Chapter 18
Delineation of Management Zones Using Satellite Imageries

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Abstract The chapter describes the development of a platform for mapping crop status and long-time trends by using EO data as a support tool for fertilizing and crop protection. The main focus of the pilot is to monitor cereal fields by high-resolution satellite imagery data (Landsat 8, Sentinel 2) and delineation of management zones within the fields for variable rate application of fertilizers. The first part of the paper is focused on analysis of strategies for recommendations derived from satellite data. The second part is focused on development of a software application with the goal to offer farmers a GIS portal. Here, users can monitor their fields from EO data, based on the specified period and select cloudless scenesfor further analysis. The tool supports collaborative communication between farmers and advisors.

18.1 Introduction, Motivation and Goals

Yield production zones are areas with the same yield level within the fields. Yield is the integrator of landscape and climatic variability and provides useful information for identifying management zones [1]. This work presents a basic delineation of management zones for site-specific crop management, which is usually based on yield maps over the past few years. Similar to the evaluation of yield variation from multiple yield data described by Blackmore et al. [2], the aim is to identify high yielding (above the mean) and low yielding areas expressed as the percentage of the mean value of the field. In addition, the inter-year spatial variance of yield data is important for agronomists to distinguish between areas with stable or unstable yields.

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Complete series of yield maps for all fields are rare; thus, vegetation indices derived from remote sensing data are analysed to determine field variability of crops [3].

(1) **Diagnosis of the nitrogen status in crops by continuous monitoring of crop stands during vegetation**

This procedure is applied especially to crops with N-splitting fertilization and top-dressing during vegetation. It is based on the relationship between the crop biophysical properties and the spectral reflectance. The nutritional status is defined by the basic parameters of the crop stand, such as the nitrogen content [%] in the leaves of plants (or other parts of plants) and the amount of aboveground biomass [g/m^2]. Nutritional indicators, such as the N-uptake [g/m^2, kg/ha], are derived from this data. For this purpose, red-edge vegetation indices are most often used, which generally show a higher sensitivity to changes in chlorophyll content—NDRE, REIP, S2REP [4].

Evaluation of the relationship between N content and the amount of aboveground biomass during vegetation is analysed using the nitrogen nutrition index (NNI), which compares the current N content according to the critical N curve in various stages of plant development determined from the amount of aboveground mass [5]. The critical nitrogen absorption curve derived from the dilution curve developed by Justes et al. [6] is a common method in deciding whether the crops require additional N [7]. The value NNI = 1 indicates optimal nutritional level N, NNI < 1 insufficient nutritional level N and NNI > 1 excessive intake of N. Curves are defined for different crops. NNI is directly estimated from the empirical relationship with chlorophyll concentration within the canopy as measured by canopy reflectance. Leaf N concentration is estimated from the empirical relationship with chlorophyll concentration (Cab), and crop LAI is measured by remote sensing [8].

(2) **Variable rate applications according to yield potential zones**. In this case, fertilization is based on the requirements to cover the nutrient uptake for the expected yield. Yield levels are defined from yield production zones based on the analysis of a time series of yield maps or the trend of distribution of vegetation status from EO data (both 5–10 years) [9]. Production zones represent the percentage deviation from the average yield value on a given field, which is later determined in absolute values of the yield by multiplying with average expected yield values per each field.

This is a procedure suitable for crops with the recommendation of fertilization before the full coverage of crop stand, when it is not possible to use diagnostics of nutritional status based on continuous monitoring.

(3) **A combination of both mentioned principles**. In this case, coverage of the N-uptake by expected crop yield from productivity zones is corrected with splitted N-applications according to the actual diagnosis of crop stand by remote sensing. This approach includes the use of EO data or proximal sensing (N-sensors) with map overlay functionality [10] (Fig. 18.1).

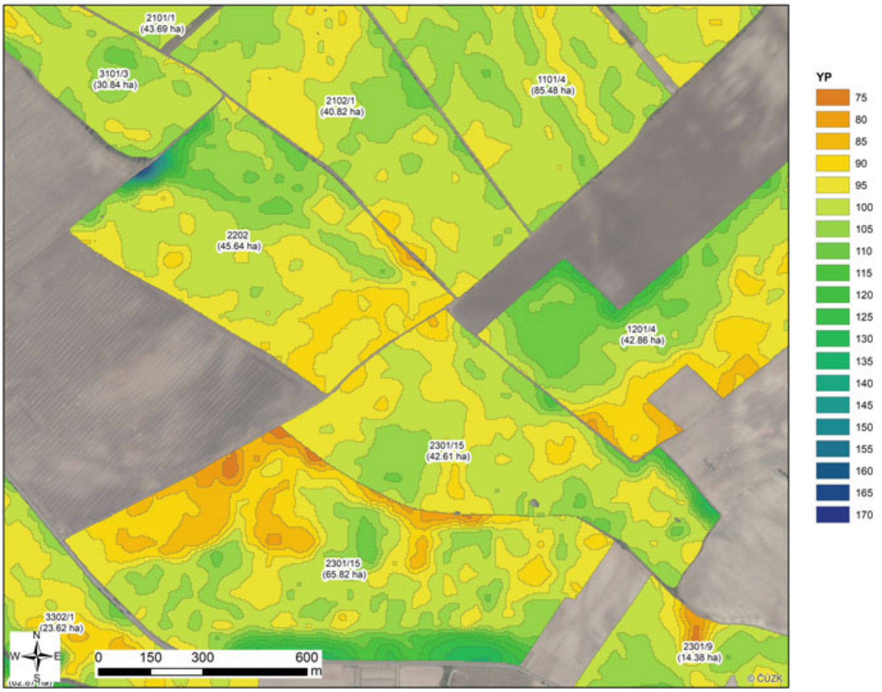

Fig. 18.1 Map of yield potential delineated from multi-temporal Landsat imagery

18.1.1 Nitrogen Plant Nutrition Strategies in Site-Specific Crop Management

The dose amount for individual management zones is determined based on two basic principles—increasing the N dosing in the zone with a higher yield (**yield-oriented**) or increasing the N rate in the below-average zones (**homogenization**).

The **yield-oriented strategy** is based on the principle of a higher requirement for nitrogen nutrient to cover a higher level of expected crop yield, which is spatially distributed by the yield productivity zones. The N rate is determined on the basis of a nitrogen balance modelling as part of the nutrient input. Areas with long-term lower crop yields are fertilized with lower N rates than places with expected higher yields. In graphical terms, this strategy is represented by a sloped curve whose inclination means the intensity of the N rate change. The curve has limit values at both ends—the minimum dose is for the plants in bad condition, which ensures at least a minimum supply of nutrients, and the maximum dose is for areas, where there could be a risk of lodging in the specific weather condition. The total amount of applied N can be specified during the growing season on the basis of continuous plant diagnosis, assessment of mineral N content in the soil or modelling of plant growth and the expected uptake of nitrogen by plants. This strategy follows the distribution of the yield potential zones within the field in a situation, where nitrogen is not considered as a yield-limiting factor. It is usually used for ear-types of cereal varieties, where the level of yield can be increased by supporting the formation of ears and ensuring an increased number of grains per ear.

The second strategy **homogenization** is based on the concept of agronomic and nutritional practice developed since the 1980s. The nitrogen is here considered a yield-limiting factor, and low-yielded areas are supported by higher doses of N. The dosing curve has a negative slope, includes capping at both ends, and its negative inclination can be specified by the user. This strategy is appropriate to increase the booting of cereals in weak places or to homogenize the qualitative parameters of the grain.

18.2 Pilot Set-Up

The pilot aimed at developing a platform for mapping of crop vigour status by using EO data (Landsat, Sentinel-2) as the support tool for variable rate application (VRA) of fertilizers and crop protection. This includes identification of crop status, mapping of spatial variability and delineation of management zones. Development of the platform was realized on a cooperative farm in Czech Republic; however, the basic datasets are already prepared for the whole Czech Republic. Therefore, the current pilot supports utilization of the solution on any farm in Czech Republic.

The pilot farm Rostenice a.s. with 8,300 ha of arable land represents a bigger enterprise established by aggregating several farms in the past 20 years. The main production is focused on the cereals (winter wheat, spring barley, grain maize), oilseed rape and silage maize for biogas power station. Crop cultivation is under standard practices, and partly conservation practices are treated on the sloped fields threatened by soil erosion. Over 1,600 ha has been mapped since 2006 by soil sampling (density 1 sample per 3 ha) as the input information for variable application of base fertilizers (P, K, Mg, Ca). Nowadays, the soil sampling covers the full area of the farm. Farm machinery is equipped by RTK guidance with 2–4 cm position accuracy. Until 2018, farm agronomists have not been using any VRA strategy of nitrogen fertilizers and crop protection because of lack of reliable solutions in Czech Republic (Fig. 18.2).

During the 2018 vegetation period, a field experiment was established for testing variable rate application of nitrogen fertilizer based on the yield potential maps computed from Landsat time-series imagery and digital elevation model (DEM). Testing was carried out on three fields with a total acreage of 133 ha. The main reason was to tailor nitrogen rates for spring barley according to the site-specific yield productivity and to avoid the crop lodging risk in the water accumulation areas. Plant nutrition of spring barley for malt production is more difficult than for other cereals because of limits for maximal N content in grain. Thus, balancing N rates to reach highest yield and simultaneously not exceeding N content in grain is crucial for successive production of spring barley.

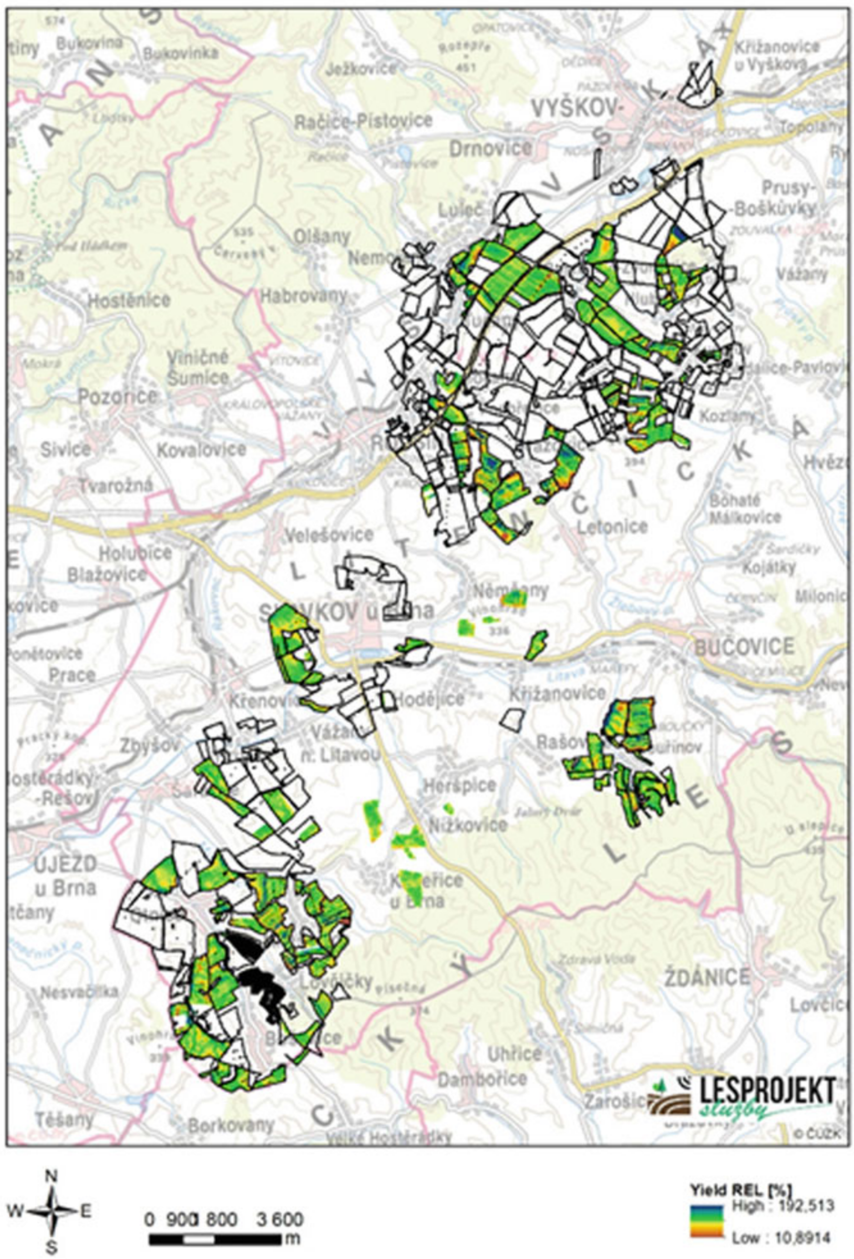

Fig. 18.2 Yield maps represented as relative values to the average crop yield of each field (harvest 2018)

For definition of yield productivity zones, a 8-year time series of Landsat imagery data was processed giving relative crop variability. The final map is represented as percentage of the yield to the mean value of each plot, later multiplied by expected yield [t ha^{-1}] as the numeric variable for each field and crop species. Values of yield potential were reclassified into three categories—high, middle and low-yielded areas, and the nitrogen rate was increased in the high expected yield areas (Figs. 18.3, 18.4 and 18.5).

Prescription maps for variable rate application of nitrogen fertilizers were prepared by reclassification and values editing tools in GIS. The valogen rate value was determined based on the agronomist experience and knowledge of the site-specific production conditions and crop variety requirements. The final step was an export of prepared maps into shapefile or ISO-XML format and upload into machinery board computers (mainly Trimble or Mueller Elektronik) (Figs. 18.6 and 18.7).

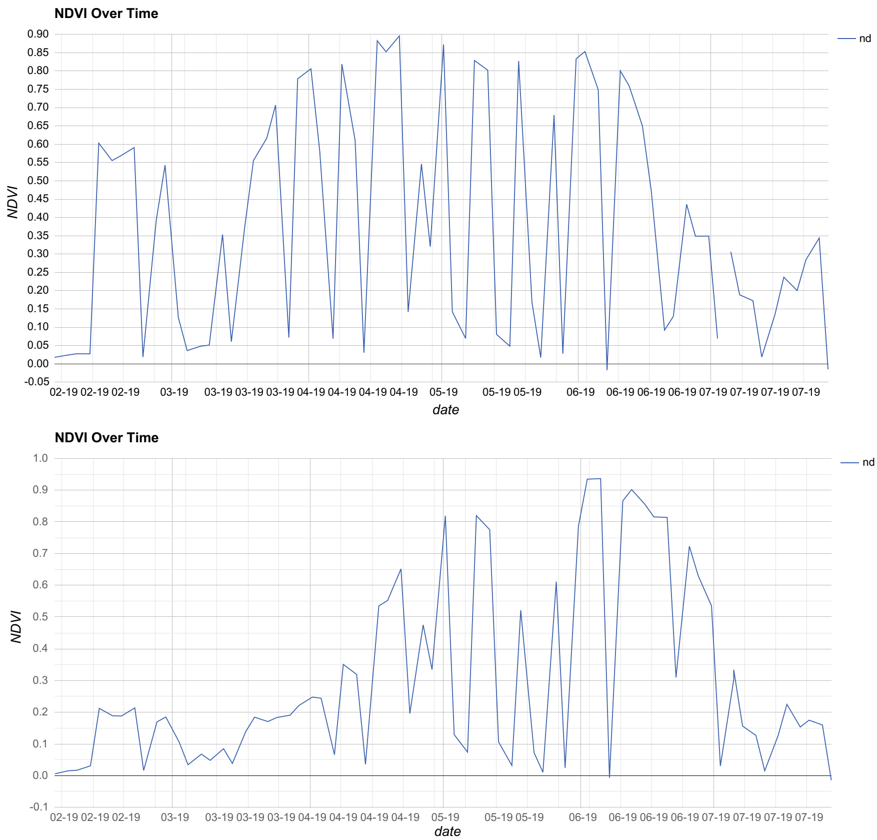

Fig. 18.3 Graphs of Sentinel-2 NDVI during the vegetation period 2019 for winter wheat (above) and spring barley (below) at locality Otnice (Rostenice farm). Low peaks indicate occurrence of clouds within the scene. *Source* Sentinel-2, Level L1C, Google Earth Engine

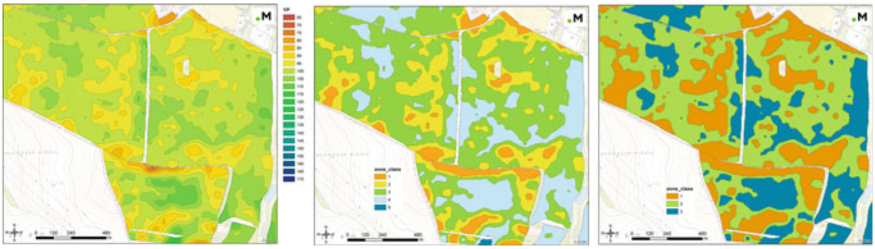

Fig. 18.4 Example of the output map products from yield potential zones classification from EO time-series analysis: classification into 5% classes (left), 5-zone map (middle) and 3-zone map (right). Blue/green areas indicate higher expected yield

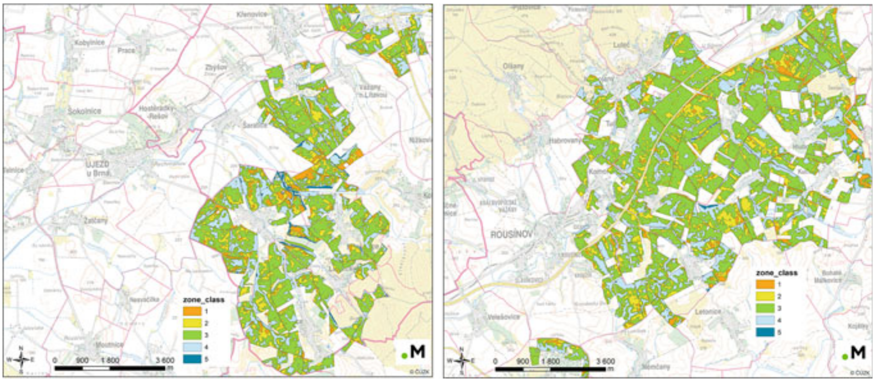

Fig. 18.5 Map of yield potential zones (5-zone map) updated for 2019 season from 8-year time-series imagery; for southern (left) and northern (right) part of Rostenice farm

Fig. 18.6 Variable rate application of solid fertilizers by Twin Bin applicator on Terragator

Fig. 18.7 Variable rate application of liquid N fertilizers (DAM390) by 36 m Horsch Leeb PT330 sprayer

18.3 Technology Used

This work was supported by the development of a platform for automatic downloading of Sentinel 2 data and automatic atmospheric correction. Through this platform, Lesprojekt is ready to offer commercial services around processing satellite data for any farm in Czech Republic. Another part in the platform development focused on transferring Czech LPIS into FOODIE ontology and on developing effective tools for querying data. Lespro did this together with PSNC, and the system is currently supporting open access to anonymous LPIS data through the FOODIE ontology and also secure access to farm data.

The main focus of the pilot discussed here is the monitoring of arable fields with high-resolution satellite imaging data (Landsat 8, Sentinel 2) and delineation of management zones within the fields for variable rate application of fertilizers. The main innovation is to offer a solution in the form of the Web GIS portal for farmers, where users can monitor their fields from EO data based on the specified time period, select cloudless scenes and use them for further analysis. This analysis includes unsupervised classification of a defined number of classes like identification of main zones, as well as generating prescription maps for variable rate application of fertilizers or crop protection products based on the mean doses defined by farmers in the Web GIS interface.

Spatial data about crop yields from the harvester were recorded in the period from June to September. Of the total 8300 ha acreage of the pilot farm, more than 3350 ha of arable land was covered by yield mapping in the cropping season 2018. We recorded crop yields specially for grain cereals (winter wheat, spring barley, winter barley), oilseed rape and for grain maize. Data were later processed for outlier analysis and by spatial interpolation techniques to obtain a final crop yield map in absolute [t ha^{-1}] and relative [%] measure.

To guarantee access for farmers and testing of yield potential, we calculated the yield potential for the 2017 season on a basic level for all Czech Republic, and

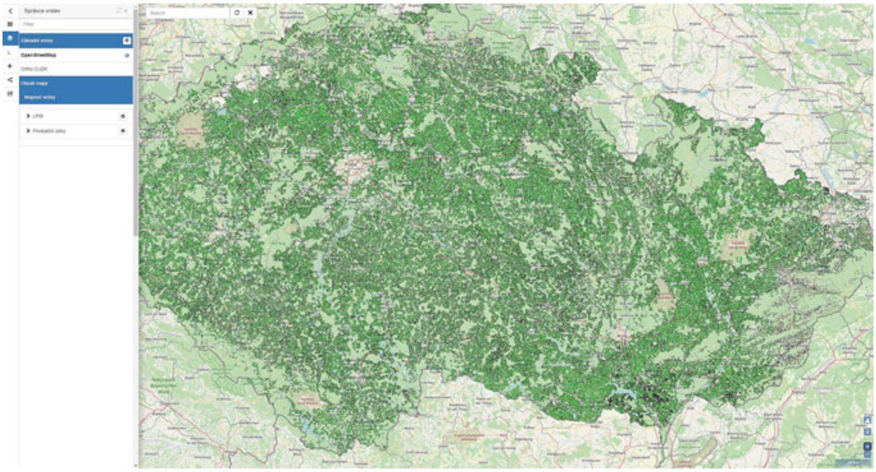

Fig. 18.8 Transformation and publication of Czech data as linked data with prototype system for visualizing

data are now available in open form on the Lesprojekt server for the whole Czech Republic. Farmers can freely test this basic data (Fig. 18.8).

Farm data

- Rostenice pilot farm data, including information about each field name with the associated cereal crop classifications arranged by year.
- Data about the field boundaries and crop map and yield potential of most of the fields in Rostenice pilot farm.
- Yield records from harvested crops on the fields in separate years.

Open data

- Czech LPIS data showing the actual field boundaries.
- Czech erosion zones (strongly/SEO and moderately/MEO erosion-endangered soil zones).
- Restricted area near to water bodies (example of 25 m buffer according to the nitrate directive) from Czech.
- The data about soil types from all over Czech (Fig. 18.9).

18.4 Exploitation of Results

The pilot's biggest success was the successful introduction of the variable application of nitrogen fertilizers based on satellite monitoring of the real plant operation on the farm fields. Although Rostěnice a.s. plays in its region a role of a pioneer in the use of precision farming technologies, they have long been hesitant about choosing the

Fig. 18.9 Visualization of results

right technology for a variable N fertilizer application. After the initial scepticism towards the use of crop sensors in their operations, they finally decided to apply a variable application based on the delineation of the management zones from the yield potential maps and on the strategy of increasing the N dose in areas with higher expected yield. This strategy has proved to be a promising option for more arid farming conditions and when irrigation is difficult, because of low soil moisture. VRA testing started on the selected fields with spring barley (over 150 ha) in 2018. In this case, spring barley for beer production was chosen as the most sensitive crop for the N application, because it is difficult to achieve malting quality in these more arid conditions, where the sum of precipitation from March till July 2018 was at the level of 152 mm. Inadequate nitrogen nutrition of plants leads to significant yield reductions, while excessive N doses decrease grain malting quality. During the growing season 2019, a variable application of N fertilizers on an area of more than 3000 ha was launched. This included base N fertilizing before sowing spring barley and maize and first N application in top-dressing of winter cereals (winter wheat, winter barley). In addition, testing of variable application of crop growth regulators in spring barley by the combination of yield potential zoning from EO time-series analysis and actual crop status monitoring from Sentinel-2 imagery was also started.

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