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Digital elevation models as predictors of yield: Comparison of an UAV and other elevation data sources

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Abstract. Topography usually plays an important role for yield variability assessment. This study provides insight into the use of surface models from different sources for agriculture purposes: unmanned aerial vehicle imagery, LiDAR data and elevation data acquired from a harvester. The dataset from an aerial vehicle was obtained in the form of ortho-mosaics and digital surface model using casual camera. The LiDAR data was provided by the State Administration of Land Surveying and Cadastre in the form of Digital Terrain Model of the 4th and 5th generation. The data of yield together with its coordinates were gained from a combine harvester in the form of a regular grid. Yield data was interpolated by kriging geostatistical method. Position data including an altitude was used for modelling the last digital surface model. All gained surface models were correlated with the spring barley yield. Results show correlation similarity across all tested models with the yield; no significant differences were sighted. Free available coarser scale data is able to predict a yield sufficiently. The study indicates less effectivity of using very detailed scale data sources due to its time-consumption or expensive data gathering and processing process.

Key words: Unmanned aerial vehicle, structure from motion, spatial resolution.

INTRODUCTION

Elevation data can be acquired from three main sources: ground surveys, existing topographic maps and remote sensing techniques (Ouédraogo et al., 2014). Imagery acquisition using unmanned aerial vehicles (UAV) is very popular elevation data gathering technique within the last years. Besides other advantages, consumer grade cameras can perform high spatial resolution and high temporal frequency imagery. It is possible to get sufficient-accuracy ortho-mosaic and elevation model of large areas. UAV-based data became a promising tool for many agronomic applications during last few years (Schmale et al., 2008; Zhang & Kovacs, 2012; Gómez-Candón et al., 2014). These systems become an effective complement for conventional agricultural approaches, especially in precision agriculture or site-specific management respectively (Primicerio et al., 2012; Honkavaara et al., 2013; Rokhmana, 2015). UAV could be less

expensive and more practical in contrast with satellite and airborne systems for high resolution remotely sensed data (Zhang & Kovacs, 2012). That is why it is possible to use UAV for the creation of topography model for agricultural purposes. Moreover, it is possible to capture actual micro-topography in any time using UAV. The Digital Elevation Model (DEM) is a stable factor compared to other variables (Schmidt & Persson, 2003), and it is generally known that spatial variability of yield can be explained by topography as one of several variables (Zhang et al., 2002). For example, Kumhálová & Moudrý (2014) used RTK-GPS, harvester yield monitor with DGPS and Airborne Laser Scanning (ALS) in their study. Using aerial systems, high spatial scale data are gained. Use of low-cost cameras and specialized software solutions make the generation of ortho-mosaic and elevation models quite easy. UAV based models usually reach resolutions within centimetres. On the other hand, there is still the question of justification of accurate digital surface models in comparison with free available coarse datasets.

The aim of this study was to discuss the effectiveness of Digital Elevation Models from different sources with different spatial resolution for explanation of yield on large agricultural plots.

MATERIALS AND METHODS

The experimental field is located near to Vendoli in Eastern Bohemia (49°43' 47.94"N, 16°24' 14.21"E) and its size is 26.4 ha large. A 15.55 ha section of the field was chosen for our experiment. The terrain of the plot is undulated with an average slope of approximately 6%. The elevation ranges from 555.3 to 571.6 m above average sea level (565.4 m on average). The soil can be classified as modal cambisoils lying on calcareous sandstone. Some parts, on sloped terrain especially, are strongly eroded. The average precipitation is 700 mm per year and the average temperature is between 6–7 °C. Conventional arable soil tillage technology based on ploughing and crop rotation system based on wheat, barley and oilseed rape crops alternation were applied on the plot.

The topographic data were obtained from four sources. The first data set was obtained from perpendicular images taken by an unmanned aerial vehicle using the photogrammetry approach. Aerial photographs were taken on September 11, 2015 by a fixed 16 mm focal length lens at consumer-grade RGB camera Sony NEX5. The camera was mounted on the Falcon 8 V-form octocopter platform manufactured by Ascending Technologies GmbH, Germany. The aerial system and the camera were managed manually by a pilot. Photoscan software solution (version 1.2.6., Agisoft LLC, Russia) was used for aligning imagery and dense cloud generation. Images were aligned using 74 ground control points, which were measured by real time kinematic GPS method using Trimble device with VRS Now corrections. Digital elevation model with its final spatial resolution of 0.05 m was created from 285 overlapping images using Structure from Motion method (Fig. 1a). More than 80 million dense cloud points were gained by this approach. The next sources of elevation data, Digital Terrain Model of the Czech Republic of the 5th generation (DMR 5G) and Digital Terrain Model of the Czech Republic of the 4th generation (DMR 4G), Airborne Laser Scanning data sets were kindly provided by the State Administration of Land Surveying and Cadastre. Both models represent natural man-modelled terrain in digital form from the year of 2013. DMR 4G

was distributed in a grid of 5×5 m with total mean elevation error of 0.3 m in open areas, while DMR 5G was distributed in a grid of 2 × 2 m with a total mean elevation error of 0.18 m (Brázdil & Dušánek, 2010; 2012).

Yield and the fourth terrain model has been measured by axial combine harvester New Holland CR9080. The harvester was equipped with a yield monitor and differential GPS receiver. The precision of this system is ± 0.1 to 0.3 m horizontally and ± 0.2 to 0.6 m vertically. The yield and elevation data were stored with the coordinates every second. The yield values of spring barley were corrected using a common statistical procedure; all values that exceeded the range defined as mean ± 3 standard deviations were removed. Because of the large amount of data for every year studied (more than 18 thousand), the MoM (Method of Moments) was used to compute the experimental variograms. Experimental variograms of yield were computed and modelled by weighted least squares approximation in GS+ (Gamma Design Software LLC, USA). Ordinary punctual kriging was done using the relevant data and variogram model parameters for yield data visualization. For detailed description of the data sets see Table 1. All spatial data were processed using ArcGIS solution (version 10.3.1., ESRI, USA).

Table 1. Summary of statistics for data sets used (m)

Source	Yield harvester	DEM harvester	DEM UAV	DEM DMR 4G	DEM DMR 5G
Count	18,537	18,537	62,188,439	6,118	38,811
Resolution			0.05 × 0.05	5 × 5	2 × 2
Mean	4.049	566.8	566.2	565.7	565.1
Median	4.111	567.0	566.7	566.0	565.0
Std	1.377	3.178	3.797	2.994	3.064
Minimum	0.204	557.0	554.0	556.6	556.0
Maximum	8.733	578.0	573.3	571.6	571.0
Skewness	-0.025	-0.310	-0.432	-0.458	-0.449

Statistical data was counted in R free software (version 3.2.2., R Core Development Team, Austria). The number of 23 random sampling points were created for the plot. At each point, the yield and altitude from all four digital elevation models were estimated. The yield spatial autocorrelation was verified by Moran's Index where presence of autocorrelation was not revealed. The estimated altitude from each model in each point was then tested for correlation with yield. R-squared error was also determined by fitting individual linear models for each digital elevation model as predictor of yield. A Hot Spot map of yield was finally created by using the Getis-Ord Gi* statistic for supporting our results.

RESULTS AND DISCUSSION

The results of the evaluation are shown in Table1. DMR 4G and DMR 5G models had similar median and also minimum and maximum values. Slightly different values can be observed in the digital model obtained by UAV (Fig. 1a). This is due to a better resolution which can capture different local roughness. Standard deviation is also slightly higher in UAV (4.15) compared to DMR 5G (3.43) and DMR 4G (3.34). The

elevation models used are highly correlated (between ≈0.98 and ≈1.00, Pearson R), see Fig. 2. To evaluate differences in the models, we provide Tests of significance for correlations (r.test). The results show that input models are equivalent as predictor of yield with probability of ≈ 100%. For a better understanding of heterogeneity of yield at the field we have created a hot spot map where statistically significant high (red colour) and low (blue colour) yields can be observed, Fig. 1b. It also reveals relative homogeneity of field yields.

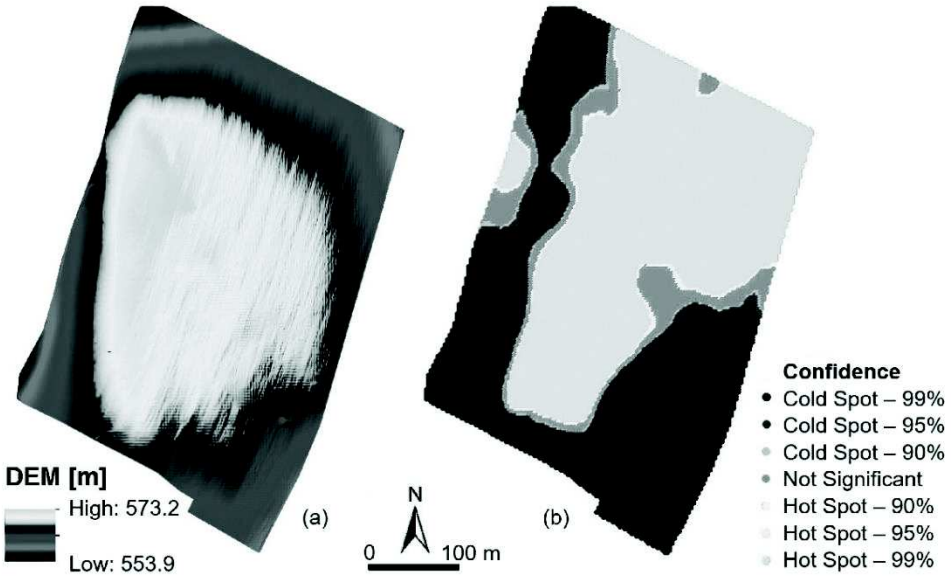


Figure 1. Elevation model using photo-reconstruction methods (a) and yield hotspot map (b) of the field study.

Elevation models were compared according to yield data using the correlation method (Table 2). The best model for yield prediction was DMR 4G explained 22.08% of yield variation followed by DEM from the UAV and DEM from the combine harvester. But all models can equally predict yield. The ability for predicting yield varies from 19% to 22% depending on the model.

Table 2. Statistics of correlation between models; yield and amount of variability in yield

Source	DEM harvester	DEM UAV	DEM DMR 4G	DEM DMR 5G
Pearson's correlation coefficient	0.480	0.502	0.477	0.506
Correlation significance (p-value)	0.020	0.015	0.021	0.014
Adjusted R-squared	0.194	0.217	0.221	0.191

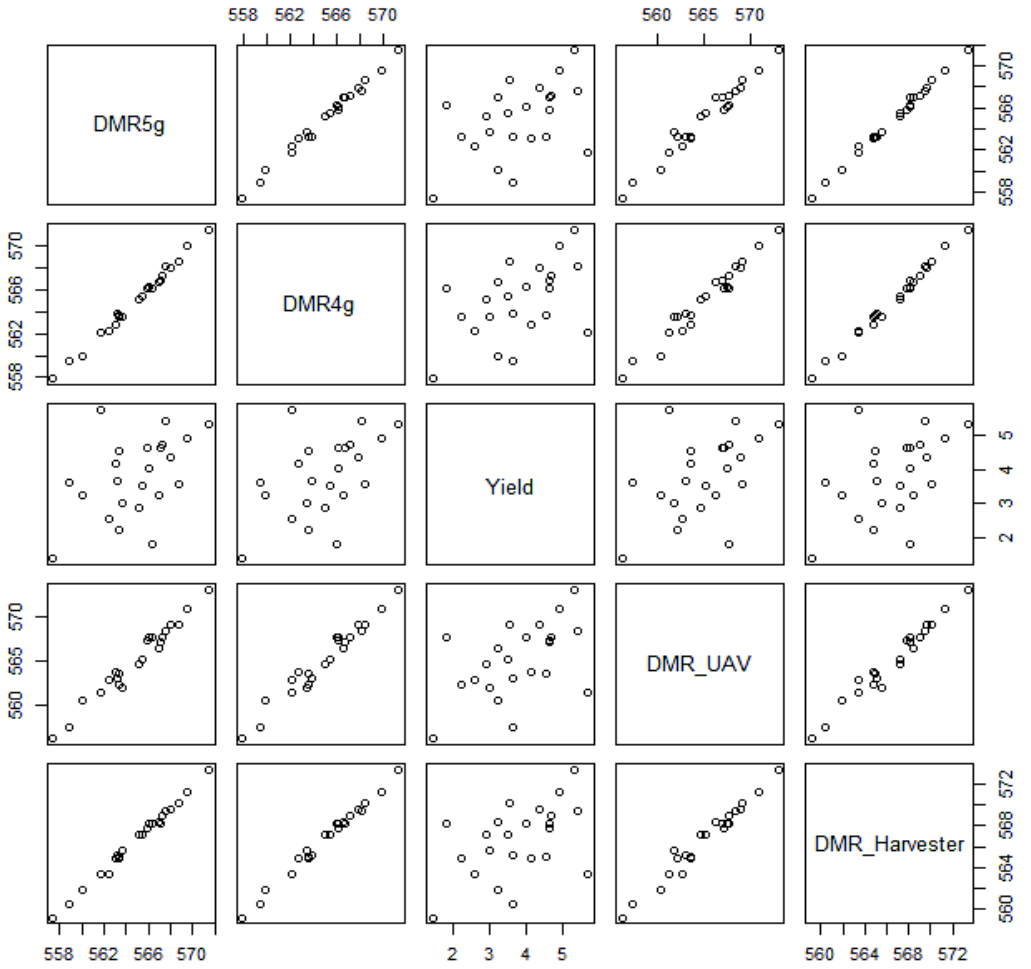


Figure 2. Matrix of input scatterplots showing dependence of input variables.

There is an effort in recent studies (Ristorto et al., 2015; Rokhmana, 2015) to use the most accurate data with the finest resolution as possible. As we show in this study, a field's yield can be relatively homogenous (Fig. 1b). In fact, using the finest resolution for prediction of yield does not necessarily bring additional information and furthermore, can have similar information value as models with coarse resolution. Uysal et al. (2015) discussed in their study the advantages of UAV systems utilization, such as low-cost, real time, high temporal or spatial resolution data. These conclusions are in accordance with our study. The UAV campaign was planned to early spring after sowing the spring barley, when the soil was bare. Belka et al. (2012) stated that the Airborne Laser Scanning was made during the spring or autumn. A large part of the Czech Republic was scanned regardless of vegetation on the fields. The flexibility in time is why the UAV possibility is suitable for monitoring the agriculture plot in different time.

Comparatively, acquisition of DEM from UAV is quite time consuming. To benefit from accurate UAV based DEM, 74 ground control points were necessary in our study. All of the points had to be measured by accurate GPS method. Moreover, special

software has been used for computation of DEM from acquired photos. As we can see from the results, the ability to predict yield is similar across our models. In this point of view, the free available DEM models (DMR 5G or DMR 4G) could be better due to less time consumption. The digital model acquired by harvester is also a better choice than UAV in this case; nevertheless, some interpolating technics have to be made in GIS software to achieve final DEM.

The explained variability of yield reached at maximum only 22% in the DMR 4G model. It can be assumed that we could obtain similar results with other predictors, i.e. amount of soil meter, fertilization distribution, distribution of water, solar radiation etc. Using coarse data for predicting future yield or plant health could bring similar information value as the more accurate ones.

CONCLUSION

In this study we compare different digital terrain models obtained from different sources. Despite the fact of different resolution and accuracy of the data (from course 5 × 5 m to 0.05 × 0.05 m UAC model), the ability of models to predict the final yield were almost the same. We did not observe any statistically significant difference between input models.

As our results show, to use the most precise data is not necessary in every case. Less accurate, free available data could be equally sufficient to data with high costs or high time consumption. UAV based data can be used for DEM generation as a low-cost and real time source.

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