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Phytomass estimation of Moroccan rangeland using Sentinel-2 satellite indices and *in situ* biomass measurements

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Abstract. The monitoring of fodder production in arid and semi-extensive rangelands of Morocco is an essential component of livestock management. An accurate estimate of rangeland phytomass information is required for supplementary feeding leading to sustainable use of rangeland resources. The objective of this study is to test several vegetation indices resulting from remote sensing to propose the most appropriate vegetation indices for phytomass estimation of Moroccan rangelands. Field data, collected during spring 2018 in the Eastern region of Morocco, and eight vegetation indices (ARVI, DVI, IPVI, MSAVI, NDVI, RVI, SAVI and TSAVI) obtained from three Sentinel-2 satellite images acquired in April 2018 are used. Correlations between measured phytomass and each of these vegetation indices were performed to identify the best estimator. The results showed that rangeland phytomass ranged from 0.02 to 4.71 tons with an average of 0.84 tons per hectare in the studied site. Vegetation indices highly correlated with measured phytomass are ARVI, IPVI, NDVI, RVI and SAVI. Also, the results showed that polynomial models were better than linear ones. The best model of phytomass estimation was RVI followed by NDVI with a coefficient of deterimination, $R^2_{,}$ of 0.84 and 0.82, respectively.

Keywords. Biomass – Vegetation index – Pasture – Remote sensing – Eastern Morocco.

Estimation de la production fourragère des terres de parcours des Hauts plateaux de l'Oriental à patir des indices de télédétection

Résumé. *Les terres de parcours des Hauts Plateaux de l'Oriental constituent un appoint important à l'alimentation du cheptel ovins et caprins. L'estimation de la production fourragère de ces terres de parcours est utile pour les gestionnaires des espaces pastoraux. L'objectif de cette étude est de tester plusieurs indices de végétation issus de la télédétection pour proposer l'indice le plus approprié pour l'estimation de la phytomasse des terres de parcours. Dans cette étude, nous avons utilisé les données collectées sur le terrain en Avril 2018 dans la région Orientale du Maroc et huit indices de végétation (ARVI, DVI, IPVI, MSAVI, NDVI, RVI, SAVI et TSAVI) issus de trois images satellites Sentinel-2 prises en Avril 2018. Des corrélations entre la phytomasse mesurée et chacun de ces indices de végétation ont été analysées pour identifier le meilleur estimateur de la biomasse à partir des données de télédétection. Les résultats obtenus ont montré que la phytomasse des parcours varie entre 0,02 et 4,71 tonnes, avec une moyenne de 0,84 tonne par hectare dans les sites étudiés. Les indices de végétation fortement corrélés avec la phytomasse sont ARVI, IPVI, NDVI, RVI et SAVI. Les modèles polynomiaux sont mieux que les modèles linéaires. Le meilleur modèle d'estimation de la phytomasse est le RVI suivi du NDVI avec un coefficient de détermination,* $R^2_{,}$ *de 0,84 et 0,82, respectivement.*

Mots-clés. *Biomasse – Indice de végétation – Pâturage – Télédétection – Maroc Oriental.*

I – Introduction

In Morocco, rangelands occupy 75% of the country's territory (Mahyou *et al.,* 2018). The accurate estimation of forage production of Moroccan rangelands and the monitoring of its spatio-temporal variation are important for the management of pastoral resources. However, the phytomass estimation using field measurements is costly and time-consuming, especially in these large regions where productivity per unit area is generally low and highly variable. The use of remote sensing has become the most effective approach for phytomass estimation (Barrachina *et al.,* 2015, Diouf *et al.,* 2015). Vegetation indices, calculated from remotely sensed reflectance, reflect the photosynthetic activity of the vegetation and are increasingly used to monitor rangeland productivity (Gao *et al.,* 2013). Indeed, the combination of remote sensing and field measurements makes it possible to estimate the phytomass and to provide decision-makers with information that can guide them in the management of natural resources. In this work, we aim to estimate the phytomass of rangelands in the highlands of eastern Morocco, by combining satellite data and field measurements. We will analyze the possibility of statistically linking the vegetation indices to phytomass measured during the growing season.

II – Materials and methods

The study area is located in the highlands of Eastern Morocco (34 ° 22 ‘12/33 ° 5’ 24 N and 1 ° 42 ‘36’ ‘/ 02 ° 31’ 12 “ W), and covers the total area of about 1 000 km². The annual average rainfall is low and irregular, about 180 mm. The average maximum air temperature is high and varies around 42.5 °C in summer, and the minimum can reach -4 °C in winter. In summer, hot and dry winds from the east and south are frequent and lead to strong sandstorms. The vegetation is composed of *Stipa tenacissima, Thymus sp, Noaea mucronata, Stipa parviflora* and *Lygeum spartum*; degraded steppes based on *Peganum harmala* or / and *Anabasis aphylla*, and steppes based on *Stipa tenacissima, Artemisia herba-alba* and / or annuals (*Schismus barbatus*) in mosaic with *Stipa parviflora, Atractilis serratuloides* and Helianthemum spp (Mahyou *et al.,* 2016).

Grazing intensity (ratio between actual animal charge and carrying capacity of rangeland) is superior to 4, indicating an overexploitation of this pasture areas.

Table 1. Description of studied vegetation indices

Index	Formula	Name	Reference
NDVI	$NDVI = \frac{(PIR - R)}{(PIR + R)}$	Normalized Difference Vegetation Index	(Rouse and Haas (1973); Tucker (1979)
RVI	$\mathrm{RVI} = \frac{R}{PIR}$	Ratio Vegetation Index	Krieger et al. (1969); Jordan (1969)
DVI	$\mathrm{DVI} = \mathrm{PIR} - \mathrm{R}$	Difference Vegetation Index	Tucker (1979)
SAVI	$\mathrm{SAVI} = \frac{(\mathrm{PIR} - \mathrm{R})}{(\mathrm{PIR} + \mathrm{R} + \mathrm{L})}$	Soil Adjusted Vegetation Index	Huete (1985)
MSAVI	$\mathrm{MSAVI} = (1 + \mathrm{L}) * \frac{(PIR - R)}{(PIR + R + L)}$	Modified Soil Adjusted Vegetation Index	Qi et al. (1994)
TSAVI	$TSAVI = \frac{\mathrm{a} * (\mathrm{PIR} - \mathrm{a} * \mathrm{R} - \mathrm{b})}{(R + a * PIR - a * b)}$	Transformed Soil Adjusted Vegetation Index	Baret et al. (1989)
ARVI	$ARVI = \frac{(PIR - RB)}{(PIR + RB)}$	Atmospherically Resistant Vegetation index	Kaufman and Tanre (1992)
IPVI	$\mathrm{IPVI} = \frac{NIR}{(PIR + R)}$	Infrared Percentage Vegetation Index	Crippen (1990)

Field data collection was carried out during April 2018. A total of 37 sampling sites were selected to measure phytomass of perennial and annual vegetation. Data were collected from three 25 m^2 quadrats within each sampling site and averaged over the quadrats to estimate the site's phytomass. The method used to measure vegetation phytomass depends on the type of plant formation: for perennial vegetation, the measurements were based on the method of the reference unit (UR) (Kirmse & Norton 1985). For herbaceous plants, the plants within a 1 m^2 quadrat was clipped at ground level and weighed. In the laboratory, all clipped phytomass were dried at 75 °C for 48 h before being weighed. Three Sentinel-2A images, with a spatial resolution of 10 m were used. These images were acquired in April. Blue, red and near-infrared spectral reflectance values were selected to calculate vegetation indices (Table 1). The vegetation indices values of the pixels of each of the 37 study sites were calculated and integrated in the statistical model described hereafter.

Linear and polynomial regressions were applied to examine the relationship between vegetation indices and the phytomass. The accuracy of the phytomass estimation models was evaluated based on two statistical indices: the coefficient of determination (R^2) and the root mean squared error (RMSE).

Table 2. Statistical models of phytomass estimation

Indices	Model	R^2	RMSE
ARVI	Linear	0.79	0.53
	Polynomial	0.81	0.50
DVI	Linear	0.31	0.94
	Polynomial	0.37	0.91
IPVI	Linear	0.79	0.52
	Polynomial	0.82	0.48
MSAVI	Linear	0.05	1.11
	Polynomial	0.53	0.79
NDVI	Linear	0.80	0.50
	Polynomial	0.82	0.49
RVI	linear	0.81	0.49
	Polynomial	0.84	0.47
SAVI	Linear	0.70	0.63
	Polynomial	0.80	0.51
TSAVI	Linear	0.69	0.63
	Polynomial	0.73	0.60

III – Results and discussion

The average phytomass of the studied sites was 0.84 T / ha, with a minimum of 0.02 T / ha and a maximum of 4.71 T / ha with a very significant variation. In fact, Among the 37 sampled sites, 22 were dominated by species indicator of degradation. The other sites are sites with weak degradation or in good condition represented by *Artemisia herba alba, Stipa parviflora* or *Stipa tenacissima*. The linear and polynomial regression models of phytomass as a function of vegetation indices were compared. The coefficient of determination (R^2) and the root mean squared error (RMSE) are presented for each model in Table 2. The result presented in this table showed that the polynomial model is globally more accurate than the simple linear regression, for all vegetation indices due to the saturation of most of the vegetation index with high phytomass production. For all studied sites, the RVI is the best polynomial model for estimating rangeland phytomass compared to other indices (R^2 = 0.84). However, it did not differ significantly from the NDVI, IPVI, ARVI or SAVI models. Indeed, the four indices were significantly correlated with phytomass in the case of the polynomial model with R^2 equal to 0.82; 0.82; 0.81 and 0.80 respectively for NDVI, IPVI, ARVI and SAVI. It should be noted that the SAVI index did not bring any improvement over the NDVI for linear and polynomial models. The RMSE results for the different vegetation indices and the two regression models for phytomass differ from one index to another. However, the different regression models remain globally inaccurate with RMSE that vary between 0.48 and 1.1. This confirms the inaccuracy noted by Mahyou *et al*. (2018) on these empirical relationships. This is due to the fact that the state of rangeland degradation affects the relationships between these remotely sensed indices and rangeland phytomasse. RVI, in particular, showed a much better performance with RMSE value of 0.47. NDVI and ARVI indices appeared also as the best predictors of phytomass in our study area, compared to the other studied vegetation indices. They actually improved the accuracy of the phytomass estimate. However, and as shown in many studies, accurate estimation of phytomass using remote sensing data remains problematic in arid and semi-arid rangelands due to low vegetation cover and mixing of green and dead leaves of *Stipa tenacissima* (Mahyou *et al.,* 2018).

IV – Conclusions

In this study, RVI, IPVI, NDVI and ARVI indices appeared to be the best predictors of phytomass in our study area. The polynomial model of the RVI index could explain 84% of the variation of the phytomass. However, accurate estimation of phytomass using remote sensing data remains problematic in arid and semi-arid rangelands due to low vegetation cover and mixing of green and dead leaves. The indices used for the estimation of phytomass in arid and semi-arid rangelands are strongly influenced by the state of degradation of rangelands and dry and / or senescent leaves, especially in case of the alfa steppes. Therefore, the spectral signals of soil and alfa steppes and their variations must be taken into account when estimating phytomass using remote sensing data in arid and semi-arid rangelands.

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