

EVALUATION OF RATIO-BASED VEGETATION INDICES FOR ANNUAL CROPS' BIOMASS ESTIMATION. LEBNA WATERSHED, CAPBON, TUNISIA

Alaya¹ I., Zitouna-Chebbi¹ R, Mekki¹ I, Jacob² F

¹INRGREF, B.P. 10, 2080 Ariana, Tunisia

²IRD/UMR LISAH, Montpellier, France

ABSTRACT

The sustainability of agricultural sector involves a wise water resources management and therefore an accurate spatiotemporal vegetation monitoring with relevant tools such as satellite-derived indices (VI). In this study we evaluate the performance of NDVI and NDWI indices to infer the annual crops' (mainly wheat and faba-bean) aboveground biomass (AGB) at a Mediterranean watershed. The temporal evolution of IV over the annual crops' area shows the presence of low-density and low water content vegetation in early and late season. Areas with well-developed canopy and high plant water content are dominant in the mid-season. The observed AGB of wheat and faba-bean shows a good correlation with NDVI and NDWI values ($R^2 > 0.71$). The used vegetation indices represent a practical tool to determine the spatiotemporal variation of annual crops' AGB in Lebna watershed, however, a large dataset for validation is needed.

Index Terms—vegetation indices, NDVI, NDWI, annual crops, aboveground biomass.

1. INTRODUCTION

With the steady effects of climate change on the Mediterranean basin, the sustainability of agriculture in the region encounters many challenges related to the water resources and the crop productivity. In Tunisia where the agriculture is mainly based on rainfed annual crops, water scarcity and inter-annual variability represent already a crucial threat. Therefore, wise water resources

management becomes a fundamental for sustainable agricultural sector, which requires an accurate monitoring of the vegetation conditions. Field measurements of crop biomass typically involve time-intensive sample collection and repeated destructive sampling of vegetation. Currently, satellite-derived vegetation indices data offer a valuable tool for the characterization of canopy biophysical variables to support agricultural field management and decision-making [1][2]. In this context, we investigate the efficiency of two vegetation indices, namely the normalized difference vegetation index (NDVI) and the normalized difference water index (NDWI) to infer the annual crops' biomass in a rainfed landscape. The aim was to model the relationships between NDVI, NDWI and field measurements of AGB. For this purpose, Sentinel-2A products were used to extract NDVI and NDWI indices. The NDVI index that assesses the photosynthetic activity is considered in this study due to its robustness as indicator of vegetation status, spatial density distribution and phenology. The NDWI is used to infer the vegetation water content. This index is more sensitive than the NDVI to the vegetation growth especially at high canopy cover.

2. MATERIALS AND METHODS

2.1. Study area

The study was conducted at the Lebna watershed (36°43'N–36°53'N; 10°45'E–10°58'E) covering about 210 km² in the Cap Bon Peninsula in northeast of Tunisia. The

climate regime is at the boundary between subhumid and semiarid [3]. From downstream to upstream, the mean annual rainfall and the mean annual evapotranspiration (Penman-Monteith reference crop) range from 450mm to 800mm and from 1000 to 1500 mm, respectively [3][4]. The soil of the study area represents a wide variety of parent material, texture, depth and fertility. Arable land covers 57% of the area with dominance of annual crops; annual crop (mainly wheat, fodder crops and legumes and spices) areas spread over 49% of the watershed and perennial crops (mainly olive trees) cover 8% of the total area of the watershed [5].

2.2. Data Collection and Analysis

The study was conducted during 2016–2017 and 2018-2019 cropping cycles. In 2016-2017, the AGB sampling was carried out on five cultivated fields (four plots of wheat and one plot of faba-bean). During 2018-2019 season, six cultivated fields were considered (five fields of wheat and one of faba-bean). The fresh matter weight of 1 m² sample were measured in the field for different stages of the growing season. The number of samples collected varied among the two years and for the two different crop types. For each plot (P1 to P6), the hemispherical photography were also performed. The collected Sentinel-2A data comprise six images for 2016-2017 growing season and four images during the 2018-2019 cropping season. The observed data of fresh biomass were linearly interpolated to cover all the survey period with a daily step in order to determine their values during the Sentinel-2 passages. The resulting values were then compared with NDVI and NDWI mean values for each plot. The R² and the root mean square error prediction (RMSE) were used to evaluate the accuracy of the models.

The vegetation indices NDVI and NDWI were calculated from the Sentinel-2A bands covering Lebna watershed via R software. The NDVI defined as the normalized reflectance ratio of the near-infrared (NIR) and visible

(RED) wavelengths is determined from the bands B4 and B8A (eq 1).

$$NDVI = (B8A - B4) / (B8A + B4) \quad \text{eq 1}$$

NDWI is calculated as the normalized reflectance ratio of the near-infrared and short wave infrared (SWIR) wavelengths from B8A and B11 bands (eq 2).

$$NDWI = (B8A - B11) / (B8A + B11) \quad \text{eq 2}$$

3. RESULTS AND DISCUSSION

The total rainfall data of the studied cropping seasons (September to May) varied from 400 mm for the 2016-2017 cycle to 480 mm for the 2018-2019 cycle. We observed an equal distribution between autumn and winter and around 4% of rainfall recorded during the spring of 2016-2017. A decreasing rainfall regime was observed from autumn to spring of 2018-2019: 43%, 35% and 22% for autumn, winter and spring respectively.

3.1 Aboveground Biomass monitoring

The temporal evolution of the ABG varied among the two years and for the two different crop types (Figure 1).

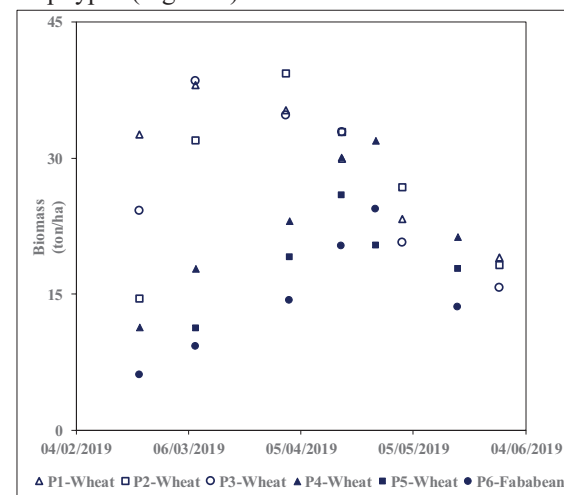


Figure 1. Temporal variation of fresh biomass during “2018/2019” season

The vegetation survey during 2016-2017 growing season occurred during a dry period, which leads to the fluctuation of the observed fresh biomass in a short monitoring duration. For wheat crop the standard deviation of the AGB varies between 3 and 8 ton/ha with

moderate inter-plots variability (variation coefficient CV between 12 and 21%). During the 2018-2019 growing season, the observed ABG was in gradual increase to reach the maximum during the heading stages for wheat and the beginning of maturity for faba-bean (Figure 1). Monitored plots represent different vegetation stages that result in a high biomass variability between fields (CV reaches 47%). For wheat crops, the P1 plot is earlier but shows a great spatial variability. All the wheat plots reach maturity between late May and early June.

3.2. Vegetation Indices of the annual crops' area

The evolution of IV over the cropping seasons shows the presence of low-density vegetation (NDVI between 0.2 and 0.4) and well-developed canopy (NDVI that exceeds 0.4) at the start of the season (November-December). The frequency of high NDVI values raises in the mid-season (February-March) with the development of the canopy cover then it decreases again in mid-May with crops senescence. The variation of NDWI values frequency shows a low vegetation water content in early (December) and late season (May). Areas with high plant water content are dominant in the mid-season.

3.3. Vegetation Indices-AGB relationship

The comparison of the fresh AGB and NDVI values for wheat plots illustrates a good correlation but with a high RMSE value (Figure 2.a). For faba-bean, the correlation is more significant with a low RMSE (Figure 2.b). However, this could be related to the low number of observations (5 observations) compared to the wheat dataset (22 observations). Similarly, the AGB shows a good correlation with NDWI for wheat (Figure 3.a) and a significant relationship for faba-bean (Figure 3.b) but with higher RMSE values. We suspect this could be caused by the differences in crop type characteristics and between the sites. The variance associated with spatial and

temporal differences in the ABG in these areas could be also associated to the spectral readings differentiating between live plants and dead material and moist soils.

The observed biomass of wheat and faba-bean shows a strong correlation with NDVI values (NDWI values respectively). However, an overestimation and an underestimation of crop biomass were detected at initial and later growth stages, which was particularly pronounced with the wheat crops. The results of this study suggest that, the spectral vegetation indices NDVI and NDWI represent a practical tool to determine the spatiotemporal variation of annual crops' biomass in Lebna watershed. However, the validation of these results might need the use of a larger dataset with more observations covering all the growth development season of the crops and the combination of sensors that may compensate the deficiencies and improve the NDVI prediction performance.

References

- [1] Rozensteina O., Haymanna N., Kaplana G. and Tannyab J. Estimating cotton water consumption using a time series of Sentinel-2 imagery. *Agricultural Water Management* 2018, 207; doi: 10.1016/j.agwat.2018.05.017.
- [2] Serrano J., Shahidian S. and da Silva J.-M., 2019. Evaluation of Normalized Difference Water Index as a Tool for Monitoring Pasture Seasonal and Inter-Annual Variability in a Mediterranean Agro-Silvo-Pastoral System. *Water*, 11, 62; doi: 10.3390/w11010062.
- [3] IAO, 2002. Land Resources of the Oued Lebna Catchment (Tunisia). 20th Course Professional Master: Remote Sensing and Natural Resources Evaluation. Istituto Agronomico per l'Oltremare, Florence, Italie 132 p.
- [4] Zitouna-Chebbi R., Prévot L., Jacob F., Mougou R., Voltz M., 2012. Assessing the consistency of eddy covariance measurements under conditions of sloping topography within a hilly agricultural

catchment. *Agric. For. Meteorol.* 164, 123–135.

[5] Mekki I, Bailly J.S., Jacob F., Chebbi H., Ajmi T., Blanca Y., Zairi, A., Biarnès A., 2018. Impact of farmland fragmentation on

rained crop allocation in Mediterranean landscapes: A case study of the Lebna watershed in Cap Bon, Tunisia. *Land Use Policy*, 75, 772–783.

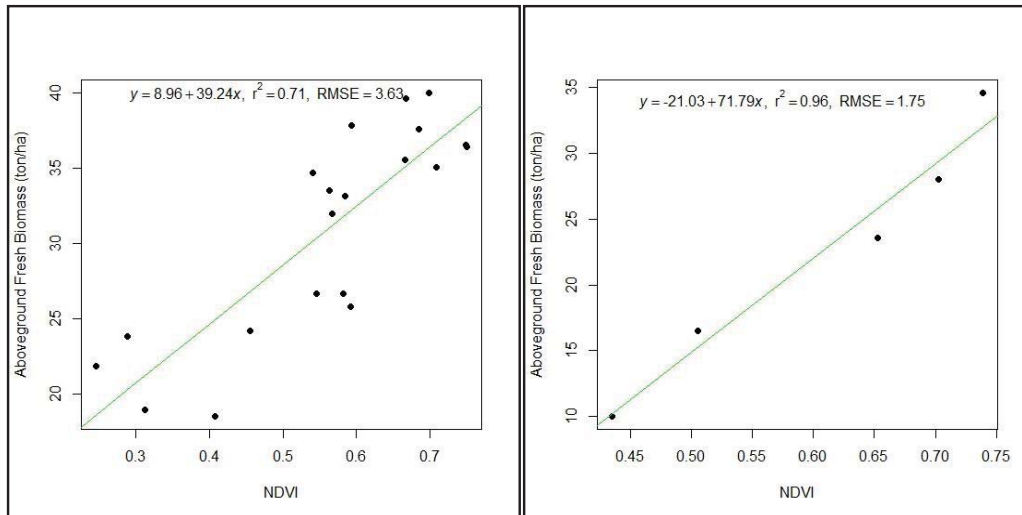


Figure 2. Variation of the aboveground fresh biomass of wheat (a) and faba-bean (b) according to NDVI values

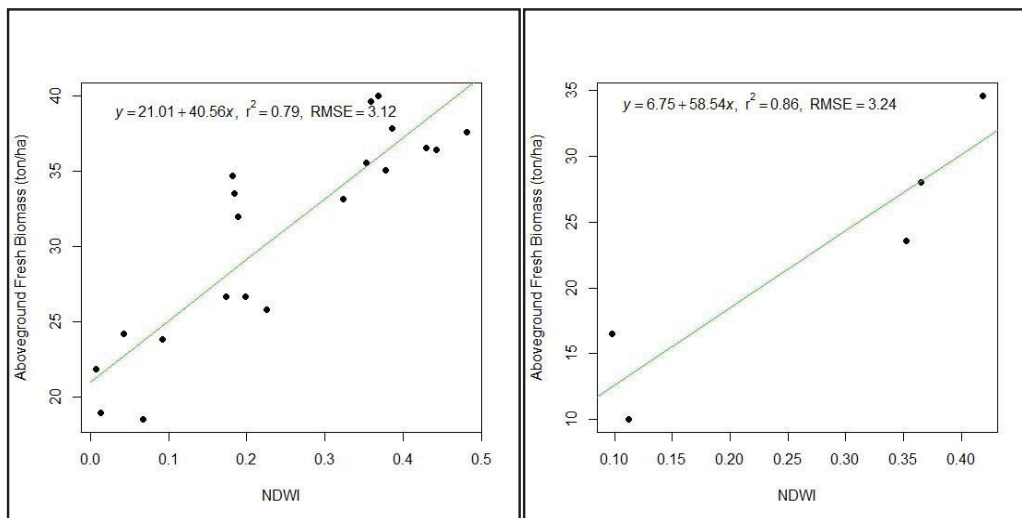


Figure 3. Variation of the aboveground fresh biomass of wheat (a) and faba-bean (b) according to NDWI values