# ESTIMATION OF CROP COEFFICIENTS (KC) OF DURUM WHEAT USING REMOTE SENSING (NDVI)

A. Bouselmi[1], R. Nciri[1], O. Ly[2], S. Arfaoui[1], R. Kalboussi[1]

[1]National Institute of Field Crops.

[2]National Institute of Agronomy of Tunisia.

**Abstract**

Globally, effective water management has become a major challenge. Agriculture is by far the largest consumer of water, with 70% (FAO, 2017). Due to the water scarcity, the use of efficient irrigation is necessary in order to better rationalize the water supply. Therefore, the correct estimation of crop water requirements is crucial. Therefore, it is essential to obtain a local crop coefficients Kc to each region, for the reason that the Kc is linked to the crop type, to the phenological cycles, to the soil and to the climate of the region (Allen et al. 1998). However, with advances in remote sensing, crop coefficients can be associated with index such as the NDVI vegetation index (Normalized Difference Vegetation Index) which provides an alternative for estimating new Kc values. From this prospective we conducted a study in two different regions in Tunisia, one in the North with semi-arid climate and the second in Central part with arid climate to estimate Kc using NDVI from sentinel 2. The results showed that there is a very good correlation between the Kc values and the NDVI values ($r2 = 0.75$ for the North plot and $r2 = 0.72$ for the Central plot). However, this study requires field applications to assess the effectiveness of the estimated crop coefficients. Especially since the irrigator has to apply a lot of water to the plot, which considerably generates erroneous values of the calculated Kc. In addition, the study shows that the simple crop coefficient approach is more effective than that of the dual crop coefficient. Based on this study and other studies it can be concluded that remote sensing could be used as a tool for agricultural management and decision support. However, this study requires other field plots to assess the effectiveness of the estimated crop coefficients. Future efforts will focus on integrating estimated Kc using NDVI in an irrigation scheduling models as CropWat, IREY App. The NDVI index can be used for early estimation of grain crops yields. In addition, other indicators from remote sensing can be used to improve the estimation of Kc.

## 1 Introduction

In the context of climate change, the North African area faces serious challenges with continuously decreasing water. Agriculture is by far the largest consumer of water, with 70% (FAO, 2017). In Tunisia, cereal growing represents the most important agricultural speculation, both in terms of the number of farmers and its driving role in the national economy (Chebbi et *al.* 2019). However, Tunisia regularly suffers from a significant climatic difference between regions and seasons. Indeed, the average rainfall varies between 100 and 700mm/year respectively in the south and north of the country and the average temperature varies between 8 and 40°C (Ben Boubaker Habib et al., 2014). The irregularity of precipitation, characterizing the Mediterranean climate, can cause certain deficit years, significant drops in yields and therefore in production (Bousselmi et al.2014).Faced with the fragility of the agricultural environment and limited water resources, it is obvious that in particular the irrigated areas in Tunisia would have to raise a challenge of increasing agricultural production, particularly strategic crop yields as durum wheat to ensure food security, while ensuring water security (Bousselmi et al.2014). Due to the water scarcity, the use of efficient irrigation is necessary in order to better rationalize the water supply. Therefore, the correct estimation of crop water requirements is crucial. Therefore, it is essential to obtain a local crop coefficients Kc to each region, for the reason that the Kc is linked to the crop type, to the phenological cycles, to the soil and to the climate of the region (Allen et al. 1998). However, with advances in remote sensing, crop coefficients can be associated with index such as the Normalized Difference Vegetation Index (Rouse et al., 1973) which provides an alternative for estimating Kc values. From this prospective we conducted a study in two different regions in Tunisia, one in the North with semi-arid climate and the second in Central part with arid climate to estimate Kc using NDVI from sentinel 2.

## 2 Materials and Methods

### *2.1 Study area*

The study was conducted in two different regions, one in The North of Tunisia El Kodia in the Governorate of Jendouba and the second in the Central of Tunisia Souk Jedid in the Governorate of Sidi-Bouzid (Figure 1).

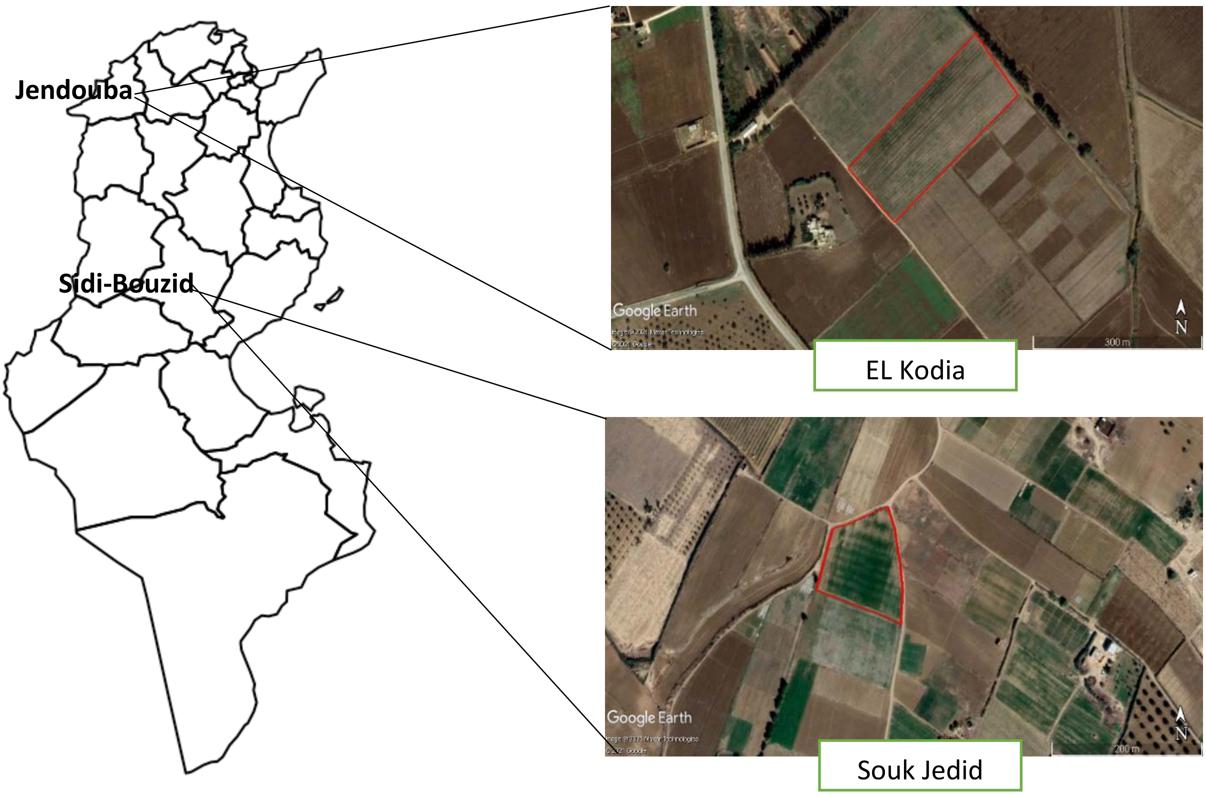



Figure 1. Study areas location of the two Regions El kodia and Souk Jedid, Tunisia. The red area represents Wheat field.

The climatological study is essential for estimating the crop water requirements. Among the factors influencing water demand for irrigation, climatic conditions are regularly highlighted and widely used in models for forecasting crop water requirements. The following tables (1 and 2) show the climatic parameters recorded in the two studied regions (temperature, humidity, wind, Solar radiation, precipitation and evapotranspiration).

Table 1. Weather data of the Station El Kodia during the crop growing season 2020-2021.

| Month | Average Temperature [°C] | Solar radiation [W/m2] | Humidity [%] | Precipitations [mm | Wind speed [m/s] | ETP [mm] |
|---|---|---|---|---|---|---|
| October | 18.42 | 176 | 61.07 | 19 | 0.9 | 80.3 |
| November | 15.73 | 107 | 74.31 | 68 | 0.7 | 41.2 |
| December | 10.91 | 93 | 82.86 | 62 | 1 | 32.3 |
| January | 10.77 | 99 | 76.13 | 13.4 | 0.9 | 36.3 |
| February | 11.42 | 146 | 81.42 | 11 | 0.8 | 46.3 |
| March | 11.42 | 184 | 83.49 | 25.6 | 0.8 | 71.2 |
| April | 15.01 | 228 | 78.96 | 22.4 | 0.8 | 99.2 |
| May | 20.79 | 277 | 62.61 | 6.2 | 0.9 | 145.5 |
| June | 27.18 | 280 | 49.53 | 1.6 | 1.3 | 178.6 |

Table 2. Weather data of the station Souk Jedid during the crop growing season 2020-2021

| Month | Average Temperature [°C] | Solar radiation [W/m2] | Humidity [%] | Precipitations [mm | Wind speed [m/s] | ETP [mm] |
|---|---|---|---|---|---|---|
| October | 14.74 | 127 | 69.36 | 27.2 | 1.2 | 75 |
| November | 11.11 | 110 | 72.71 | 10.6 | 1.5 | 34.3 |
| December | 12.1 | 135 | 55.83 | 0.2 | 1.7 | 45 |
| January | 11.75 | 160 | 56.96 | 0.4 | 1.4 | 66.6 |
| February | 11.71 | 145 | 78.46 | 6.2 | 1.4 | 26.5 |
| March | 19.74 | 293 | 58.59 | 0 | 1.2 | 112.4 |
| April | 21.95 | 280 | 50.84 | 6.2 | 1.6 | 171.7 |
| May | 26.39 | 284 | 45.42 | 2.2 | 1.4 | 154.9 |

### *2.2 Crop and sowing date*

In Sidi Bouzid, the wheat grown there is durum wheat, the sowing date is November 20, 2020 and the harvest date is around the begging of June. As for the wheat grown on the El Kodia plot, the sowing date is December 9, 2020. On the other hand, the harvest date is around mid-June.

### *2.3 Satellite data and NDVI development*

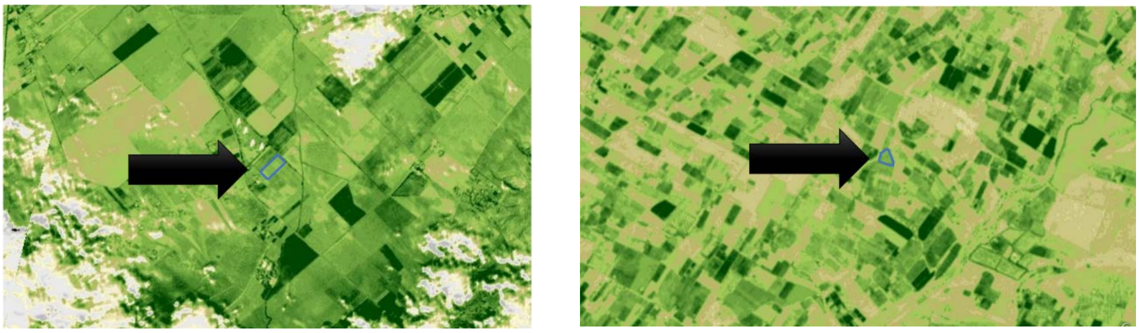
For this study we opted for the Sentinel-2 satellite, this choice is based on three main advantages, first its spatial resolution: We will have better precision and more detailed mapping at the scale of the study area compared to maps obtained from other images (Landsat for example), second its spectral resolution (the presence of several spectral bands in the near and middle infrared will allow better analysis of the spectral responses of the vegetation.) and, finally its temporal resolution (the frequency is 5 days for the same area). The Sentinel-Hub site interface (Figure 3) has several features, so we can choose the satellite used to extract the images.


Figure 3. Screenshot of Sentinel-Hub website.

The normalized difference vegetation index NDVI, is calculated from the red (R) and near infrared (NIR) bands. The normalized vegetation index highlights the difference between the visible red band and the near infrared band. This vegetation index was given by:

$$NDVI = \frac{NIR-R}{NIR+R} \quad (1)$$

This index is sensitive to the vigor and quantity of vegetation. The range of values for the NDVI index goes from -1 to 1. Negative values corresponding to surfaces other than plant cover, such as snow, water or clouds for which the reflectance in the red is greater than that of the near infrared. Values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock, sand or snow. Low and positive values represent shrubs and grasslands (approximately 0.2 to 0.4), while high values indicate temperate and tropical rainforests.



(a) (b)

Figure 3. NDVI images of the wheat plot El kodia (a) and Souk Jedid (b) from Sentinel2 (February 15, 2021).

### *2.4 Crop coefficient calculation*

For the Souk Jedid plot, we used the dual cropping coefficient approach, which allows soil evaporation and vegetation transpiration to be calculated separately (Allen et al., 1998). For this plot we calculated the fraction vegetation cover (FC) by a model that we obtained by a correlation with the NDVI. As for the plot of El Kodia, we used the single crop coefficient Kc of the FAO 56 adjusted with growing degree days GDD to determine the Kc corresponding to each phenological stage. GDDs are calculated using equation 2:

$$GDDs = \frac{Tmax - Tmin}{2} - Tbase \quad (2)$$

Where Tmax= Daily maximum temperature (°C), Tmin= Daily minimum temperature (°C) and Tbase= Base temperature (0°C) below which the process of plant growth does not progress. For Durum Wheat Tbase is 0.0 °C. Any temperature below Tbase is set to Tbase before calculating (Matzarakis et al., 2007; Kumar et al., 2020). Subsequently we used the method of multiple linear regression and simple linear regression to make a correlation between the Kc and the values of the decadal NDVI obtained by the SENTINEL-2.

### *2.5 Estimation of durum wheat water requirements by capacitance probes in Souk Jedid plot*

The Capacitance probes electromagnetically count the water molecules present in a volume of soil defined around the sensor. This makes it possible to know the water stock (in mm) over the depth explored by the probe. There are 2 types of capacitive probes: fixed ones which continuously measure the soil humidity in a given place of the plot and mobile probes which are moved to several places in one or more plots, where tubes are already installed. Each probe is equipped with several sensors arranged in a tube, one below the other, every 10 cm. Thus, for each horizon of 10 cm of soil, the probe provides a percentage of humidity, convertible into millimeters of water. Generally, the recorded data is transmitted to the server by a GPRS modem. They are then compiled into graphs.

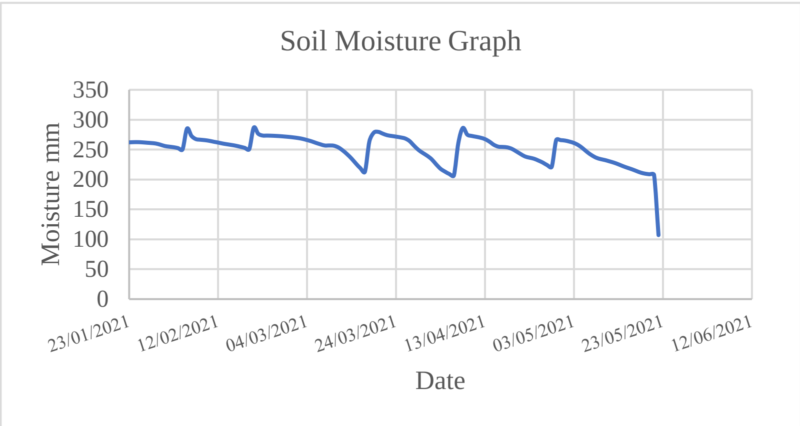



Figure 4. On the left a Photo of Capacitance probe Sentek, on the right a graph of soil moisture of Souk Jedid Plot.

## 3 Results and discussion

### *3.1 EL Kodia Durum Wheat Plot*

The data obtained from Sentinel2 was sorted in order to remove the values presenting 100 to 60% of clouds (C0/Clouds) which could possibly distort the real values of the NDVI. The following graph represents the evolution of the average NDVI values of EL Kodia Durum wheat plot.

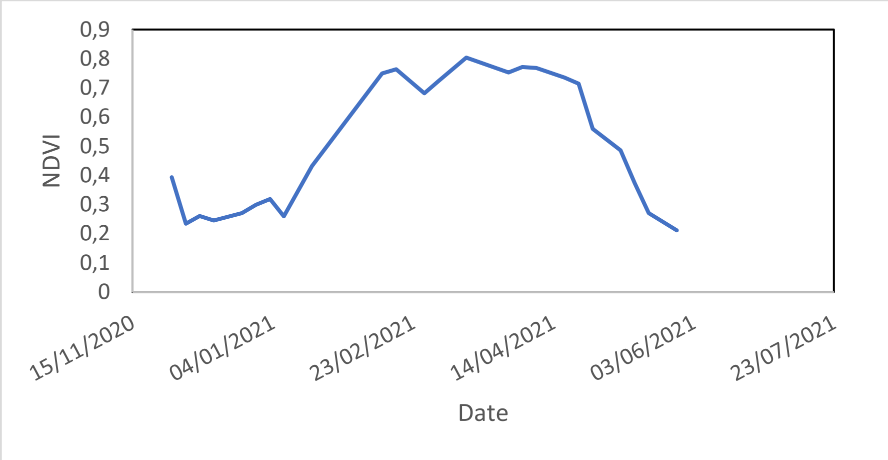



Figure 5. Evolution of the NDVI values of EL Kodia Durum wheat plot.

The graph below (Fig 6) shows a very good correlation between Kc and NDVI. This shows that these two parameters are intimately correlated.

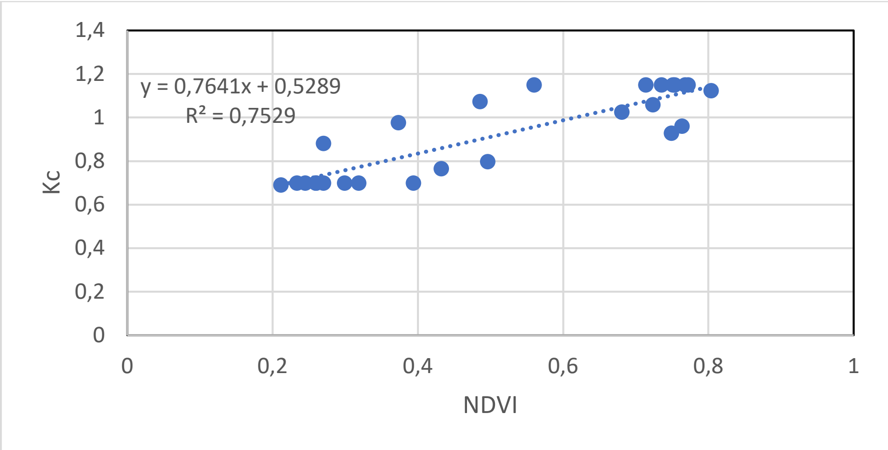



Figure 6. Correlation between Kc and NDVI of EL Kodia Durum wheat plot.

On the other hand, the multiple linear regression provided a better correlation with $R^2$ equal to 0.882, using NDVI min, NDVI max and NDVI mean.

Table 3. The results of the multiple linear regression for the plot of El Kodia

| ***Statistics Regression*** | |
|---|---|
| Multiple coefficient of determination | 0.88213813 |
| Coefficient of determination R^2 | 0.77816768 |
| Coefficient of determination R^2 | 0.74791782 |
| Erreur-type | 0.09793472 |
| Observations | 26 |

*3.2 Souk Jedid Durum Wheat Plot*

For the Souk Jedid plot, we used two methods, the dual crop coefficient approach taking into account the Ke, Kcb and the single crop coefficient approach.

### *3.2.1 Approach Single Crop Coefficient*

Similarly, for the plot of El Kodia, the following graph represents the evolution of the average NDVI values according to the months for the plot of Souk Jedid

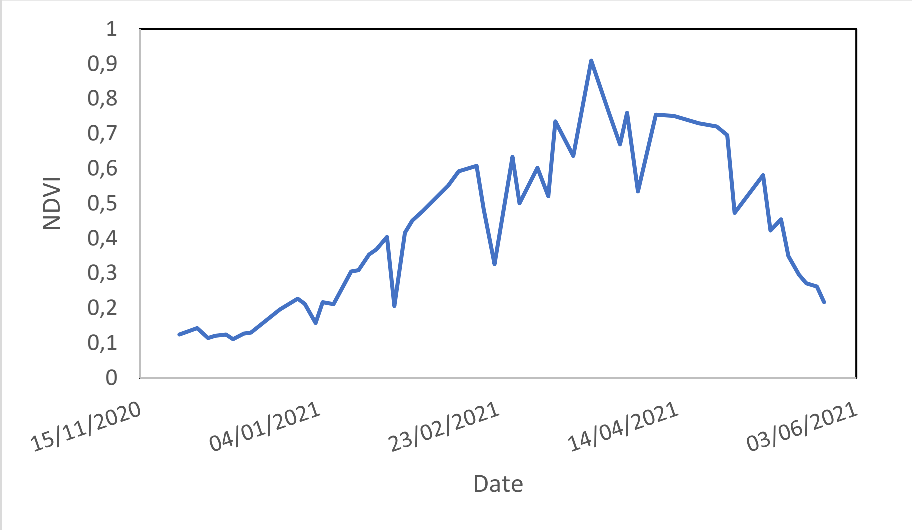



Figure 7. Evolution of the NDVI values of Souk Jedid Durum wheat plot.

We obtained a good correlation between Kc and NDVI with $R^2$ equal to 0.7. Same for multiple linear regression we obtained a better correlation with $R^2$ equal to 0.8061.

Table 4. The results of the multiple linear regression for the plot of Souk Jedid

| ***Statistics Regression*** | |
|---|---|
| Multiple coefficient of determination | 0.806168564 |
| Coefficient of determination R^2 | 0.649907753 |
| Coefficient of determination R^2 | 0.602167901 |
| Erreur-type | 0.458918107 |
| Observations | 26 |

### *3.2.1 Approach Dual Crop Coefficient*

As explained in the materials and methods section, we used a model provided by the correlation between FC and NDVI (FC = 1.6106*NDVI – 0.1532) to calculate the FC for different growth stage Table 5 shows the results.

Table 5. The correspondence between the growing stage and the FC

| Stage | C0/date | C0/mean | FC |
|---|---|---|---|
| Sowing | 19/11/2020 | 0.10531819 | 0 |
| 3 leaves | 08/01/2021 | 0.2111641 | 0.25 |
| End of tillering | 30/01/2021 | 0.45048796 | 0.5 |

| | | | |
|---|---|---|---|
| Heading | 12/02/2021 | 0.5916981 | 0.75 |
| Total converge | 29/03/2021 | 0.66925414 | 1 |

We obtained a very good correlation between NDVI and FC and Figure 8 shows the correlation.

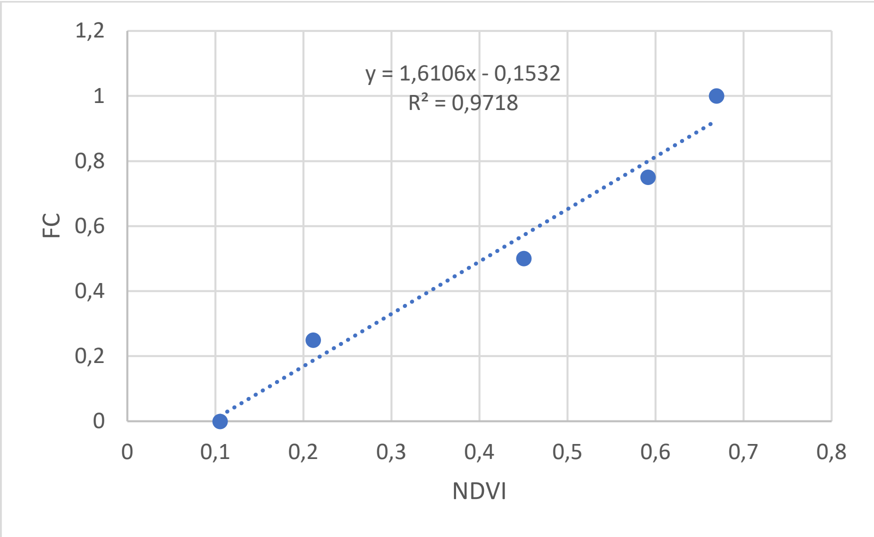



Figure 8. Correlation between NDVI and FC.

For the calculation of Ke and Kcb parameters we applied the formulas mentioned above. We can notice that the calculated FC values become constant from November 21, this is explained by the fact that we estimated these values by those of the NDVI and that the latter decrease when the plant biomass begins to dry. Therefore, we took the maximum value of FC as corresponding to complete coverage, since the biomass does not decrease when it reaches its maximum. Simple linear regression provided an acceptable correlation between Kcb and NDVI with $R^2$ equal to 0.5. On the other hand, the multiple linear regression provided a better coefficient of determination compared to the simple linear regression with $R^2$ equal to 0.722. Table 6 shows statistical results obtained by multiple linear regression.

Table 6. The results of the multiple linear regression for the plot of Souk Jedid

| ***Statistics Regression*** | |
|---|---|
| Multiple coefficient of determination | 0.722674867 |
| Coefficient of determination R^2 | 0.522258964 |
| Coefficient of determination R^2 | 0.421681904 |
| Erreur-type | 0.190906544 |
| Observations | 24 |

## 4 Conclusions

The rationalization of water supply and efficient agricultural management requires the estimation of appropriate Kc values. Indeed, the Kc is the essential parameter for the evaluation of crop water requirements. In this regard, we used the NDVI vegetation index to estimate the Kc for the El Kodia and Souk Jedid plots. Our results showed that there is a very good correlation between the Kc values and the NDVI values ($R^2$ = 0.7529 for the El Kodia plot and $R^2$ = 0.7226 for the Souk Jedid plot).However, this study requires other trials with different crops to assess the effectiveness of the estimated crop coefficients. In addition, the study shows that the simple crop coefficient approach is more effective than that of the dual crop coefficient. Finally, we can admit that, remote sensing is an effective and coveted means nowadays in the field of irrigation, it is also a tool for agricultural management and decision support that can achieve optimum yield.

**Acknowledgements**

This study was carried out by INGC the National Institute of Field Crops-Tunisia and supported by the project Sustainable Production in water limited environments of Mediterranean agro-ecosystem (SUPROMED), financed by PRIMA program Section1 and coordinated by University of Castile-La Mancha (Spain).

**References**

A. Bouselmi, M. Khammassi, S. Abidi, S. Arfaoui, R. Nasraoui, (2014) The impact of rainfall on the evolution of harvested and sown cereals areas in Tunisia. Euro Med Crop Monitoring Conference, November 19-21, 2014 Rabat Moroco.

A. Bousselmi, R. Kalboussi, S. Chamseddine, S. Abidi et M. Khammassi.2014. Etude de l'efficience de l'eau et de l'azote pour la culture de blé dur (variété Khiar) conduit sous le système goutte à goutte pour différents espacements. Journées Scientifiques de l'INAT 2014 « Changements Climatiques et mesures d'adaptation » 20-21- 05/ 2014 /l'INAT, Tunis, Tunisie.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration: guidelines for computing crop water requirements. In: Proceedings of the Irrigation and Drainage Paper No. 56. Food and Agricultural Organization, United Nations, Rome, Italy.

Ben Salem M., Daaloul A., Ayadi A. Le blé dur en Tunisie. In : Di Fonzo N. (ed.), Kaan F. (ed.), Nachit M. (ed.). Durum wheat quality in the Mediterranean region . Zaragoza : CIHEAM, 1995. p. 81-91.

FAO, 2017. FAOSTAT. Food and Agriculture Organization of the United Nations, Rome, Italy.

Habib Ben Boubaker, Zeineb Benzarti et Latifa Hénia. « Les ressources en eau de la Tunisie : contraintes du climat et pression anthropique »,2014 ENS Éditions, p. 37-52

H.E. Chebbi, J.-P. Pellissier, W. Khechimi, J.-P. Rolland. Rapport de synthèse sur l'agriculture en Tunisie. [Rapport de recherche] CIHEAM-IAMM. 2019, pp.99. ffhal-02137636f

Kumar et al., 2020). Kumar, P., Herndon, E., and Richter D. (2020): Critical Agents of Change at Earth's Surface.

Matzarakis, A. Climate, thermal comfort and tourism. Clim. Chang. Tour. Assess. Coping Strateg. 2007, 139–154.

Rouse, J. W., Haas, R. H., Schell, J. A., and Deering, D. W. (1973). Monitoring vegetation systems in the Great Plains with ERTS. In Proceeding of third ERTS symposium, Washington, DC, USA, 10-14 December 1973; Volume 1, pp. 309-317.