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107. Quantifying the benefits of variable rate fertilizer application on Finnish cereal farms

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Abstract

Variable rate nitrogen application (VRNA) is an effective strategy to save nitrogen when applied correctly. There is however lack of knowledge on the outcomes of VRNA as applied by Finnish farmers. The aim of this study is to explore the benefits of VRNA in Finland using commercial farming equipment. Two case studies on the application of VRNA along with the used strategies are presented and the yield outcomes are analyzed. The results indicate that precision farming has clear potential for N savings also in Finnish conditions. These benefits rely heavily on the expertise of the farmer in being able to forecast the attainable yield and thus nitrogen need of the crop and identifying the drivers of yield variability in the growing season.

Keywords: on-farm experiments, variable rate application

Introduction

There is a demand for quantified information on the economic and environmental effects of Precision Farming in commercial farms and local conditions. Variable rate nitrogen application (VRNA) has been shown to yield significant nitrogen (N) savings in several studies, however the outcome depends on the used strategy, climatic conditions and farmer expertise. There is currently no quantified data using commercial VRNA technology in Finnish conditions characterized with short thermal growing season due to Finland's Northern location. The main cereal producing regions exceed 1000 cumulated degree days (°Cd) in approx. 80% of years from sowing to harvest (Peltonen-Sainio & Niemi, 2012).

There is clear evidence on the potential of using precision farming for more increasing nitrogen use efficiency with VRNA technologies. Several studies have shown 5 – 40% reductions in nitrogen use with 0–10% yield increase when VRNA is used as top up fertilizer (Balafoutis *et al.*, 2017; Cordero *et al.*, 2019; Stamatiadis *et al.*, 2019) as compared to uniform management during the growing season. However, obtaining these improvements on farms require spatially specific information support, such as high quality application maps, correctly identifying the source of variability in the field and a good forecast of the yield potential of the crop on the application date.

It is common practice in Finland to only apply nitrogen to spring cereals at sowing and there is increasing interest from farmers to use VRNA at sowing. This strategy has also been suggested to be economically optimal for spring malting barley when compared to split fertilization (Hyytiäinen *et al.*, 2011). New seed drills commonly have the capability for variable rate application of both N and seeds and several relatively easy to use software tools exist. The challenge is to find the right management zones to estimate the basis for an application map and to estimate the site specific yield potential from historical yield maps (Blasch *et al.*, 2020) or remote sensing (Lenoir *et al.*, 2024) or soil scanning data (Becker *et al.*, 2022). Videgain *et al.* (2024) recently demonstrated increased N use efficiency when variable rate N application was carried out at seeding, using management zones that were delineated based on soil electrical conductivity maps.

The comparison of precision and uniform management is commonly done by using parallel strips or plots withing strips on fields aligned with the main axis of variability in the field. The width of

the strips can vary from narrow research plots e.g. 7 m in (Stamatiadis *et al.*, 2018) to working width of commercial centrifugal spreaders e.g. 32 m (Gobbo *et al.*, 2022).
The aim of this study was to measure the effectiveness of precision nitrogen fertilization of cereals compared to conventional management in Finland using commercial farming equipment.

Materials and methods

On-farm experiments using commercial precision farming equipment were conducted in four different locations in Finland during 2023 and 2024. In 2023, all farms produced spring cereals, while in 2024 winter wheat was also included in the experiments. The experiments were planned and implemented in collaboration with researchers, equipment manufacturers (Tume-Agri Oy, Turenki, Finland; Junkkari Oy, Ylihärmä, Finland and Dometal Oy, Loimaa, Finland) and three farmers.
Field parcels were split into 40-60 m strips, according to the fertilizer spreader working width, and managed with even and variable rate application. The average applied N amount between the strips was constant. There were 2–6 strips fitted into each field with a total experimental area of 4–5 ha in each field.
Documentation from work tasks was collected from the machinery yielding five different data formats, including ISOBUS tasks and Trimble agdata format for fertilizer application data and yield maps as ISOBUS tasks, shapefiles, Case New Holland CN1 and Ceres .X01 format. Satellite images of the parcels were downloaded from Copernicus Data Space service. Canopy chlorophyl content (Weiss *et al.*, 2022) predicted from Sentinel 2 images was used to analyze the N uptake of the canopy during growing season.
Data preprocessing included creating the strips for different treatments based on field parcel boundaries, cutting out the outer edge of the strips and also some area between the strips in order to avoid mixing up the different treatments. The harvester yield map data was pre-processed using a linear quantile function to remove the extreme values at both ends. The yield data was also scaled with the actual grain weight measured after each strip was harvested. Data from different sources were aggregated to hexagonal zones using discrete global grid h3 (Uber Technologies, 2024). Each hexagon has an area of approx. 33 m^2 and represents the median value of observations for that area.
In 2023 all fields received an even fertilizer amount at sowing according to the farmers yield target and in-season fertilizer according to farmers' estimate of crops condition and yield forecast. The VRNA tasks were made using either Yara AtFarm or NSensor (Yara, Oslo, Norway). The yield of each experimental strip was weighed in with front loader scales or trailer equipped with a scale and harvester yield maps from farmers' harvester were collected. The area around the experimental areas was harvested first and full combine cutting widths were used to harvest the experimental plots to avoid measurement errors in the yield data. During 2024, the experiments were repeated on the same four farms with three fields focusing on VRNA at sowing and three fields to in-season VRNA.
This paper presents the results from two field parcels as a case study: (1) VRNA at sowing based on soil scanning data and farmer expertise and (2) in-season VRNA applied before crop anthesis using satellite based prescription map.

Case 1: VRNA at sowing
Case 1 field focused on spring barley. The dataset included ISOBUS task files for sowing and seed fertilization, harvester yield map as a shapefile and field parcel boundaries as a shapefile. The field parcel was divided into two strips, one treated as variable rate for both sowing and seed fertilization, and the other received even amounts of seeds and fertilizer. The variable rate strip had three different sectors: 250 kg/ha seed+80 kg N/ha (zone VRNA-A), 280 kg/ha seed+100 kg N/ha (VRNA-B) and 310 kg/ha seed+120 kg N/ha (VRNA-C). Each evenly treated parallel control strip received 280 kg/ha seed+100 kg N/ha (Figure 1).

Case 2: in-season VRNA

This case is from spring wheat with even fertilization at sowing and in season VRNA before crop anthesis. Case 2 dataset included machinery data recorded in Trimble agdata format for sowing, seed fertilization and in-season fertilization, harvester yield map as .cn1 file and field parcel boundaries as a shapefile. A custom parser was used to read the .agdata files and CN1 ADAPT Plugin (CNH N.V.) was used to read the CN1 files. The field parcel was divided into two strips, one treated as variable rate for in-season fertilization, and the other received even amount in-season fertilizer. The sowing and seed fertilization was done as even treatment for both strips. The VRNA in-season fertilization was implemented based on Sentinel 2 images using the Yara Atfarm software and setting the average N amount to match the evenly treated strip.

Results

Case 1: VRNA at sowing

The cultivation plan for the variable rate application strip was to use more inputs on the areas with higher yield potential (according to farmer's records) and less inputs on the lower yielding area with high soil sand content (Figure 1A). Both fertilization and seeding levels were varied in the same manner. The control strip was treated at same level as the middle part of the variable rate strip. Figure 1 shows soil scans that were used for variable rate seeding and fertilization plan. The field was sown on 11 May with barley (cultivar Arild) and the fertilization was done using YaraMila Y25 with N content of 24.6%. The different input levels can be seen clearly in the satellite image taken during the growing season (26 June 2024). The differences, however, fade out by the time of harvest and the decision of saving inputs on the areas where the expectations for yield were not so good turned out to be a good one. The extra inputs used for the better soil also resulted in better yield.

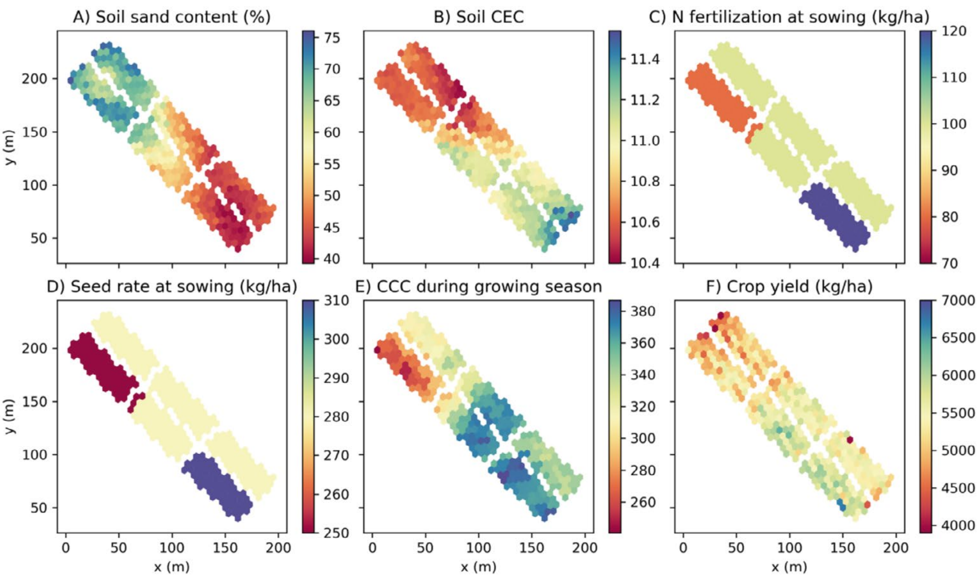

Figure 1. Maps of soil and crop characteristics, management, and yield for case 1 VRNA at sowing. Areas at the bottom half are managed with VRNA and at the top half with uniform management. (A) Soil sand content from soil scan. (B) Soil cation exchange capacity from soil scan. (C) N applied at sowing (kg/ha). (D) Seed amount at sowing (kg/ha). (E) Canopy chlorophyl content (CCC) before fertilization from Sentinel 2. (F) Wheat yield map (kg/ha).

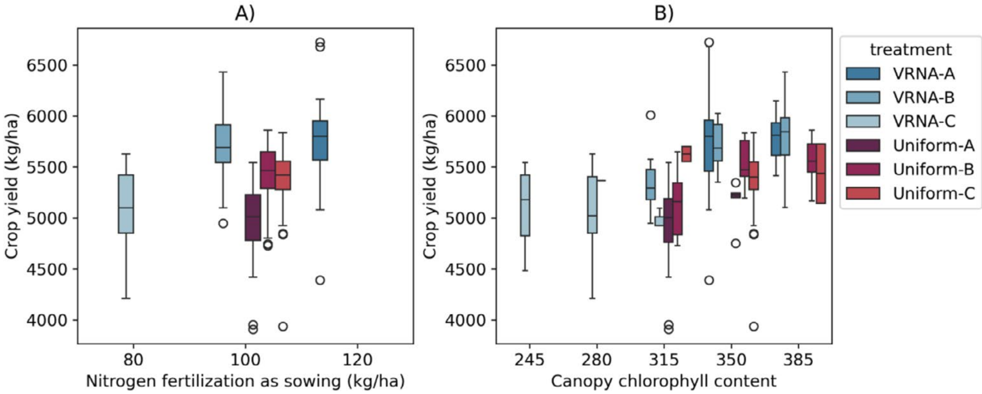

Figure 2. Boxplots of (A) Crop yield (kg/ha) and N rate (kg/ha) and (B) crop yield (kg/ha) and canopy chlorophyll content close to anthesis in different experimental zones from case 1.

The middle part (Zone B) of the field has same inputs for both variable rate and uniform rate strip. These two areas look very much alike in in-season satellite image. The yield for the variable rate (VRNA-B) area was slightly (4.5%) higher. This can be caused by the difference in the soil cation exchange capacity between the zones as seen in Figure 1B. The field was harvested on 21 August and the average yield for the field was 5200 kg/ha.

The yield increase in zone VRNA-A compared to Uniform-A was 13.8% (5770 kg/ha vs 4975 kg/ha) where nitrogen response (kg yield/kg N fertilizer) was 3.5% higher (48.1 vs 49.8 kg/kg) for the uniform treatment. The highest nitrogen response (63.7 kg/kg) was achieved for VRNA-C treatment with 18% improvement as compared to Uniform-C.

Case 2: in-season VRNA

The cultivation plan was to apply in season N according to the canopy status as measured using remote sensing. Spring wheat (cultivar Troy) was sown on the 6th of May 2023 and 110 kg of N (Yara, Hiven Y4) was applied at sowing. The yield target for the field was set to 7000 kg/ha based on farmers' prior experience. The Robin Hood scheme (Guerrero *et al*., 2021), where less N is applied to canopy with higher N content, was adopted for the in-season fertilizer application. In-season fertilizer was applied on 22 June with the rate of 46 N kg/ha for the uniform area and with the same average rate on the VRNA area. Figure 4B) shows the in-season N application rate and CCC one day before the fertilization. The variability of CCC was very similar in both treatments. The in-season N rate was reduced from the initially planned 60 N kg/ha due to the crop suffering from moderate water stress due to a low amount of rainfall in June. The crop was harvested on 22 September.

The average amount N used on the VRNA and uniform regions were 158.6 kg/ha and 156 kg/ha and the crop yields were 6850 kg/ha and 6970 kg/ha, respectively. Comparison of yield outcome with respect to N rate and CCC is shown in Figure 4. The highest yield was achieved in both treatments in the areas with high CCC at fertilization time. The plots indicate that the selected strategy for VRNA was likely correct, however the total N application amount was too high. This is indicated by highest crop yields in the areas with least applied N and no improvement in yield as compared to even management in the areas with the highest N application rate.

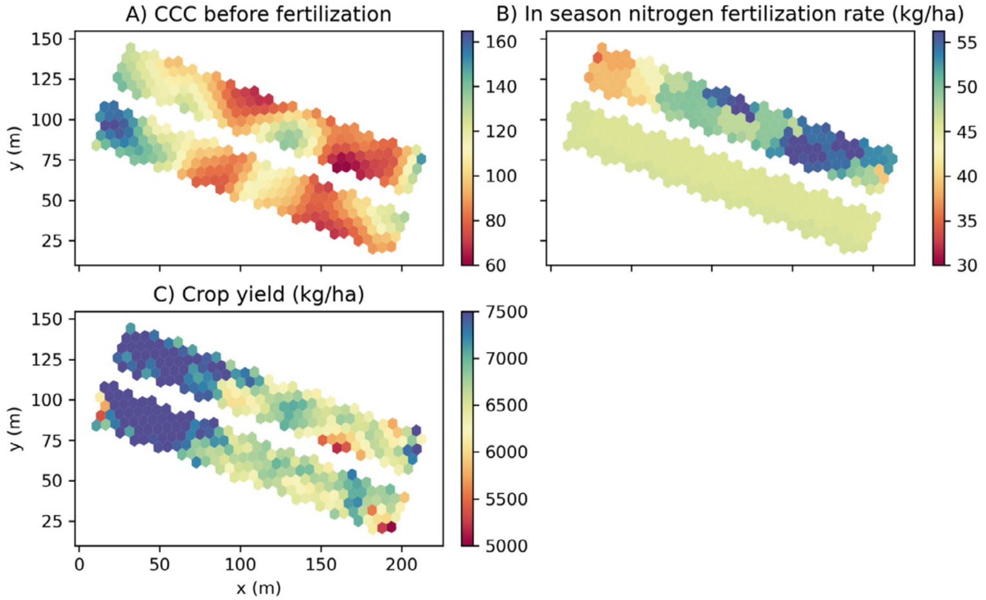

Figure 3. Maps about management and outcomes "from case study in season VRNA". Area on the top is managed with VRNA and bottom with uniform management. (A) Canopy chlorophyl content (CCC) before fertilization from Sentinel 2. (B) Applied in season N rate (kg/ha). (C) Wheat yield map (kg/ha).

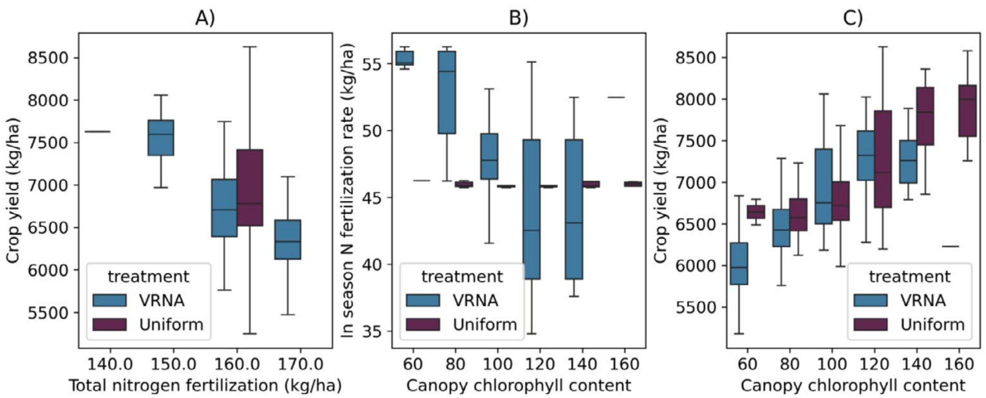

Figure 4. Boxplots of (A) crop yield (kg/ha) and total N rate (kg/ha), (B) applied in season N rate (kg/ha) and canopy chlorophyl content and (C) crop yield (kg/ha) and canopy chlorophyl content close to anthesis in different experimental zones from case 2.

Discussion

This paper presents two case studies from on-farm precision farming experiments using commercial hardware. The results indicate that there is clear potential in applying VRNA also in Finnish conditions with short growing season.

In the case study of using VRNA at sowing, a significant yield increase of 13.8% was achieved with the highest yielding VRNA zone compared to control zone and 18% increase in yield response was achieved in the lowest yielding zone. Soil scanning data was helpful for the farmer to identify the borders of management zones and the N amounts were based on farmers' observations from previous years. Similar benefits from VRNA at sowing were shown by Videgain *et al.* (2024).
Working together with the farmers revealed several points for improvement in the software they use. The software provided limited customization options for precision fertilizer tasks, for instance the amounts could not easily be customized based on soil structure or water status information. For instance the farmers would have wanted to have the ability to customize the in-season VRNA map based e.g. on their local knowledge of the field or yield maps from previous seasons. For planning of sowing tasks the farmers would have wanted the software to automatically generate management zones based on soil scans or previous yield maps. In practice, the VRNA sowing task for case 1 needed to be drawn by hand by comparing to image (with coordinates) of clustered soil scanning data. A common wish was to be able to overlay data from several information sources when planning VRNA maps highlighting the need for user centered planning tools like the ones suggested by Heiß *et al.* (2023).
We also encountered a few cases where ISOBUS task data was not properly recorded (e.g. task files with coordinates, but no recorded application rate) and lost yield monitor data. These occurred despite having experienced operators for all machinery the testing of the equipment before handling the experimental parcels. The loss ISOBUS data could indicate lack of reliability of the used terminals in saving as applied time log data. These challenges were not detrimental for the overall project as we had several experimental sites. The readings from the yield monitors were calibrated by weighing the yield in from each experimental plot, which significantly enhances the reliability of the data.
Majority of the work records could not be used by the farmers effectively as their FMIS software could not read in the data from the recorded format. This makes it challenging for the farmers to analyze the effect of their spatial management decisions.

Conclusions

Precision farming has clear potential for N savings also in Finnish conditions. The benefit of VRNA with current tested commercial software relies heavily on the expertise of the farmer in setting reasonable yield targets and identifying the drivers of yield variability in the growing season.

Acknowledgements

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