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ORIGINAL ARTICLE

Crop Vigor fluctuation as affected by Irrigation water shortage Case study: Rahad Agricultural Scheme, Sudan

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ABSTRACT

The national agricultural schemes are considered as major parameters in the distribution of the population density in most of the Sudanese regions. This study aimed at employing remote sensing techniques along with the crop evapotranspiration (ET_c) to monitor the development of crops cultivated in Rahad Scheme and to assess the sufficiency of the scheme water supply (SWS) for crops satisfaction. The Normalized Difference Vegetation Index (NDVI) extracted from national oceanic and atmospheric administration (NOAA-15) satellite for the Rahad agricultural scheme was extracted and correlated with SWS and the crop ET_c. The study also intended to identify the periods of high water demand for crops according to the crop's growing stages throughout the season, NDVI and ETc. Results obtained from the analysis revealed a consistent positive relationship between NDVI and ET_c with determination coefficients (R^2) ranging between 0.67 to 0.73, indicating that as the NDVI raises the ET_c increases accordingly. A negative correlation was also observed between the SWS and ET_c during period from August to October, with R^2 ranging between 0.64 and 0.69 over the two selected fields, which assured the existence of irrigation water shortage problem during the mid-season. Satellite NDVI has been proven as an efficient indicator for monitoring vigor and phonological statement of crops throughout their growth stages.

Keywords; *Remote sensing, Rahad scheme, Irrigation, Evapotranspiration.*

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INTRODUCTION

Agriculture is among the most worldwide human economic pursuits, which is practiced in each and every physical environment where it's possible to increase crops or domestic animals. In certain areas of the world land holdings are very small and application of labor so rigorous that the farmer works less than one acre of land, as opposed to other places where one man plants hundreds of acres. There are nearly numberless variations in agriculture as a result of various combinations of physical environment, culture, economic systems, and individual practices in farming. The variety of agriculture generates a variety of demands for information. Agriculture in Sudan is an extremely economical provider financially and socially, due to the huge, flat and fertile areas as well as the good water resources [1]. The national agricultural schemes are considered as a major parameter in the distribution of the population density in most of the Sudanese regions. It shares in the settling of the population, livelihood of thousands of the families whose members work by these schemes as farmers, transporters or labors in the service sectors which belong to their schemes. The agricultural sector in Sudan is definitely the principal contributor to Sudanese economy in relation to GDP regardless of rising crude oil exports [2, 3]. Agriculture adds up about 39% of the GDP and 90% of non-oil exports. Agriculture is additionally demonstrated within the activities of some other areas for example transportation, business, and trade. Agriculture and associated pursuits supply 80% of the work force in Sudan [2, 3]. Year-to-year alterations in agricultural output significantly impact the degree of lower income and food security of the Sudanese people. Additionally, the agricultural sector has been the primary supply of Sudanese exports before oil extraction in 1991[2]. Agricultural subsectors in Sudan consist of either traditional or mechanized rain-fed farming; irrigated farming schemes based on the River Nile and its tributaries, livestock, as well as the forest sector [2]. Conventional rain-fed farming is principally present in northern and central Sudan. This sector is described as small farms which range from 2-30 or 10-50 hectares counting on the labor intensive utilization of hand tools [4, 5]. Traditional rain-fed farming within the eastern and central areas of the northern states of Sudan would be to some extent mechanized, where traditional farming depends on tractors for plowing however employs manual labor for many other farming practices. The farm dimension in this instance is normally greater than the typical [5].Farmers within the traditional sector are likely to rotate crops, carry out more regular and repeated planting, weed more, and also have larger sowing rates compared to mechanized rain-fed farming [5]. The conventional rain-fed sector in 2010 brought about 90% of millet, 38% to sorghum, 67% of groundnuts, and 38% of sesame produced in the country however, these numbers can differ from one growing season to a different because of rain imbalances [5]. Mechanized rain-fed agriculture can be viewed as a comprehensive transferring farming with tractors taking advantage of the land and leading to soil exhaustion [5]. Consequently, mechanized rain-fed agriculture has ecological, social, and economic implications, for instance, interruption of forests and pre-existing social systems and soil erosion because of incorrect crop rotation [4]. Nevertheless mechanized rain-fed agriculture continues to be a primary supply of agricultural production and induced domestic production to develop 40% in 2006 [4]. Farming techniques in irrigated schemes are usually more increased compared to rain fed sectors and consist of crop rotation, mechanized land preparation, along with a typical usage of enhanced seeds, fertilizers, pesticides, and herbicides supplied by credit companies via a program called scheme-based credit [5]. The standard yield produced in the irrigated sector is fiscally greater than in the rain-fed sector; it contributed 26% to the Sudanese GDP in 2002 [3, 5]. The government possessed many of these irrigated schemes till 2010, when a privatization policy was applied being a means to fix aging and ineffective infrastructures of those schemes [5]. In the Gezira scheme, irrigation was moved to land owners with the name of water user associations, and crop decisions were given to farmers [5]. Mechanized irrigated schemes are related to some ecological concerns which include continuous usage of pesticides plus a legacy of outdated pesticide stocks. Water pollution occurs from sugar factories, canal siltation, soil salinization, in addition to yield reduction [4]. Sudan's economic development is covered with agricultural sector participation and it makes up about approximately 45% of GDP, provided employment for 55% of the work force, provided by 85% in the export revenue. A significant boost in this sector within the nineties is the breakthrough of the livestock sub-sector as major export product. Livestock exports rose from US$ 22.6 million in 1990/91 to US$ 120 million in 1998, whilst revenue from cotton dropped from US$ 162.8 million to US$ 95.6 million through the same interval. This decrease is principally related to the inadequacy and decrease of the irrigation sub-sector. However, the period demonstrated considerable boost in sesame export, with comparable earning information like livestock exports. In Sudan, sesame is generally cultivated in the rain-fed sector. Irrigation sub-sector contributes about 27% of agricultural GDP, and it provides the majority of the cotton, wheat, sorghum, sugar cane, legumes, orchard crops (sunflower), peanuts and green forage [6].

The economical value of the national schemes in Sudan became less than before, and it is getting deteriorated efficiently in a gradual manner. The irrigation efficiency has tremendously dropped due to the malfunctioning of the irrigation vessels as well as the infra-structure, and also the absence of the full-control of the applied water. The expensive costs of the annual re-habitation and maintenance also stood against the good management of the irrigation water. Sometimes these amounts of irrigation water become more than the subjected, due to some over-estimation. In addition, the inadequacy of the empirical models and methods which are being used for the assessment of crop water requirement (CWR) are considered as hindering problem itself [1]. Nowadays, remote sensing provides a dependable and efficient tool for irrigated agriculture since the technique has the capacity of covering huge areas rapidly, cheaply. In agriculture, remote sensing means the processes of backing off and looking at fields from a remote perspective in contrast to close-up conventional viewing. Frequently it is anticipated that lots of or all of the answers can be provided by study at a single scale, such as from Landsat, but this is normally not the case. There is information to be produced from each different scale of images, and each scale can be expected to supply data which will be of great benefit to studies at other scales [7-11].

This study was intended to follow remotely sensed approaches to examine the nature of the relationship between the Rahad scheme water supply compiled with rainfall contribution and the spectral and meteorological aspects of the cultivated crops. The study also aimed at identifying the periods of demand for irrigation water based on the water supply-demand correlation during the season of 2001.

METHODS

The study Area

The Rahad scheme is among the recently settled areas in Sudan, and there has been relatively new enlargement to irrigated agriculture in the country, that was recommended right after the construction of the Rosieries dam in 1966. The Rahad irrigated scheme is located within a latitudes of 14°23′and 13°43′ north, and between longitudes of 34°23′and 33°30′ east [12]. The scheme politically falls in two states: Gedarif and Gezira. El Fau locality lies about 260 km southeast of Khartoum (capital city of Sudan) and is the headquarters of the scheme [13]. The scheme covers an area of 140 km in length (north-south, and 15-25 km in width. The entire scheme area is 334,728 hectares however, the grown area is 147,698 hectares. The Rahad scheme (Fig.1) is situated on an extremely fertile soil and the scheme is fully mechanized with a two-course rotation of cropping system (100% utilization). The grown crops primarily include cotton and groundnuts. The soil of the scheme is 95% heavy clay with 5% light clay and it has also been classified as a very fine silt-soil 75% in the south and reduces steadily from the south to the north. The Rahad scheme is irrigated by gravity from the east bank of Blue Nile River throughout the remaining no-rain season. Electrical pumps provide the scheme with irrigation water through a 79 km length canal [8]. The scheme lies in a semi-arid climate; the area's yearly rainfall differs from 300 mm in the north to 450 mm in the south with a draught duration of about 8 months. The Rahad River owns a variety of ideal conditions that makes it an excellent site to use of the Blue Nile waters. Land is provided with homogeneous topography and slope, very good clay soils along with fairly little clearing required. Climate of low average rainfall meant few options to irrigation for additional rigorous utilization of the land. A local population of 80,000 people with an unpredictable subsistence-based economy could possibly be benefitted by more increased cultivation. Lastly, the Rahad River, seasonal as a water resource, assists as an additional source of irrigation water when waters of the Blue Nile are included with the Rahad River via a diversion supply canal. Generally, the Rahad area was built with a high productive possibility to use the Rosieries water supply.

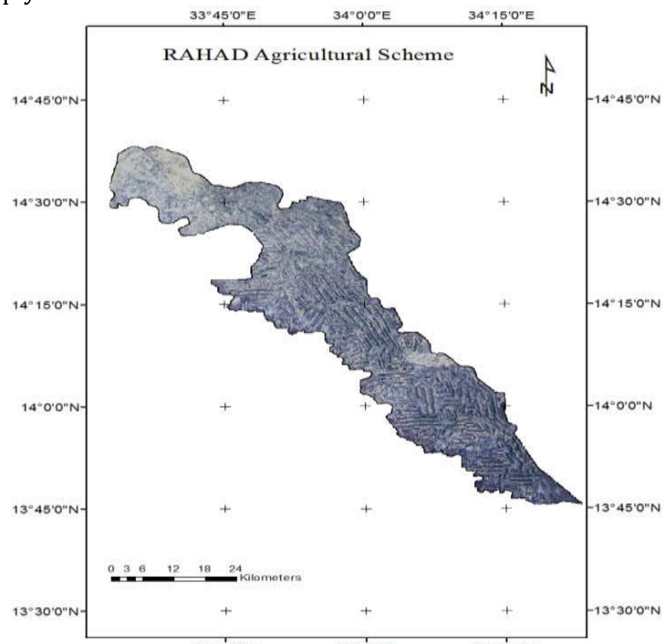

Figure 1; Rahad Agricultural scheme in Sudan

Data Collection and Analysis

Data on effective rainfall, irrigation water supply and satellite images were collected for the cropping season 2000-2001 on the base of 10-day interval. Data on irrigation water supply was collected from Hydraulic Research Station, (Ministry of Irrigation & Water Resources), Sudan. Satellite images from the advanced very high resolution radiometer (AVHRR–NOAA 17) over the study area were acquired for 10-day interval. The crop season 1-June-2000 to 31-March-2001 was divided into three stages namely Stage-1, Stage-2 and Stage-3 to ease assessment of crop growth progress. Stage-1 spans from 1-June to 31-July and marks the planting period. Stage-2 spans from 1-August to 30-October and represents crop growth and maturity period. Stage-3 spans from 1-November to 31-March and represents harvesting period. Since different crops (Cotton, Sorghum, Wheat, Groundnut, Fodder and Vegetables) were cultivated in the study area the harvesting time therefore varied between different crop types and hence the harvesting period spans over a six month period. Using the visible (0.63 – 0.69 µm) and near infrared (0.76 – 0.90 µm) bands of the AVHRR–NOAA 17satellite images the NDVI was extracted using a remote sensing software through the following formula [14],

$$NDVI = \frac{NIR-RED}{NIR+RED} \qquad (1)$$

Where: RED and NIR stand for the spectral reflectance measurements acquired in the red and near-infrared regions, respectively. These spectral reflectances are themselves ratios of the reflected over the incoming radiation in each spectral band individually; hence, their values are in the range between 0.0 and 1.0.

The flow chart below (Fig. 2) represents the processes that have been followed to achieve the research investigation over the scheme.

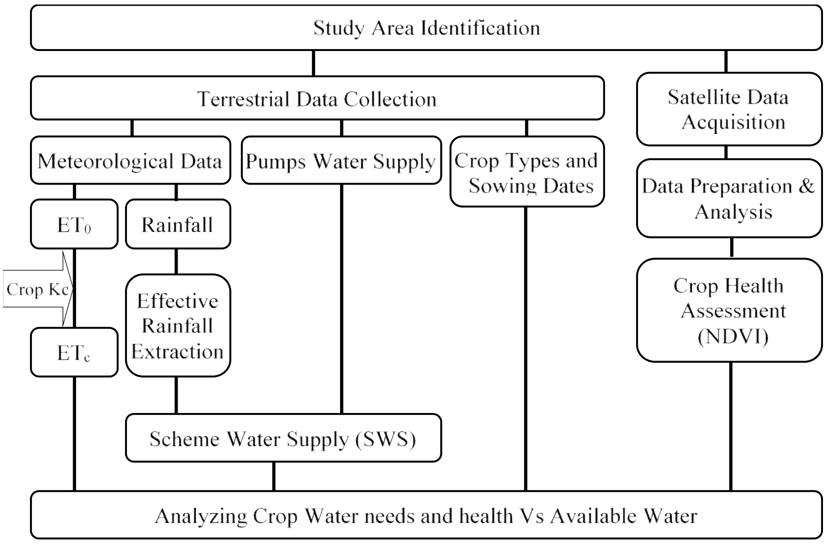

Figure 2;flow chart for crop water need analysis.

Effective rainfall (Pe) for the Rahad scheme was collected for 32 years return period along with pumps water supply (PWS) were represented by the total scheme water supply (SWS) available to plant as it expressed by,

$$SWS = PWS + Pe \qquad (2)$$

Potential evapotranspiration (ET_0) information over the area and crop coefficients (K_c) for the grown crops were collected from the water management & irrigation institute, University of Gezira (Wad Medani), which is formed as,

$$ET_c = K_c \times ET_0 \qquad (3)$$

All data were formed on the base of 10 days. A statistical representation of the acquired and extracted data is shown in Table 1 where the SWS and ET_c values are given in Mm^3. The project area is divided into zones according to major canals that serve the fields, counted from Major 1, Major 2,,.. up to Major 7. In this study, two irrigated field of the scheme were selected and analyzed as representative agricultural areas, namely (Major 2 and Major 5).

Table 1;statistical representation of the collected data.

	Major 2 (Area = 10,264 ha)				*Major 5 (Area = 21,070 ha)*			
	Min	*Max*	*Avg.*	*Stdv.*	*Min*	*Max*	*Avg.*	*Stdv.*
Effective Rainfall (Pe) Mm^3	0.00	5.00	1.05	1.46	0.00	10.25	2.15	3.00
Scheme water supply (SWS) Mm^3	0.04	0.48	0.23	0.12	0.20	1.10	0.56	0.31
ET_c Mm^3	0.31	2.12	1.03	0.55	1.30	8.92	4.32	2.30
NDVI	0.01	0.38	0.14	0.11	0.01	0.34	0.12	0.10

RESULTS AND DISCUSSION

Time series of rainfall along with the pumps water supply which form the total scheme water supply (SWS) were correlated against the crop NDVI and ET_c over the two selected fields (Fig. 3 a & b). It can be noticed from Figure 3 that the irrigation water applied at the fields were mostly quantified and affected by the seasonal fluctuation of water source. So that, during the first stage (from June to late August) the increasing trend of the excess water was due to the share from the seasonal Rahad River which satisfies the required need for irrigation. This was followed by the general progression in crops maturity and vitality represented by the rise of NDVI and ET_c. However, it appears that the effect of full available irrigation water lasts for a short period of about 2 months which is between June up to September.

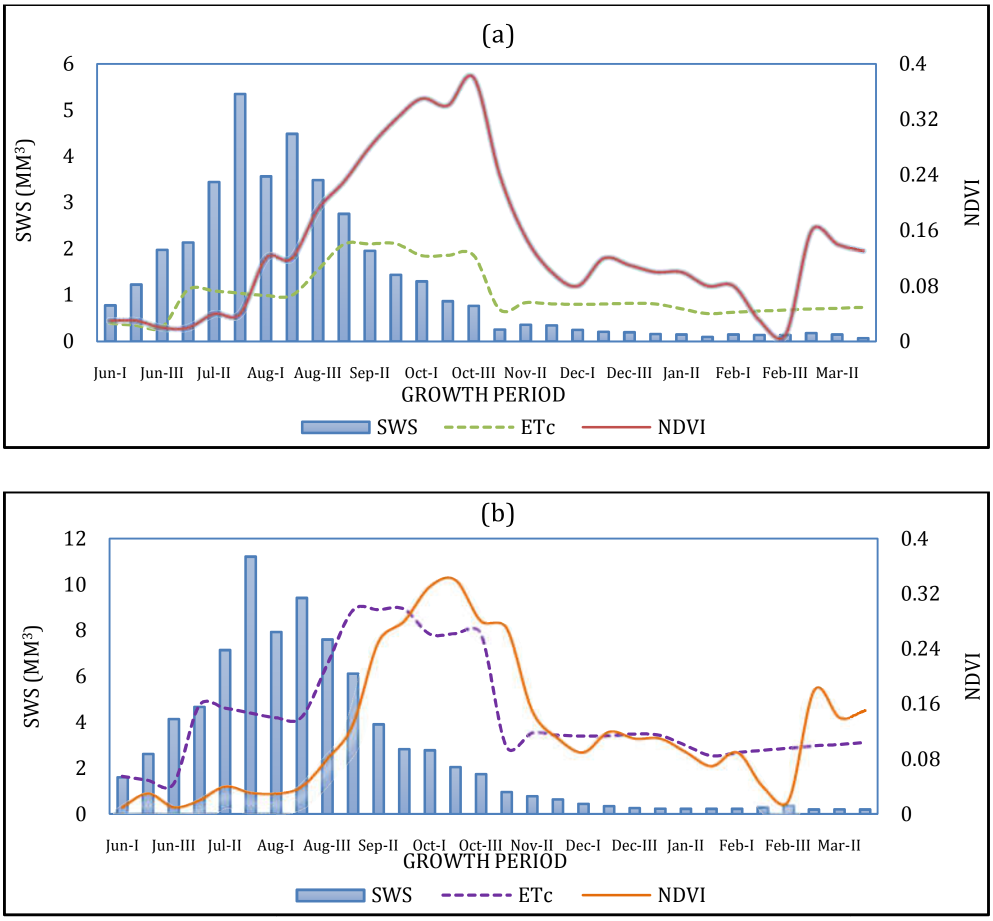

Figure 3;the general trend of crop NDVI and ET_c Vs SWS for (a) Major 2 and (b) Major 5.

At the second stage of the season (stage-2, from late August to October), growing crops tend to reach maturity which is followed by high photosynthetic activities represented in the relative high NDVI and ET_c. Figure 4 (a and b) describes the common behavior of crop vigor (NDVI) and water need (ET_c) assured by the positive correlation determined by R^2 of 0.73 for Major 2 and 0.67 for Major 5. At stage-3 (Between September-I and March-III), the NDVI values mostly show a steady decline because most of the crops reach maturity as a result, their internal activities are reduced to support yield processes and changes color as they finally become dry. Other factor associated with the steady decline of NDVI values during this period is the harvest of crops which reduces vegetation cover in addition to drying out the rest.The relatively longer time of NDVI declination crop Stage-3 can be justified by the fact that, not all crops are harvested at the same time. Usually, Groundnuts and Sorghum are harvested at the end of October followed by other crops as their harvesting time reaches.

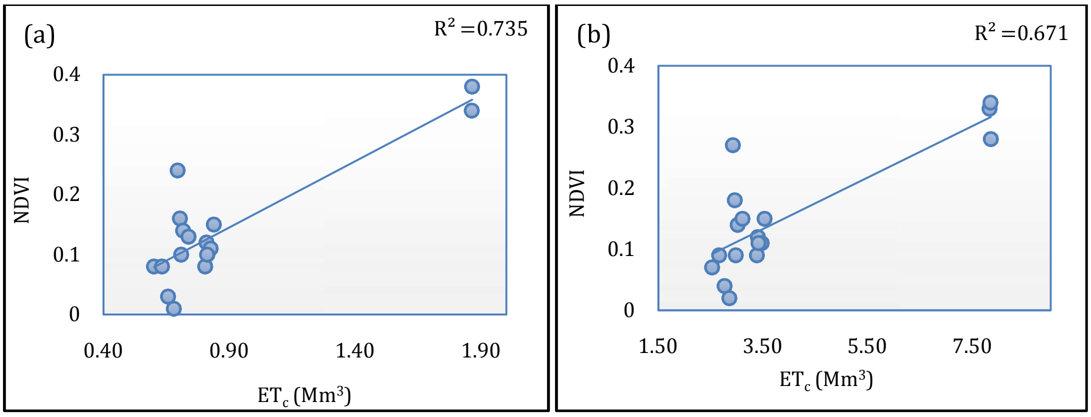

Figure 4;representation of the common NDVI and ET_c responses for the crops over (a) Major 2 and (b) Major 5.

Effect of water shortage

The area of the scheme normally witnesses a short season of rainfall extends from July to October every year (Fig. 3), during which a satisfactory irrigation water volumes are applied with the aid of Rahad River (the temporary supply) to meet the scheme requirements. However, for the rest of the season a severe water shortage strikes the scheme area causing unaffordable demand at the pumping station in order to meet the designed water need. Moreover, this water shortage mostly occurred during the periods of high water demand as the crops reach the full vegetation cover. On the other hand, the water conductance capability at the pumps station has been decreased tremendously due to siltation from the Blue Nile River, so that the working power of the supply pumps are no longer capable of delivering the required irrigation quota.

It can be seen obviously over Major 5 (Fig. 3 b) that the time that ET_c increases as an indicator of maturity progression, the irrigation water availability decreases during the period from August-II to October-III, indicating the water scarcity defect on crops health as stated by the NDVI. Figure 5 (a and b) shows clearly the shortage in irrigation water (SWS) that was supposed to meet the crop needs (ET_c), in the form of a negative linear correlation for the period from August to October.

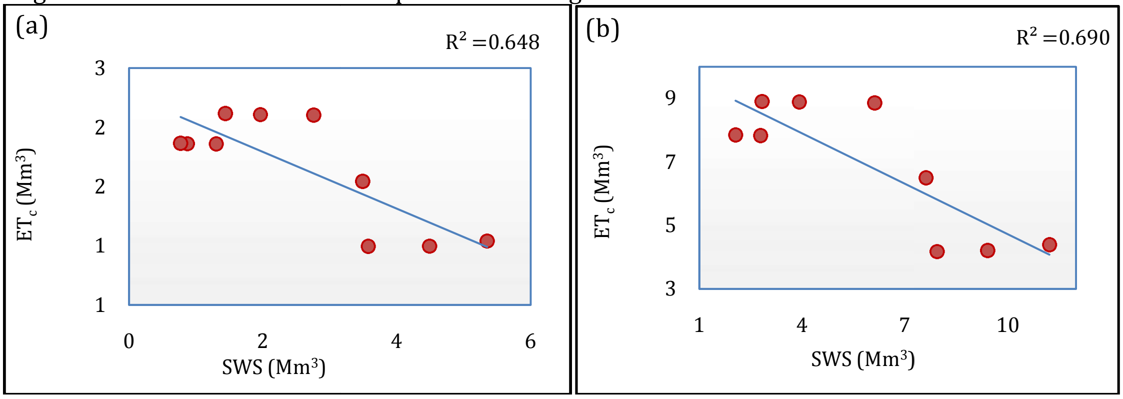

Figure 5; The inverse relationship between crop ET_c and SWS from August to October over (a) Major 2 and (b) Major 5.

Having the graphical representation (Fig. 3), and as the SWS is designed to satisfy the crop ET_c, the estimated water shortage can possibly be measuring through assessing the difference between the two values. It has been found that irrigation water shortage over Major 2 and Major 5 during August to October is estimated to reach 0.7 Mm^3 and 29.6 Mm^3, respectively.

CONCLUSION

The study intended to employ remote sensing techniques along with the crop evapotranspiration (ET_c) to monitor the scheme crops development through 2001 season and to assess the sufficiency of the Scheme water supply (SWS) for crops satisfaction. The outcomes assured that NDVI values derived from remotely sensed data was found to be an effective tool for assessing vegetation growth which could also be related to the study of irrigation water requirement. The relationship between NDVI and water supply established in this work was proved to be useful in identifying crop vigor fluctuation as affected by variability in scheme water supply. Some remarks from the work results can be highlighted in the next points:

- The crop NDVI reflected a typical ET_c behavior throughout the growth season as an indicator of the vital bond between the spectral and the meteorological responses of vegetation.
- Positive correlations were found between crop NDVI and ET_c throughout the whole growth stages yielding R^2 of 0.73 and 0.67 over Major 2 and Major 5, respectively.
- A severe irrigation water shortage was observed at the mid-season (August to October) due to the limited pumps capability, in addition to the shortness of seasonal rains.

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