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A pilot study on determining approximate date of crop harvest on the basis of Sentinel-2 satellite imagery

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Abstract: The paper presents a pilot study which was designed to determine whether Sentinel-2 satellite data can be applied for assessing the approximate date of crop harvest. The in-situ data collection is demonstrated, and further analysis of spectral reflectance of crops in selected spectral bands, in the period before and after harvest, is presented. The relation between the reflectance of Shortwave Infrared (SWIR) spectral bands and the crops status was found. The results are discussed and the need for further studies is indicated.

Keywords: crop harvest, SWIR, NDVI, Sentinel-2, precision agriculture, insurance, crop residue, harvest date

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1. Introduction

Since the 1970s, when the Earth Resources Technology Satellite (ERTS) – the first satellite of the Landsat programme – was launched, the number of applications of remote sensing for agriculture has grown significantly (Atzberger, 2013; Mulla, 2013). Remote sensing has become an important tool for agricultural production management from the farmers' perspective but also has recently gained the interest of paying agencies and insurance companies. The goal of the latter is to obtain a tool which would increase the efficiency of their activities concerning the monitoring of the cropping practices performed from the farm to the regional/national level.

Each crop type is grown according to the individual characteristics, which are impacted by various soil and atmospheric conditions. Remotely sensed data was found helpful in monitoring crop growth by delivering precise and timely information on the phenological status and development of vegetation (Veloso et al., 2017). At the same time, the applicability of remote sensing for monitoring of cropping practices was proven by many authors (Bégué et al., 2018).

One of the cropping practices which is of high interest to various institutions and agencies, is collecting information on the most up to date status of the crops on individual fields, including approximate date of harvest.

The request of one of the insurance company (operating in Poland) for assessing the applicability of remote sensing data for detection of the date of harvest was the initial motivation of the research presented in the following paper.

The proposed study was based on the assumption that certain combination of satellite's image spectral bands available from Sentinel-2 satellite would allow for crop harvest detection. In order to determine which spectral bands would be useful, the accurate data on crop harvest was required. That is why, the in-situ campaigns were performed. Further, the comparison of spectral reflectance of selected crops, before and after harvest, has been examined on the basis of Sentinel-2 satellite data.

The presented approach, if proven viable, was designed to be incorporated into an existing System for automatic satellite data processing and analysis for agriculture – Advance Sustainable Agriculture Production (ASAP). The existing System is based primarily on the Sentinel-2 satellite data and thus the applicability of this source of satellite data was exploited under the proposed research.

Firstly the review of studies on remote sensing data application for detection of crop harvest has been conducted. Yet, there are a low number of research papers concerning this subject.

According to Bégué et al. (2018), only four examples of sugarcane harvest detection were demonstrated in the remote sensing literature. Much more attention has been given to the research on crop residue and tillage detection (Zheng et al., 2014) which is strongly correlated with the presented work.

Prior to the Sentinel-2 launch, various remote sensing platforms have been applied for monitoring and demarcation of the spatial distribution of crop residues (Daughtry et al., 2005). Significant difference between green vegetation, soil, and residue reflectance, which is presented in Figure 1, can be observed. The residue has significantly higher spectral reflectance in 2200 nm (which corresponds to the Sentinel-2 SWIR 2 band) than soil and green vegetation, which has become the first assumption for the research.

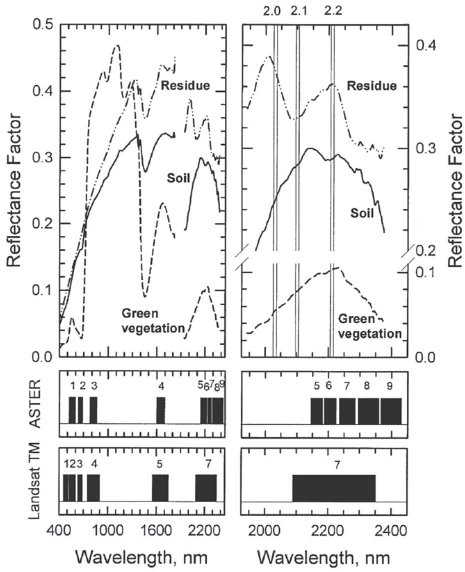


Fig. 1. The spectral reflectance of green vegetation, soil and residue (source: Daughtry, 2005)

There has been a significant number of research on spectral properties of plants (e.g. Gates et al., 1965; Zwiggelaar, 1998) as well as characteristic of their reflectance in visible and near infrared (e.g. Penuelas, 1998) but very few studies were performed on applicability of Short-wave Infrared (SWIR) spectrum for crops properties assessment (Kim et al., 2015).

Since there is lack of studies correlating harvest detection with any of the spectral bands or vegetation indices, it was decided to consider in this study the spectral reflectance in all spectral bands available on Sentinel-2 satellite data.

2. Study area

In-situ measurements were carried out on three Test Sites (TS 1–3) located in the north-western quarter of Poland which is one of the main crops producing area in the country:

Test Site 1: West Pomeranian Voivodeship, area 9.8 km × 6.4 km;

Test Site 2: Kuyavian-Pomeranian Voivodeship, area 5.4 km × 5.8 km;

Test Site 3: Kuyavian-Pomeranian Voivodeship, area 5.7 km × 10.1 km.

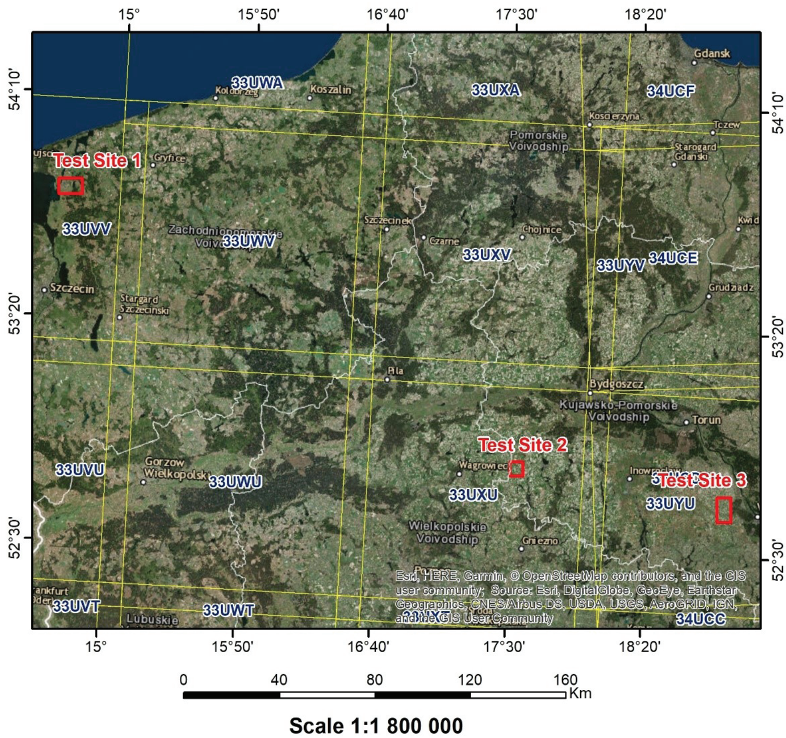


Fig. 2. Location of Test Sites and distribution of the Sentinel-2 tiles

Every Test Site contains a number of arable fields characterized by a mixture of agricultural crops, predominantly barley, wheat and rapeseed. The fields differ in size from 0.3 ha up to 65 ha.

For the purpose of this study, 39 fields were selected. Test Site 1 consist of 8 fields: 3 winter barley, 2 winter wheat, and 3 winter rapeseed. Test Site 2 consists of 19 fields: 4 barley, 9 wheat, and 6 rapeseed. Test Site 3 consists of 12 fields: 2 barley, 4 wheat, and 6 rapeseed.

3. Input data and methods

3.1. Field measurements

For the research 39 test fields were examined. Three most common (for the study area) crop types were selected: rapeseed, barley and wheat along with their winter varieties. Within the study area the earliest harvest usually occurs in mid to late June (winter barley), most crops, however, are harvested throughout July. Having regard to the above, specific time of the in-situ measurements was established and field work took place on four dates: 22/06/2018, 05/07/2018, 19/07/2018 and 31/07/2018. During the field examination information about crop type and the approximate date of harvest (in some cases the exact date) was collected.

While choosing test fields, dimensions of the field had to be taken into account. These must be adapted to the resolution of the satellite images used in the study. In the research presented, two spectral bands of 20 m spatial resolution were used, therefore recommended width of a test field is 100 m. This size allows obtaining at least 4 rows of clear pixels located within the field boundaries. In our study area however, many fields would not fulfil this rule, for that reason fields of 70 m and wider were accepted for this research.

3.2. Satellite data

The Sentinel-2 mission is a part of Europe's Copernicus Earth Monitoring Programme. This high

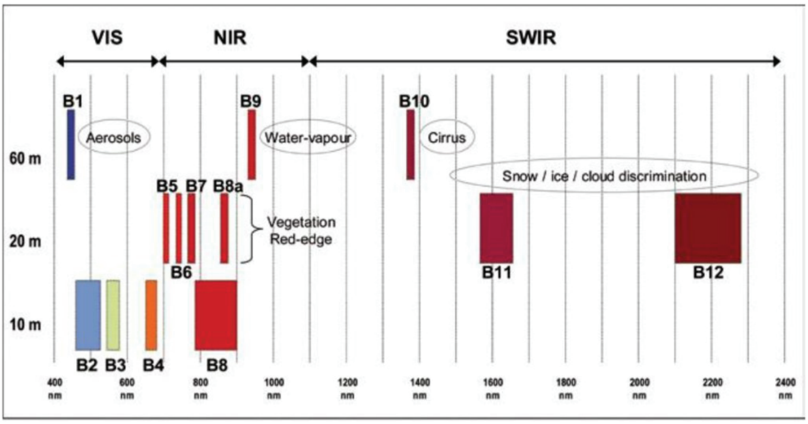


Fig. 3. Sentinel-2 spectral bands versus resolution[1]

resolution, multispectral imaging mission consist of two polar-orbiting satellites: Sentinel-2A and Sentinel-2B. The twin satellites are placed on the same sun-synchronous orbit (but 180°apart) at the altitude of 786 km. Such placement allows for relatively high revisit time of 5 days. Every satellite carries a passive optical MultiSpectral Instrument (MSI) capable of sampling 13 spectral bands in three different spatial resolutions: 10 m, 20 m, and 60 m (Fig. 3). The mission was designed for monitoring land and vegetation cover and is used in various applications, among others in agriculture.

This study was conducted using cloud-free Sentinel-2A and Sentinel-2B imagery processed at the Level-2A which provides the Bottom Of Atmosphere (BOA) reflectance in cartographic geometry. Level-2A products are derived from the associated Level-1C images using the Sen2Cor processor[2],[3].

The main difference between Level-1C and Level-2A images is the place of the reflectance measurement. In case of Level-1C images, one is provided with the Top of Atmosphere (TOA) reflectance which is measured at the sensor. On the Level-2A images atmospheric correction is applied. This process removes atmospheric distortion and as a result BOA is obtained, which is a measure of reflectance on the surface of the ground. Therefore BOA equals Surface Reflectance (SR).

Surface reflectance is a fraction of incoming solar radiation that is reflected from Earth's surface (Qu Y., 2018). As a proportion it is within the range of 0-1, where 0 means that all radiation is absorbed, and 1 means that all radiation is reflected. However, for storage efficiency (which is important when processing satellite images) it is recommended to work on the integer data. In order to convert the reflectance value from float (numerical data with decimal places) to integer, multiplication by quantification value of 10 000 was applied.

For every Test Site, six Sentinel-2 images were used. The acquisition dates of those images differ slightly from one Test Site (TS) to another as follows: 08–06, 28–06, 16–07, 23–07, 26–07, 31–07 (TS 1), 31–05, 20–06, 05–07, 15–07, 20–07, 04–08 (TS 2) and 06–07, 20–06, 07–07, 15–07, 20–07, 01–08 (TS 3).

The choice was dictated by cloudless condition and the time proximity to field measurements.

In order to assess if Sentinel-2 satellite data is applicable for detecting the moment of crop harvest, several band compositions and indexes were examined. The Atmospheric Penetration composition was selected due to its high sensitivity to the phenomenon studied. The Atmospheric Penetration is a combination of three bands: Shortwave Infrared 2 (SWIR 2, band 12), Shortwave Infrared 1 (SWIR 1, band 11) and Narrow Near Infrared (NIRn, band 8a).

[1] source: https://www.spectralcam.com/2019/02/12/maia-s2-and-sentinel-2-multispectral-images-for-agriculture/)

[2] https://earth.esa.int/web/sentinel/user-guides/sentinel-2-msi/product-types/level-2a (status on 05/02/2019)

[3] https://earth.esa.int/web/sentinel/user-guides/sentinel-2-msi/processing-levels (status on 04/03/2019)

In this band combination, the variety of reflectance between healthy, lush vegetation and sparse, dry vegetation is efficiently distinguished. This band combination is commonly used to define soil humidity and texture[4].

Using pin points placed on the test fields polygons, a pixel-based analysis of the surface reflectance values of the Atmospheric Penetration composition' bands (SWIR 2, SWIR 1, NIRn) was conducted. Detailed examination revealed significant increase in SWIR 1 and SWIR 2 reflectance values after the event of harvest. No significant changes were observed in the reflectance values of the Narrow NIR band. Therefore in the further study only two SWIR bands were used.

3.3. Methods

Consecutive surface reflectance analysis was conducted, this time based, not on single pixels, but on the polygons representing examined test fields.

In the QGIS software a Zonal statistics tool was used for calculating statistical mean of the surface reflectance in both SWIR bands.

created. 60 m spatial resolution bands were omitted due to insufficient spatial resolution.

Figure 4 presents the spectral reflectance curves for a barley field (AJ) located within Test Site 2.

According to the result of in-situ investigation, the examined field was harvested sometime between 22.06 and 05.07.2018.

On the Sentinel-2 image acquired shortly after the harvest (image taken on the 05.07.2018) a significant increase of reflectance in SWIR 1 and SWIR 2 bands was observed. The same pattern was observed for all analysed fields.

Based on the data obtained, three tables were created (Tables 1-3). Each table contains the following information: crop type, statistical mean of BOA reflectance in SWIR bands given for every test field for every Sentinel-2 image, and two columns with approximate period (date) of harvest based on: in-situ data (In-situ a.p.h.) and satellite data (S-2 a.p.h.).

To increase clarity of the data, the observed change of reflectance has been highlighted in colours: green – SR values before harvest, and red – after harvest.

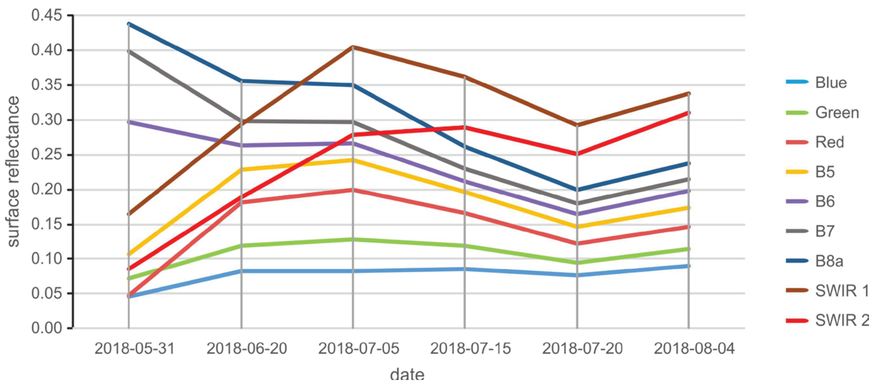


Fig. 4. Surface reflectance in Sentinel-2 spectral bands for barley field

Since it was assumed that after the event of harvest the change of surface reflectance (SR) in at least one of the Sentinel-2 spectral bands will be observed, the SR curves for nine Sentinel-2 spectral bands (all of the 20 m spatial resolution bands plus Red, Green and Blue) for every test field were

Additionally, a Normalized Difference Vegetation Index (NDVI = NIR – R / NIR + R) was derived for every test field and the statistical mean values were calculated. The two parameters: surface reflectance in SWIR bands and the NDVI coefficient, were compared. It was found that there is an inverse relationship between them. It is caused by the fact that the SWIR bands (1610 and 2190 nm) are strongly

[4] https://eos.com/atmospheric-penetration/ (status on 05/02/2019)

Table 1. Mean surface reflectance (integer) in bands SWIR 1 and SWIR 2 for Test Site 1. Values of reflectance factor in SWIR bands for the test fields just before and just after the harvest marked in green and faded red respectively. Abbreviations: a.p.h. – approximate period of harvest; bef. – before; aft. – after, o.sth.p. – only southern part

Crop	Field	S-2 band	Date od S-2 imagery / mean BOA reflectance (integer)						In situ a.p.h.	S-2 a.p.h.
			08/06	28/06	16/07	23/07	26/07	31/07		
Winter rapeseed	D	SWIR 1	1502	1918	2046	3205	3114	3029	aft.19/07	16-23/07
		SWIR 2	802	1145	1666	2439	2713	2833		
Winter rapeseed	E	SWIR 1	1770	2082	3045	3188	2777	3400	at 15/07	28/06-16/07
		SWIR 2	1006	1290	2247	2880	2403	3218		
Winter rapeseed	F	SWIR 1	1688	2050	2101	3157	2755	3053	at 16/07	16-23/07
		SWIR 2	946	1241	1647	2802	2284	2848		
Winter barley	B	SWIR 1	2119	4365	3394	3864	3429	3257	at 26/06	08-28/06
		SWIR 2	1181	2990	3363	3629	3157	2758		
Winter barley	G	SWIR 1	2151	3788	3407	3873	3476	3309	at 20/06	08-28/06
		SWIR 2	1214	2824	3355	3659	3217	2833		
Winter barley	N	SWIR 1	2383	3970	3474	3740	3381	3423	at 20/06	08-28/06
		SWIR 2	1371	2609	3108	3650	3277	3144		
Winter wheat	M	SWIR 1	2301	2794	2804	3719	3531	3318	bef.19/07; 05/07 (o.sth.p.)	16-23/07
		SWIR 2	1401	1887	2360	3200	3069	2690		
Winter wheat	S	SWIR 1	2310	2732	2208	2720	3157	3199	aft. 19/07	23-26/07
		SWIR 2	1539	2010	1864	2362	2793	2736		

affected by water content in the vegetation. Diminishing amount of water gives higher values of reflectance in SWIR bands and lower values of NDVI.

Stand-alone NDVI coefficient, however, was proven to be not suitable for the determination of the approximate date of harvest. Since the crops drying up before harvest, the NDVI value decrease but there is no noticeable difference in NDVI values before and after harvest.

Based on the statistics obtained for crops reflectance in SWIR, the threshold values were set. This step was necessary for the purpose of creating raster layers which could visualise the phenomenon studied.

The QGIS (v.3.4.1-Madeira) with Semi-Automatic Classification Plugin (v.6.2.9-Greenbelt) was used.

Due to the fact that the calculated values were statistical means, the threshold had to be modified in order to avoid underestimation. However, the changes required attentive adjustment to not lead to overestimation. The best result was obtained by subtracting 200 from the mean BOA reflectance values (integer) so the thresholds were set to 2800 for SWIR 1 and 2000 for SWIR 2. Every pixel inside a test field holding value exceeding the threshold would be automatically classified as harvested.

In the Semi-Automatic Classification Plugin (SCP) a Band Calc function was used. New decision role was created: 'B11 > 2800; B12 > 2000'.

Pixels that fulfilled above decision rule where classified as 'harvested' and assigned the value of 1 and the rest of pixels were classified as 'not harvested' and assigned with the value of 0.

Next, the result layers were clipped to the extent of the Test Sites (in QGIS: Raster → Extraction → Clip Raster by Extent) and masked to the test fields boundaries (in QGIS: Raster → Extraction → Clip

Table 2. Mean surface reflectance (integer) in bands SWIR 1 and SWIR 2 for Test Site 2. Values of reflectance factor in SWIR bands for the test fields just before and just after the harvest marked in green and faded red respectively. Red gradient-fill applied to fields partially harvested. Abbreviations: a.p.h. – approximate period of harvest; bef. – before; aft. – after, o.p. – only partially

Crop	Field	S-2 band	Date of S-2 imagery / mean BOA reflectance (integer)						In-situ a.p.h.	S-2 a.p.h.
			31/05	20/06	05/07	15/07	20/07	04/08		
Rape	NR	SWIR 1	1310	1838	3173	3711	2868	3614	at 05/07	20/06-15/07
		SWIR 2	717	1057	2049	2992	2288	3450		
Rape	OR	SWIR 1	1632	2014	2694	3425	2581	2573	05-19/07	05-15/07
		SWIR 2	972	1263	1761	2683	2091	1700		
Rape	PR	SWIR 1	1304	1754	2995	3980	3021	2821	05-19/07	05-15/07
		SWIR 2	693	1026	1941	3173	2594	1973		
Rape	RR	SWIR 1	1219	1633	2773	3605	2749	2979	05-19/07	05-15/07
		SWIR 2	579	867	1725	2875	2203	2756		
Rape	SR	SWIR 1	1616	2056	2879	3502	2752	2841	05-19/07	05-15/07
		SWIR 2	971	1241	1890	2798	2387	2097		
Rape	TR	SWIR 1	1503	2172	2944	3745	3194	3038	at 05/07	05-15/07
		SWIR 2	796	1292	1915	3063	2938	2265		
Barley	AJ	SWIR 1	1647	2935	4047	3629	2929	3376	bef. 05/07	20/06-05/07
		SWIR 2	862	1895	2793	2891	2506	3099		
Barley	BJ	SWIR 1	1725	3073	4107	3695	3083	3422	bef. 05/07	20/06-05/07
		SWIR 2	882	1951	2843	2941	2635	3250		
Barley	CJ	SWIR 1	1796	2582	3934	3390	2951	3380	bef. 05/07	20/06-05/07
		SWIR 2	1045	1688	2720	2689	2361	2577		
Barley	DJ	SWIR 1	1861	2223	2815	2320	2027	3464	aft. 19/07	20/07-04/08
		SWIR 2	1124	1475	1894	1717	1604	2958		
Wheat	EP	SWIR 1	1714	2193	2853	2302	1963	3726	aft. 19/07	20/07-04/08
		SWIR 2	880	1311	1825	1766	1664	3287		
Wheat	FP	SWIR 1	1839	2162	2607	2590	2295	2981	05-19/07 (o.p.)	15/07-04/08 (o.p.)
		SWIR 2	1145	1420	1766	2081	1922	2718		
Wheat	GP	SWIR 1	1787	2389	2940	2449	2045	3522	aft. 19/07	20/07-04/08
		SWIR 2	918	1437	1894	1881	1742	3125		
Wheat	HP	SWIR 1	1780	2223	2723	2429	2213	3596	aft. 19/07	20/07-04/08
		SWIR 2	996	1370	1800	1879	1898	3188		
Wheat	IP	SWIR 1	1847	2456	2869	2278	1950	3379	aft. 19/07	20/07-04/08
		SWIR 2	1054	1611	1948	1771	1668	3183		
Wheat	JP	SWIR 1	1834	2092	2615	2190	1945	3400	aft. 19/07	20/07-04/08
		SWIR 2	1003	1278	1752	1732	1673	2878		
Wheat	KP	SWIR 1	1743	2349	2882	2295	1938	3913	aft. 19/07	20/07-04/08
		SWIR 2	863	1402	1823	1753	1675	3547		
Wheat	LPP	SWIR 1	1950	2402	2799	2915	2640	3669	aft. 19/07	20/07-04/08
		SWIR 2	1089	1472	1778	2194	2183	3390		
Wheat	MPZ	SWIR 1	1777	2149	2740	2291	1989	3505	aft. 19/07	20/07-04/08
		SWIR 2	933	1287	1784	1755	1693	3310		

Table 3. Mean surface reflectance (integer) in bands SWIR 1 and SWIR 2 for Test Site 3. Values of reflectance factor in the SWIR bands for the test fields just before and just after the harvest marked in green and faded red respectively. Abbreviations: a.p.h. – approximate period of harvest; bef. – before; aft. – after

Crop	Field	S-2 band	Date of S-2 imagery / mean BOA reflectance (integer)						In-situ a.p.h.	S-2 a.p.h.
			07/06	20/06	07/07	15/07	20/07	01/08		
Rapeseed	7R	SWIR 1	1325	1940	2787	3213	2632	3614	05-19/07	07-15/07
		SWIR 2	732	1150	1867	2547	2222	3083		
Rapeseed	8R	SWIR 1	1156	1741	3885	2807	2823	4041	05-19/07	07-15/07
		SWIR 2	564	963	3478	2280	2445	3708		
Rapeseed	9R	SWIR 1	1300	2646	2889	3457	2998	3533	05-19/07	07-15/07
		SWIR 2	708	1982	1895	2646	2240	3193		
Rapeseed	10R	SWIR 1	1549	2358	3109	3652	3597	3531	05-19/07	07-15/07
		SWIR 2	958	1503	2087	2745	2793	3092		
Rapeseed	11R	SWIR 1	1258	1596	2689	3176	2909	3128	05-19/07	07-15/07
		SWIR 2	640	897	1701	2358	1991	2495		
Rapeseed	12R	SWIR 1	1168	1443	2606	3421	2937	3449	05-19/07	07-15/07
		SWIR 2	601	813	1699	2680	2669	2821		
Barley	1J	SWIR 1	2042	2240	2455	1928	1758	3244	07-19 to 07-31	20/07-01/08
		SWIR 2	1124	1282	1609	1501	1492	3016		
Barley	2J	SWIR 1	1452	1832	2406	2053	2234	3734	07-19 to 07-31	20/07-01/08
		SWIR 2	795	1080	1535	1542	1822	2785		
Wheat	3P	SWIR 1	1790	2074	2727	2132	2015	3304	07-19 to 07-31	20/07-01/08
		SWIR 2	955	1252	1782	1533	1602	2868		
Wheat	4P	SWIR 1	1786	2142	2637	1979	2194	3966	07-19 to 07-31	20/07-01/08
		SWIR 2	1163	1472	1882	1433	1745	2910		
Wheat	5P	SWIR 1	2050	2366	2676	2016	1885	3256	07-19 to 07-31	20/07-01/08
		SWIR 2	1359	1605	1953	1494	1460	2560		
Winter wheat	6PO	SWIR 1	1634	2563	2654	2143	2122	4071	07-19 to 07-31	20/07-01/08
		SWIR 2	837	1787	1721	1607	1733	3386		

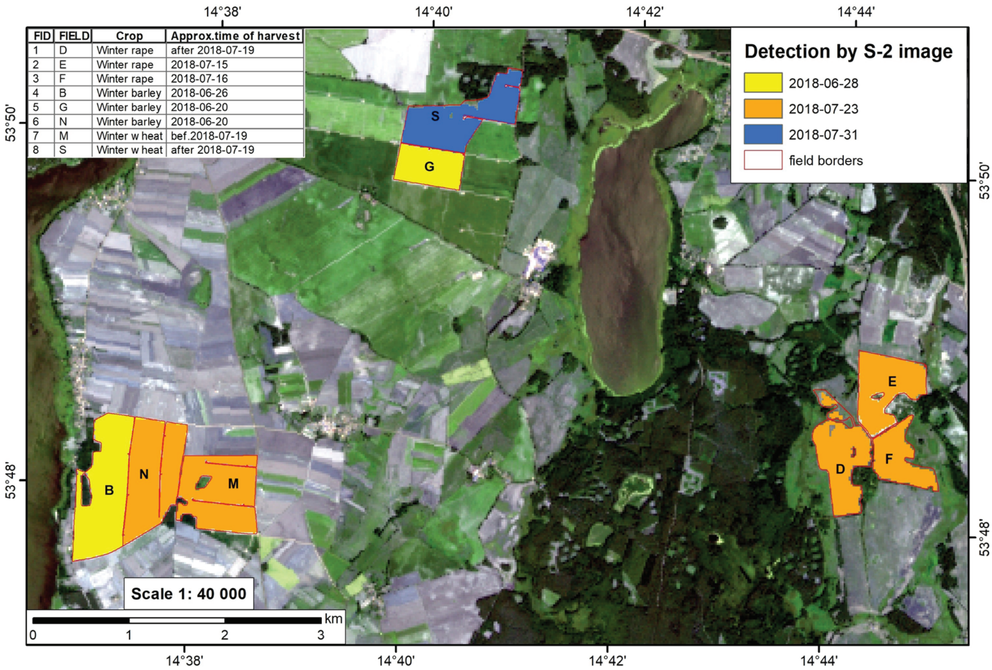
Raster by Mask Layer). In order to smooth the output, the sieving operation was conducted (SCP → Postprocessing → Classification sieve).

4. Results

As a result, three maps, showing the approximate date of harvest within the three analysed Test Sites, were created (Fig. 5–7). Colours indicate the satellite-derived approximate date of harvest.

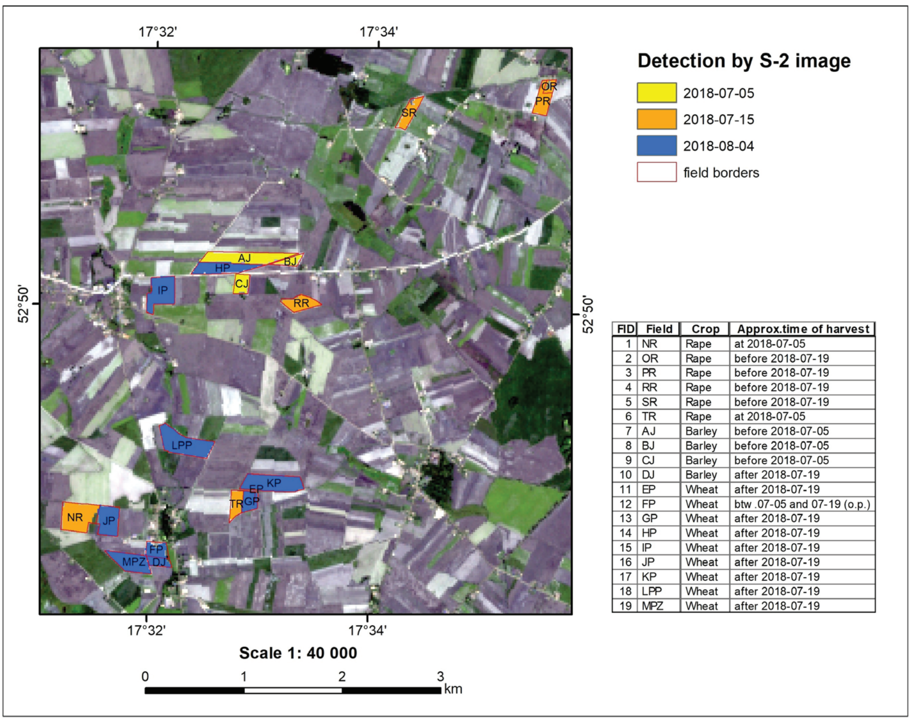
5. In-depth analysis

Three winter rape fields (D, E, and F) were chosen for performing in-depth analysis. The relationship between surface reflectance in SWIR bands and the NDVI coefficient is presented on the chart below (Fig. 8). It can be noted that during analysed period reflectance values have been increasing whereas NDVI had a downward trend. Reaching the surface reflectance values above 0.30 (in SWIR 1) and



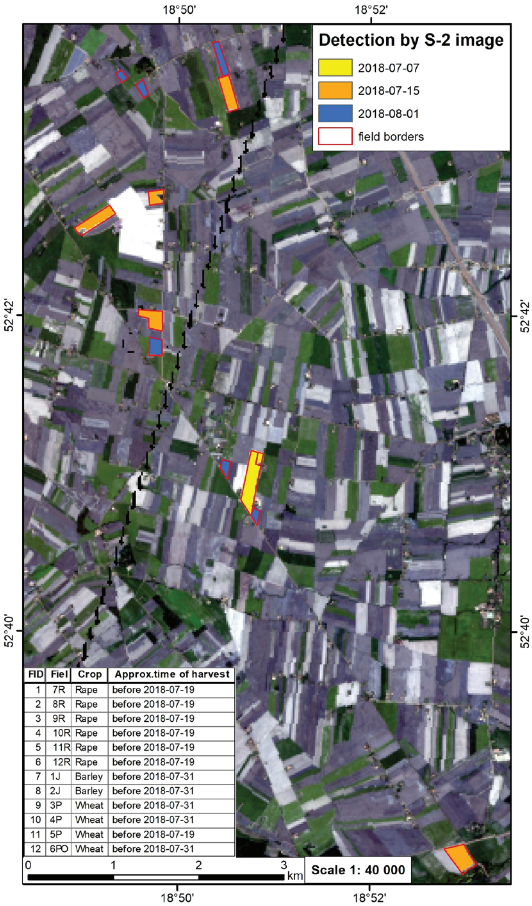
FID	FIELD	Crop	Approx.time of harvest
1	D	Winter rape	after 2018-07-19
2	E	Winter rape	2018-07-15
3	F	Winter rape	2018-07-16
4	B	Winter barley	2018-06-26
5	G	Winter barley	2018-06-20
6	N	Winter barley	2018-06-20
7	M	Winter w heat	bef.2018-07-19
8	S	Winter w heat	after 2018-07-19

Fig. 5. The approximate date of harvest derived from Sentinel-2 imageries. Test Site 1



FID	Field	Crop	Approx.time of harvest
1	NR	Rape	at 2018-07-05
2	OR	Rape	before 2018-07-19
3	PR	Rape	before 2018-07-19
4	RR	Rape	before 2018-07-19
5	SR	Rape	before 2018-07-19
6	TR	Rape	at 2018-07-05
7	AJ	Barley	before 2018-07-05
8	BJ	Barley	before 2018-07-05
9	CJ	Barley	before 2018-07-05
10	DJ	Barley	after 2018-07-19
11	EP	Wheat	after 2018-07-19
12	FP	Wheat	btw .07-05 and 07-19 (o.p.)
13	GP	Wheat	after 2018-07-19
14	HP	Wheat	after 2018-07-19
15	IP	Wheat	after 2018-07-19
16	JP	Wheat	after 2018-07-19
17	KP	Wheat	after 2018-07-19
18	LPP	Wheat	after 2018-07-19
19	MPZ	Wheat	after 2018-07-19

Fig. 6. The approximate date of harvest derived from Sentinel-2 imageries. Test Site 2. Abbreviations: btw – between, o.p. – only partially



FID	Fiel	Crop	Approx.time of harvest
1	7R	Rape	before 2018-07-19
2	8R	Rape	before 2018-07-19
3	9R	Rape	before 2018-07-19
4	10R	Rape	before 2018-07-19
5	11R	Rape	before 2018-07-19
6	12R	Rape	before 2018-07-19
7	1J	Barley	before 2018-07-31
8	2J	Barley	before 2018-07-31
9	3P	Wheat	before 2018-07-31
10	4P	Wheat	before 2018-07-31
11	5P	Wheat	before 2018-07-19
12	6PO	Wheat	before 2018-07-31

Fig. 7. The approximate date of harvest derived from Sentinel-2 imageries. Test Site 3

0.22 (in SWIR 2) indicates harvest. After the harvest, reflectance values remain at similar level while NDVI continues to fall.

This example also reveals the divergence of the reflectance in SWIR bands for crops harvested at a different time. The compiled fields: E, F, and D were harvested on 15 July, 16 July, and 19 July, respectively. It can be noted that in the case of field E the threshold values for harvested fields (SR in float values: SWIR 1 > 0.30 and SWIR 2 > 0.22) was reached on 16 July (which is the day after harvest), whereas for fields D and F, on the next available image, that is on 23 July. It is assumed that the Sentinel-2 satellite flew over Test Site 1 while field F was being harvested and for this reason, there is no sign of harvest detection for this field on the 2018-07-16 image.

For visualisation of the findings, the same winter rapeseed fields were presented on the time series mosaic in RGB, SWIR and NDVI images (Fig. 9). Images from the first date (28 June) shows the analysed fields before harvest while on the last date (31 July), after harvest. In the case of field E, the moment of harvest can be already noticed on the 16 July images. On the RGB image, field E is whiter than the other two, while on the SWIR image it takes on a yellowish colour. The NDVI image shows no clear distinction between the neighbouring fields. The RGB image from the next date, 23 July, presents all fields in uniformed shades. On the SWIR composite, field D, harvested on the 19 July looks yellowish while fields E and F, harvested earlier, become faded. The NDVI image presents a progressing decrease in the coefficient value. The last RGB and SWIR images presents all fields in uniformly bright shades while NDVI takes on very low values. This illustrates dry conditions which characterise the fields at this time.

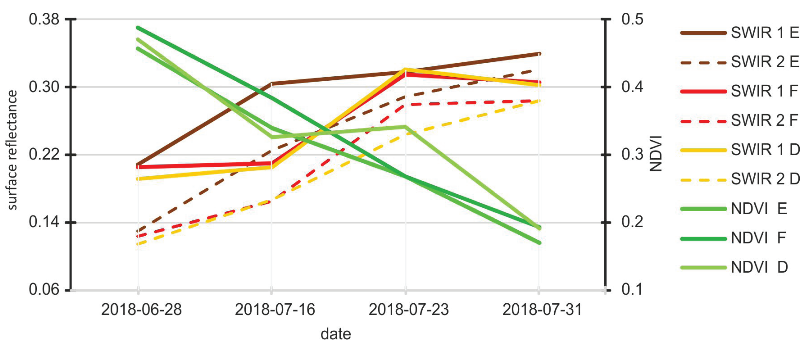


Fig. 8. The relationship between surface reflectance in SWIR bands and the NDVI coefficient

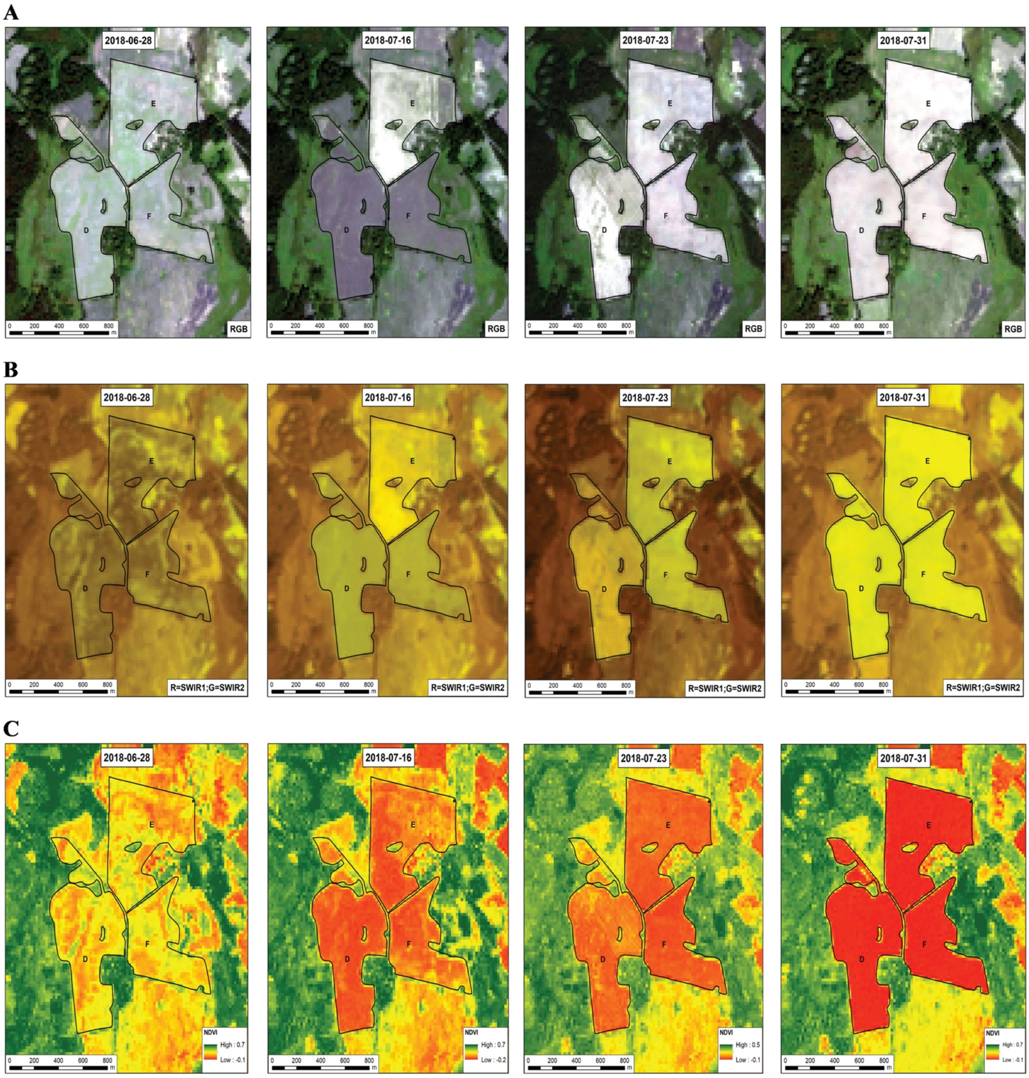


Fig. 9. Analysed rapeseed fields: D, E and F presented on colour maps. A – RGB; B – reflectance in SWIR (R=SWIR 1; G=SWIR 2); C – NDVI (colour palette red to green)

6. Discussion

The review of scientific papers has not delivered the ultimate answer to the question why the reflection of crops after harvest in short-wave infrared (SWIR) part of spectrum is growing significantly. As it was mentioned, not enough attention was given to studies on SWIR applicability for plants characteristic. The simplest explanation would be that the change in SWIR reflectance is caused by change of water content in crops, due to their cut and partial removal. The other explanation considered is the sudden change of crops biomass and texture which is being registered by satellite. Further researches are needed to answer this question more accurately.

As it was also indicated, the proposed pilot study aimed at assessing the applicability of Sentinel-2 satellite data for approximate harvest date detection. Since the pilot study is considered to be successful and the results are satisfactory, it is expected that this approach would be further investigated and in the future it would become operational. In order to automatize the proposed method, the thresholds of spectral reflectance in SWIR must be indicated. Within the study, slight differences in the reflectance values for every crop variety were revealed. In the case of rapeseed fields the SWIR SR threshold, indicating the harvest, was the lowest SR (3000 in SWIR 1 and 2200 in SWIR 2), and for wheat the highest SR (3100 in SWIR 1 and 2500 in SWIR 2). It is necessary to validate the above proposed thresholds with a robust amount of data of high accuracy, preferably acquired from insurance company. Moreover, in order to achieve operability of this method, there is a need for analysis for other crops of high importance for insurance companies in Poland.

7. Conclusions

The presented research proves the applicability of Sentinel-2 satellite data for detecting the approximate date of harvest of the following crops: wheat, barley and rapeseed along with their winter varieties. The possibility to use SWIR bands with high repetition provides a tool for the recognition of the date of harvest.

There are two drawbacks resulting from application of optical data: issues with obtaining cloudless images – insufficient frequency of images, which impact the estimated length of the period in which harvest was performed (the approximate period of harvest) as well as the spatial resolution of SWIR bands (20 m) which limits the number of fields which can be investigated with this method (over 100 m in width wherein 70 m is acceptable).

It shall be underlined that in order to prove repeatability of obtained results and to obtain a fully operable method, more in situ data should be collected and this study should be carried on over a longer time period. Additionally, it is recommended that optical images will be used in conjunction with radar imagery as they contain complementary information. Moreover, the synergic use of optical data with radar data is considered to be feasible for this purpose.

Finally, the proposed method has a high potential for use by insurance companies for investigating the date of crops harvest at the level of the individual field as well as for institutions supervising agriculture production for assessing the area of crops harvested at a regional and national level.

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Badanie pilotażowe prezentujące możliwości określenia przybliżonej daty zbiorów na podstawie zdjęć satelitarnych Sentinel-2

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Streszczenie: W artykule zaprezentowano badanie pilotażowe, którego celem było określenie, czy dane optyczne Sentinel-2 mogą być zastosowane do określenia przybliżonej daty zbiorów upraw. Przedstawiono zgromadzone dane in-situ oraz analizę współczynnika odbiciowości roślin w wybranych pasmach spektralnych w okresie przed i po zbiorach. Stwierdzono zależność między współczynnikiem odbiciowości w pasmach podczerwieni krótkofalowej (SWIR) a statusem upraw. Wyniki omówiono. Wskazano na potrzebę przeprowadzenia poszerzonych badań w omawianym zakresie.

Słowa kluczowe: żniwa, SWIR, NDVI, Sentinel-2, rolnictwo precyzyjne, ubezpieczenie, poplon