GEOSPATIAL DATASET FOR EVALUATION OF FIELD SCALE EXPERIMENT

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Abstract
Successful implementation of precision agriculture technologies is subject of reliable experimental data. Field scale experimentation plays an important role as a source of information for farmers. Due to the inherent spatial variability of the field, this type of research, requires use of robust methods to ensure the statistical significance. Geospatial multidataset offers advantages compared to traditional data collection methods. Presented paper shows on an example of long-term field scale experiment on CTF technology, benefits of using geospatial dataset. Results showed that combining the satellite data and the combine harvester yield monitoring data help to assess the field scale experiment outputs during the growing season as well as at the harvest stage. Beneficial is most of all the overall view across long term period comprising weather extremes as well as typical years.

Key words: *traffic management, CTF, yield, remote sensing, cereal.*

INTRODUCTION

The technologies of precision agriculture have been the subject of scientific research for last decades (*Gebbers & Adamchuck, 2010; Shafi et al., 2019; Galambosova et al., 2020*). All scale of experiments has been established, however, to provide a realistic view of a technology implementation in practical farming conditions, long term field scale experiments play an important role (*Godwin et al., 2015; Kravchenko et al., 2017*). According to *Godwin et al. (2015)* a robust experimental design and adequate replication is necessary when field studies are undertaken. Hence, limitations in terms of statistical significance are present. Author claims that the experiment layout often cover big areas and so inherent field variability effects the data and causes variability of the data obtained (*Godwin et al., 2015*).
Traditional hand sampling and ground-based sensing might be challenging from the time as well as financial considerations, therefore non-contact methods offer potential advantages. Free satellite data are reliable tool to assess the field variability (*Skakun et al., 2021*)
The aim of this paper was to show the possibility of use of geospatial multidata sets obtained from remote sensing and combine yield monitoring systems to assess the crop yield of selected cereals at two experimental fields: a controlled traffic farming (CTF) field and a random traffic farming (RTF) field. Accent was placed to comparison in several seasons with different climate conditions.

MATERIALS AND METHODS

Experimental site
To evaluate the differences between selected traffic treatments, two fields were selected (Fig. 1). This fields are situated close together (4 km away by bee line) at the University farm of the Slovak University of Agriculture in Kolinany, located in south-west of Slovakia.
Field A: CTF system with 6m OutTrac modul (63,8% non-compacted soil, 36,2% compacted soil) was established in 2009 on 16 ha field "A" (48°22'16.97" N, 18°12'25.43" E). Commercially available machinery with standard wheel spacing (as they are manufactured) is used for all work operations. Since 2009, this field (A) is cultivated within soil conservation tillage technology (without ploughing) up to depth of 15 cm. In 2021 no till technology was used and the crop was drilled directly into the previous crop stubble. On this field ("A") the tree band areas were established in 2010, by reason of modelling

RTF traffic management in the same field. This bands were generated by wheel-by-wheel movement of tractor (JD 8230 with RTK guidance system) in right angle to direction of CTF lines, ones pre year, after harvest annually from 2010 (Fig. 1). More detailed information is available in published papers *Macák, et al. (2018) ; Galambošová et al. (2017); Barát et al. (2017), Goodwin et al. (2015).*

Field B: As a reference field a 23ha field (48°20’36.61” N, 18°13’39.15” E) with conventional management system (random traffic during all field operations) and conventional tillage technology with ploughing (up to depth 30 cm) was selected.

According to soil classification (BPEJ units), the soil type at both experimental fields is classified as loamy soil (*Džatko, et al., 2009*), and the elevation ranged from 178 to 212 m a.s.l. with average slope about 6%.

For this study, barley and wheat crops were selected and seasons where these two crops were grown at the two fields were selected. Choice of crop and their variety was done by the agronomist´s best practice in each year and the overview is provided in Results (Tab. 1). Year average precipitation throughout the assessed time period (2009-2021) is displayed in Fig. 2. Source data sets were obtained from meteorological station situated in university farm (in Kolinany), between the fields A and B.

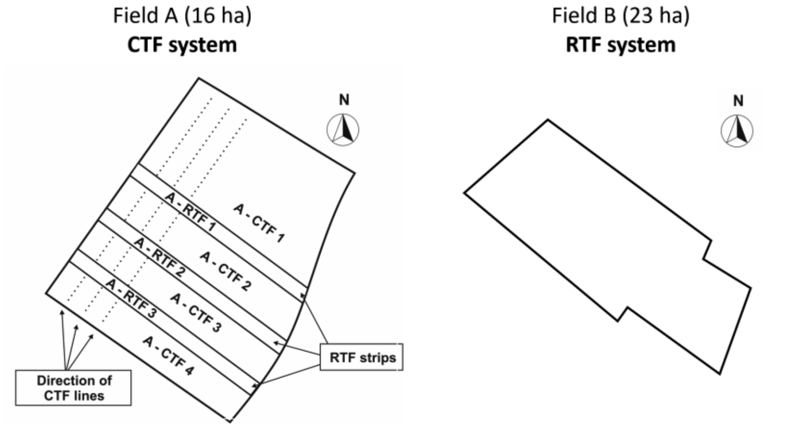

Fig. 1 Experimental site and detail pattern of the fields; (field “A”: areas of CTF system: A - CTF1, A - CTF2, A-CTF3, A-CTF4; and areas with modelling RTF traffic system = RTF strips labelled as A-RTF1, A-RTF2, A-RTF3; field “B” – whole of parcel is defined as area named B – RTF)

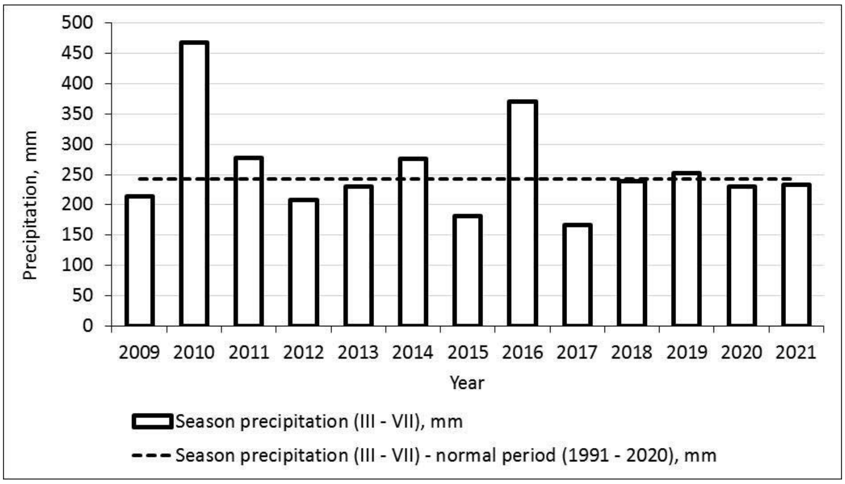

Fig. 2 Seasonal (March-July) average of precipitation thought the assessed period of time (2009-2021) for location of university farm - Kolinany (data source climate normals: SHMU, 2020)

Multiannual data used from Remote sensing and yield monitoring

Experimental fields were monitored by satellite images and yield mapping. Evaluation was done with multiannual data sets for selected cereal crops (field “A” was monitored from 2009 and yield “B” from

2007). Calculation of Normalized Vegetation Index (NDVI) was carried out for every downloaded satellite image by SNAP (version 8.0.7) and ENVI (version 5.6.1) software. Detail overview of used satellite platforms is listed in Table 1.
For yield mapping the John Deere combine with impact sensor or Claas harvester with optical sensor were used too. Available yield maps (in selected years, see Table 1) were processed by ArcGIS Pro software (version 2.8.3) by geostatistical methodology (detailed described at Kumhálová et al., 2011) to the resulting kriging maps. Yield maps obtained from yield monitoring systems were available for seasons from 2011 to 2021 (field A), and for 2014, 2017, 2019 and 2021 (field B). In other monitoring years (when the map is not available), the yield was calculated as average from data available only from cargo balance.
In order to standardize the data, NDVI and yield data were transformed to relative numbers. Then the frequency maps (FM) were computed by "Cell Statistics tool" (in ArcGIS Pro software). Thus, calculated frequency maps allow view areas with potential of crop vitality and structure (in the event of NDVI maps) and yield (in the event of using yield maps).

RESULTS AND DISCUSSION

Relative yield and relative NDVI values for targeted seasons is summarised in Table 1. When assessing performance of given technology, many factors effect the yield and yield potential. Crop varieties and agroecological conditions of the fields are very important for the resulting yields and yield potential (*Jelínek et al., 2020; Balážová et al., 2021*). From the results it is evident that conversion of the conventional technology to soil conservation brought decrease on yield in the first years of the experiment in "field A" with relative improvements further after season. A drop in yield was detected on 2021 season, when no-till drill was used for the first time.

Tab. 1 Crop, average yield and mean relative values of NDVI and yield for fields A and B

Field	Year	Remote sensing platform**	Crop and variety	Yield - field average ($t.ha^{-1}$)	CTF Yield (%)	CTF NDVI (%)	RTF Yield (%)	RTF NDVI (%)
A	2009	L5 TM	Spring barley cv. Kango	5.01*	-	101.35	-	100.97
	2011	L5 TM	Winter wheat cv. Augustus	6.17	94.58	100.23	98.43	101.17
	2014	L8 OLI	Spring barley cv. Kango	4.8	95.85	99.98	98.47	101.37
	2016	L8 OLI	Winter wheat cv. HYFI	7.94	101.00	100.95	100.77	100.20
	2017	L8 OLI	Winter barley cv. Wintmalt	6.73	105.35	100.93	104.80	100.37
	2019	S2 MSI	Winter wheat cv. RGT Reform	7.8	103.23	100.60	101.87	100.47
	2021	S2 MSI	Spring barley cv. IS Maltigo	3.04	99.18	96.73	102.53	99.4
B	2007	L5 TM	Spring barley cv. Ebson	4.81*	-	-	-	98.36
	2008	L5 TM	Winter wheat cv. Armelis	5.77*	-	-	-	100.44
	2010	L5 TM	Winter wheat cv. Vendur	2.47*	-	-	-	99.74
	2014	L8 OLI	Winter wheat cv. Globus	5.80	-	-	101.90	100.11
	2017	L8 OLI	Winter wheat cv. Fabius	4.66	-	-	98.26	99.96
	2019	S2 MSI	Winter wheat cv. Genius	7.37	-	-	100.86	100.06
	2021	S2 MSI	Spring barley cv. IS Maltigo	4.5	-	-	106.08	100.39

Note: parameters: CTF Yield (%), CTF NDVI (%), RTF Yield (%) and RTF NDVI (%) are calculated from remote sensing data as mean relative value
* data is available only from weighting whole grain mass by cargo balance; symbol " – " indicates that data are not available
** satellite images were downloaded from USGS archive (*https://earthexplorer.usgs.gov/*) and Open Access Hub of ESA Copernicus program (*https://scihub.copernicus.eu/dhus/#/home*)

Use of geospatial datasets make it possible to compare the A-CTF with A-RTF areas with sufficient data robustness. It is obvious from the data, that the A-CTF outperformed the A-RTF after initial 5 years (in seasons 2016, 2017, 2019). These results are of great importance as the 2016 was the extremely wet season and as opposite 2017 was extremely dry season (Fig. 2). As the yields are calculated as relative values – A-CTF area can be compared also with field B. Relative yields were higher at A-CTF up to 7.09 % in comparison with B-RTF system in the dry season 2017 when the total precipitation during main growing season was lower by 32% compared to long term average. This increase of yield (favour of CTF system) was observed despite that, in the 2017 the winter barley (crop incoherent to soil air deficiency and sensitive to soil compaction) was growing on field A and winter wheat (specie “Fabius” with middle drought tolerance) has been sowed on field B. The CTF method seems to be more appropriate and gentler in this respect. *Busari et al. (2015)* also concluded that for dry years, it might be better to implement tillage management avoiding soil compaction and support its conservation.

In normal precipitation year (e.g., 2019) when winter wheat was growing on both fields, difference in mean relative values of yield was up to 2,37 % for benefit of field A (managed under CTF system). When comparing real measured yields (from cargo balance) the increase of the yield is up to 5,8% for CTF field in 2019. It can be stated that over the years, the field managed by the CTF traffic systems has stabilize yields of cereals with potential for their growth in drier years and compared with compacted soil at A-RTF areas the benefit is visible also during extremely wet yeas (season 2016).

Data from Yield monitoring systems always follows the NDVI data. This is an important information as yield monitoring data are not always available or are not correct and hand sampling might be non-efficient for such a type of experiment.

Use of satellite data in 2021, no till drill was used for the first time at the CTF field, what was reflected in lower yield, this effect was clearly detected by the NDVI as well as yield monitoring system. The reduction was present at CTF as well as RTF areas of the field A, compared to the RTF at field B.

To have an overview of the whole time period, summary statistics of relative yield and NDVI frequency maps for different management systems (CTF and RTF) is provided in Table 2. The results show that different mean values were found between the relative yield and NDVI frequency maps for yield potential estimation. While the mean value for NDVI frequency maps was around 110 %, for yield frequency maps it was around 120 %. The difference in the results is due to the different way of obtaining the source data. While the Yield frequency map is based on the yield maps of the monitored years derived from the final harvest data, NDVI frequency maps are averaged images of the current state of the stand in each year captured in the pre-ripening phase.

Tab. 2 Summary statistics of relative (%) frequency maps (FM) for NDVI index and yield on both experimental fields (A and B) characterized by different management system: controlled traffic farming (CTF) and random traffic farming (RTF), α=0.05

Parameter	A-CTF		A-RTF (modelled RTF)		B-RTF	
	FM NDVI	*FM yield*	*FM NDVI*	*FM yield*	*FM NDVI*	*FM yield*
Mean	110.39	119.95	110.76	121.27	109.54	119.94
Error of mean value	0.31	0.58	0.27	0.52	0.38	0.66
Median	107.02	114.73	106.94	115.03	109.85	114.14
Modus	111.82	113.85	104.71	115.07	109.96	107.23
St.Dev.	9.72	18.23	10.49	20.31	5.78	30.23
Variance	94.80	336.18	110.11	412.70	33.38	914.04
Kurtosis	0.47	2.10	0.36	1.55	2.34	11.96
Skewness	1.19	1.49	1.21	1.40	0.92	3.19
Difference max. min.	41.57	112.19	42.74	126.74	37.13	244.29
Minimum	97.78	83.73	97.78	76.32	99.59	61.92
Maximum	139.35	195.92	140.52	203.06	136.72	306.21
Sum	113750.52	123845.96	169474.69	185553.02	25084.95	250547.06
Count	1029.50	1029.50	1530.00	1530.00	229.00	2089.00
level of sign. (95.0%)	0.61	1.13	0.53	1.02	0.75	1.30

FM – frequency map, NDVI -Normalised Difference Vegetation Index, sign. – significance, St.Dev. – Standard Deviation

CTF management has generally proved to be a management method that is able to provide stable yields on the whole plot in the long run (see individual measured years in Table 1), especially in dry years. Although the mean value of the relative yield potential was relatively lower, compared to the RTF field B management. As Table 2 shows, Yield_CTF was 119.95%, while Yield_RTF was 121.27% on field A. On the field B, where RTF management was fully operated, the value of the relative yield frequency map reached 119.94 %. The values related to NDVI frequency maps had the same trend, where field B

with complex RTF management showed the worst mean values. NDVI as a green crop vitality indicator can show current state of the canopy related to a certain date or period of the growth stage and is usually related to the agroecological conditions of the field.
The standard deviation and variance also differed with presented management methods. CTF management in field A showed lower values of standard deviation and variance for both: Yield and NDVI frequency maps than for modelled RTF management. Field B showed relatively large differences between yield and NDVI in this respect, with the resulting yield potential achieving high variability on this field. Again, when looking at the variability of the CTF field (*Galambošová et al., 2017*), decrease of the standard deviation at A-CTF an areas throughout the seasons (*Rataj et al., 2022*) and overall (Tab. 2) compared to A-RTF and B-RTF shows the potential for management the variability and stabilisation of yields via avoiding soil compaction.

CONCLUSIONS

In this study we used multiannual datasets to assess the vitality of selected cereals growing under two different traffic management systems (CTF and RTF). Combining the satellite data and the combine harvester yield monitoring data help to assess the field scale experiment outputs during the several growing seasons as well as at the harvest stage.
Results showed that performance of a tested technology (CTF) can be reliably evaluated after each growing season and relative yield and NDVI data enable to compare the performance with a technology where random traffic is used.
Data confirmed the potential of CTF technology to stabilise the yield during extremely weather conditions and given them potential for growth in drier years (up to 7%). Beneficial is most of all the overall view across long term period of time comprising weather extremes as well as typical years.

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