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Assessment of the effect of optimised field plot size on the crop yield

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Abstract: The presented research deals with the effect of plot size changes on the crop yield. Three plots were chosen in a company engaged in conventional agriculture, on which yields were monitored from 2019 using yield maps. In 2020, the plots (initial size > 30 ha) were divided into different parts sized < 30 ha. In 2021, these newly arisen parts of the plots were harvested. Changes in the yield of grown crops were analysed using yield maps acquired by the harvesting machines. Relative yields (%) and absolute yields (t/ha) were determined on all experimental land parts arising from the initial plots' division. The values were then compared with yields recorded before the division of individual plots using zonal statistics. Measured relative yield values clearly show ($P < 0.05$) that the division of plots resulted in the increased heterogeneity of crop yields. On the initial plots as well as on the newly arisen plots, the relative yield was divided into the following categories: < 70, 70–85, 85–95, 95–105, 105–115, 115–130 and > 130%, with the value of 100% representing average yield. The analysis of measured yield data showed that the division of plots into smaller parts resulted in an uneven yield distribution because if a divided plot was heterogeneous in terms of yield levels, a cumulation of "higher yield levels (> 100%)" could have occurred in one specific newly arisen plot at the expense of another one. Moreover, new marginal parts of lands came into being during the division of larger soil complexes, and hence zones with potentially reduced yields.

Keywords: yield monitoring system; precision agriculture; GIS; soil heterogeneity; soil fertility

Modern agriculture in the European Union currently faces and will face new challenges, especially those relating to climate change. An increased occurrence of extreme meteorological phenomena (torrential rains, storms, drought periods) is expected, which have adverse effects on the health and quality of agricultural soils (SHQ) (Trnka et al. 2020). These phenomena, namely show in soil erosion and subse-

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quently in impaired soil fertility (Menšík et al. 2020). Therefore, EU farmers drawing subsidies from the single area payment scheme (SAPS) are motivated to improve SHQ by fulfilling standards for good agricultural and environmental land conditions (GAEC). These standards (Table 1) are implemented differently in EU member countries. GAEC implementation is thus a process in which member states play a decisive role as they are granted flexibility by the European legislation framework to define a precise content of the minimum GAEC requirement with considering local conditions (Angileri et al. 2011).

In the Czech Republic, precise conditions of GAEC are determined by the government and its regulations, currently by the Government Regulation No. 48/2017 Sb. The fulfilment of GAEC standards is controlled by the State Agricultural Intervention Fund. This control authority uses both remote sensing of the Earth and fieldwork to find out whether the applicant meets the GAEC standards and, hence, conditions required to receive the SAPS. Within the GAEC standards implemented in the Czech Republic, a condition has arisen for drawing subsidies from the EU through the SAPS, which prohibits monocultures growing on an area > 30 ha. The condition was first applied to lands threatened by erosion only (from 2019) but was later extended to include all arable lands in the country. Farmers had thus to face the difficult task of searching optimal ways for how to split the individual plots.

One of the possibilities to efficiently fulfil the GAEC conditions and improve SHQ is to use precision agriculture technologies (Kumar and Ilango 2018, Mezera et al. 2022). These technologies represent a complex solution that allows the farmers not only to manage the grown crops efficiently but, for example, also to plan machine travel or optimise the shape of lands so that the risk of erosion phenomena is minimised (Abdullahi et al. 2015, Yost et al. 2017). The basic and available technology includes geographical information systems (GIS), which can provide important information about the terrain topography direction of water runoff from the site or can be used to visualise the travel of machines across the site (Mani et al. 2021). The land parcel identification system (LPIS) represents a basic GIS for the wide agricultural public not only in the Czech Republic but also in other EU countries, as it is a necessary component for drawing the SAPS (Kocur-Bera 2019). The Czech LPIS is operated

Table 1. Standards for the good agricultural and environmental condition of land (GAEC; Council Regulation No. 1306/2013 (Regulation EU 2013))

Area	Main issue	Requirements and standards
Environmental, climate change, good agricultural condition of land	water	GAEC 1: Establishment of buffer strips along water courses
		GAEC 2: Where use of water for irrigation is subject to authorisation, compliance with authorisation procedures
		GAEC 3: Protection of groundwater against pollution: prohibition of direct discharge into groundwater and measures to prevent indirect pollution of groundwater through discharge on the ground and percolation through the soil of dangerous substances, as listed in the Annex to Directive 80/68/EEC in its version in force on the last day of its validity, as far as it relates to agricultural activity
	soil and carbon stock	GAEC 4: Minimum soil cover
		GAEC 5: Minimum land management reflecting site-specific conditions to curb erosion
		GAEC 6: Maintenance of soil organic matter level through appropriate practices, including a ban on burning arable stubbles, except for plant health reasons
	landscape, minimum level of maintenance	GAEC 7: Retention of landscape features, including, where appropriate, hedges, ponds, ditches, trees in line, in group or isolated, field margins and terraces, and including a ban on cutting hedges and trees during the bird breeding and rearing season and, as an option, measures for avoiding invasive plant species

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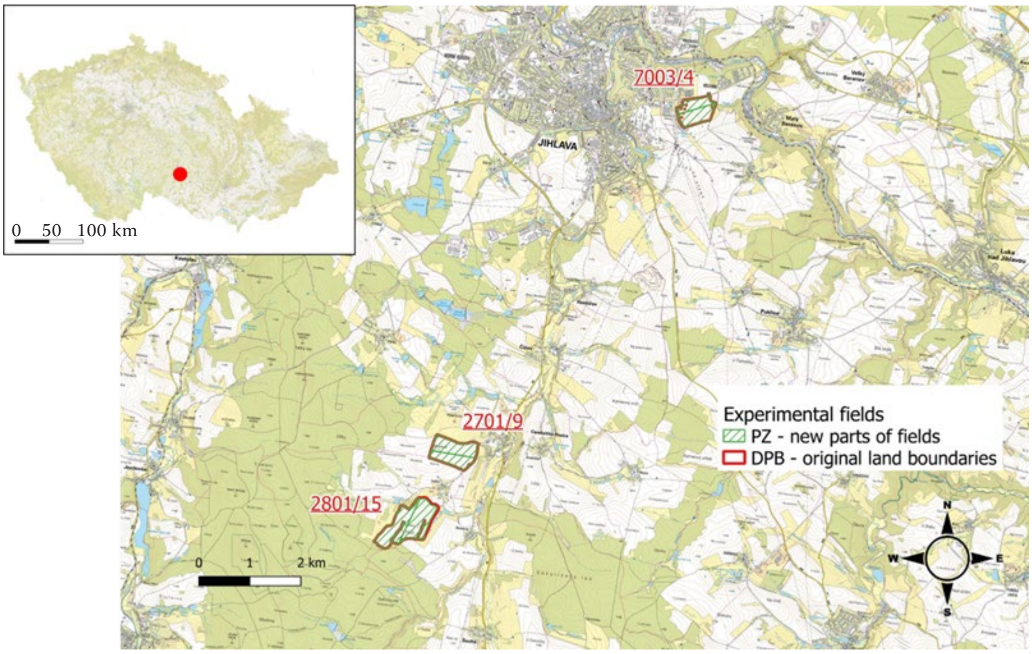

Figure 1. The location of experimental plots within Eurofarms Jihlava, Ltd., Czech Republic

by the Ministry of Agriculture, and apart from the mandatory records of agricultural land, it also serves in the visualisation of some landscape parameters (Trojáček 2002), of which the most important ones are erosion risk, surface runoff from individual sites, watercourses, contours and agrochemical analyses of soils (Trojáček 2002, Lošák et al. 2012, Skaloš et al. 2017). The system also makes it possible to modify the shape and size of agricultural lands to reduce the risk of soil erosion and degradation (Trojáček 2002).

The presented study's goal was to determine whether the division of plots in line with GAEC 5 and 7 using the yield data from combined harvesters affects the crop yield.

MATERIAL AND METHODS

In 2019, all field plots (DPB) in the company Eurofarms Jihlava Ltd. (EF) > 30 ha were divided into smaller parts (15–20 ha) using virtual working diagrams (PZ) in the national program land parcel identification system (LPIS, Ministry of Agriculture of Czech Republic). The division of plots was necessary because a condition for drawing EU subsidies stipulated in the good agricultural and environmental conditions (GAEC) implemented in the Czech Republic prohibits the growing of crop monocultures in an area > 30 ha. Thus, new and smaller parts came into existence within the original land boundaries.

Table 2. Experimental plots – crop structure

Experimental plot	Original area (ha)	Land division – newly arisen parts (ha)		Crop structure				
				2019	2020		2021	
		A	B		A	B	A	B
2701/9	41.78	24.33	17.45	oil seed rape	winter wheat	spring barley	field pea	oil seed rape
7003/4	32.40	13.71	18.69	oil seed rape	winter wheat	field pea	spring barley	winter wheat
2801/15	58.90*	26.67	29.25	lacy phacelia	winter wheat	spring barley	field pea	oil seed rape

*2.97 ha of total area were used as an erosion control measure – grass strip

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The first wave of the division concerned all plots classified in the category of mild and strong erosion risk. The second wave of division comprised all other DPB > 30 ha, i.e., even those not classified in the abovementioned categories. The change in the area of individual DPB and the total area of concerned DPB are shown in the map (Figure 1). Three DPBs of different sizes were chosen from the total area of EF Jihlava (Figure 1, Table 2). Apart from the area, the plots differed in exposure, slope, erosion risk and other soil parameters. All selected plots are managed by conventional methods. The division of lands was made based on several criteria in order to: (a) lead to water erosion risk mitigation; (b) to respect the movement of machines on the land, and (c) to make the newly arisen PZ accessible to agricultural machines. The principle of land division is illustrated in Figure 6, an overview of selected plots, including their original areas and areas of newly arisen parts, is presented in Table 2.

All selected fields (Table 2) are under conventional management, i.e. standard fertiliser application and soil cultivation in accordance with GAEC (Table 3 and 4). Meteorological parameters (Table 5) were measured by DAVIS Vantage Pro2 meteorological station (Davis Instruments, California, USA). Weather station location: Jihlava-Heroltice (538 m a.s.l.; 49°26'1.98"N, 15°37'38.60"E). The long-term standard (1991–2020) for the area of our interest (Vysočina region) was obtained from the Czech Hydrometeorological Institute (http://portal.chmi.cz/historicka-data/). Yields of crops on the plots were monitored from 2019 using the technology of yield maps. In the research period (2019–2021), the data were acquired by combined harvesters New Holland (CX 8080), then downloaded from the machine control terminal, and processed using ArcGIS geographical software (ESRI, Redlands, California, USA) and Python (Python Software Foundation, Wilmington, Delaware, USA) programming language. The principle of data processing is shown in Figure 2. Yield was measured by the harvest thrasher with an automatic scaling system and a system for measuring the grain moisture content. The measured yield was not further calibrated, for example, using data from the scale obtained from the production weighing before storage in silos.

RESULTS AND DISCUSSION

Relative yield (%) and absolute yield (t/ha) were determined on all experimental plots. The relative yield was established based on data provided by the combined

Table 3. Experimental plots – basic fertilisation

Experimental plot	Original area (ha)	Land division – newly arisen parts (ha)		Basic fertilisation				
				2019	2020 – A	2020 – B	2021 – A	2021 – B
		A	B	dose per hectare				
2701/9	41.78	24.33	17.45	300 kg DS 60	–	–	5 000 kg saturation sludge	–
				80 WIGOR S	100 kg MAP	–	–	–
				158 kg N_{min}	154 kg N_{min}	91 kg N_{min}	–	163 kg N_{min}
7003/4	32.40	13.71	18.69	300 kg DS 60	–	–	–	–
				14 500 kg digestate	–	–	–	–
				158 kg N_{min}	141 kg N_{min}	14 kg N_{min}	51 kg N_{min}	128 kg N_{min}
2801/15	58.90*	26.67	29.25	–	150 kg UltraKali	–	4 000 kg saturation sludge	4 000 kg saturation sludge
				–	100 kg MAP	51 kg MAP	–	50 kg DS 60
				69 kg N_{min}	154 kg N_{min}	90 kg N_{min}	–	190 kg N_{min}

*DS 60 – potassium chloride (60% KCl content); WIGOR S – elemental sulphur (90% S content); N_{min} – amount of applied N from mineral fertilisers

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yield meter as a percent category expressing achievement (= 100%), non-achievement (< 100%) or exceeding (> 100%) of average yield in the individual parts of the land, weighted average for the whole plot being always 100%. Furthermore, histograms of relative yield categories were prepared for each divided field area and observed years (Figures 4–6). The absolute yield represents the value of harvested crop yield in t/ha. The relative and absolute yield values were calculated for each year of the experiment (2019–2021) for individual parts of the land, as they were created based on PZ in LPIS (Figure 1, Figure 6). Thus, the selected experimental plots (DPB) are com-

Table 4. Experimental plots – soil cultivation

Experimental plot	Original area (ha)	Land division – newly arisen parts (ha)		Soil cultivation*				
				2019	2020		2021	
		A	B		A	B	A	B
2701/9	41.78	24.33	17.45	soil cultivation with Väderstad Carrier (8–15 cm)	soil cultivation with Väderstad Carrier (8–15 cm)	soil cultivation with Väderstad Carrier (8–15 cm)	soil cultivation with Horsch Terrano MT cultivator (15–20 cm) in autumn	soil cultivation with Horsch Terrano MT cultivator (8–15 cm)
				soil cultivation with Horsch Terrano MT cultivator (20–25 cm)	soil cultivation with Horsch Terrano MT cultivator (20–25 cm)	soil cultivation with Horsch Terrano MT cultivator (20–25 cm)	soil cultivation with Horsch Terrano MT cultivator (20–25 cm) in spring	soil cultivation with Horsch Terrano MT cultivator (20–25 cm)
				seeding with Väderstad Spirit ST900C				
7003/4	32.40	13.71	18.69	soil cultivation with Väderstad Carrier (8–15 cm)	soil cultivation with Väderstad Carrier (8–15 cm)	soil cultivation with Horsch Tiger (8–15 cm)	–	soil cultivation with Horsch Terrano MT cultivator (8–15 cm)
				soil cultivation with Horsch Terrano MT cultivator (20–25 cm	soil cultivation with Terrano MT cultivator (20–25 cm)	soil cultivation with Terrano MT cultivator (20–25 cm)	soil cultivation with Horsch Terrano MT cultivator (15–20 cm)	soil cultivation with Horsch Terrano MT cultivator (20–25 cm)
				seeding with Väderstad Spirit ST900C				
2801/15	58.90	26.67	29.25	soil cultivation with Väderstad Carrier (8–15 cm)	soil cultivation with Väderstad Carrier (8–15 cm)	soil cultivation with Väderstad Carrier (8–15 cm)	soil cultivation with Horsch Terrano MT cultivator (15–20 cm) in autumn	soil cultivation with Horsch Terrano MT cultivator (8–15 cm)
				soil cultivation with Terrano MT cultivator (20–25 cm)	soil cultivation with Terrano MT cultivator (20–25 cm)	soil cultivation with Terrano MT cultivator (20–25 cm)	soil cultivation with Horsch Terrano MT cultivator (20–25 cm) in spring	soil cultivation with Horsch Terrano MT cultivator (20–25 cm)
				seeding with Väderstad Spirit ST900C				

*Main work operations are included only, used to cultivate the soil and establish the stand

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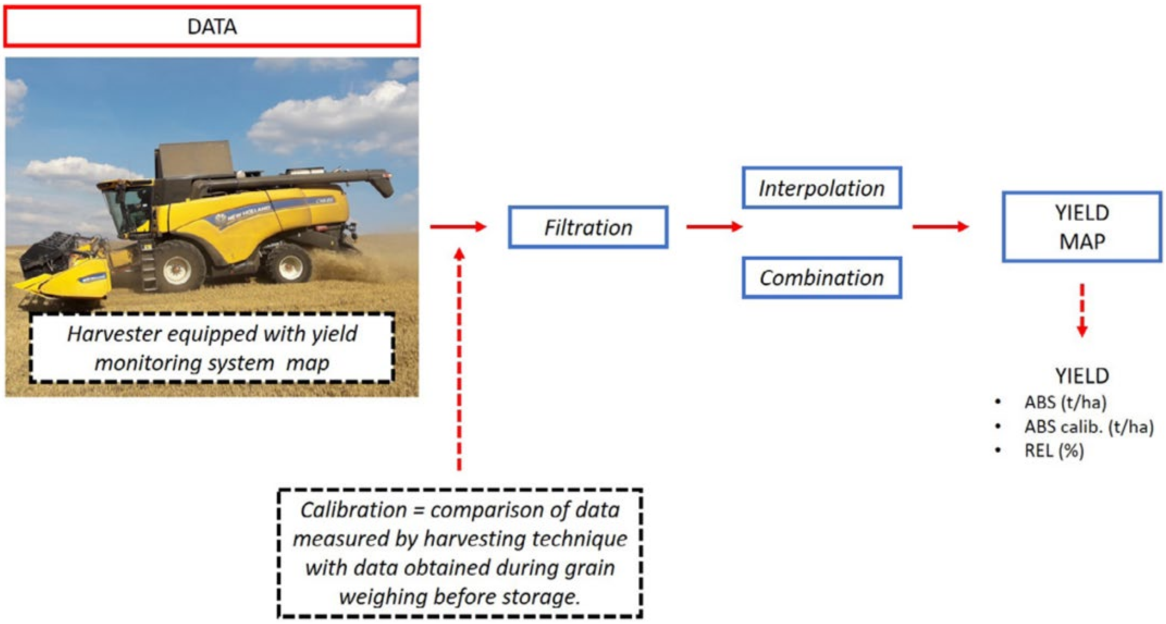

Figure 2. The process of yield data processing (Elbl et al. 2021). ABS – absolute yield; REL – relative yield

pared for the distribution of yield levels and average yields in the individual PL parts – the initial processing and evaluation of data used the relative yield values. The reason was that different crops were grown on the plot in 2020–2021 and absolute yield values were used as a complementary parameter (Table 7) as two PZs with different crops cannot be compared in terms of absolute yield (t/ha).

Experimental plot 2701/9

The data of relative yield (Figure 7; Table 6) measured in 2019 indicate that zones with below-average (< 100%) yield occurred evenly in the western and eastern parts of DPB already before the DPB division. When different crops began to be grown in 2020 after the DPB division into two PZ (A; B), a change

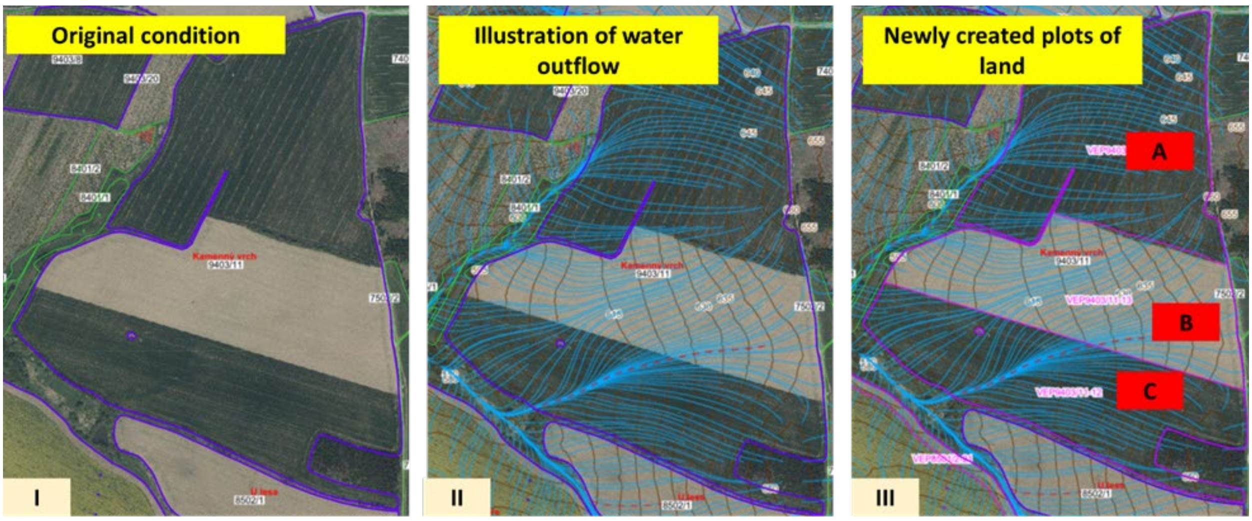

Figure 3. The principle of dividing all field plots (DPB) into new virtual working diagrams (PZ) in the geographical information systems (GIS)program of land parcel identification system (LPIS) (Ministry of Agriculture of the Czech Republic; https://eagri.cz/public/app/lpisext/lpis/verejny2/plpis/). Model example: I – initial situation (DPB boundary in dark purple), original plot area 70.47 ha; II – runoff lines as originators of water erosion; III – optimal direction of new PL was selected based on runoff lines direction and directions of machine travel. There were altogether three new PZ created: A = 26.58 ha; B = 21.77 ha; C = 22.12 ha

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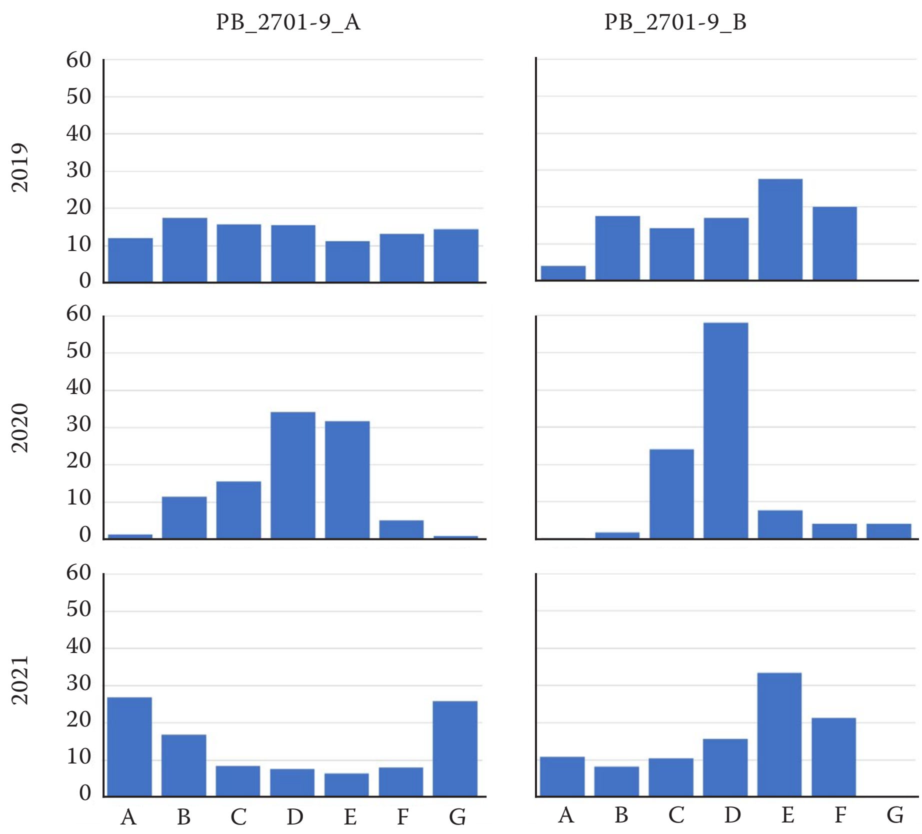

Figure 4. Histogram of relative yield categories (axis X) for each divided field area (rows) and observed years (columns) – experimental field 2701/9. A – 0–70 cm; B – 70–85 cm; C – 85–95 cm; D – 95–105 cm; E – 105–115 cm; F – 115–130 cm; G – >130 cm

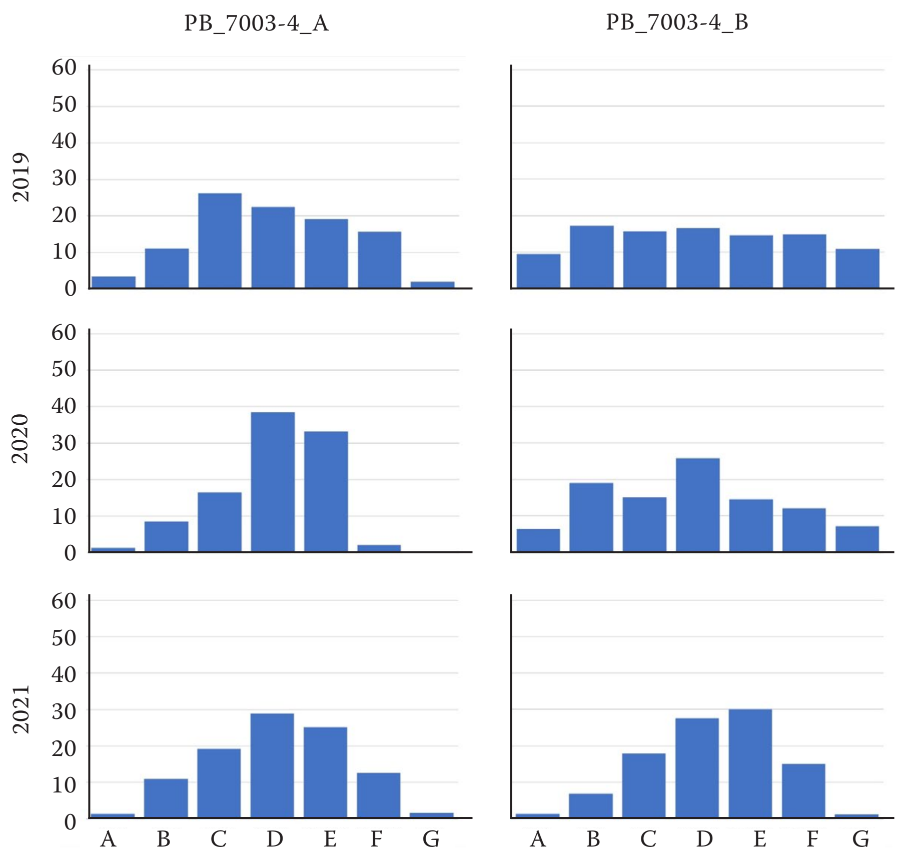

Figure 5. Histogram of relative yield categories (axis X) for each divided field area (rows) and observed years (columns) – experimental field 7003/4. A – 0–70 cm; B – 70–85 cm; C – 85–95 cm; D – 95–105 cm; E – 105–115 cm; F – 115–130 cm; G – >130 cm

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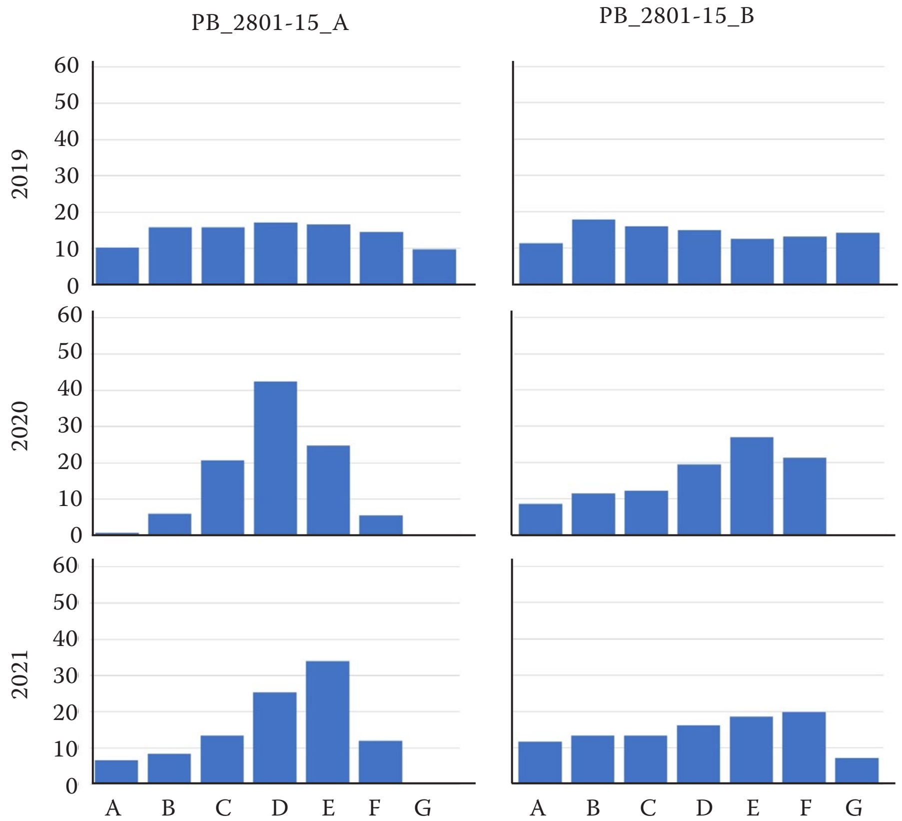

Figure 6. Histogram of relative yield categories (axis X) for each divided field area (rows) and observed years (columns) – experimental field 2801/15. A – 0–70 cm; B – 70–85 cm; C – 85–95 cm; D – 95–105 cm; E – 105–115 cm; F – 115–130 cm; G – >130 cm

happened in the yield distribution, which follows from data for 2020 and 2021 (Table 5).

This change was different in the two years. In 2020, the category of average relative yield (95–105%) occurred on 83 025 m^2 on PZ "A" and on 100 800 m^2 on PZ "B". Contrariwise, the values in 2021 were 18 653 m^2 on PZ "A" and 27 261 m^2 on PZ "B". The categories of relative yield 115–130% and > 130% exhibited significant changes in their area on the new parts of DPB (A; B). The changes were to the benefit of PZ A for the category of 115–130% in 2020 and for the category of > 130% in 2021. The respective categories' graphical representation follows from the histogram in Figure 4, which shows increased heterogeneity of relative yield (%) on the newly arisen PZ. Both newly arisen DPBs were applied similar methods of tillage and fertilisation (Tables 3 and 4).

The measured values (Table 6, Figure 7) indicate that the DPB division resulted in such an effect that individual new parts of the plot have different suitability for growing individual crops (cereals, legumes and oil seeds). In contrast, similar yield levels are recorded when the same crop occurs on the plot (oil seed rape in 2019). The situation may be associated with the ruggedness of the original DPB and the newly arisen PZ A and B. The difference in altitude between the western and eastern parts of the plots PZ A and PL B is 51 m and 33 m, respectively. This situation shows a higher susceptibility of PZ A to developing spots with excessive or lacking nutrients. The slope and management method are dominant factors affecting soil erosion and subsurface water runoff and transport of nutrients within the soil profile (Wang et al. 2019). On the other hand, it is necessary to state that the level of soil erosion was not measured in the presented work. These factors are very likely to have affected the yields of the grown plants as there is a fundamental difference between winter and spring crops in resistance to water log-

Table 5. Meteorological and climatological parameters

Year	Mean annual precipitation (mm)	Mean annual temperature (°C)
2019	499.6	10.0
2020	945.6	8.7
2021	646.9	7.9
Long term standard	677	7.9

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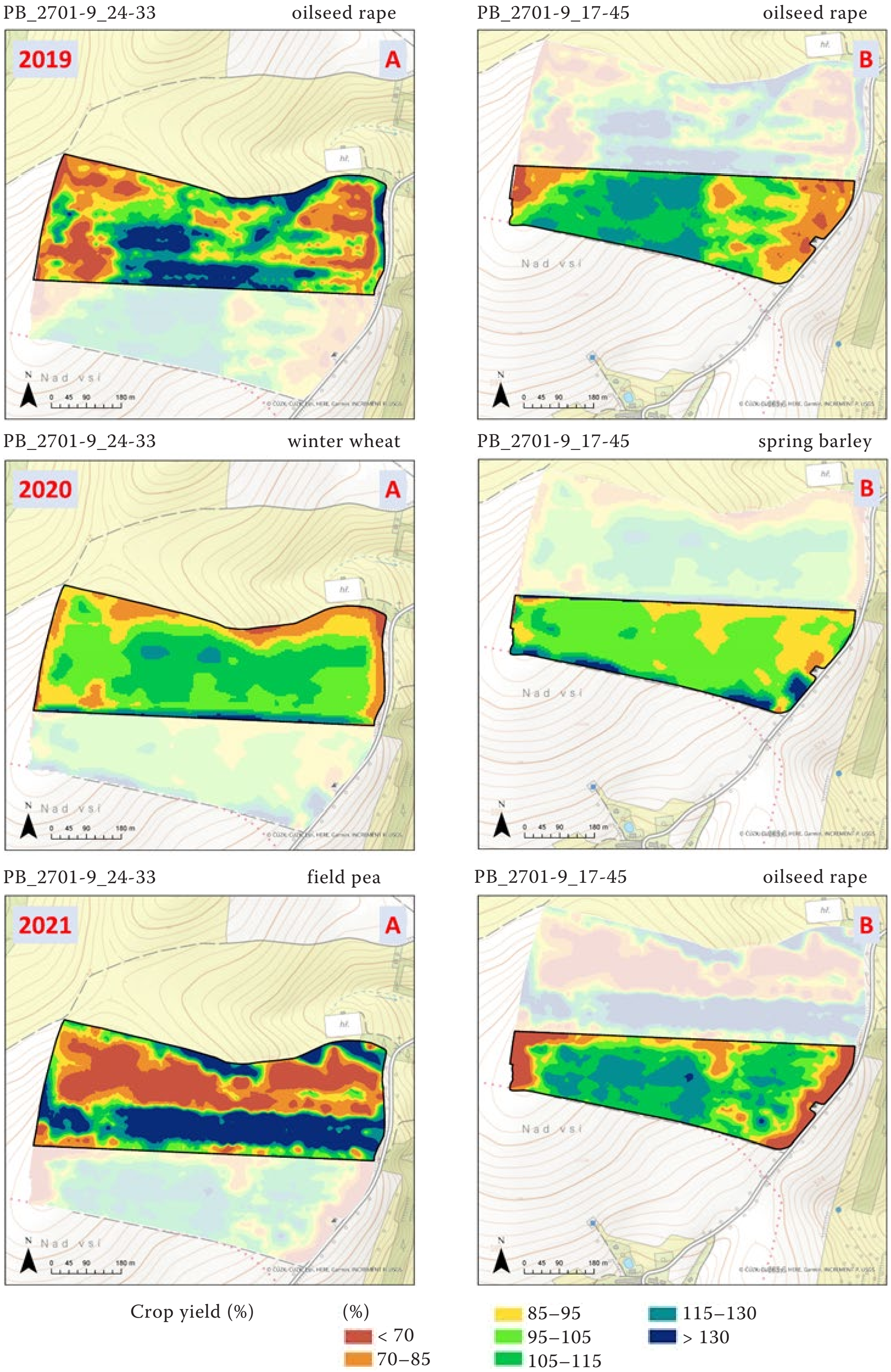

Figure 7. Relative yield (%) of crops grown on Experimental Plot 2701/9

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Table 6. Zonal statistics for the experimental plot 2701/9 – area of individual percent categories of relative yield

	Relative yield (%)							Area (ha)
	0–70	70–85	85–95	95–105	105–115	115–130	> 130	
2019 (m^2)								
A	29 399[a]	42 495[a]	38 233[a]	37 830[a]	27 441[b]	32 048[a]	35 225	24.29
B	6 739[b]	30 210[b]	24 634[b]	29 339[b]	47 509[a]	34 433[a]	0	17.36
2020 (m^2)								
A	3 300[a]	27 550[a]	37 850[a]	83 025[a]	76 975[a]	12 275[a]	2 250[b]	24.29
B	325[b]	3 050[b]	41 825[a]	100 800[a]	13 500[b]	7 150[b]	7 175[a]	17.36
2021 (m^2)								
A	65 444[a]	40 732[a]	20 234[a]	18 653[a]	15 720[b]	19 512[b]	62 640[a]	24.29
B	18 756[b]	14 200[b]	17 980[a]	27 261[a]	58 044[a]	36 926[a]	482[b]	17.36

[a,b]Different lowercase letters confirm honestly significant difference (P < 0.05) in relative yield between individual variants of experiment

ging or drought (Basic et al. 2004, Menšík et al. 2020). Cultivation of spring crops brings a higher risk of erosion events (Basic et al. 2004), and crops such as spring peas may exhibit worse emergence on the fragmented lands (Gollner et al. 2019). On the other hand, neither the yield maps nor the field observations confirmed an erosion event.

An interesting fact is that the plot's division in 2019 was likely to reduce the negative influence of the machine turning on the original DPB boundary

Table 7. Absolute yield (t/ha) for individual experimental plots and years of monitoring

		Area (m^2)	Min	Max	Range	Mean	SD	MED	Crop
2019									
2701/9	A	242 871	0.84	3.72	2.88	2.13	0.54	2.1	oilseed rape
	B	173 604	1.38	3.36	1.99	2.63	0.42	2.7	oilseed rape
7003/4	A	125 421	1.39	4.25	2.86	2.94	0.45	2.9	oilseed rape
	B	178 200	0.97	4.19	3.22	2.41	0.54	2.4	oilseed rape
2801/15	A	266 701	0.11	0.82	0.71	0.46	0.11	0.5	lacy phacelia
	B	292 499	0.14	0.76	0.62	0.37	0.10	0.4	lacy phacelia
2020									
2701/9	A	242 871	3.81	10.20	6.39	7.17	0.86	7.31	winter wheat
	B	173 604	3.56	10.67	7.11	6.28	0.71	6.14	spring barley
7003/4	A	125 421	6.21	10.74	8.53	7.31	1.16	7.59	winter wheat
	B	178 475	2.62	5.24	3.62	4.48	0.96	4.47	field pea
2801/15	A	266 701	2.64	7.56	4.92	5.79	1.05	5.85	winter wheat
	B	292 499	3.64	7.64	4.00	5.85	0.58	6.04	spring barley
2021									
2701/9	A	242 871	0.58	4.33	3.75	2.04	0.77	1.88	field pea
	B	173 604	0.80	3.73	2.93	2.55	0.53	2.73	oilseed rape
7003/4	A	125 421	3.80	8.92	6.12	6.93	0.94	7.03	spring barley
	B	178 301	3.32	10.99	7.67	8.07	1.01	8.07	winter wheat
2801/15	A	266 701	1.07	3.12	2.05	2.33	0.36	2.41	field pea
	B	292 499	0.74	4.83	4.09	3.23	0.70	3.31	oilseed rape

SD – standard deviation; MED – median

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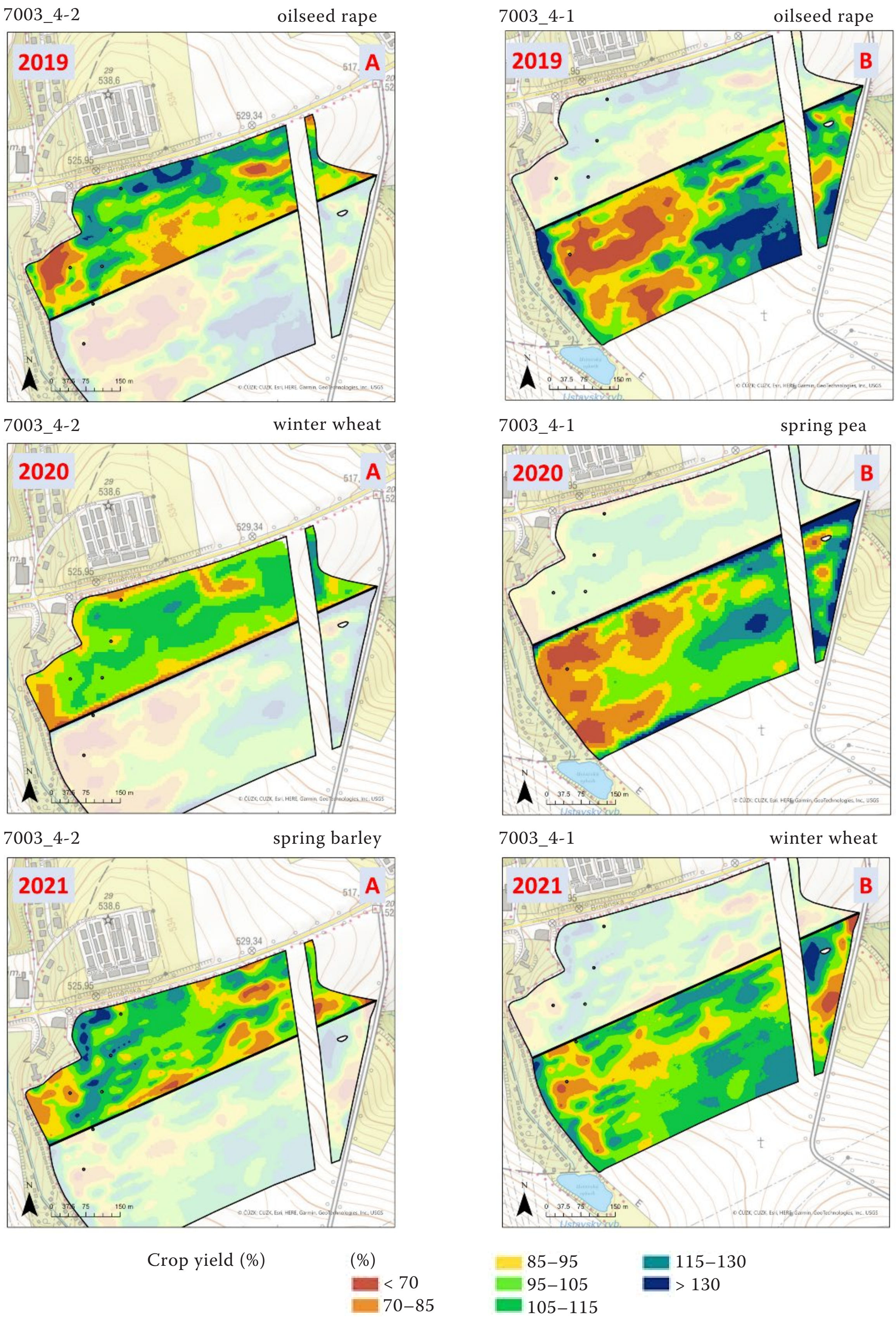

Figure 8. Relative yield (%) of crops grown on Experimental Plot 7003/4

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Table 8. Zonal statistics for the experimental plot 7003/4 – area of individual percent categories of relative yield

	Relative yield (%)							Area (ha)
	0–70	70–85	85–95	95–105	105–115	115–130	> 130	
2019 (m^2)								
A	4 306[b]	13 929[b]	32 847[a]	28 274[a]	23 969[a]	19 602[b]	2 494[b]	12.54
B	1 702[a]	30 878[a]	28 149[a]	29 722[a]	26 253[a]	26 591[a]	19 586[a]	17.82
2020 (m^2)								
A	1 675[b]	10 700[b]	20 775[b]	48 550[a]	41 825[a]	2 600[b]	0	12.54
B	11 350[a]	34 150[a]	26 925[a]	45 925[a]	25 925[b]	21 475[a]	12 725	17.82
2021 (m^2)								
A	1 732[b]	13 901[a]	24 258[b]	36 569[b]	31 811[b]	15 947[b]	2 137[a]	12.54
B	2 330[a]	12 276[a]	31 812[a]	49 243[a]	53 552[a]	26 943[a]	2 145[a]	17.82

[a,b]Different lowercase letters confirm honestly significant difference ($P < 0.05$) in relative yield between individual variants of experiment

and multiply the negative effect of the "newly arisen boundary" inside the original DPB. On the PZ A and PZ B boundary, a zone of low yield level came into existence (< 70%), which was detected both in 2020 and 2021 (Figure 7), with this yield level being demonstrably larger in PZ A.

Experimental plot 7003/4

Experimental plot 7003/4 (32.4 ha) was the smallest DPB included in our monitoring. It was split in 2019 due to its classification as endangered by erosion, more precisely in the category of sites severely endangered by erosion. At the time of division into two PZ (A, B), it was unclear whether the control authorities would accept an area larger than 30 ha, e.g. if exceeded by up to 4%. This was why the DPB was divided into two PZ (A = 12.61 ha; B = 17.85 ha). Relative yield (%) was monitored (Figure 8) on the respective PZ (A; B) from 2019 to 2021. A corridor running through the middle of the site was created for operational reasons in the first year of measurements. This strip was artificially created in the following years of measurements (2.04 ha from the overall area) to have a possibility for data comparison.

The measured data show that the northern part of DPB is more heterogeneous due to different yield levels than the southern part. This was apparent in 2019 when oil seed rape was grown on the DPB and alternating winter wheat and spring crops in the following years. In 2019, winter oil seed rape yield was 2.13 t/ha (PZ A) and 2.63 t/ha (PZ B). In 2020, the winter wheat yield was 5.79 t/ha on PZ A; in 2021, it was 7.8 t/ha in the other part of the site (PZ B) (Table 7). These data indicate that the site was divided into a fertile part (PZ B) and a less fertile part (PZ A) in which a greater number of zones with a lower relative yield is accumulated (Table 8). The yield heterogeneity is also apparent from the histogram (Figure 5) of measured relative yields in the respective years. Different crops and the newly arisen PZ A and PZ B caused significant changes in the yield distribution, as compared with PZ B, categories with a greater relative yield dominated in PZ A in the individual years. This new part of DPB exhibited a greater spread of relative yields among the categories (from 0–70% up to > 100%). This might indicate the effect of the cultivated crop but also the effect of the partition of DPB that could have brought a shift of zones with a lower yield potential to PZ B. The detected difference between PZ A and PZ B could have been caused by the effect of the year, i.e. by changes in total precipitation amounts (Lošák et al. 2012). However, the relative yield being taken into account, it follows that PZ A shows an increased representation of zones with below-average yields. The influence of tillage or fertilisation is not assumed, as differences between agrotechnical measures used in PZ A and PZ B were not essential (Tables 3 and 4). The area topography is very articulated, with altitudes ranging from 517 m a.s.l. to 556 m a.s.l. The site is situated in a region with several soil types (loam and sandy loam). The terrain ruggedness is affected by surface and sub-surface water runoff that has a fundamental influence on the formation of water erosion and hence on the soil fertility (Evans 2005, Menšík et al. 2020). The slope map

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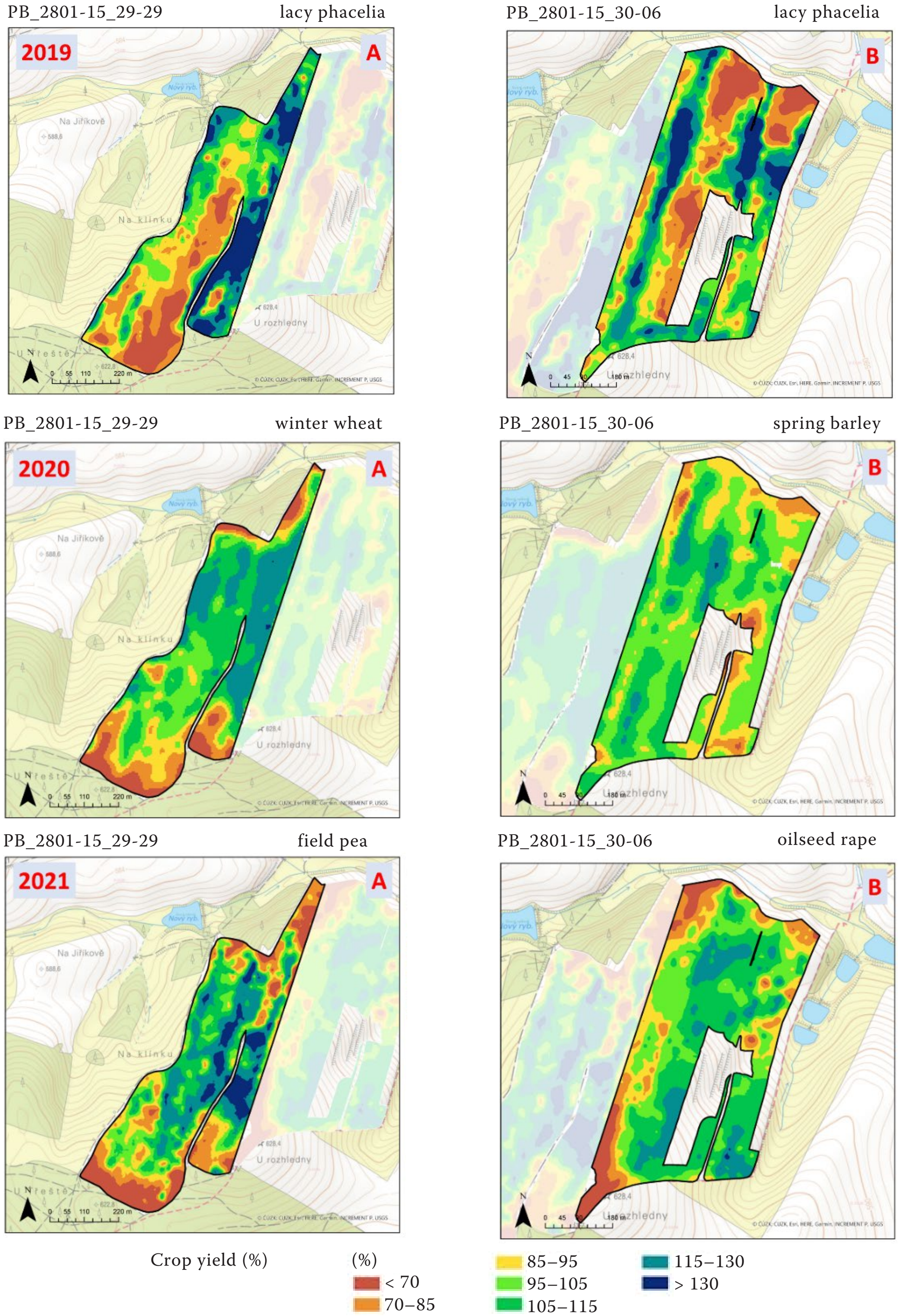

Figure 9. Relative yield (%) of crops grown on Experimental Plot 2801/15

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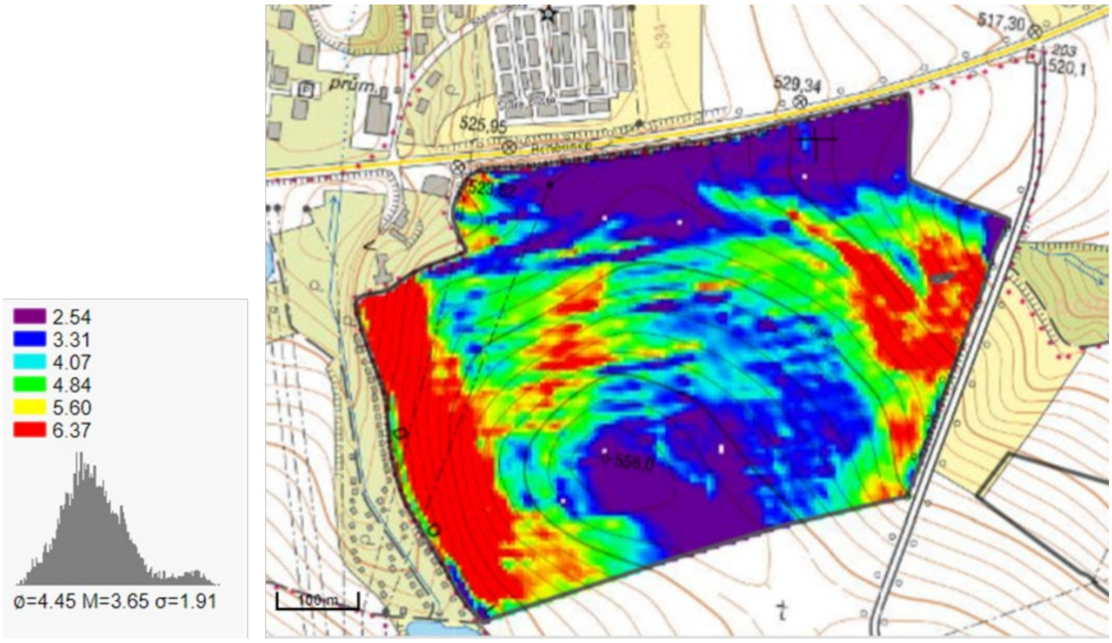

Figure 10. Terrain inclination on Experimental plot 7003/4

(Figure 10) identifies two zones with the slope > 6°. As these zones point mostly to PZ B, this could be an explanation to the transport of nutrients in that direction and to the increasing nutrient supply for plants at the cost of PZ B.

The different soil types also influence interactions of plants and the drawing of nutrients from the soil and hence also their capability of plant biomass formation (Li et al. 2021). The entire plot (PZ A + PZ B) is made up of light or medium-heavy soils; these soil types are more susceptible to the transport of nutrients from the upper soil by the action of water. This is why an assumption exists that the fact was in the past facilitated by the nutrient transfer from the northern part of the plot. On the other hand, erosion control technologies (direct seeding into intermediate crops, organic matter application) implemented in the given area strive for the elimination of this potential adverse effect.

Experimental plot 2801/15

Following the harvest in 2019, Experimental Plot 2801/15 was divided into two parts the reason being

Table 9. Zonal statistics for Experimental plot 2801/15 – area of individual percent categories of relative yield

	Relative yield (%)							Area (ha)
	0–70	70–85	85–95	95–105	105–115	115–130	> 130	
2019 (m²)								
A	27 329[b]	42 304[b]	42 160[a]	45 770[a]	44 390[a]	38 806[a]	25 942[b]	26.67
B	33 010[a]	52 263[a]	46 777[a]	43 808[a]	36 672[b]	38 396[a]	41 574[a]	29.25
2020 (m²)								
A	1 975[b]	15 950[b]	55 275[a]	112 900[a]	65 735[a]	14 650[b]	167[a]	26.67
B	25 420[a]	33 575[a]	35 550[b]	57 000[b]	79 050[a]	62 375[a]	225[a]	29.25
2021 (m²)								
A	18 503[b]	22 339[b]	35 891[a]	67 282[a]	90 509[a]	31 984[b]	192[b]	26.67
B	34 014[a]	39 076[a]	38 859[a]	47 314[b]	54 255[b]	57 950[a]	21 045[a]	29.25

[a,b]Different lowercase letters confirm honestly significant difference (P < 0.05) in relative yield between individual variants of experiment

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a severe risk of water erosion. The relative distribution of yield (Figure 9) shows that the plot is very heterogeneous. Already in 2019, before the DPB was split into two PZ (A, B), two continuous and very different yield levels were detected on the plot (< 70% and > 130%; Table 9). This confirms that a part of the DPB exhibited very low yields already in the past, probably due to terrain ruggedness. The impact of terrain ruggedness on the soil susceptibility to erosion which then adversely affects crop yields is generally known and characterised (Menšík et al. 2020). The assumption was corroborated also by the values from 2020 and 2021. Although different crops were grown on PZ A and PZ B (winter wheat (A) and spring barley (B) in 2020; field spring pea (A) and winter oil seed rape (B) in 2021), relative yields (%) demonstrated a similar variability (Table 9), i.e. the presence of zones with above-average or below-average yields. The only changes in the period from 2019–2021 happened in the area of these zones. The heterogeneity could have been caused for example by the variability of soil types and the presence of skeletons on the plot or by the sub-surface transport of nutrients as no signs of water erosion were detected during the monitoring of yield, and erosion control measures were implemented on all plots. The above-described heterogeneity in relative yields is apparent also in the histogram (Figure 6) which clearly shows that the distribution was homogeneous before the DPB division. After the division, the heterogeneity in relative yield increased in PZ A both in 2020 and 2021.

The zonal statistics show that no significant differences were found in the representation of main categories of relative yield (85–95% and 95–105%) of the same crop in 2019, i.e. before the physical division of the plot. By contrast, a demonstrably larger area of zones with a relative yield of 85–105% was recorded in 2020 and 2021 in plot part A as compared with plot part B following the physical division of the plot into two parts. The situation is most likely to have been caused by the plot topology with PZ A exhibiting a lower difference (36 m) between the highest and lowest points as compared with PZ B (56 m). The influence of the topology of the plot on its yield potential for the cultivation of conventional crops was confirmed by Wart et al. (2013), this of course being not the sole factor affecting their growth; other factors include climate conditions etc. (Lošák et al. 2012, Menšík et al. 2020, Kaur et al. 2023). We proceed from the assumption that the plots were applied very similar or the same management method (Tables 3 and 4), either for fertilisation or tillage.

Marginal areas of plots with the lowest productivity and irregular shape will be then chosen for the proposal of non-production plots, which is required from 2023 by the implementation of the EU Common Agricultural Policy (CAP) in the Czech Republic. This will simplify the shape of plots and optimise travel lines of agricultural machines when turning on headlands of complicated shapes. Thus, the implementation of CAP could have more favourable environmental and economic impacts. An example can be fragments of land on the eastern part of Experimental Plot 7003/4 which have arisen following the proposal of an erosion belt (Figure 8), or the southern corner of Experimental Plot 2801/15 B (Figure 9). At the same time, the non-production plots with crop mixtures without market valorisation will be established only in places with the lowest exhibited productivity (e.g.) the southwestern part of Experimental Plot 2801/15 A – Figure 9). Last but not least, the methods of tillage will have to be gradually innovated, and the process was already launched in 2022 (direct seeding and reduced number of land cultivation).

In conclusion, the decreased crop yield on the divided plots is apparent where relatively small parts (PZ) arise due to the division of field plots (DPB). The reason is that such areas feature zones with lower yield levels, e.g. new boundaries between the individual PZ where marginal effect develops, which results in a mild yield reduction. The analysis of measured yield data showed that the division of plots into smaller parts resulted in an uneven yield distribution because if a divided plot was heterogeneous in terms of yield levels, accumulation of "higher yield levels (> 100%)" could have occurred in one specific newly arisen plot at the expense of another one. New marginal parts of lands came into being during the division of larger soil complexes, and hence zones with potentially reduced yields. For example, a DPB-sized 35 ha has two headlands and two boundaries where the machines do not turn, yet the marginal effect is evident (shading, competition of another crop, etc.). Following the (virtual) division of such a DPB in the land parcel identification system, two new PZs come into existence sized 17.5 ha. Thus, not only two "new plots" arise but also new boundaries, and often also surfaces for entering the plot, turning of machines and the like, which results in increased areas with below-average yields.

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