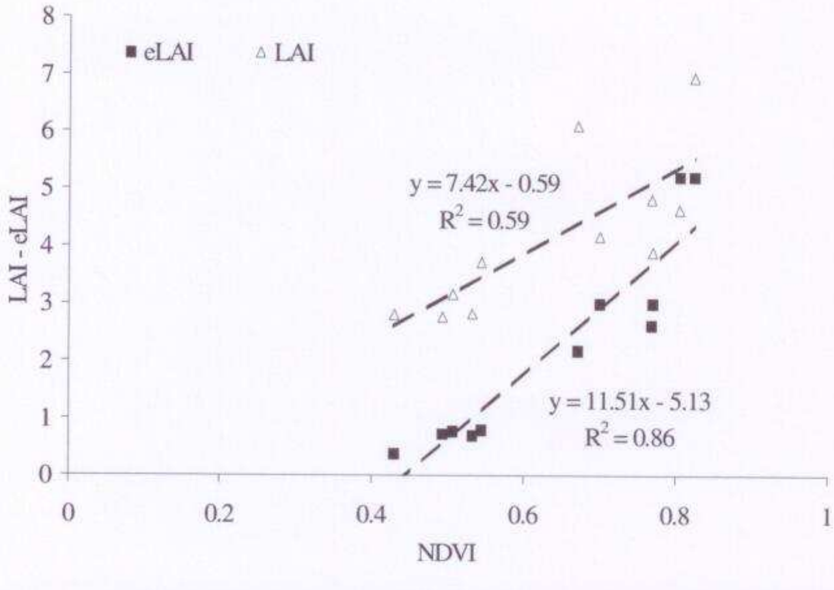

Figure 2. Relationship between NDVI, LAI and eLAI. Both linear regressions are statistically significant (P<0.01).

The contribution of necromass on the total phytomass proved to be very high (between 30% and 50% during the vegetative period) due to the abundance (40%) of *Nardus stricta*, whose previous year leaves were still slowly decomposed because of the low temperatures occurred in the study area. Figure 1 shows that NDVI correlation with phytomass is much better than the ones with necromass and biomass. This confirms the strong link existing between the total production and vegetation reflectance. At the same time, however, the poor correlation of NDVI with biomass sets a limit on the use of this index for the prediction of the actual forage availability, namely for pastures constituted by species having a low decomposition rate.

A significant (P<0.01) positive linear relation was found between NDVI and LAI ($r^2 = 0.59$), as well as between NDVI and eLAI ($r^2 = 0.86$) (Figure 2). The better r^2 of the correlation between NDVI

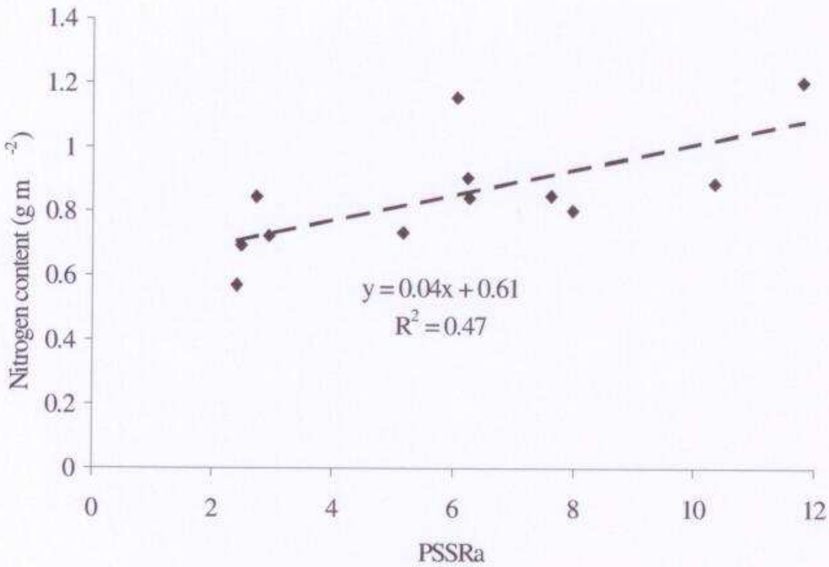

Figure 3. Relationship between PSSRa and Nitrogen content. Linear regression is statistically significant (P<0.05).

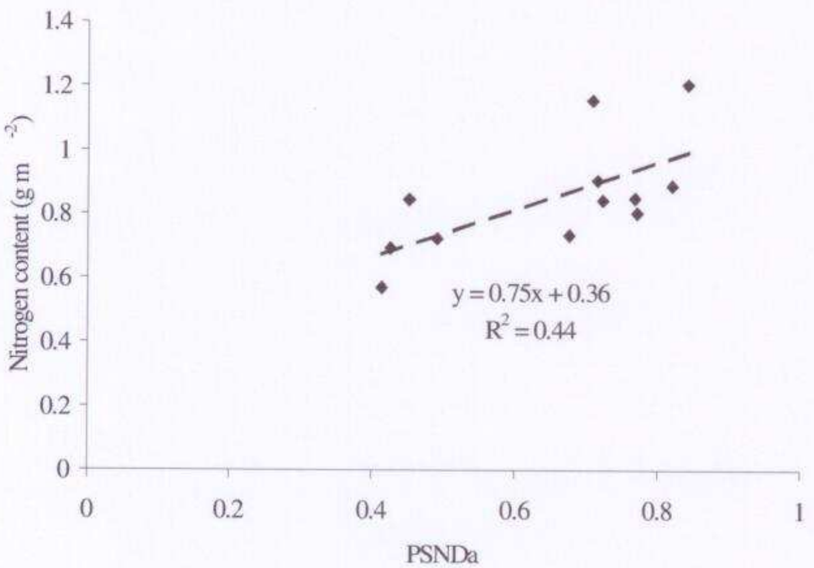

Figure 4. Relationship between PSNDa and Nitrogen content. Linear regression is statistically significant (P<0.05).

and eLAI is probably due to the strong dependence of both indices on canopy structure and density (see also Vescovo *et al.* 2003 for the differences between LAI and eLAI).

The relations between total biomass nitrogen and PSSRa ($r^2 = 0.47$, Figure 3) and PSNDa ($r^2 = 0.44$, Figure 4) are statistically significant ($P<0.05$). No significant correlation was found, instead, between the two indices and phytomass or necromass nitrogen. The two indices, normally used for chlorophyll estimation, should also be potentially good predictors of biomass nitrogen content.

The study results indicate that the spectral indices discussed above may provide a reliable estimate of some significant canopy parameters such as phytomass, eLAI and biomass nitrogen in natural grassland ecosystems. They may also allow to extend local data at regional level by calibrating remote sensing data. Therefore, it can be said that spectroradiometer measurements may be a suitable, quick and