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Dry-season vegetation mass and cover fraction from SWIR1.6 and SWIR2.1 band ratio: Ground-radiometer and MODIS data in the Sahel

L. Kergoat[a,*], P. Hiernaux[a], C. Dardel[a], C. Pierre[a], F. Guichard[b], A. Kalilou[c]

[a] GET (CNRS/IRD/Université de Toulouse), 14 Avenue E. Belin, 31400 Toulouse, France
[b] CNRM-GAME (CNRS/MétéoFrance), 42 Avenue Coriolis, 31057 Toulouse, France
[c] ILRI, ICRISAT Sahelian Centre, B.P. 12404, Niamey, Niger

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ABSTRACT

The potential of the short-wave infrared (SWIR) bands to detect dry-season vegetation mass and cover fraction is investigated with ground radiometry and MODIS data, confronted to vegetation data collected in rangeland and cropland sites in the Sahel (Senegal, Niger, Mali). The ratio of the 1.6 and 2.1 μm bands (called STI) acquired with a ground radiometer proved well suited for grassland mass estimation up to 2500 kg/ha with a linear relation ($r^2 = 0.89$). A curvilinear regression is accurate for masses ranging up to 3500 kg/ha. STI proved also well suited to retrieve vegetation cover fraction in crop fields, fallows and rangelands. Such dry-season monitoring, with either ground or satellite data, has important applications for forage, erosion risk and fire risk assessment in semi-arid areas.

1. Introduction

Observing dry-season herbaceous vegetation in semi-arid areas is important for a number of applications: forage monitoring, resource management, fire risk and emissions, and also erosion risk assessment (Marsett et al., 2006; Hagen et al., 2012; Ludwig and Tongway, 1995). Still, satellite survey of dry-season vegetation has received far less attention than green vegetation so far. There is now increasing evidence, though, that current sensors like MODIS have strong capabilities to detect dry vegetation, often referred to as non-photosynthetic vegetation, crops residues, or litter (Guerschman et al., 2009; Hagen et al., 2012; Okin et al., 2013). Spectral bands in the SWIR domain have proved particularly efficient, due to the presence of absorption features of different components of dry vegetation tissues like cellulose, hemicellulose or lignin (Asner and Lobell, 2000; Daughtry, 2001). These features are best detected with high spectral resolution data, for instance with the Cellulose Absorption Index (CAI, Nagler et al., 2003), but Guerschman et al. (2009) showed that MODIS bands 6 (B6, 1.6 μm) and 7 (B7, 2.1 μm) could be combined to match CAI ability to detect dry plant tissues. In the same vein, Jacques et al. (2014, hereafter referred to as J14) showed that MODIS ratio B6/B7, also called the Soil Tillage Index (STI), was strongly related to the mass of dry vegetation in Sahelian grasslands.

Using a sensor like MODIS is appealing, since it has a very good temporal resolution (daily time-step) and global coverage. The spatial resolution however is coarse: 500 m at nadir for the SWIR bands. As for other satellite products like Leaf Area Index or Net Primary Productivity, validation and training of algorithms face a scaling issue. Field data are typically collected over a few m^2 for mass, or even less, when pins or lasers are used to estimate vegetation cover fraction (Muir et al., 2011; Nagler et al., 2003). Ground data sampling protocols, in most cases, are tedious and expensive. In the case of the SWIR bands, the situation is particularly complex, since the variables of interest are difficult to measure, even on the ground. For instance, the cover fraction of green vegetation is relatively easily measured using hemispherical or vertical photographs. Conversely, at least over Sahelian bright sandy soils, the contrast between dry vegetation, soil and shadows is weak and the use of classical processing software proved difficult. In the field, it is easier to measure the mass of dry vegetation than its cover fraction. Still, it requires a scaling scheme to be compared with MODIS data.

J14 addressed this issue with an extensive set of 536 satellite-scale mass estimations collected during 8 years over a network of one kilometer long lines in rangelands of Sahelian Mali. They obtained a linear relationship between mass and STI (MODIS B6/B7) characterized by an r^2 of 0.65 and a RMSE of 280 kg of dry matter per hectare (kg DM/ha). This result is potentially very useful for wind erosion risk and forage monitoring applications in the Sahel, and

* Corresponding author. Tel.: +33 561332987; fax: +33 561 33 2888.
E-mail address: laurent.kergoat@get.obs-mip.fr (L. Kergoat).

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probably in other semi-arid grasslands, since it provides a simple method based on easily accessed data. This study raises a number of questions, though. Firstly, there is a significant scatter in the J14 STI-mass relation, which causes have not yet been identified. It might be due to the ground sampling scheme applied to the mass estimation, to the quality of MODIS STI data, or to the variability of target spectral signatures. Any progress in understanding the scatter should lead to improved relationships. Secondly, it would be very valuable to characterize not only pastoral but also agro-pastoral landscapes, consisting in mosaics of crops, fallows and rangelands, especially for erosion risk assessment. Thirdly, it is necessary to investigate the respective importance of vegetation mass and cover fraction in driving STI variability over different dry vegetation canopies.

The objectives of the present study are to document these three questions using MODIS data together with ground radiometry in the 1.6 and 2.1 μm SWIR bands. The Sahelian sites and datasets are presented in Section 2. The results from ground radiometry and MODIS STI, and their relationships with mass and vegetation cover for grasslands, fallow and millet crops are shown in Section 3, and further discussed in Section 4.

2. Sites, data and methods

Data were collected over three Sahelian areas, in Senegal, Mali and Niger (Fig. 1). They consist in ground measurement of vegetation mass and cover fraction, plus ground radiometry in Senegal, together with coinciding MODIS observations, as explained below.

2.1. Vegetation data

In Senegal, data were collected in December 2013 in the Ferlo region. As elsewhere in pastoral Sahel, the vegetation is dominated by annuals grasses and dicots with scattered trees and shrubs. *Aristida mutabilis*, *Schoenfeldia gracilis*, *Eragrostis tremula*, *Dactyloctenium aegyptiacum*, *Chloris prieurii*, *Cenchrus biflorus*, *Alysicarpus ovalifolius*, and *Zornia glochidiata* were the dominant species in the sampled sites. The tree cover was usually within the 0–10% range. Annual rainfall in 2013 was close to normal and ranged from 200 to 350 mm. Herbaceous vegetation mass was measured for groups of 1 m^2 plots or along 500 m lines (Fig. 1). For each plot, dominant species were recorded and vertical pictures were taken for cover fraction estimation. Aboveground vegetation was cut, dried and weighed, with standing and laying parts treated separately.

In the Ferlo rangelands, 500 m lines were sampled over sites belonging to a long-term ecosystem survey (Diouf and Lambin, 2001) and next to two recently installed soil moisture stations. Over each line, the average mass is estimated using a stratified random scheme (Hiernaux et al., 2009 J14). Each 1 m^2 of the line

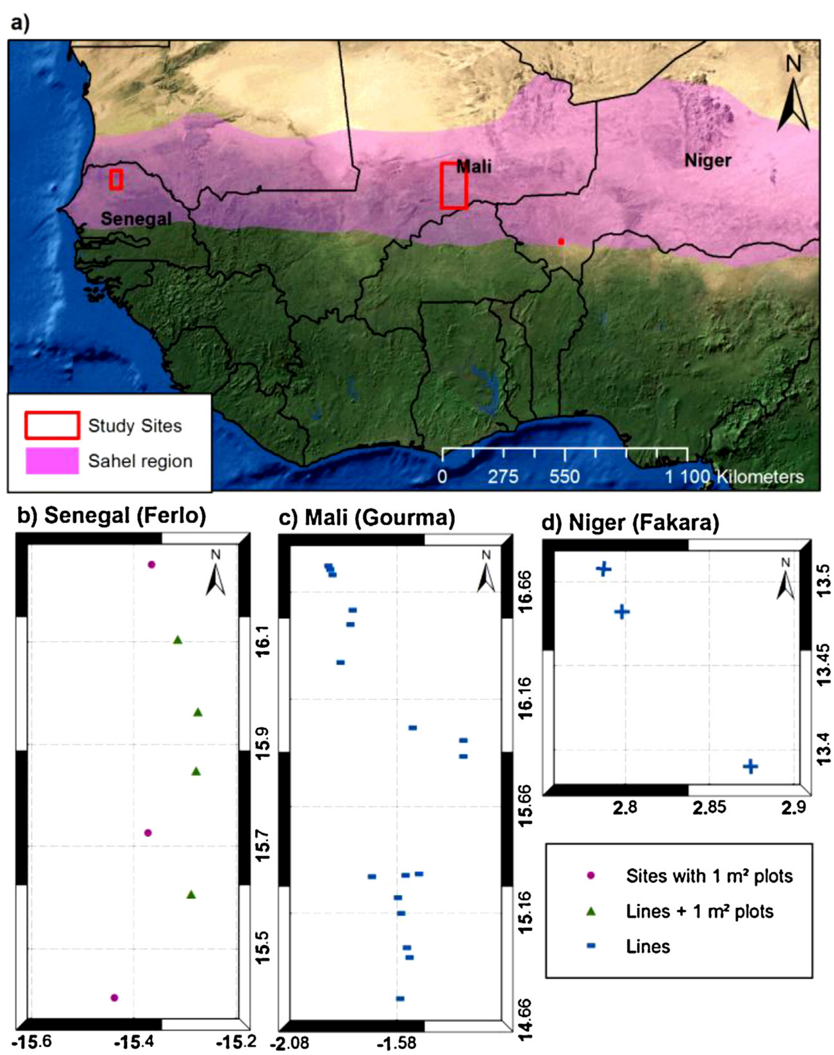

Fig. 1. Location of study sites in the three sahelian countries.