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COST-EFFECTIVE AND TIME SAVING METHOD OF PHENOLOGICAL MONITORING USING SATELLITE IMAGERY IN DRIP-IRRIGATED RICE

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Abstract

Phenological monitoring is a necessary part of crop production. Fertilization, plant care measures, irrigation scheduling and plant protection are closely related in their efficiency to timely and precise determination of certain phenological phases of the cultivated plants to ensure the best out pay of the technological operations. Phenological observations are usually time-consuming and require some extra expenditures due to the need to visit each field of a farm or agricultural holding and cross it several times to assess the growth and development of the cultivated plants on the large scale. Modern technologies, mainly remote sensing, provide an opportunity to estimate crops development both on the scale of a local field or whole farm in time-saving and cost-effective manner through vegetation indices. The purpose of this study was to determine the correspondence between the values of the normalized difference vegetation index and phenological phases of drip irrigation rice, cultivated in the south of Ukraine during 2016-2017, to ensure the possibility of remote phenological monitoring in such crops. As a result, the highest values of the vegetation index were determined to be recorded in the tillering-heading period, and usually coincides with the period of July. The determined rice vegetation patterns are not only for rice growers due to time and cost savings for crop phenological monitoring, but are also of great importance for intelligent agriculture in the sense of crop recognition automation and mapping.

Key words*: *digital agriculture, normalized difference vegetation index, phenology, remote sensing, rice

INTRODUCTION

Phenological monitoring plays a crucial role in rational cultivation technology. Crop growth and development observations are necessary for efficient plant production management, playing a decisive role in fertilization, irrigation, plant protection scheduling, etc. In addition, it is of great scientific significance in the studies of crop reactions to various environmental conditions, technological operations, and in the studies related to the cycles of matter exchange in the biosphere [6].

Because agricultural activities and plant production are usually held in large spatial areas, which makes the conventional field observations time-consuming and costly, the need for finding cost-effective and time-saving alternative to in-field records is relevant to provide the highest possible profitability of plant production [3].

Integration of remote sensing into agriculture opens new opportunities for large-scale phenological monitoring.In this regard, normalized difference vegetation index recordings from satellite imagery are extremely helpful to provide a robust, precise, and easy-in-use tool for farmers to ensure timely and cost-saving control for the cultivated plants growth [4].

Previous studies, conducted in different regions for different crops, proved a high reliability of crop phenological monitoring through satellite data [12, 13]. Although the issue seems to be thoroughly studied, some areas remain *terra incognita* for modern digital agriculture. For example, the question of rice phenological monitoring using satellite imagery has been studied in numerous works; however, none of these studies was devoted to drip-irrigated rice, which can have absolutely different growth and development due to alternative environmental and cultivation conditions [2, 11, 17, 18, 20]. As far as rice is one of the most important food crops in the world, we are convinced that comprehensive study of its phenological monitoring is of a great relevance and significance to ensure food security in current conditions of global food guarantee problems [1].

Therefore, this study aims to determine the correspondence between the values of normalized difference vegetation index and drip-irrigated rice phenological phases. This is the first work to provide an annual pattern of the crop development in the conditions of drip irrigation in the relation to the spatial vegetation index for further use in crop mapping and automation monitoring systems of precision agriculture.

MATERIALS AND METHODS

The study on drip-irrigated rice phenological monitoring using remote sensing data was conducted in 2016-2017 within the framework of the field experiment on its cultivation technology in the South of Ukraine, Kherson region.

The experiment embraced 96 variants randomly located in four replications within the square of the coordinates (provided as Google maps decimals):46.4724N, 33.1575E; 46.4706N, 33.1579E; 46.4711N, 33.1619E; 46.4729N, 33.1614E. The area of the plot was 125 m^2, while the experimental field total area was 1.2 ha.

Rice cultivar Flahman (var. *italic Alef*), included into the list of the State Register of Plant Varieties Suitable for Dissemination in Ukraine since 2009 [19], was used as a biological material in this study. Cultivation technology treatments embraced various tillage (discing at 10-12 cm; chisel plowing at 30-32 cm), fertilization (N_0P_0; $N_{90}P_{30}$; $N_{120}P_{45}$; $N_{150}P_{60}$), and watering rates under drip irrigation (starting with ETc adjusted from 120%, 140%, and 160%), although, these parameters are not the subject this study, they had some influence on rice growth patterns, resulting in changes in the crop phenology by the variants of the experiment. These discrepancies in the terms of phenological phases start were considered and smoothed in this study.

Most variants had similar phenological pattern regardless cultivation treatments, however, the unevenness in phenology that had been recorded in field surveys, were taken into account when finding the correspondence between NDVI values and stages of the crop growth. We recorded following phases of the crop growth and development, namely: Sowing-emergence; Emergence-tillering; Tillering-internode elongation; Internode elongation-heading; Heading-Maturity [8].

Remote sensing technique was applied to find the correspondence between drip-irrigated rice phenology and NDVI values. Satellite imagery was obtained at the free online platform for digital farming OneSoil AI, which uses combined Sentinel ½ screens with the resolution of 250 m to minimize possible distortions.

Table 1. Rice phenology and dates of NDVI imagery used for analysis in 2016 (the date with the highest NDVI is in bold)

Phase	Calendar dates (field records)	NDVI dates (satellite records)
I. Sowing-emergence	05/18-06/01	05/25
II. Emergence-tillering	06/01-06/23(26)	06/04; 06/11; 06/14; 06/21; 06/24
III. Tillering-internode elongation	06/23(26)-07/13(17)	07/01; 07/11; 07/14
IV. Internode elongation-heading	07/13(17)-08/12(20)	07/21; 07/24; 07/31; 08/10; 08/20
V. Heading-Maturity	08/12(20)-09/30(10/11)	09/20; 09/09; 09/12; 09/22; 10/09

Source: Own study.

The imagery on the platform is provided on the regular basis, however, we used cloud-free images only in our study that made the number of NDVI screens less than totally available. Each pixel of OneSoil NDVI image corresponds to the square of 5×5 m. Therefore, each experimental plot is represented by 5 pixels of OneSoil gridded screen. The correspondence between the plots in the field and gridded OneSoil image were manually established before accounting. The dates, when the NDVI images were taken and processed for each phenological phase of the crop within the time span of the study are presented in the Tables 1-2 for the year 2016 and 2017, respectively.

Mean values of NDVI index ± standard deviation wascalculated by the common statistical methodology in the Microsoft Excel 365 software [5].

The figures were created using standard diagrams toolkit included in Microsoft Excel 365.

Table 2. Rice phenology and dates of NDVI imagery used for analysis in 2017(the date with the highest NDVI is in bold)

Phase	Calendar dates (field records)	NDVI dates (satellite records)
I. Sowing-emergence	05/16-05/31	05/17; 05/30
II. Emergence-tillering	05/31-06/25(28)	06/16; 06/19; 06/26
III. Tillering-internode elongation	06/25(28)-07/16(20)	06/29; 07/01; 07/06; 07/11; 07/16
IV. Internode elongation-heading	07/16(20)-08/11(19)	07/21; 07/24; 07/31; 08/03; 08/05; 08/08; 08/13; 08/18
V. Heading-Maturity	08/11(19)-09/29(10/10)	08/20; 08/23; 08/25; 09/07; 09/09; 09/12; 09/14; 09/17; 09/27; 09/29; 10/04

Source: Own study.

RESULTS AND DISCUSSIONS

As a result, average NDVI values for each phenological phase of rice were established, as well as mean monthly values.

It is interesting that average NDVI values for first two phases of rice growth and development are similar (Table 3). This fact makes it impossible to clearly distinguish between the phase of Sowing-emergence and Emergence-tillering when remotely controlling the crop growth. Therefore, unfortunately, it might be necessary at the beginning of the crop vegetation to visit fields and make visual surveys regarding rice phenology. Peak development of rice green biomass corresponds to the phases of Tillering-internode elongation and Internode elongation-heading, with further gradual senescence and drying of green biomass in pre-harvesting period.

Table 3. Correspondence between phenological phases of rice and average NDVI values for each stage, ± standard deviation

Phase	NDVI value
Sowing-emergence	0.29±0.15
Emergence-tillering	0.29±0.15
Tillering-internode elongation	0.56±0.10
Internode elongation-heading	0.53±0.17
Heading-Maturity	0.27±0.15

Source: Own study.

Successful rice phenology monitoring using MODIS NDVI data was also reported by other scientific groups [10, 14]. Besides, some authors also assume enhanced vegetation index (EVI) to be also feasible and prospective option for rice phenological monitoring, even though it is modestly presented in available free and commercial products for farmers [7, 16].

Yearly dynamics of NDVI presented in the Table 4 testifies about comparatively sufficient difference between the monthly values of the index, apart from the months of May and June representing the initial stages of the crop growth similarly to the mentioned above regularity. The established grades would be useful for identification of drip-irrigated rice in the systems of automatic crop mapping based on artificial intelligence and remote sensing data that is supported by previously conducted studies [9, 15].

Table 4. Mean monthly NDVI values on the drip-irrigated rice field, ± standard deviation

Month	NDVI value
May	0.29±0.15
June	0.31±0.16
July	0.64±0.11
August	0.40±0.17
September	0.29±0.17
October	0.16±0.01

Source: Own study.

For better understanding of the study results, it is essential to present a move of the vegetation index values through the growing season of the crop and on yearly scale through the diagrams.

Visual presentation of the crop growth dynamics depicted by NDVI values is provided in the Figures 1 and 2.

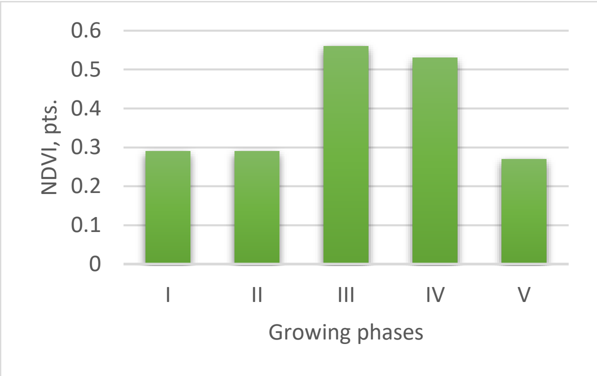

Fig. 1. Average NDVI values of the drip-irrigated rice by the phases of its growth

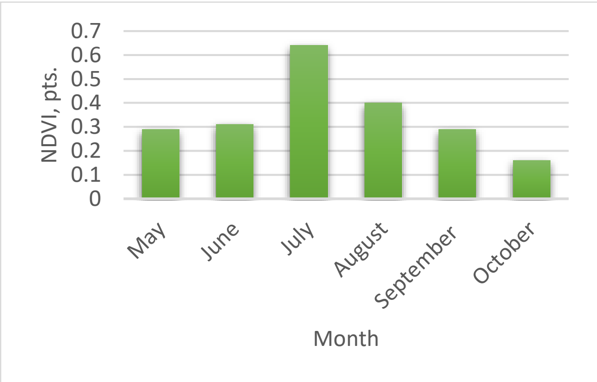

Fig. 2. Mean monthly NDVI values on the drip-irrigated rice field
Source: Own results.

CONCLUSIONS

The results of the study revealed the patterns of NDVI move on the drip-irrigated rice field in the context of the crop's phenology and on yearly scale. It was proved that remote sensing NDVI data could be utilized for precise, cost-effective, and timesaving phenological monitoring of drip-irrigated rice. The only limitation relates to extremely slight difference between the beginning stages of the crop growth, namely, Sowing-emergence and Emergence-tillering. Yearly pattern could be further implemented in the systems of automatic crop mapping in the systems of precise digital agriculture.

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