IRSTI 36.33.27 https://doi.org/10.26577/JGEM.2023.v71.i4.07

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MONITORING OF CROP GROWTH PARAMETERS USING TEMPORAL SAR AND OPTICAL REMOTE SENSING DATA IN THE KARASAI DISTRICT, ALMATY REGION

Using Remote sensing data is essential in monitoring agricultural crop phenology and food security. The availability of optical and SAR imagery can provide the best insights into understanding the behavior of temporal characteristics of phenological stages of multiple agricultural crops. The study was carried out in the region situated in the Karasai district of Almaty region using the temporal Sentinel-1 data and Sentinel-2 optical data during the growth period of agricultural crops. NDVI values from the Sentinel-2 and Multitemporal VH/VV backscatter intensity from Sentinel-1 SAR with the sample data were used to characterize the backscatter and vegetation stage behavior of multiple crops. Crop growth parameters were calculated using Google Earth Engine platform. Google Earth Engine is a cloud-based platform that allows users to visualize and analyze satellite images of the Earth and make geospatial analysis. The results indicate that the phenological stages of the agricultural crop growth cycle may be recognized and distinguished based on the temporal variations of NDVI values and in SAR parameters that were detected. Also according to the result of the study it is visible that the trend charts of backscattering values are quite correlated with the NDVI value. NDVI with backscatter values of VV/VH can be considered as one of the beneficial tools for distinguishing and analyzing the phenological changes of different types of agricultural crops.

Key words: crop growth parameters, backscatter intensity parameters, NDVI, Sentinel-1, Sentinel-2.

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Алматы облысы Қарасай ауданында уақытша радиолокациялық және қашықтықтан зондтаудың оптикалық бейнелерін пайдалана отырып, дәнді дақылдардың өсу параметрлерін бақылау

Қашықтықтан зондтау деректерін пайдалану ауыл шаруашылығының дәнді дақылдарының фенологиясын бақылау және азық-түлік қауіпсіздігін қамтамасыз ету үшін маңызды. Оптикалық және радиолокациялық кескіндердің болуы бірнеше ауыл шаруашылығының дәнді дақылдарының фенологиялық кезеңдерінің уақыт сипаттамаларына жақсы түсінуге мүмкіндік береді. Зерттеу ауыл шаруашылығының дәнді дақылдарының вегетациялық кезеңінде Sentinel-1 уақыт аралық суреттерін және Sentinel-2 оптикалық деректерін пайдалана отырып, Алматы облысы Қарасай ауданы Жалпақсай ауылында орналасқан егіншілік алқабында жүзеге асырылды. Sentinel-2 суреттерінен алынған NDVI мәндері және Sentinel-1 радиолокациялық суреттерінен алынған VH/VV кері шашырау қарқындылығының көп уақыттық көрсеткіштері бірнеше дәнді дақылдардың кері шашырау көрсеткіштері мен вегетациялық күйінің сипаттамасын сипаттау үшін пайдаланылды. Дәнді дақылдардың өсу параметрлері Google Earth Engine платформасы арқылы есептелді. Google Earth Engine-бұл пайдаланушыларға жердің спутниктік суреттерін визуализациялауға және талдауға және геокеңістіктік талдау жасауға мүмкіндік беретін бұлтты платформа. Нәтижелер ауыл шаруашылығының дәнді дақылдарының өсу циклінің фенологиялық кезеңдерін NDVI мәндерінің уақытша вариациялары мен радар параметрлері негізінде тануға және ажыратуға болатынын көрсетеді. Сондай-ақ, зерттеу нәтижелері бойынша кері шашырау мәндерінің трендтік графиктері NDVI мәндерімен өте сәйкес келетіндігін көруге болады. VV/VH кері шашырау мәндері бар NDVI әртүрлі ауыл шаруашылығының дәнді дақылдарының фенологиялық өзгерістерін ажырату және талдау үшін пайдалы құралдардың бірі ретінде қарастырылуы мүмкін.

Түйін сөздер: дәнді дақылдардың өсу параметрлері, кері шашырау қарқындылығының параметрлері, NDVI, Sentinel-1, Sentinel-2.

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Мониторинг параметров роста зерновых культур с использованием временных радарных и оптических снимков дистанционного зондирования в Карасайском районе Алматинской области

Использование данных дистанционного зондирования имеет важное значение для мониторинга фенологии сельскохозяйственных культур и обеспечения продовольственной безопасности. Доступность оптических и радарных изображений может обеспечить лучшее понимание поведения временных характеристик фенологических стадий нескольких сельскохозяйственных культур. Исследование проводилось в местности, расположенном в Карасайском районе Алматинской области, с использованием временных снимков Sentinel-1 и оптических данных Sentinel-2 в период вегетации сельскохозяйственных культур. Значения NDVI из снимков Sentinel-2 и многовременные показатели интенсивности обратного рассеяния VH/VV из радарных снимков Sentinel-1 с выборочными данными использовались для характеристики показателей обратного рассеяния и поведения вегетационного состояния нескольких сельскохозяйственных культур. В качестве параметров роста зерновых культур были выделены показатели вегетационного инедкса NDVI и показатели значения обратного рассеяния VV/VH Параметры роста зерновых культур были рассчитаны с применением алгоритма на языке JavaScript в платформе Google Earth Engine. Google Earth Engine — это облачная платформа, которая позволяет пользователям визуализировать и анализировать спутниковые снимки Земли и проводить геопространственный анализ. Результаты показывают, что фенологические стадии цикла роста сельскохозяйственных культур можно распознавать и различать на основе временных вариаций значений NDVI и параметров радарных снимков. Также по результатам исследования видно, что графики трендов значений обратного рассеяния вполне коррелируют со значениями NDVI. NDVI со значениями обратного рассеяния VV/VH можно рассматривать как один из полезных инструментов для различия и анализа фенологических изменений различных видов сельскохозяйственных культур.

Ключевые слова: Параметры роста зерновых культур, параметры интенсивности обратного рассеяния, NDVI, Sentinel-1, Sentinel-2.

Introduction

One of the essential components of crop management is knowing agricultural growing trends and crop spatial distribution. For effective farmer and decision-maker interventions during the phenological phases, such as fertilization, pesticide application, and irrigation, crop phenology monitoring and the detection of the main phenological stages are essential (Xie et al., 2022). Additionally, the temporal and spatial variances of phenology changes can be valuable information for the differentiation of various vegetation types, particularly crops.

Due to the lower economic efficiency, bigger area, and significant seasonal and spatial variation, obtaining crop information using traditional survey methods is quite problematic. The more efficient method for resolving this issue is using remote sensing technology (Kumar et al., 2021) So far, the monitoring of plant dynamics has been hampered by the unavailability of satellite time series with high temporal and spatial resolution. A new era began with the launch of the first Sentinel satellite, developed by the European Space Agency, which provided a large and unprecedented amount of free data for the operational needs of the Copernicus program. Sentinel-1A, the first SAR satellite launched in April 2014, has started to provide a multi-temporal series of SAR images (C-band) with an excellent time interval of 12 days. For Sentinel-1B, launched in April 2016, data delivery is expected every 6 days. Sentinel-2A, the optical satellite launched in June 2015, provides data every 10 days. For Sentinel-2B, the time interval is 5 days (Veloso et al., 2021).

Vegetation indices are typically used to monitor crop phenology in optical satellite images. Optical data (such as Sentinel-2, Landsat 8, and MODIS) have been widely utilized to investigate the relationship between plant optical characteristics and photosynthetic activity (Veloso et al., 2021). Due to its strong correlation with several biophysical measures, including leaf area index, leaf nitrogen content, and grain yield NDVI is one of the most widely used vegetation indices (Venancio et al., 2020). For example, Kganyago (2021) analyzed the changes in the winter-planted areas between the reference year (2019) and COVID-19 year (2020) using Sentinel-2 Multispectral Imager (MSI) data and Google Earth Engine (GEE) Cloud Computing Platform.

SAR data is less frequently employed in agricultural areas than optical data. However, recently, with a new generation of high-resolution SAR data, particularly since the Copernicus program Sentinel-1 C-band high spatial-temporal resolution images became available, SAR data has started to attract interest, especially for its benefit of having its source of energy, making it almost independent of weather conditions (Elders et al., 2022). Evaluation of the backscattering coefficient features at a different stage of growth is an alternative for other crops (Tuvdendorj et al., 2022). Thus, in the study (Nasirzadehdizaji et al., 2019) multi-temporal polarimetric Sentinel-1 SAR images were used to examine the various crop varieties' temporal backscatter changes and crop growth stages. According to the reported variations in backscatters, they discovered that important information regarding crop status may be retrieved from the backscattering analysis, such as estimating irrigation and harvesting time. A vegetation index from dual-pole (DpRVI) SAR data was published by Mandal et al. (2020) comparing the cross and co-pole scattering ratio, the dual-pole radar vegetation index (RVI), the polarimetric radar vegetation index (PRVI), and the dual polarization SAR vegetation index (DPSVI) with the temporal Compare analysis of biophysical variables of plants at different phenological stages. Compared to other indices, the results showed that the DpRVI index has a high correlation and good retrieval accuracy with the biophysical parameters of the selected plant species (Nasirzadehdizaji et al., 2019).

The superiority of Synthetic Aperture Radar (SAR) technology has created various opportunities in agricultural studies, mainly for crop monitoring and management. Thus, Nasirzadehdizaji et al. (2019) observed that polarimetric composite images for different dates are useful to roughly identify plant species and have been validated by the application of classification methods in the study area. Gansukh et al. (2020) monitored wheat using normalized differential vegetation index, vegetation water content, and backscatter value from VV, and VH channels in Bornuur Soum of Tuv Province, Mongolia. Umutoniwase et al. (2021) indicated that the backscatter coefficient of the VH polarization and the polarimetric decomposition parameters showed high sensitivity to rice growth.

Sentinel-1 has been used in numerous studies to classify crops to avoid S2 constraints. According to various research studies, using S1 and S2 images as input can result in high accuracy (Tuvdendorj et al., 2022).

The availability of a powerful processing framework is crucial for making approaches operationally applicable. The Google Earth Engine (GEE), which allows for the cloud-based processing of petabytes of satellite data, has recently become known as a tempting high-performance computing platform. GEE offers robust computational capacity for processing data at a global scale and even enables the development and training of well-known machine learning algorithms (Salinero-Delgado et al., 2022)

This paper aims to analyze temporal variations of NDVI time series from available cloud free Sentinel-2 optical data, Multi-temporal C-band VH and VV polarized Sentinel-1 SAR data of corn, spring oats, oats, winter wheat, sugar beet, soy, spring barley, corn, safflower, winter barley, and the correlation of their trend behavior. The ability of these data to distinguish between the crops was investigated.

To monitor the phenology of agricultural crops, LLP "Kazakh Research Institute of Agriculture and Plant growing" was chosen as the object of study (Figure 1). The Institute is located 22 km west of Almaty and 4 km east of Kaskelen.

The territory of the institute is located on the foothill plain of the Zailiysky Alatau, within 700-800 m above sea level, and represents the watershed of the Aksai and Kaskelen rivers. From north to south, it is crossed by the Kazachka River with steep steep banks, with a narrow floodplain (50-100 m), often swampy. The depth of groundwater in the middle part of the territory (along the valleys and logs) is 5-6 m, and in the hilly-ridged part it is 10-20 m or more (Erlepesov M.N, Tegisov T.A. 1975).

Materials and methods

All the calculation in this study was made according Google Earth Engine which represents magnificent and powerful tool for cloud stored data calculation of space images.

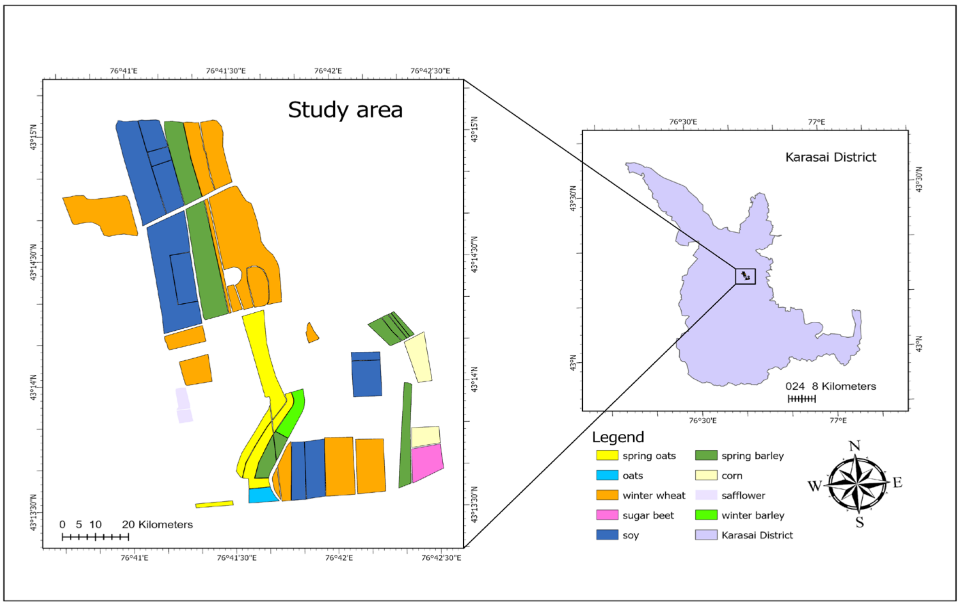

Figure 1 – Location of the study region and representation of the crop areas

Figure 2 – The code for analysis Sentinel 2 data

In this study Sentinel 2 and Sentinel 1 space images were used. Calculation of NDVI and VV/VH backscattering coefficient values were made with the code. See figure 2 and figure 3.

Samples Selection and Set

Initially, the shapefiles of the study area were created in ArcGIS from the map of crop types 2021 conducted by LLP "Kazakh Research Institute of

Agriculture and Plant growing" with the WGS 84 UTM 43N zone projection system and imported into the Google Earth Engine code editor.

Table 1 – Area of study regions

Type of crop	The study area (sqm)
corn	65314.16
oats	17567.43
Winter wheat	746078.42
Winter barley	28992.38
safflower	20695.03
Sugar beet	43946.25
soy	575686
spring oats	170888.66
spring barley	319976.71

The main sample types are winter barley, safflower, corn, spring barley, soy, sugar beet, winter wheat, oats, and spring oats. The area of each study region is represented in Table 3.

Sentinel 2 data preprocessing

The Sentinel 2 data were filtered by choosing images with clouds less than 10% from April to September 2021. The clouds were masked with maskS2clouds function. The shapefiles were merged into one variable, called "region" and then the boundaries were buffered (-10m) to take more precise areas of the crops. Then the Sentinel 2 data were filtered by choosing images with clouds less than 10% from April to September 2021. The clouds were masked with maskS2clouds function. See Table 1.

Vegetation index calculation (NDVI)

Spectral vegetation index NDVI (Rouse, J.W et al., 1974) was calculated in GEE with function *addNDVI* (See Table 2) using the surface reflectance values of the crops.This indice was formulated by using the following equation:

$$NDVI = \frac{rNIR - rRed}{rNIR + rRed}$$

where rRed, rNIR are the surface reflectance values of Band 4 (red, 0.64–0.67 µm), Band 5 (near-infrared, 0.85–0.88 µm) in the Sentinel-2 images.

Sentinel 1 data preprocessing

The Sentinel 1 data were filtered by choosing images from April to September 2021.

The preprocessing of VV/VH backscattering analysis data were made according the code in GEE (See Figure 3).

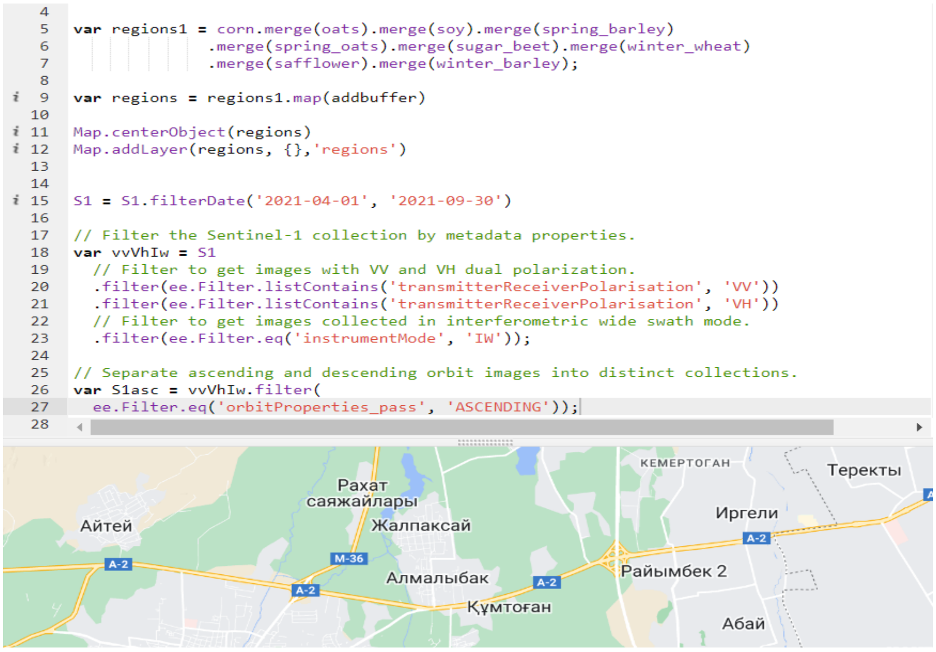

Figure 3 – The code for analysis Sentinel 1 data

Results and discussion

In this section, the results of the study are reported. The preliminary results obtained from Sentinel-1 and Sentinel-2 have been presented as well as the spatial distribution of the study areas (Section 3.1, Section 3.2) in the Karasai region from April to September 2021. Temporal profiles of crops are also presented in these sections as a scatter plot is shown. The graphs were obtained in Excel as a result of exporting values in CSV format from Google Earth Engine.

NDVI temporal analysis of crops

The NDVI value for major crops area – corn, oats, soy, spring barley, spring oats, sugar beet, winter wheat, safflower, and winter barley – between April and September 2021 was mapped in Figure 2 and Figure 3.

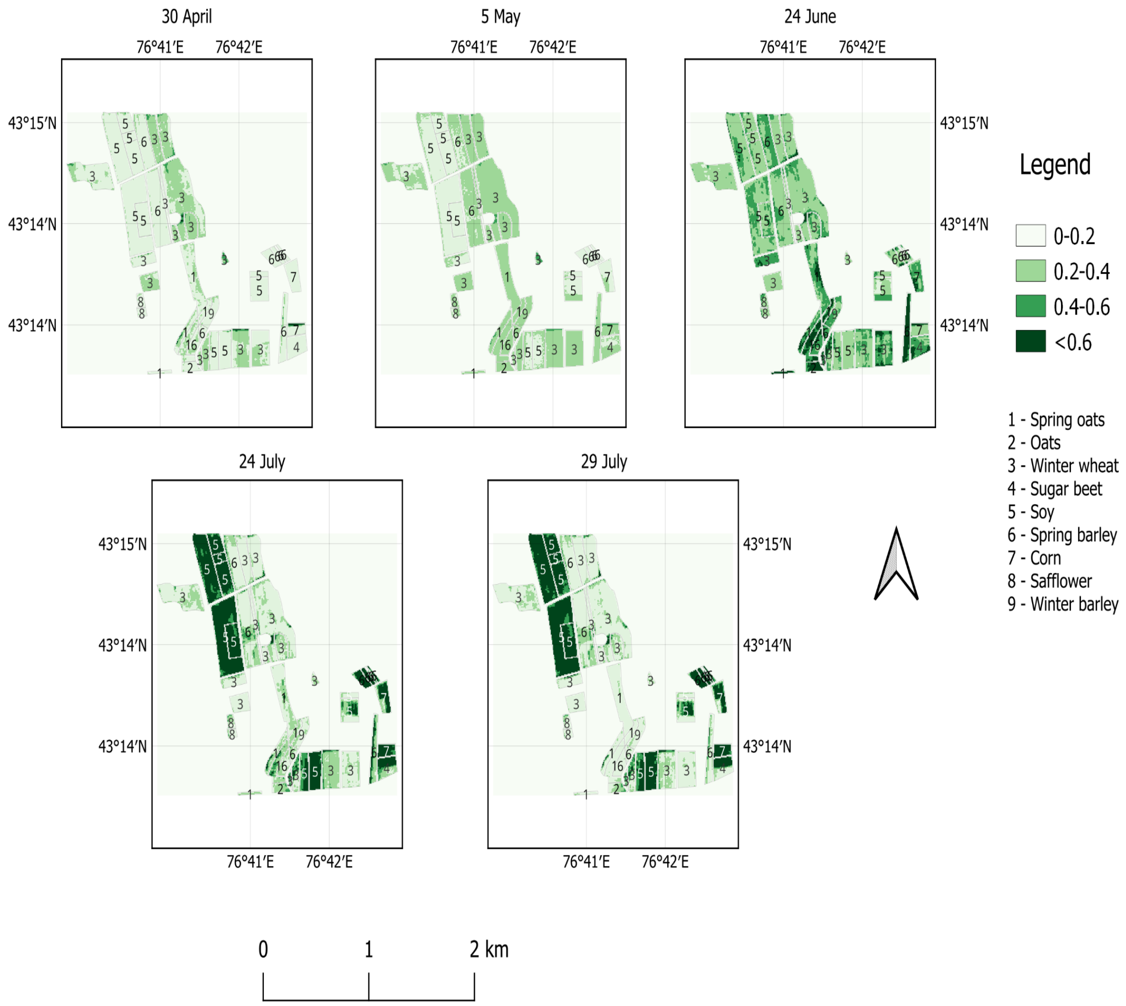

Figure 4 – Spatial distribution of NDVI values in the study region from April to July

For visual interpretation, the NDVI values are divided into four classes. The difference between dark and light green in each image indicates the vegetation stage.

It is obvious that NDVI varies throughout the growth cycle by viewing the images through their acquisition dates.

Through the visual interpretation, it is evident that the greenest values (>0,6) belong to oats (June), corn and soy (from July to September). For most of the crops from April to the beginning of May, the NDVI values are slightly green <0,2 which indicates the earlier stages of growth period while from June start decreasing which indicates the decline in vegetation.

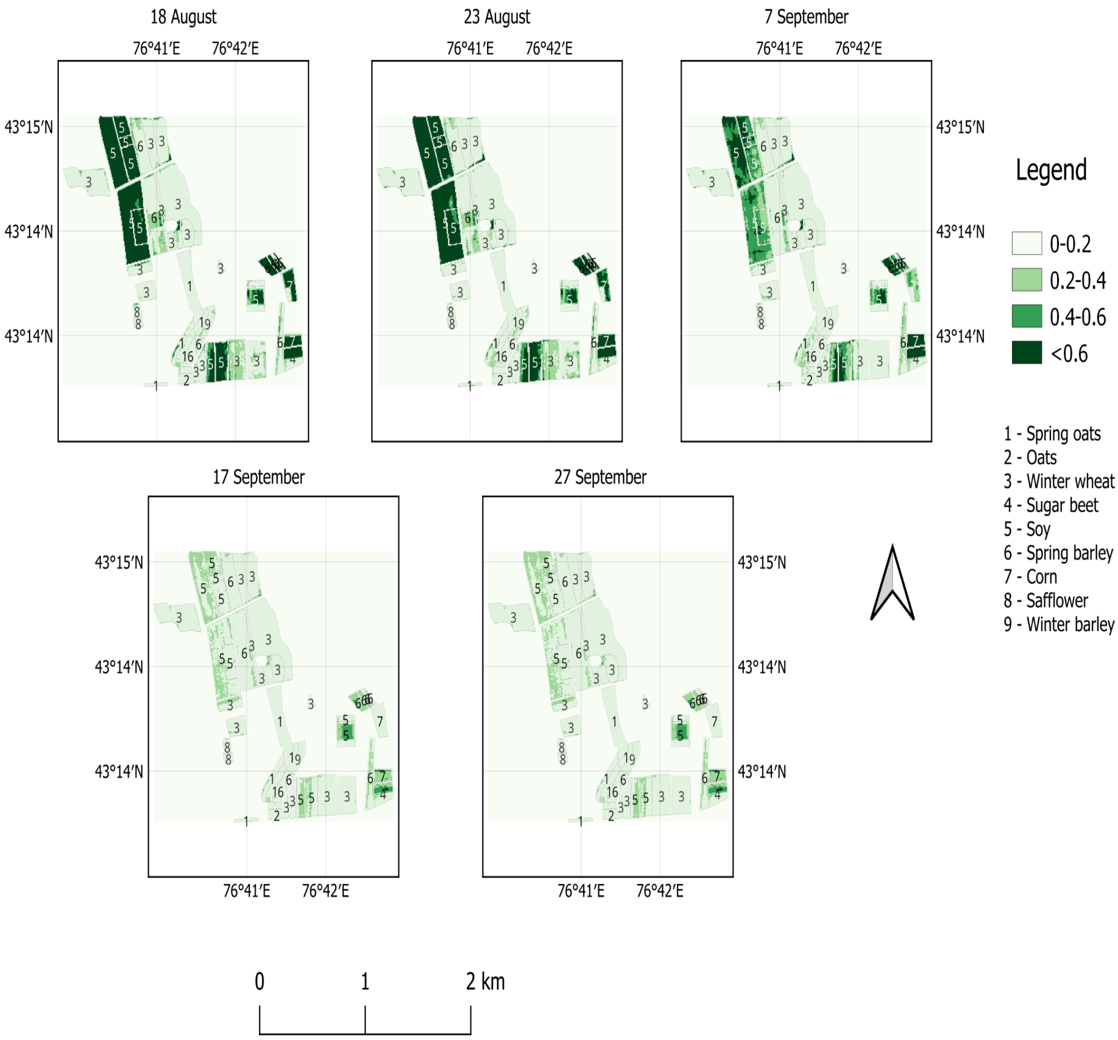

Figure 5 – Spatial distribution of NDVI values in the study region from August to September

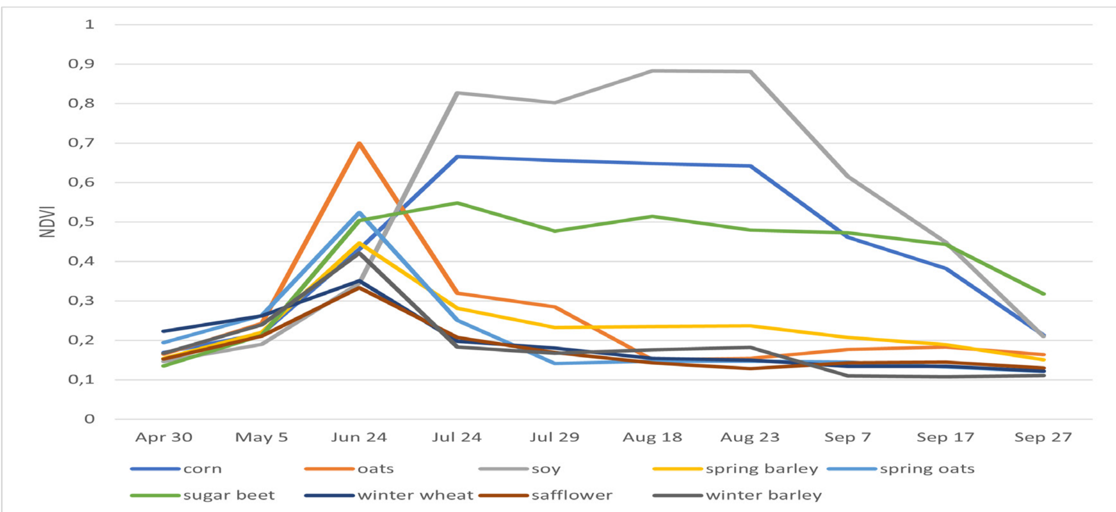

Figure 6 – Temporal NDVI profiles of crops grown in the Karasai district using multispectral Sentinel-2 images

The spectral plot for studying major crops is shown in Figure 6. In the plot, the germination is marked by the beginning of the rising spectral profile. From Figure 4, it is evident that the germination time for most of the crops is late April (Apr 30). The maximum biomass period according to the plot and Table 2 occurs approximately in June for spring barley(0,446), safflower(0,333), winter wheat(0,351), winter barley(0,421), oats(0,699), late July for sugar beet (0,548), during July for corn(0,665) and late August for soy (0,883). Leaf senescence is evident in late August for soy and corn, mid-September for sugar beet, and July for oats, spring oats, spring barley, winter barley, winter wheat, and safflower. These differentiating spectral characteristics were taken advantage of by distinguishing various crops.

Table 2 – Mean NDVI values of the crops grown in the Karasai district

date	corn	oats	soy	spring barley	spring oats	sugar beet	winter wheat	safflower	winter barley
Apr 30	0,169	0,165	0,146	0,154	0,194	0,135	0,223	0,152	0,167
May 5	0,217	0,243	0,19	0,22	0,263	0,212	0,262	0,211	0,239
Jun 24	0,431	0,699	0,345	0,446	0,524	0,504	0,351	0,333	0,421
Jul 24	0,665	0,319	0,827	0,281	0,251	0,548	0,198	0,207	0,183
Jul 29	0,656	0,285	0,802	0,232	0,141	0,477	0,18	0,169	0,167
Aug 18	0,648	0,151	0,883	0,235	0,147	0,514	0,154	0,143	0,176
Aug 23	0,642	0,154	0,881	0,237	0,147	0,479	0,15	0,128	0,182
Sep 7	0,461	0,177	0,615	0,207	0,145	0,472	0,134	0,143	0,11
Sep 17	0,382	0,183	0,448	0,189	0,132	0,443	0,134	0,145	0,107
Sep 27	0,213	0,164	0,21	0,151	0,121	0,318	0,122	0,13	0,111

Therefore, in the early stages of growth, healthy vegetation had a limited growth rate that was related to the NDVI since the photosynthetic process was constrained by many variables, including temperature and chlorophyll concentration. Then, because of the appropriate temperatures, rising chlorophyll content, and other factors, the growth rate rose. Due to a lack of nitrogen, a lack of water, a change in temperature, etc., the development rate slowed down in the later stages (Lambers et al., 2008).

Spatial distribution and the temporal variations of the backscattering intensity of crops

The sensitivity of C-band Sentinel-1 SAR to crop phenological stages in our test site was demonstrated by visual interpretation of multi-temporal images of VH and VV backscattering power (see Figure 7 and Figure 8). The difference between the dark gray and the white in each image indicates the VH backscattering intensity and the contrast between dark blue and light blue is shown by the values of VV backscattering intensity.

The backscattering intensity values of crops as the NDVI values trend varies throughout the growth cycle. According to the maps and the charts it is obvious that in the period of the growth cycle, the higher values belong to soy and corn. And the lower values for both backscattering values for most of the crops are observed in April, between August and September, and in June for VV backscattering intensity.

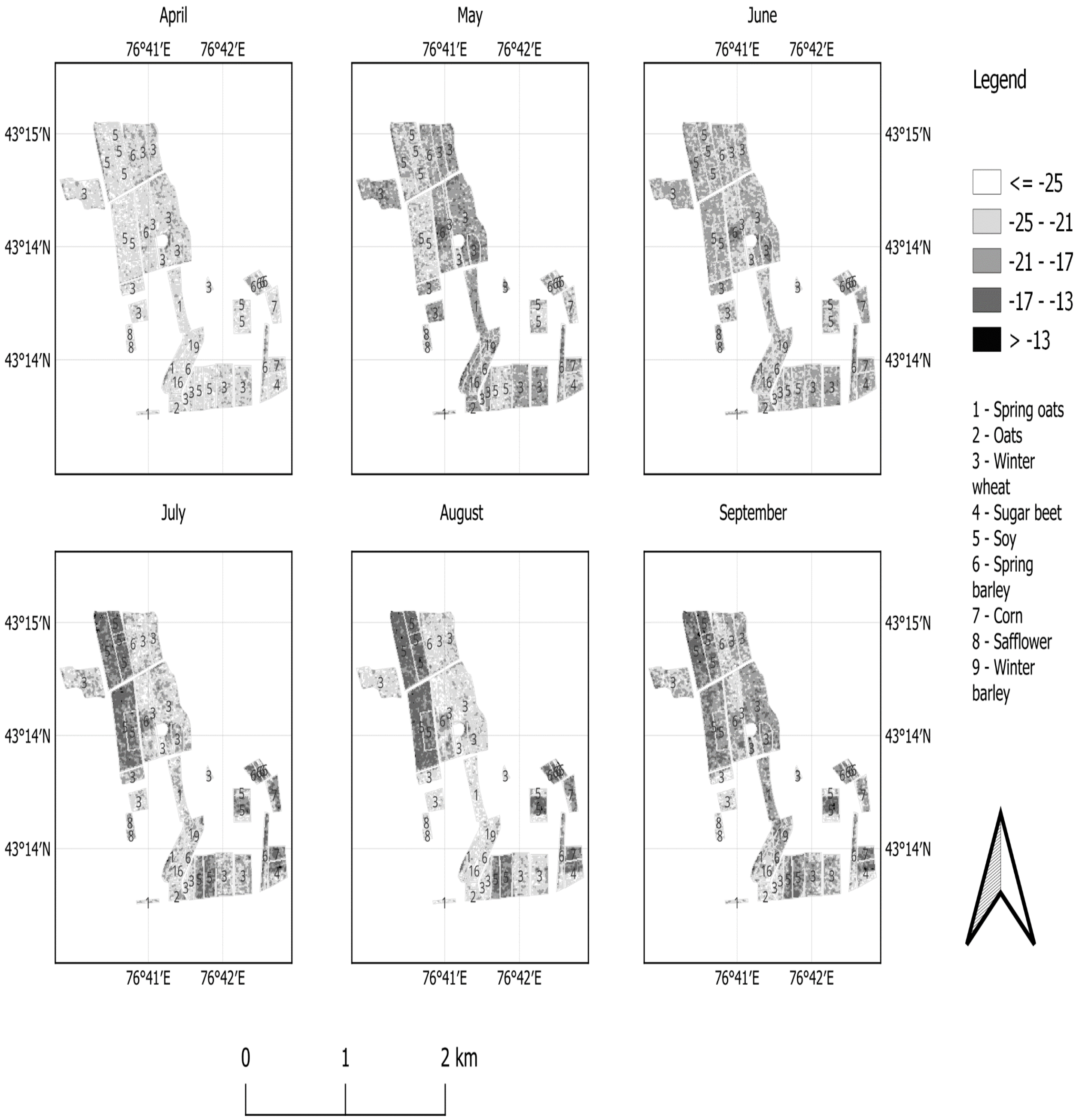

Figure 7 – Monthly interval spatial distribution of the VH backscattering coefficient values in the study region using Sentinel-1 images from April to September

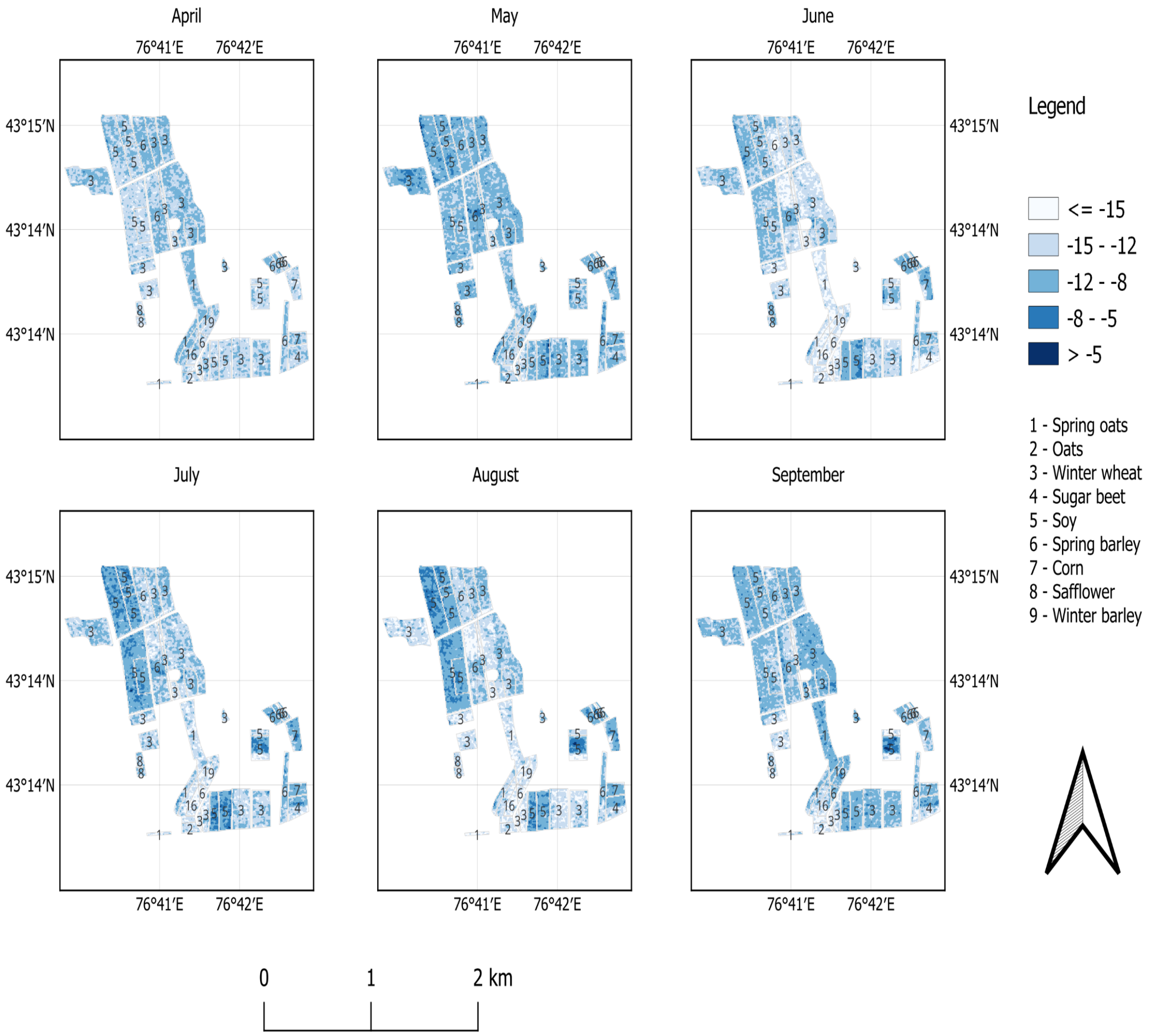

Figure 8 – Monthly interval spatial distribution of the VV backscattering coefficient values in the study region using Sentinel-1 images from April to September

If to look at the chart (Figure 9), it is evident that the remarkable increase of backscattering intensity of VH is observed in late May reaching a high stage on 21 May with the corresponding values (as shown in Table 3) of -18,85, -16,53, -18,97, -17,194, -16,82, -18,798, -17,246, -17,632, -17,661 dB for corn, oats, soy, spring barley, spring oats, sugar beet, winter wheat, safflower, winter barley respectively. This change implies the period of the beginning of full biomass period (21 May). In the period of higher biomass values for most of the crops according to Figure 7 and Table 2, it is observed that relatively higher values are obtained on 26 June with the values of -18,27 dB for corn, -18,8 dB for oats, -20,24 dB for soy, -20,078 dB for spring barley,-19,383 dB for spring oats,-18,116 dB for sugar beet, -20,268 dB for winter wheat, -19,517 dB for safflower. Through the period between July and August, most cereals have lower marks, while soy and corn experienced higher values compared with the other crops, with soy having the highest value of -14,389 dB on 20 July.

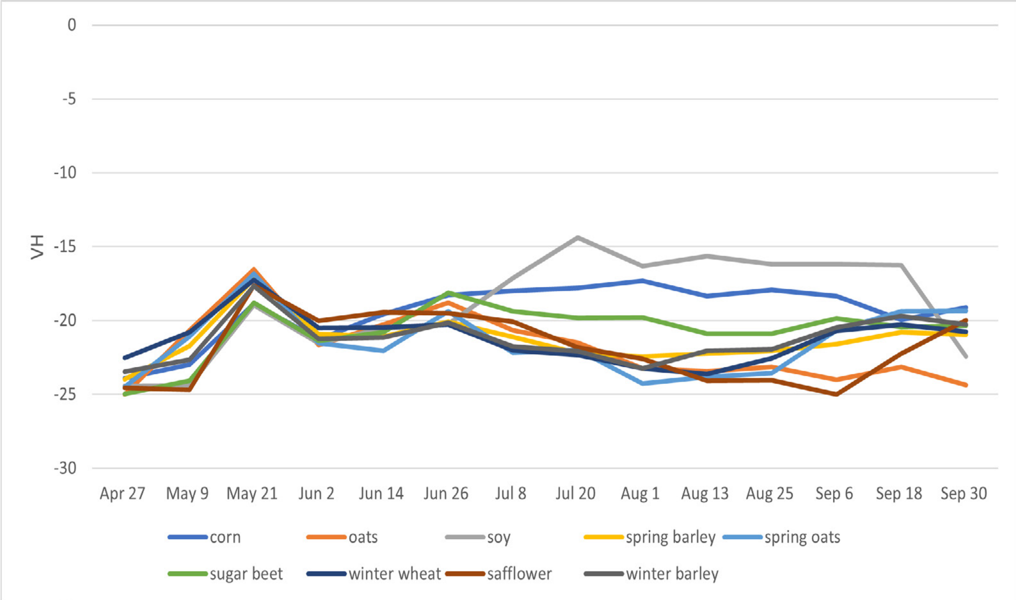

Figure 9 – The backscatter values (dB) of crops on multi-temporal Sentinel-1 images in VH polarization

Similar to the VH backscattering coefficient (Figure 10), the VV backscattering coefficient values also significantly increase at the beginning of the chart reaching the highest values (as shown in Table 4) of -8,581 dB for corn, -10,93 dB for oats, -7,467 dB for soy, -9,457 dB for spring barley, -11,404 dB for spring oats, -9,729 dB for sugar beet, -9,652 dB for winter wheat, -9,323 dB for safflower, -10,246 dB for winter barley on 21 May. Same as in Figure 7 from June to September it is observed that VV exhibited lower values, while corn and soy obtained higher values compared to other crops.

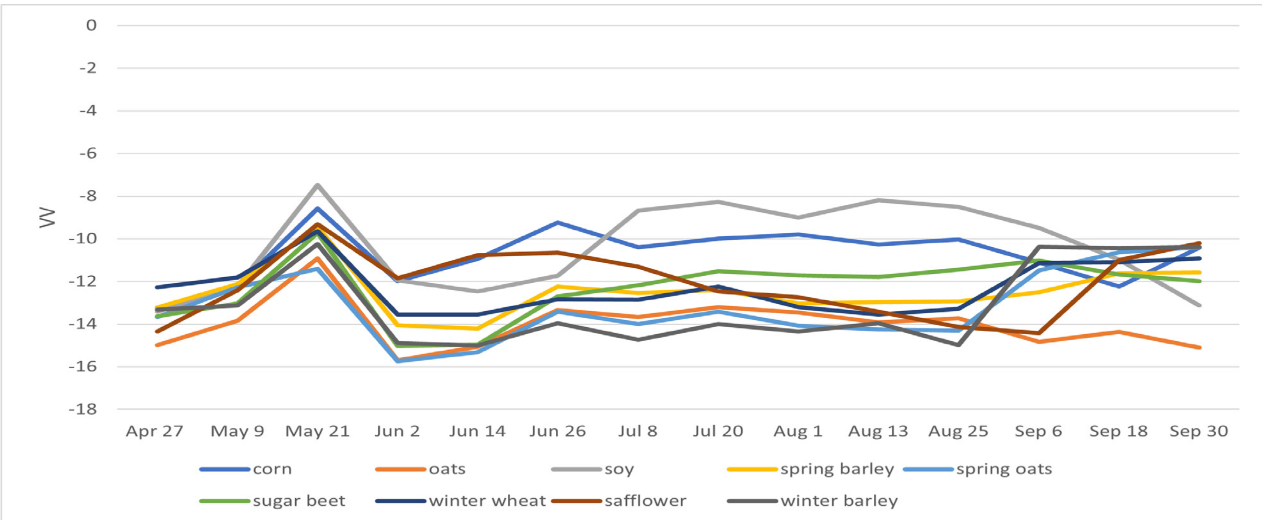

Figure 10 – The backscatter values (dB) of crops on multi-temporal Sentinel-1 images in VV polarization

The radar backscattering intensity gives valuable information about the shapes and properties of the crops. SAR sensors are sensitive to significant crop structural elements like height, shape, leaves, and stems in crop fields (Soria-Ruiz et al., 2007).

Table 3 – Backscatter intensity values of temporal VH band for the crops in the Karasai district region from April to September 2021

Date	corn	oats	soy	spring barley	spring oats	sugar beet	winter wheat	safflower	winter barley
Apr 3	-21,146	-20,266	-21,811	-21,513	-20,997	-21,544	-21,904	-22,222	-21,776
Apr 15	-23,919	-24,406	-24,28	-22,911	-24,447	-24,321	-23,551	-24,979	-24,452
Apr 27	-23,91	-25,02	-24,44	-23,967	-24,503	-24,964	-22,527	-24,546	-23,45
May 9	-22,98	-20,67	-24,4	-21,73	-21,098	-24,074	-20,802	-24,703	-22,663
May 21	-18,85	-16,53	-18,97	-17,194	-16,82	-18,798	-17,246	-17,632	-17,661
Jun 2	-21,29	-21,68	-21,55	-20,914	-21,533	-21,389	-20,499	-20,02	-21,255
Jun 14	-19,56	-20,29	-20,55	-21,087	-22,055	-20,809	-20,486	-19,437	-21,159
Jun 26	-18,27	-18,8	-20,24	-20,078	-19,383	-18,116	-20,268	-19,517	-20,139
Jul 8	-18,01	-20,65	-17,12	-21,128	-22,176	-19,394	-22,003	-20,078	-21,769
Jul 20	-17,79	-21,5	-14,39	-22,196	-21,999	-19,829	-22,354	-21,84	-22,07
Aug 1	-17,33	-23,25	-16,31	-22,426	-24,26	-19,809	-23,238	-22,597	-23,249
Aug 13	-18,35	-23,45	-15,64	-22,255	-23,805	-20,9	-23,615	-24,088	-22,061
Aug 25	-17,94	-23,15	-16,18	-22,042	-23,567	-20,881	-22,567	-24,056	-21,943
Sep 6	-18,34	-24,01	-16,21	-21,601	-20,678	-19,87	-20,692	-25,016	-20,465
Sep 18	-19,95	-23,14	-16,25	-20,782	-19,368	-20,453	-20,273	-22,255	-19,711
Sep 30	-19,13	-24,36	-22,42	-20,948	-19,347	-20,341	-20,755	-19,985	-20,293

In the figures the backscattering values at the beginning of the growing stage present relatively similar values and regarding the mid-stage of the growth period crops have significant differences in backscatter values due to variations in the physical characteristics of the crops and the SAR's sensitivity to the geometrical features of the patterns.

Table 4 – Backscatter intensity values of temporal VV band for the crops in the Karasai district region from April to September 2021

Date	corn	oats	soy	spring barley	spring oats	sugar beet	winter wheat	safflower	winter barley
Apr 3	-11,126	-10,689	-10,532	-10,576	-10,001	-11,013	-11,275	-11,396	-11,144
Apr 15	-14,013	-14,246	-12,265	-12,121	-11,535	-13,443	-12,848	-13,923	-14,451
Apr 27	-13,23	-14,99	-13,42	-13,216	-13,662	-13,626	-12,267	-14,355	-13,323
May 9	-12,22	-13,84	-12,24	-12,117	-12,273	-13,029	-11,806	-12,402	-13,137
May 21	-8,581	-10,93	-7,467	-9,457	-11,404	-9,729	-9,652	-9,323	-10,246
Jun 2	-11,99	-15,7	-11,95	-14,062	-15,745	-15,015	-13,555	-11,851	-14,891
Jun 14	-10,95	-15,06	-12,47	-14,208	-15,32	-14,96	-13,553	-10,776	-15,003
Jun 26	-9,245	-13,35	-11,73	-12,233	-13,409	-12,708	-12,846	-10,657	-13,957
Jul 8	-10,4	-13,68	-8,668	-12,548	-14,007	-12,173	-12,852	-11,316	-14,729
Jul 20	-10	-13,21	-8,261	-12,397	-13,418	-11,523	-12,229	-12,47	-14,006
Aug 1	-9,792	-13,47	-9,005	-13,039	-14,07	-11,719	-13,204	-12,746	-14,349

Table continuation

Date	corn	oats	soy	spring barley	spring oats	sugar beet	winter wheat	safflower	winter barley
Aug 13	-10,27	-13,93	-8,194	-12,967	-14,253	-11,799	-13,546	-13,423	-13,955
Aug 25	-10,02	-13,73	-8,505	-12,927	-14,317	-11,435	-13,286	-14,131	-14,991
Sep 6	-11,12	-14,83	-9,486	-12,516	-11,485	-11,022	-11,139	-14,418	-10,389
Sep 18	-12,24	-14,37	-10,98	-11,625	-10,637	-11,669	-11,088	-11,001	-10,429
Sep 30	-10,43	-15,1	-13,12	-11,582	-10,4	-11,988	-10,912	-10,202	-10,37

The results also indicate that there is an association between Sentinel-1 SAR backscatter values and plant variables during the different phenological stages.

Conclusion

According to the results of the study of satellite images, the period of higher biomass values for most crops was observed around in June and NDVI values ranged from 0,3 to 0,7. Leaf senescence is evident in late August in soy and corn, mid-September in sugar beet, and July in oats, spring oats, spring barley, winter barley, winter wheat, and safflower. Also, it is observed that among all of the crops oats, soy and corn showed higher NDVI values during the growth stages. The trend charts of backscattering values are quite correlated with the NDVI values trend. However, the maximum values for most of the crops are observed in the period of the beginning of full biomass and range between -6 and -12 dB in VV and -20 and -15 dB in VH. Thus, this study has found that NDVI with backscatter values of VV/VH can be considered one of the effective tools for distinguishing and analyzing the phenological changes of different types of crops. The reviewed method may be helpful for agriculture managemen t and monitoring of crop identification and cropland mapping, crop growth stages, crop damage/health monitoring, precision agriculture, etc.

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