Effect of variable rate phosphorus and nitrogen fertilizing on winter wheat *(Triticum aestivum L.)* in Mezőföld, Hungary

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Abstract
Variable rate technology (VRT) in nutrient management has been developed in order to apply crop inputs according to the required amount of fertilizers. There is an ongoing debate among experts on how to define management zones as well as how to define the required amount of fertilizers for phosphorus and nitrogen replenishment for winter wheat (Triticum aestivum L.) production. The objective of the study reported in this paper was to investigate the effect of variable rate phosphorus and nitrogen fertilizer application in winter wheat in Mezőföld, Hungary. Winter wheat production based on variable rate nutrient treatment resulted in 1.19 t/ha more yield than the farm average while applying an average 108 kg/ha less nitrogen and 37 kg/ha more phosphorus fertilizer.
Keywords: winter wheat, VRA phosphorus and nitrogen fertilizing

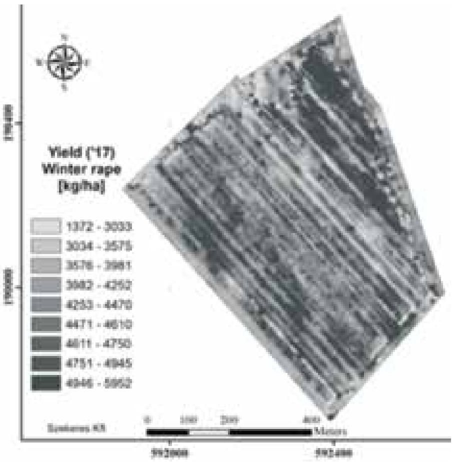
Introduction
Fields in Mezőföld region in Hungary are not uniformly structured in terms of soil types and fertility. Variable rate technology (VRT) in nutrient management allows application of a variable amount of fertilizer on each plot of land, depending on the initial content of soil nutrient. There is an ongoing debate among experts and practicing farmers on how to define management zones, as well as how to define the required amount of fertilizers for phosphorus and nitrogen replenishment for winter wheat (Triticum aestivum L.) production.
In order to manage within-field differences, management zones have to be defined. For this reason, management zone delineation techniques are used (Peralta et al., 2015).
The basis of all management zone delineation (MZD) techniques is the grouping of data values into similar classes so that the members of the class are closer in relation than to members of other classes (Lark, 1998). A management zone, therefore, is a portion of a field that is more homogenous than the overall field based on a certain measurable characteristic (Zhang et al., 2002). Various authors have proposed criteria for the delineation of management zones (Mulla, 1991; Basso et al., 2001; Fleming et al., 2001; Franzen et al., 2002). Depending on the available input data, management zones can be decided in practice with relatively high accuracy.
Variable rate application of nitrogen and phosphorus increases the efficiency of winter wheat production (Raun et al, 2001; Raun et al., 2002). There is a general perception that P fertilizer use is very inefficient because P recovery by the crop rarely exceeds 25% in the year of application and more often is only 10-15% of the P applied. The P not taken up by the crop (i.e. the residual P) has been believed to be irreversibly fixed in the soil in unavailable forms, but those views are changing as agronomic field experiments have shown that that is not the case (Johnston et al., 2014).
One approach of nitrogen fertilizing is to split applications between fall and spring. In Hungary, nitrogen fertilizer for winter wheat is generally applied when the soil is still cold in early spring (usually early March), and top-dressing is carried out in April in order to ensure a sufficient amount of nutrients for the plants throughout the growing season. Crop sensing technology is able to "fine-tune" the amount of variable rate nitrogen fertilizer (Schwalbert et al., 2019), however, it requires sensors and machinery for precise application.
Applying a spatially variable rate of nitrogen is challenging because it deals with the adoption of site-specific practices that aim at maximizing crop N uptake, minimizing N losses, and optimizing the indigenous soil's N supply (Basso et al., 2011).
The economic optimum rate of nitrogen fertilizer varies for each geographical location. However, most studies point out that nitrogen application rates are much higher than they should be. For example, Stamatiadis et al. (2017) reported that in their high spatial resolution study, VRA delivered an economic optimum N rate using 72% less in-season N or 38% less total N (131 kg N/ha) than that applied by the farmer (212 kg N/ha) in practice.
The objective of the work reported here was to investigate the effect of variable rate phosphorus and nitrogen fertilizer application in winter wheat (Triticum aestivum L.) in Mezőföld, Hungary.

Materials and methods
Location
The investigated field was a 40 ha plot of land planted with winter wheat (Triticum aestivum L.) near Polgárdi, Mezőföld, Hungary (N 47°03'11", E 18°17'17") (Fig. 1a, b).

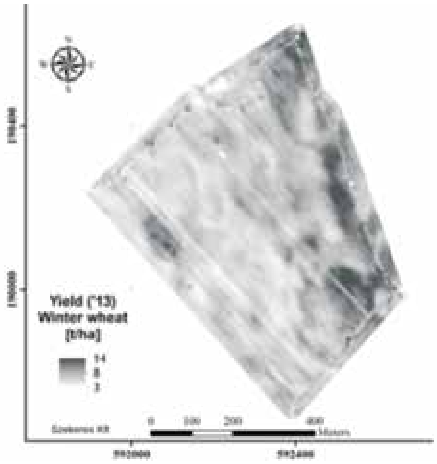
a) b)

Figure 1. Satellite image of the investigated field in 2015 (a) and 2017 (b) (Source: Google Earth).

The previous crop was autumn rape in 2017 (Fig. 2a). Within the last 5 years, winter wheat had been grown in 2013 (Fig. 2b.) and 2016. Maize yield data were collected from the field in 2013, 2014. Yield map for 2016 is not available due to sensor failure.



a,



b,

Figure 2. Yield map of winter wheat (2013) (a) and previous crop winter rape (2017) (b).

Management zone delineation was based on remotely sensed data segmentation, several year's yield map analysis and farmer's experience. Based on the data, seven management zones were determined (Fig. 3.). Areas without assigning a zone to them were treated according to the long-term, conventional management practice of the farm.

Figure 3. Management zones in the investigated field

Instrumentation

Potassium fertilizing was carried out by a Bogballe M3W (Bøgballe A/S, Bøgballe, Uldum, Denmark) fertilizer spreader. Cultivation was carried out by a Bednar Terraland 4000 (Bednar FMT s.r.o., Rychnov nad Kněžnou, Czech Republic) deep cultivator. Seeding was carried out by a Case IH 240 CVX (CNH Industrial Austria GmbH, St Valentine, Austria) tractor and a Horsch Pronto 6DC (Horsch Maschinen GmbH, Schwandorf, Germany) precision seeding machine on 25 September, 2017, the earliest possible date. Weed control was carried out in autumn by a Dammann DT2000 (Herbert DAMMANN GmbH, Buxtehude-Hedendorf, Germany) fertilizer. Variable rate nitrogen fertilizer replenishment was carried out by a Bogballe (Bøgballe A/S, Bøgballe, Uldum, Denmark) fertilizer spreader. For top-dressing a Dammann fertilizer was used.

Yield estimation was carried out based on the data collected by a Topcon CropSpec (Topcon Positioning Systems, Inc., Livermore, USA) instrument using a Fendt 716 (AGCO GmbH, Marktoberdorf, Germany) tractor. For harvesting, a Case IH 8120 (CNH Industrial America, LLC., USA) combine harvester was used. For control and data collection, an AFS700 (CNH Industrial America, LLC., USA) monitor was installed in the machines.

Soil sampling and experiment

The soil type is calcareous chernozem on a loess base. Soil samples were collected from each management zone and sent for laboratory analysis. Potassium (60%K2O) was applied in a uniform amount of 60 kg/ha prior to seeding. Phosphorus and nitrogen rates for each management zone were determined by K-Prec Ltd. (Piliscsaba, Hungary) advisory system. Phosphorus was applied in the form of Monoammonium phosphate (MAP 12N:52P) during seeding in late September, the prescribed rates were between 136 and 350 kg/ha. Winter wheat is treated as a highly intensive crop on the experimental field, therefore, splitting the amount of nitrogen fertilizer is practiced. Variable rate nitrogen was applied in the form of Calcium ammonium nitrate (CAN 27%N) in early March, the prescribed rates were between 240 and 300 kg/ha (Table 1., Fig. 4.). Top-dressing was applied in early April in the form of Nitrosol (UAN 30%N) at a uniform 180 kg/ha.

Table 1. Variable Rate Phosphorus and Nitrogen application rates (kg/ha) for the management zones.

Management zone	MAP (12N:52P) [kg]	CAN (27%N) [kg]	Planned yield [t/ha]
MZ 0	200	370	9
MZ 1	136	240	12
MZ 2	215	248	12
MZ 3	313	249	12
MZ 4	197	255	11
MZ 5	350	269	10.75
MZ 6	270	274	10.5
MZ 7	179	300	12
Average	237	262	11.5
Control	200	370	9

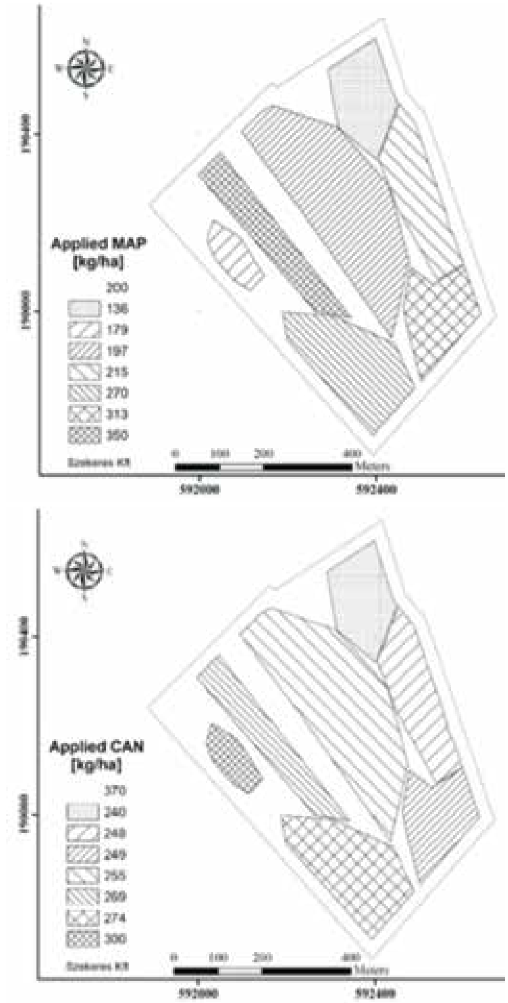


Figure 4. The applied amount of variable rate phosphorus (MAP) and nitrogen (CAN)

During the vegetation period of 2018, yield estimation was carried out before harvest with the help of a Topcon CropSpec (Topcon Positioning Systems, Inc., Livermore, USA) canopy greenness sensor aiming to monitor in-season differences within the investigated field. Differences between the management zones were visible on the map created by the sensor (Fig. 5.)

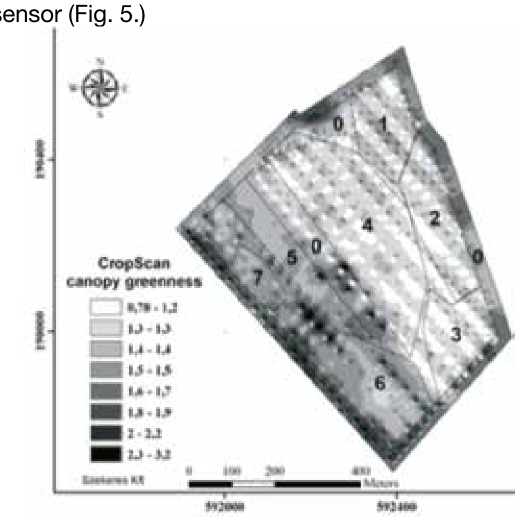


Figure 5. Topcon CropSpec canopy greenness map

Estimation was carried out on 10 May for each management zone by counting the number of harvestable heads and kernels on 1 m2.

Results

The planned yield was between 10.5 and 12 t/ha. Due to the drought in April and May, the yield was predicted at a much lower level during crop canopy measurements and counting for each management zone (8.9-10.3 t/ha). Measured yield data showed even lower values (8.13-9.31 t/ha) (Table 2, Fig 6.). The yield in the commercially treated control area (MZ 0) was 7.76 t/ha, whereas the lowest and highest yield in the site-specifically treated management zones were 0.2-1.38 t/ha above the control. The farm average for winter wheat production was 7.76 t/ha, which is 1.19 t/ha lower than the average 8.95 t/ha in the experimental field.

Table 2. Planned, estimated and measured yield in the investigated field

Management zone	Planned yield [t/ha]	Estimated yield [t/ha]	Measured yield [t/ha]
MZ 0	9	8.5	7.76
MZ 1	12	10.3	9.46
MZ 2	12	10.1	9.37
MZ 3	12	10.2	9.58
MZ 4	11	9.35	8.81
MZ 5	10.75	9.1	8.18
MZ 6	10.5	8.92	8.25
MZ 7	12	10.2	8.97
Average	11.5	9.7	8.95
Control	9	8.5	7.76

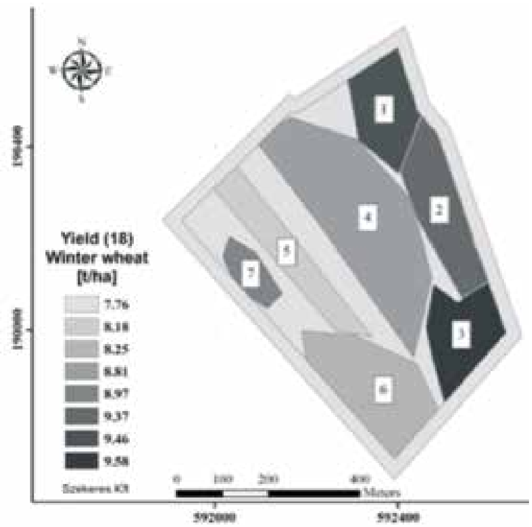


Figure 6. Yield map of winter wheat (2018) related to the management zone

Discussion

Winter wheat production in Mezőföld, Hungary, currently has great potential. One important goal of the farmers in the region is a simultaneous increase of the yield and a decrease in the environmental effects by decreasing the amount of nitrogen applied. Variable rate application of phosphorus and nitrogen is a key element for applying only the required amount of ferti-

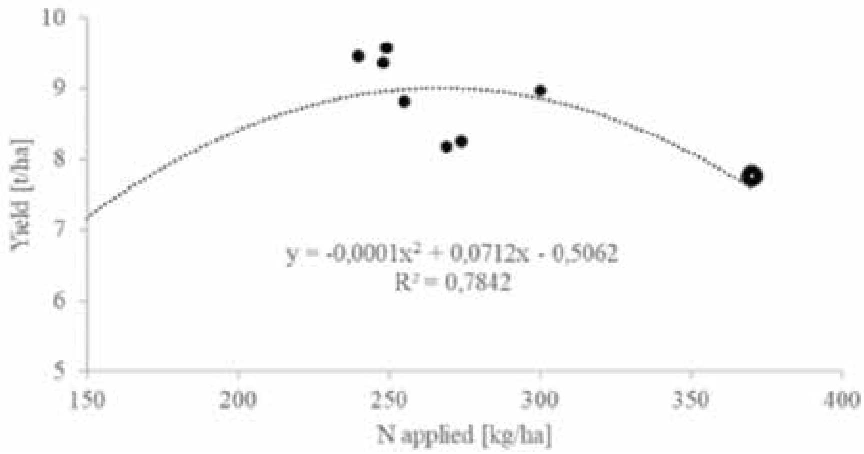


Figure 7. Effect of variable rate N fertilizing in the experimental field (The highlighted dot shows conventional - 370 kg/ha N - farm practice)

lizers. The experimental field was divided into seven management zones. Delineation was based on remotely sensed data segmentation, several year's yield map analysis and farmer's experience. Differences in the topographic location and soil properties required variable rate fertilizer application. In the experimental field, winter wheat production was on average 8.95 t/ha for the 40 ha field compared to the farm average of 7.76 t/ha. It has to be emphasized that this yield was achieved by reducing the amount of N fertilizer applied by slightly more than 100 kg/ha for the experimental field (Fig. 7.).

Conclusions

Variable rate phosphorus and nitrogen fertilizing in Mezőföld, Hungary, positively affected the yield in winter wheat production. Management zone delineation was carried out correctly on the investigated field. Each management zone produced a higher yield than the farm average despite the unfavourable conditions compared to the other fields of the farm. Variable rate phosphorus and nitrogen fertilizer application had a positive effect on the winter wheat yield. Despite the shortage of rainfall in the vegetation period, each management zone produced a higher yield than the farm average.

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