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CARTOGRAPHIC EDITING OF AGRICULTURAL CROPS FROM THE SATMIROL PROGRAM ON CADASTRAL PLOTS AS AGRICULTURAL PARCELS

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A b s t r a c t

The study was aimed at comparing the land cover classified on the basis of satellite imagery with data from soil and agricultural maps and state registers. The analysis covered the areas of the Panki commune in the Kłobuck county (Silesian voivodeship). The data collected included satellite land cover classification (obtained from the Central Statistical Office by the Space Research Centre), information on declared crops from area applications (Silesian Regional Branch of the Agency for Restructuring and Modernisation of Agriculture), and soil and agricultural data compiled from soil maps and land registers.
The main task was to harmonise these data to a common coordinate and altitude system. A vectorisation of the crop maps was carried out, making it possible to assign specific crops to agricultural parcels. This was followed by a natural and economic assessment of the crops in the given soil-agricultural complex and an analysis of crop succession in the fields.
On the basis of the processed data, a comparison was made between the satellite land cover classification and data from soil-agricultural maps and state registers. The aim of the analysis was to investigate the correspondence between the different data sources and to assess the suitability of satellite imagery in relation to traditional methods of agricultural land classification. The results made it possible to assess the potential discrepancies and advantages of different land registration and classification systems.

Keywords: satellite imagery, land cover classification, SATMIROL, crop assessment, data harmonization

1. INTRODUCTION

The planet's population growth, economic development and increasing urbanisation are driving a continuous increase in demand for agricultural products. Increased demand can be met by improving agricultural productivity and increasing food production. In order to promote global food security,

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agricultural production statistics and crop classification are essential. This will allow the development of consistent and efficient agricultural policies on a nationwide basis. Access to accurate and timely crop information can also help farmers. They can obtain up-to-date information on crop growth, and estimate yields [12].

Satellite imagery can be used to provide accurate and nationwide agricultural statistics. In recent years, there has been a dynamic development of satellite imaging techniques. This development has resulted in programmes offering free access to up-to-date satellite data recorded at high frequency. In addition to current data, archive data is also stored, which is a valuable source of information. Using available satellite data and new digital technologies, it is possible to solve the problems faced by agricultural statistics. The implementation of new technologies makes it possible to obtain statistical data more cheaply and quickly, as well as to georeference them, i.e. to assign individual crops to cultivation plots [3][7][8][9][10].

In Poland, agricultural statistics are the responsibility of the Central Statistical Office, which has undertaken cooperation with scientific research institutions in the field of obtaining nationwide agricultural data. The result of this cooperation was the scientific-research project “SATMIROL - Satellite-based crop identification and monitoring for agricultural statistics”, which was carried out with the Institute of Geodesy and Cartography and the Space Research Centre of the Polish Academy of Sciences. The task of the project was to develop and implement an innovative system for the identification and monitoring of agricultural crops, using satellite data. This was to lead to the modernisation of the system for obtaining statistical data on agriculture in Poland. The result of the conducted project was to obtain the crop classification of Poland for the years 2019, 2020 and 2021. The data resulting from this project was used in this article [11][16].

The article discusses the cartographic editing of agricultural crops based on SATMIROL data, focusing on the assignment of these data to cadastral parcels (Land and Building Register (LABR) and land parcels). It analyses the accuracy of the satellite data and the possibilities of extending the results to include comparisons with cadastral data and land registers.

2. SATMIROL SYSTEM

The SATMIROL system was developed as a tool to identify and monitor agricultural crops in Poland for agricultural statistics. Based on data from Sentinel-1 radar and Sentinel-2 optical satellites, it enables automatic image retrieval, classification and monitoring of crop condition. The SATMIROL system uses advanced machine learning algorithms and polarimetric processing of the data, which enables accurate differentiation between different types of crops [11].

The project formulated seven basic objectives:

1. To develop the concept of a satellite system for crop recognition and monitoring for agricultural statistics, to define its structure and to develop system, methodological and functional solutions;
2. To develop a method of using satellite data to identify crops in Poland;
3. Development of a system for assessing the condition of crops and monitoring emergency situations;
4. Field verification (in situ) of satellite data;
5. Construction of procedures for implementation of algorithms for the area of crop recognition;
6. Construction of procedures for the implementation of algorithms for the area of crop condition assessment and crisis monitoring;
7. Implementation and commissioning of the system for identification and monitoring of agricultural crops [11].

The system was based on the Statistical Production Process Model. It is a process approach comprising 8 phases:

1. needs specification;
2. design;
3. construction;
4. data collection;
5. processing;
6. analysis;
7. sharing;
8. evaluation [4].

The model is based on the Generic Satatistical Business Process Model (GSBPM). The GSBPM is a model developed in New Zealand by the United Nations Economic Commission for Europe (UNECE), is a model used for economic surveys and serves as a tool for describing statistical surveys in the context of particular processes leading to expected results. It is regarded as a universal industry standard and is used by statistical institutions in more than 80 countries. The model is complemented by processes including geospatial, verification and quality assessment, and planning segments. The models have a process approach and cover the entire activities of the organisation [1][14].

SATMIROL is divided into 4 modules:

1. retrieval and pre-processing - tools for automatic retrieval of Sentinel-1 radar and Sentinel-2 optical imagery and subsequent processing (including multi-temporal polarimetric processing of dual-polarisation imagery) [5][6];
2. crop segmentation and classification - tools for automatic imagery segmentation and classification, including a machine learning component and output validation;
3. automatic assessment of crop growth and condition conditions and monitoring of crisis situations;
4. reporting and compilation of agricultural statistics for municipalities, districts and provinces [11].

Crop recognition and area estimation consists of modules 1, 2 and 4. Module 3 is responsible for providing plant condition data.

3. RESEARCH AREA

The commune of Panki is located in the north-western part of the Silesian Province (Fig. 1). It is located 30 km north-west of Częstochowa and 14 km south-west of Kłobuck. According to the LABR for 2021, 22 types of land use were distinguished in the Panki commune. Agricultural land occupied the largest area, accounting for 46.57% of the total area of the commune, followed by forests with a share of 34.15% of the commune's area. The third land use was permanent pastures with a share of 7.85% of the total area of the Panki commune. The total agricultural land occupies almost 60% of the commune's area [13] [15].

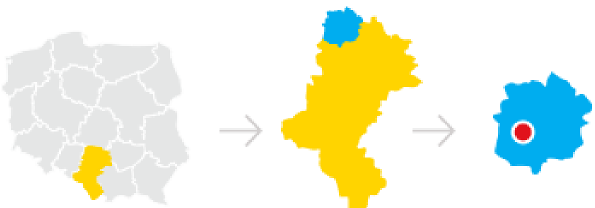

Fig. 1. Location of Panki municipality [15]

4. METHODOLOGY

The research involved assigning crops to the boundaries of cultivation plots from the LABR. The process was based on analysing the course of the pixels marking a given classified crop with the boundary of the cultivation plots, and then assigning them to the corresponding plot. In some cases, this required the division of one plot into several parts. For plots oriented north-south or east-west, the raster marking of the classified crops fitted relatively well with the boundaries of these plots (Fig. 2), whereas for plots oriented in other directions, the pixels marking the crop in question deviated from their boundaries (Fig. 3).

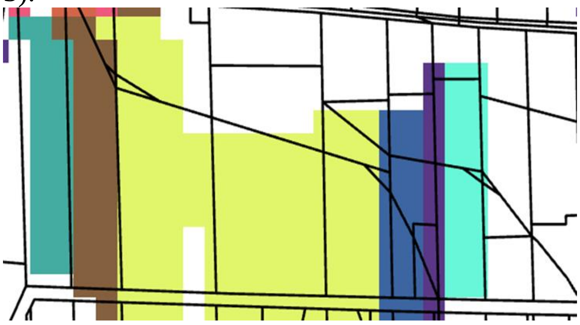

Fig. 2. Classified crops for plots oriented north-south (scale 1:2500)

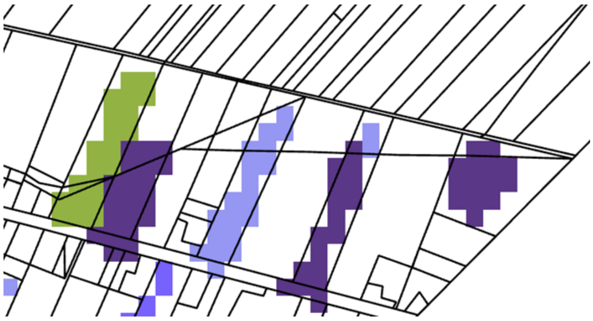

Fig. 3. Classified crops for plots oriented in other directions (scale 1:5000)

In addition, some cultivation plots did not have crops on the entire plot or more than one crop was planted on the plot. This required an additional adjustment of the cultivation plots. An example of such a case and the division of the plot is shown in Figures 4 and Figures 5 (red colour indicates the boundaries of the plot division, according to the course of the cultivated crop). It also happened that pixels with a classified crop were located in non-agricultural areas, such as a road or a river.

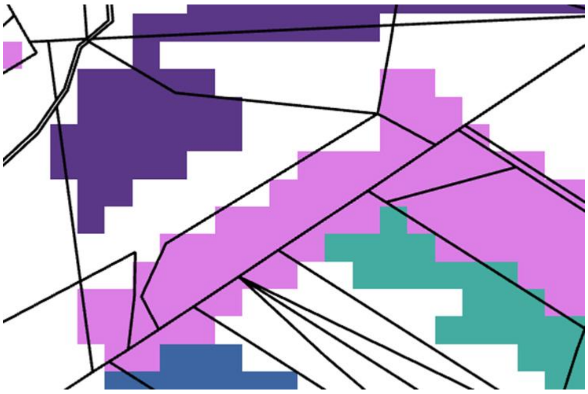

Fig. 4. Example of plots that are not fully cultivated (scale 1:2500)

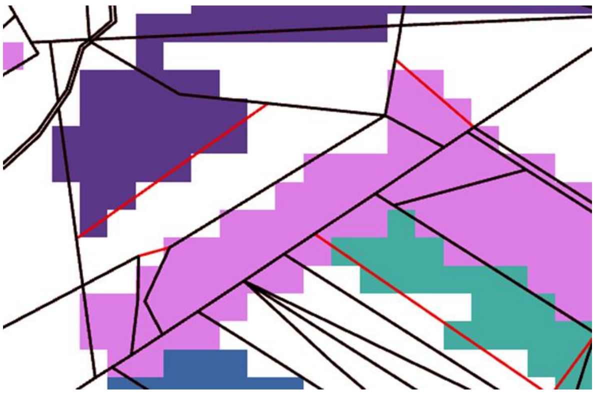

Fig. 5. Example of subdivision of plots not fully cultivated (scale 1:2500)

Due to the problems outlined above, it was considered that the classified crops should be assigned to the attribute table of the individual crop parcels. This will result in a more accurate sown area of the respective crop. The soil and agricultural vector layer was updated in this way. The cultivation parcel layer thus updated with the assigned crops had to be compared with the data in the input format. This resulted in two vector layers of crop maps for 2019 and 2020 with their original geometry preserved, which contained the combined polygons for each classified crop with their area. The areas of crops assigned to the plots were then compared with those in the input format for both years. It was checked whether the crop areas assigned to the plots differed significantly from those in the source format. At this stage, the data in the attribute table of the vector layer was also compared with the crops assigned to the parcels. The land use data in 2021 according to the LABR and the crop data in both years were compared. This checked whether crops were detected and classified on non-agricultural land and what area of agricultural land has no classified crop. It was also determined what land use according to the LABR was designated as unclassified land.

The next step was to compare the classified crops with the soil conditions. The classified crops were evaluated from an economic and natural point of view. For the purposes of this analysis, the entire area of the municipality of Panki was treated as an agricultural area of arable land cultivation. On the basis of the soil profile, the complex of agricultural suitability of arable land was determined in areas for which it was not defined on the soil-agricultural maps.
A crop assessment based on soil conditions was carried out for crops assigned to the plots. They divided unclassified areas into land uses according to the LABR. Unclassified areas on arable land were defined as satellite-detected crops on agricultural land.

The next step was to assess the rotation of crop species. The classified crops were assessed in terms of their succession in the field. Crops assigned to plots were assessed. Based on the layer containing the crops assigned to the plots, a new layer with crops in both years was extracted. In the attribute table of the newly created layer, a column for the crop succession assessment was added. Then, taking into account the characteristics of each crop, as well as the rotation criteria, the crop succession was assessed.

The data obtained on the satellite classified crops was compared with the data collected by the Agency for the Restructuring and Modernisation of Agriculture. At this stage, the area of a given crop and its percentage in relation to the total was collated. The data from the state register was compared with both the crops assigned to the cultivation plots and those in the input format. The data for 2019 and 2020 were compared.

5. RESULTS

The results prepared in the form of tables made it possible to characterise the correctness of the land classification on the basis of satellite imagery, as well as to compare this usage with data from state records.

Crop designations in the tables:
0 - unclassified land (includes unclassified land on agricultural land, built-up land, railway land, roads, forest and shrub land and surface water);
1 - winter wheat;
2 - potatoes;
3 - maize;
4 - grass and grassland;
5 - winter barley;
6 - spring rape;
7 - winter rape;
8 - sugar beet;
9 - fruit tree plantations;
10 - strawberry;
11 - spring wheat;
12 - winter triticale;

13 - spring barley;
14 - fruit bush plantations;
15 - herbs and spices;
16 - buckwheat;
17 - oats;
18 - winter rye;
19 - legumes;
20 - mustard;
21 - spring triticale;
22 - millet;
23 – vegetables [16].

Marking of ratings in terms of economics and nature in the tables (Tables 3-6):
3 - there are no restrictions to growing this crop on the soils of the complex;
2 - there are some, generally minor, restrictions;
1 - there are major restrictions;
'-' - the plant is not suitable for cultivation on the given complex [17].

Determination of ratings of crop consequences (Table 15)
3 - means favourable condition, which allows the potential of the habitat and crop species to be realised;
2 - denotes an acceptable condition, but with habitat and economic reservations;
1 - denotes a poor condition, an abnormal succession [17].

The first dataset that was produced was the areas of classified crops for both years. Two tables were created (Tables 1 and 2) showing a comparison of crop area and percentage for 2019 and 2020 for crops assigned to cultivation plots and crops in input (raster satellite) format.

Table 1. Comparison of area and percentage of cultivation between data assigned to cultivation plots and data in input format for 2019

Cultivation	Crop area based on input format		Cultivation area allocated to cultivation parcels		Difference	
	Area [ha]	Percentage of municipal area	Area [ha]	Percentage of municipal area	Area [ha]	Percentage change
0	3586,3894	65,35	3590,1184	65,26	3,7290	0,10
1	172,8935	3,14	174,2413	3,17	1,3478	0,78
2	4,0503	0,06	4,0036	0,07	-0,0467	-1,15
3	8,4362	0,14	8,0196	0,15	-0,4166	-4,94
4	296,7961	5,40	290,2113	5,27	-6,5849	-2,22
5	13,7123	0,24	13,3268	0,24	-0,3854	-2,81
6	10,3103	0,18	10,5979	0,19	0,2876	2,79
7	11,9900	0,21	11,9089	0,22	-0,0811	-0,68
9	47,0175	0,85	45,8644	0,83	-1,1531	-2,45
10	15,0937	0,26	16,0276	0,29	0,9339	6,19
11	95,5895	1,73	100,7750	1,83	5,1854	5,42
12	153,2566	2,78	153,4625	2,79	0,2058	0,13

13	241,9956	4,40	238,0173		4,33	-3,9783	-1,64
14	189,4783	3,44	186,0630		3,38	-3,4153	-1,80
15	21,9083	0,39	22,0569		0,40	0,1485	0,68
16	118,7848	2,15	115,5599		2,10	-3,2249	-2,71
17	181,3861	3,29	186,7305		3,39	5,3444	2,95
18	202,0938	3,67	202,3579		3,68	0,2640	0,13
19	12,1026	0,21	12,2979		0,22	0,1953	1,61
20	26,2074	0,47	25,7311		0,47	-0,4763	-1,82
21	83,3380	1,51	85,2505		1,55	1,9125	2,29
22	1,0942	0,01	0,9919		0,02	-0,1024	-9,35
23	7,7212	0,13	8,0321		0,15	0,3108	4,03
Total	5501,6461	100	**Total**	5501,6461	100		

Table 2. Comparison of area and percentage of cultivation between data assigned to cultivation plots and data in input format for 2020

Cultivation	Crop area based on input format		Cultivation area allocated to cultivation parcels			Difference	
	Area [ha]	Percentage of municipal area	Area [ha]		Percentage of municipal area	Area [ha]	Percen-tage change
0	3598,1067	65,56	3533,3031		64,27	-64,8037	-1,80
1	82,0328	1,48	82,0878		1,49	0,0550	0,07
2	6,6221	0,11	6,2673		0,11	-0,3548	-5,36
3	13,9480	0,24	13,6216		0,24	-0,3263	-2,34
4	364,6382	6,63	385,0081		7,01	20,3699	5,59
5	21,9740	0,39	22,3998		0,40	0,4258	1,94
6	4,0331	0,06	3,6593		0,06	-0,3738	-9,27
7	28,1564	0,50	27,8465		0,50	-0,3099	-1,10
9	29,0997	0,52	35,6030		0,64	6,5034	22,35
10	22,2913	0,39	24,2588		0,43	1,9676	8,83
11	90,0349	1,63	95,9975		1,74	5,9626	6,62
12	288,4949	5,25	290,1466		5,28	1,6517	0,57
13	103,8892	1,88	103,9115		1,89	0,0223	0,02
14	82,2539	1,49	95,0848		1,73	12,8310	15,60
15	12,9014	0,22	14,0775		0,25	1,1761	9,12
16	126,1024	2,29	128,5552		2,34	2,4528	1,95
17	168,7458	3,06	172,8706		3,14	4,1248	2,44
18	285,1223	5,18	290,1117		5,28	4,9894	1,75
19	23,2575	0,41	23,5093		0,42	0,2518	1,08
20	53,8330	0,97	57,6156		1,04	3,7826	7,03
21	96,1085	1,74	95,7104		1,74	-0,3981	-0,41
Total	5501,6461	100	**Total**	5501,6461	100		

Tables 1 and 2 show the characteristics of the first stage of input processing. This stage consisted of manually assigning classified crops to cultivation plots. As a result of this exercise, crop plots for 2019 changed by an average of 1.6364 ha and the area of unclassified land increased by 3.7290 ha. For 2020, cultivated areas changed by an average of 3.4165 ha and unclassified land area decreased by 64.8037 ha. The average percentage change in the area of classified cropland for 2019 was 2.66% and for 2020 was 5.17%. The areas of unclassified land for both years are similar. The change in the area of crops is due to the fact that the spatial extent of crops in the original format is not consistent with the actual state. Closer to this state is the attribution of crops to the cultivation plots on which farmers grow crops. Due to this factor, it was decided to assign crops to plots. In this study, crop data assigned to plots were used for spatial analyses.

In the next stages of the work, the satellite-classified land cover was compared with the land use as defined by the LABR (Fig. 6.). In 2019 among the arable land, 63.12% of the area was classified as cultivated land. This means that over ⅓ of the arable land was unclassified. For grasslands such as meadows and permanent pastures, as well as orchards, around 50% of the area was classified. For non-agricultural areas, the vast majority, over 99%, were correctly designated as unclassified land. In 2020 about ⅓ of the arable land area is unclassified. Meadows and permanent pastures and orchards oscillate within half of the classified and unclassified land. For non-agricultural land use, more than 99% of the area was identified as unclassified land. The 2020 figures for the percentage of classified land are very similar to those of 2019.

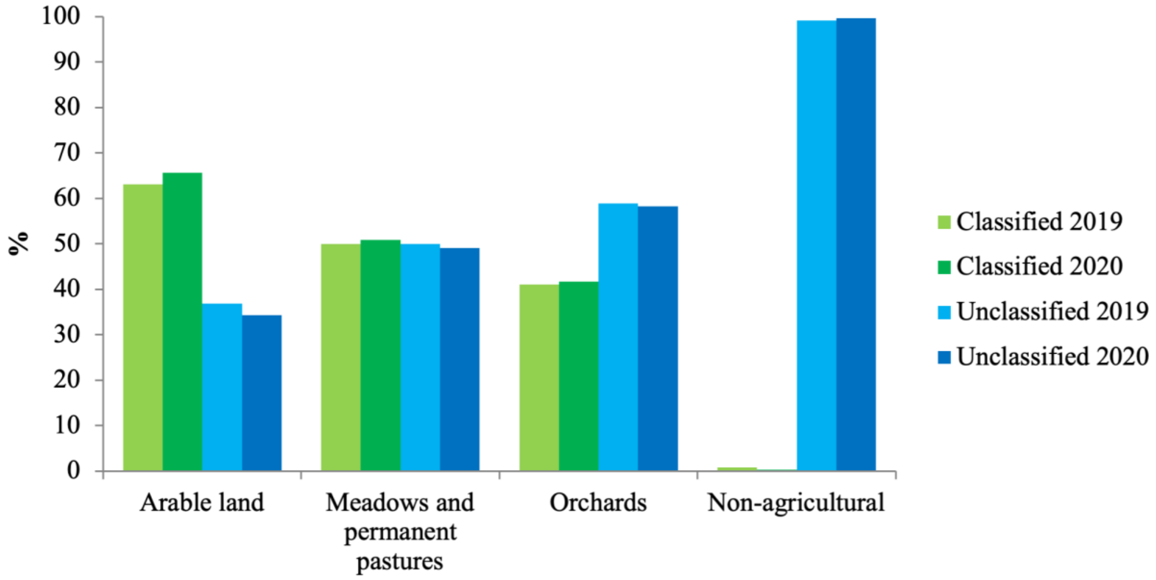

Fig. 6. Comparison of land use by LABR with classified crops for 2019 and 2020

Figure 7 provides more detailed information on unclassified land in 2019 and 2020. In 2019 over half of the unclassified land is woodland. Unclassified arable land accounts for more than ¼ of such land and about 7% is built-up land and permanent grassland and pasture. In 2020 the satellite unclassified land use pattern is very similar to that of the previous year.

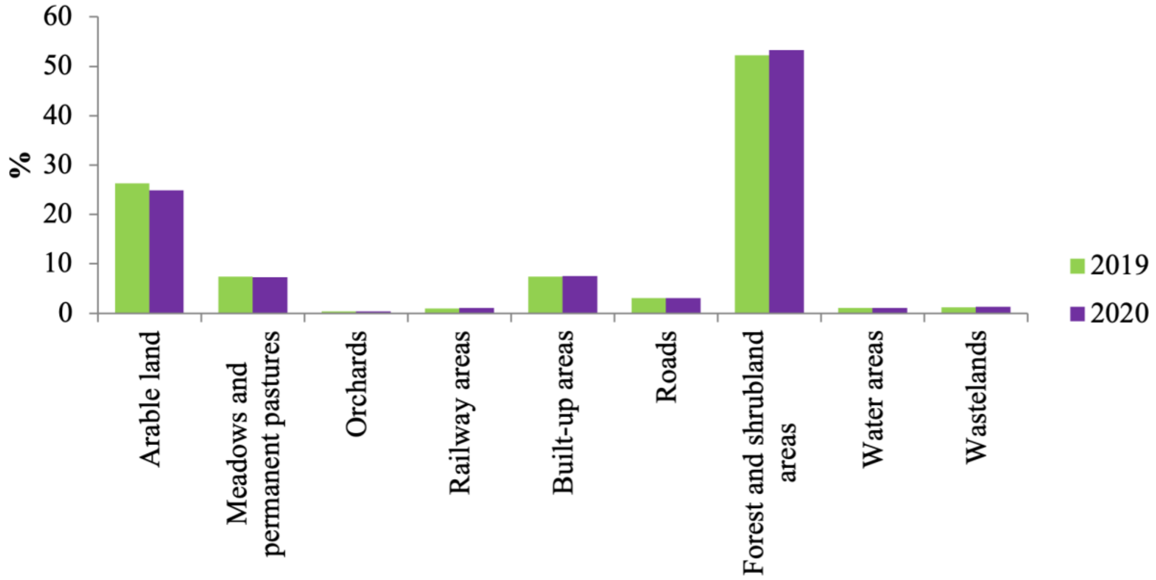

Fig. 7. Land use types according to the LABR designated as unclassified land for 2019 and 2020

Tables 3 to 6 present information on the natural and economic assessments for individual crops on the given agricultural suitability complexes. Information on the structure of these assessments is also included, as well as a comparison of them to the area of the municipality and arable land.

Table 3 shows the natural assessments of each crop and Table 4 shows the economic assessments. For 2019, 16 classified crops were assessed, 2 classified land cover types are not assessed, 1 crop is not present and 5 crops were not assessed due to lack of criteria. The area of the assessed crops covers 1343.2726 ha.

Table 3. Nature assessment of classified crops for 2019

Cultivation	3		2		1		-	
	Area [ha]	Percentage of the area of the crop concerned	Area [ha]	Percentage of the area of the crop concerned	Area [ha]	Percentage of the area of the crop concerned	Area [ha]	Percentage of the area of the crop concerned
0	Unclassified areas are not subject to assessment							
1	3,9254	2,25	104,1402	59,77	6,0114	3,45	60,1643	34,53
2	0,0000	0,00	3,3031	82,50	0,7005	17,50	0,0000	0,00
3	0,0000	0,00	4,6976	58,58	2,8756	35,86	0,4465	5,57
4	Grasses and grasslands are not assessed							
5	0,0000	0,00	0,0000	0,00	0,0000	0,00	13,3268	100
6	0,0000	0,00	0,0000	0,00	0,0000	0,00	10,5979	100
7	0,0000	0,00	0,0000	0,00	0,0000	0,00	11,9089	100
8	Sugar beet has not been graded in the municipality in 2019							
9	Fruit tree plantations have not been assessed							
10	Strawberries have not been graded							
11	1,1965	1,19	52,9213	52,51	4,1310	4,10	42,5262	42,20
12	13,1472	8,57	140,3153	91,43	0,0000	0,00	0,0000	0,00
13	13,4824	5,66	11,1699	4,69	0,0000	0,00	213,3650	89,64
14	Fruit bush plantations have not been assessed							
15	Herbs and spices have not been assessed							
16	8,1796	7,08	42,1186	36,45	28,2441	24,44	37,0176	32,03
17	90,6343	48,54	63,1111	33,80	0,0000	0,00	32,9851	17,66
18	14,0479	6,94	171,8921	84,94	0,0000	0,00	16,4179	8,11
19	0,2769	2,25	10,6062	86,24	1,4148	11,50	0,0000	0,00
20	0,0000	0,00	1,2539	4,87	0,0000	0,00	24,4772	95,13
21	4,9836	5,85	80,2669	94,15	0,0000	0,00	0,0000	0,00
22	0,3647	36,76	0,0000	0,00	0,1414	14,25	0,4859	48,98
23	Vegetables have not been assessed							

Table 4. Economic evaluation of classified crops for 2019

Cultivation	3		2		1		-	
	Area [ha]	Percentage of the area of the crop concerned	Area [ha]	Percentage of the area of the crop concerned	Area [ha]	Percentage of the area of the crop concerned	Area [ha]	Percentage of the area of the crop concerned
0	Unclassified areas are not subject to assessment							
1	6,4896	3,72	101,5760	58,30	6,0114	3,45	60,1643	34,53
2	0,8452	21,11	2,4579	61,39	0,7005	17,50	0,0000	0,00
3	0,1044	1,30	0,0000	0,00	7,4687	93,13	0,4465	5,57
4	Grasses and grasslands are not assessed							
5	0,0000	0,00	0,0000	0,00	0,0000	0,00	13,3268	100
6	0,0000	0,00	0,0000	0,00	0,0000	0,00	10,5979	100
7	0,0000	0,00	0,0000	0,00	0,0000	0,00	11,9089	100
8	Sugar beet has not been graded in the municipality in 2019							
9	Fruit tree plantations have not been assessed							
10	Strawberries have not been graded							
11	1,2745	1,26	52,8433	52,44	4,1310	4,10	42,5262	42,20
12	83,3833	54,33	67,6830	44,10	0,0000	0,00	2,3962	1,56
13	13,4824	5,66	11,1699	4,69	0,0000	0,00	213,3650	89,64
14	Fruit bush plantations have not been assessed							
15	Herbs and spices have not been assessed							
16	49,1175	42,50	1,1808	1,02	0,0000	0,00	65,2617	56,47
17	85,4452	45,76	67,3826	36,09	0,9177	0,49	32,9851	17,66
18	137,7103	68,05	46,0877	22,78	0,0000	0,00	18,5598	9,17
19	6,8310	55,55	4,0521	32,95	1,4148	11,50	0,0000	0,00
20	0,0000	0,00	1,2539	4,87	0,0000	0,00	24,4772	95,13
21	42,0562	49,33	41,3670	48,52	0,0000	0,00	1,8274	2,14
22	0,3647	36,76	0,0000	0,00	0,1414	14,25	0,4859	48,98
23	Vegetables have not been assessed							

Table 5. Nature assessment of classified crops for 2020

Cultivation	3		2		1		-	
	Area [ha]	Percentage of the area of the crop concerned	Area [ha]	Percentage of the area of the crop concerned	Area [ha]	Percentage of the area of the crop concerned	Area [ha]	Percentage of the area of the crop concerned
0	Unclassified areas are not subject to assessment							
1	4,0292	4,91	64,1549	78,15	0,6367	0,78	13,2671	16,16
2	0,0000	0,00	3,4813	55,55	0,4771	7,61	2,3089	36,84
3	1,0936	8,03	2,0462	15,02	10,2602	75,32	0,2216	1,63
4	Grasses and grasslands are not assessed							
5	1,6330	7,29	0,7646	3,41	0,0000	0,00	20,0021	89,30
6	0,6721	18,37	0,0000	0,00	0,0102	0,28	2,9770	81,36
7	4,6598	16,73	0,0000	0,00	0,0000	0,04	23,18673	83,27
8	Sugar beet has not been graded							
9	Fruit tree plantations have not been assessed							
10	Strawberries have not been graded							
11	2,4162	0,83	46,6434	16,08	11,4964	3,96	35,4415	12,22
12	31,1260	29,95	259,0206	249,27	0,0000	0,00	0,0000	0,00
13	1,7088	1,80	0,7711	0,81	0,0000	0,00	101,4316	106,67
14	Fruit bush plantations have not been assessed							
15	Herbs and spices have not been assessed							
16	4,5130	2,61	48,3705	27,98	25,5864	14,80	50,0852	28,97
17	66,0201	22,76	81,3037	28,02	0,0000	0,00	25,5469	8,81
18	13,8334	58,84	247,4085	1052,39	0,0000	0,00	28,8697	122,80
19	0,0000	0,00	23,5093	40,80	0,0000	0,00	0,0000	0,00
20	0,7962	1,38	0,4890	0,85	0,0000	0,00	56,3304	97,77
21	4,5670	4,77	91,1434	91,14	0,0000	0,00	0,0000	0,00
22	4,5130	2,61	48,3705	27,98	25,5864	14,80	50,0852	28,97
23	Vegetables have not been assessed							

Table 6. Economic evaluation of classified crops for 2020

Cultivation	3		2		1		-	
	Area [ha]	Percentage of the area of the crop concerned	Area [ha]	Percentage of the area of the crop concerned	Area [ha]	Percentage of the area of the crop concerned	Area [ha]	Percentage of the area of the crop concerned
0	Unclassified areas are not subject to assessment							
1	4,3301	5,27	63,8539	77,79	0,6367	0,78	13,2671	16,16
2	3,3161	52,91	0,1652	2,64	0,4771	7,61	2,3089	36,84
3	2,1545	15,82	0,0000	0,00	11,2455	82,56	0,2216	1,63
4	Grasses and grasslands are not assessed							
5	2,1169	9,45	0,0000	0,00	0,2807	1,25	20,0021	89,30
6	0,0000	0,00	0,6823	18,64	0,0000	0,00	2,9770	81,36
7	4,6598	16,73	0,0000	0,00	0	0,00	23,18673	83,27
8	Sugar beet has not been graded							
9	Fruit tree plantations have not been assessed							
10	Strawberries have not been graded							
11	3,1355	3,27	45,9241	47,84	11,4964	11,98	35,4415	36,92
12	143,4093	49,43	139,1271	47,95	0,0000	0,00	7,6102	2,62
13	1,7088	1,64	0,7711	0,74	0,0000	0,00	101,4316	97,61
14	Fruit bush plantations have not been assessed							
15	Herbs and spices have not been assessed							
16	52,8086	41,08	0,0750	0,06	0,0000	0,00	75,6716	58,86
17	61,0210	35,30	85,9885	49,74	0,3142	0,18	25,5469	14,78
18	177,0322	61,02	81,9892	28,26	0,0000	0,00	31,0904	10,72
19	11,7933	50,16	11,7160	49,84	0,0000	0,00	0,0000	0,00
20	0,0000	0,00	1,2852	2,23	0,0000	0,00	56,3304	97,77
21	54,0617	56,48	41,3958	91,14	0,0000	0,00	0,2529	0,26
22	52,8086	41,08	0,0750	0,06	0,0000	0,00	75,6716	58,86
23	Vegetables have not been assessed							

The rating structure of the classified crops (Fig. 8.) shows that, in terms of nature, more than half of the assessed crops received a rating of 2. For these crops, there are some, generally minor, limitations to cultivation on the complex. More than ⅓ of the assessed crops received a ‘-’, which means that these crops are completely unsuitable for the given soil conditions. For the economic assessments, the structure is more even. The largest proportion, 37.10%, is occupied by areas marked '-'. Areas with no or few restrictions on cultivation each occupy about 30% of the total assessed area, and less than 2% are occupied by areas with major restrictions. As can be seen from Figure 9, assessed areas occupy only just over half of the borough's arable land and about ¼ of the borough's area. In contrast, areas with an assessment account for over 71% of the areas of arable land with a classified crop in 2019.

According to Figure 8, out of the 1414.3107 ha of the nature-assessed crop area, as much as 61.45% received a rating of 2. Crops marked with this number have minor restrictions on cultivation in the complex. Approximately ¼ of the assessed crops are unsuitable for cultivation on a given complex, while crops without cultivation restrictions occupy about 10% of the crops. In economic terms, areas of crops with no restrictions occupy 36.88%, while those with minor restrictions occupy 33.44%. An area corresponding to 27.95% of the area is made up of crops not suitable for cultivation in the complex. As in the previous year, the area of crops subject to assessment exceeded half of the arable land and occupied about ¼ of the municipal area. The assessed crops (Fig. 9) account for 72% of the areas of classified crops on agricultural land. The structure of the natural and economic assessments, as well as the comparison to the area of the municipality and arable land for 2019, is very similar to that of 2020.

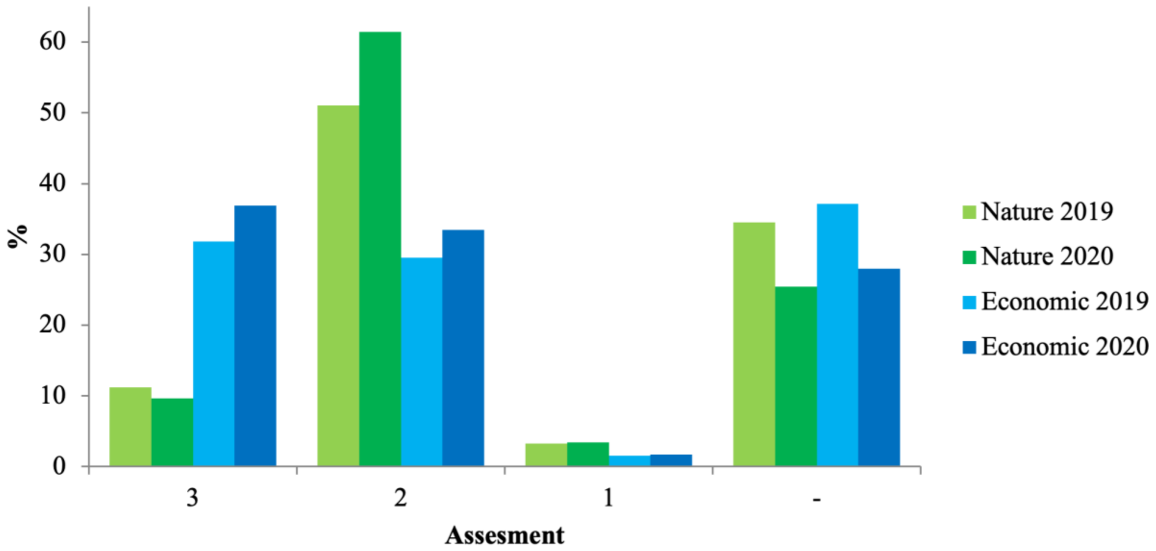

Fig. 8. Rating structure of classified crops for 2019 and 2020

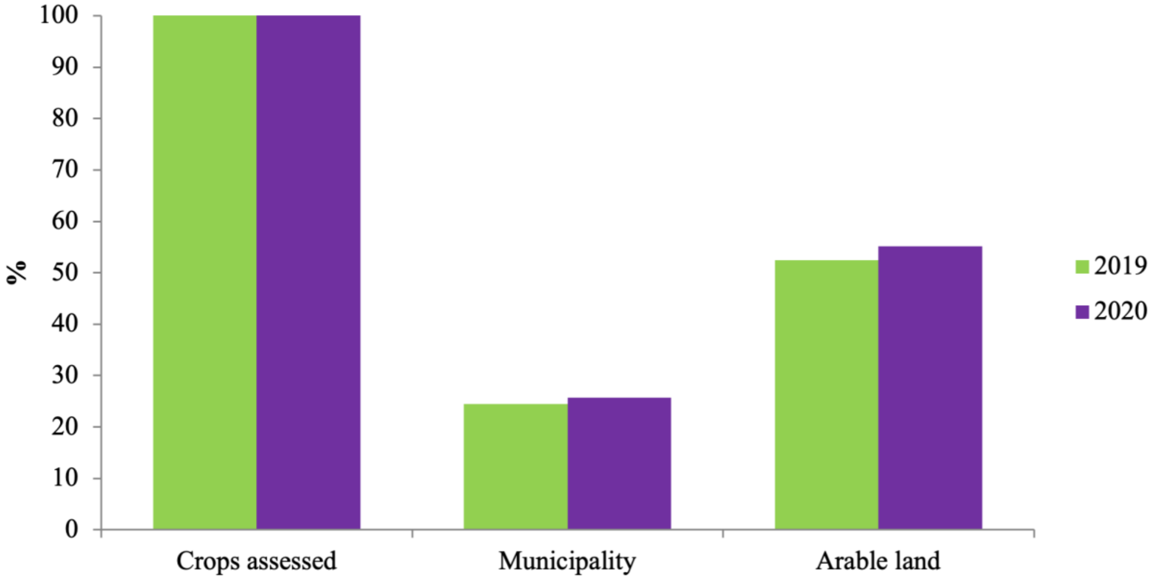

Fig. 9. Comparison of assessed crops to communal area and arable land for 2019 and 2020

Table 7 shows the assessment of crop consequences.

Table 7. Succession assessment of classified crops in 2019 and 2020

Assessment	3	2	1	No assessment		
Land cover	Classified crops for both years			Unclassified land on agricultural land	Classified plant in one year	Other uses
Area [ha]	403,146 8	743,062 5	503,079 0	960,8562	557,5195	2333,9822
Percentage of municipal area	7,33	13,51	9,14	17,46	10,13	42,42

The crop areas assessed occupied an area of 1649.2883 ha. Crop rotations assessed with a favourable rating occupy ¼ of the total area assessed. An acceptable rating accounts for nearly half of the total assessed area, while a poor rating accounts for 30.50%. There were also areas that could not be assessed. These were primarily sites that were satellite-classified as unclassified sites. Land labelled in this way meant that it was not cultivated by any crop. Land so designated was divided into unclassified land on agricultural land and other uses, i.e. unclassified land on land such as built-up areas or roads. Sites for which only one of the two years was identified as cultivated were also not assessed. The land that was assessed for crop succession occupied 30% of the municipal area and 64.37% of the arable land [2].

The final stage of the research was data on the comparison of satellite classified plant areas with those that were in the state registers as land subject to agricultural subsidies according to farmers' area declarations.

In 2019, an area of 1890.7464 ha and 1222.6586 ha of unclassified agricultural land were classified as crops. Farmers declared an area of 2027.4900 ha as crops. The area of land designated as classified crops is similar to the area of declared crops. In the municipality of Panki, agricultural land covers 3113.4050 ha, which means that declared crops and classified crops account for ⅔ of this area. The declared crops had to be grouped into classes, for which crops were identified and classified by satellite. Not every classified crop had a counterpart among the declared crops. This may be due to the fact that 421.2500 ha of declared crops are undesignated crops. The declared and classified areas of some crop classes are close to each other, such as for maize, and some are significantly different, such as legumes.
For 2020, an area of 1960.3673 ha was classified as crops and 1153.0377 ha was classified as unclassified agricultural land. Crops declared by farmers occupied 2045.66 ha. The areas of classified and declared crops are similar and account for approximately ⅔ of the agricultural area in the municipality. As in the previous year, the declared crops were grouped into classes of classified crops. Not every classified crop had its counterpart in the declared crops. Among the crop classes are those for which the areas are almost identical, e.g. winter triticale. An example of a crop with a large difference in area covered is spring wheat.

6. CONCLUSIONS

Satellite-based land cover classification still faces problems with the raster data format, which affects the accuracy of the representation of individual crop boundaries. The use of pixels to represent the surface introduces distortions that make it difficult to accurately perform spatial analyses and comparisons with other data sources, such as soil maps or national registers. The accuracy of crop classification depends largely on the spatial resolution and quality of satellite imagery. In the case of low-resolution imagery, detection of finer crops or smaller objects, such as transition or marginal fields, may be impossible or subject to high error. High resolution satellite imagery (e.g. 10 m or less) allows more accurate distinction of individual crops, but requires more computing power and may involve higher data acquisition costs. There are difficulties in fully identifying the area of agricultural land, especially for crops that are not clearly identifiable from the available satellite images. The problem may be due to insufficient resolution of the classification, lack of precise data on the type of crop or errors in identifying areas excluded from agricultural use (e.g. fallow land). In contrast, classification of non-agricultural land shows better performance, suggesting the need for further calibration of classification algorithms. To improve the accuracy of the classification, it is recommended to include additional information, such as layers on soil agricultural suitability complexes. Such data can help to assess the suitability of a site for agricultural crops, taking into account both economic and natural constraints. The use of crop rotation information can also increase the accuracy of the classification, allowing better matching of crops to environmental conditions. Integrating different data sources into a single analytical system is both technically and methodologically challenging. Differences in the accuracy, spatial and temporal scale of these data can lead to difficulties in combining them correctly.

The satellite classification should also be compared with the declared crop data, which is closest to the actual condition in the area. In case of differences between the classification results and the declared data, the possibility of some crops not being declared should be taken into account. It is expected that the area of a crop in the satellite classification will be larger than the area declared, which may indicate incomplete declaration of crops by farmers. In order to obtain more reliable results, further refinement of satellite classification algorithms is needed, taking into account natural, spatial and economic variables. Introducing more precise data (raster size) and considering the environmental context can significantly improve the accuracy of the identifications and thus contribute to better monitoring and management of agricultural areas.

In conclusion, satellite-based land cover classification is a powerful tool in crop monitoring, but needs further improvements, both in terms of image analysis technology and in integration with additional geographic data and farmers' declarations, to ensure the accuracy and reliability of the results.

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