

**Session 11**  
**Site-Specific Nutrient, Lime and Seed Management**



## 104. Variable rate N application in wheat with precision agriculture technologies and near real-time data

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### Abstract

Variable-rate nitrogen (VR-N) application enables farmers to optimize nitrogen (N) rates site-specifically within a field, enhancing economic and environmental efficiency. This study applied VR-N technology to durum wheat in two commercial fields (3–4 ha each) located in different agro-climatic zones of Thessaly, central Greece. Using a well-established algorithm, VR-N doses were calculated based on near real-time data acquired via unmanned aerial vehicle (UAV) imagery, tailored to the plants actual needs. Results showed that VR-N reduced N fertilizer usage by up to 50% compared to the uniform rate nitrogen (UR-N) application traditionally employed by producers. Importantly, this reduction did not significantly impact wheat yields or grain quality. Additionally, soil analysis revealed lower residual nitrate levels in VR-N zones compared to UR-N zones, indicating a reduced risk of groundwater N pollution.

**Keywords:** efficiency, N management, near-real-time data, remote sensing, vegetation index, UAV

### Introduction

Durum wheat (*Triticum turgidum* subsp. *durum* (Desf.) Husnot) is one of the most important cereal species and its cultivation is concentrated in the Mediterranean Basin. Growers try to maximize crop yields and at the same time to increase the protein content by applying well-adjusted in-season nitrogen (N) fertilization therefore, are called upon to balance at that point on the curve of maximum economic return where yield and protein are in the ideal ratio (Argento *et al.*, 2021). However, N fertilization in wheat is commonly based on yield goals and N fertilizers are distributed in a uniform way across fields without considering in-field spatial and temporal variability (Gobbo *et al.*, 2022). The dominant practice for farmers is to apply a fixed rate of N fertilizer onto the whole fields and even entire farms. This represents the prevailing fertilization practice among wheat growers in Greece resulting in irrational application of N-containing fertilizers which could be the cause of significant environmental and health problems.

Site specific N management (SSNM) and precision agriculture can contribute to the sustainable management of crop production inputs by addressing the real needs of specific regions in the field rather than the average needs of whole fields (Spiertz, 2010). Moreover, SSNM can increase the N use efficiency (NUE) at field scale (Basso *et al.*, 2016; Raun *et al.*, 2002; Sharma and Bali, 2018) which has been confirmed for small to medium scale agriculture systems similar to Greek agriculture (Argento *et al.*, 2021; Van Loon *et al.*, 2018). NUE in wheat production in Greece is around 30% which is low and similar to Swiss agriculture (Argento *et al.*, 2021) but lower compared to Danish agriculture, for instance, showing a NUE of 41% (Hansen *et al.*, 2017).

Among the factors that contribute to relatively low NUE are the uniform fertilizer N application rates to spatially and/or temporarily variable landscapes. Therefore, variable rate N application

(VR-N) has been proved that improves NUE in small to large-scale agricultural cropping systems (Evangelou *et al.*, 2020; Ravier *et al.*, 2018; Stamatiadis *et al.*, 2020).

Even though studies have largely considered heterogeneity of large size fields, until now small-scale heterogeneity within fields (<1–2 ha) are typically neglected (Argento *et al.*, 2021; Hausherr Lüder *et al.*, 2020). To achieve the goal of VR-N, fields should be treated on the basis of their smallest scale of significant variability. Small fields (<3 ha) representing the vast majority (87%) of the world's agricultural land, show great variability in yield (Lowder *et al.*, 2016; Ricciardi *et al.*, 2018). Therefore, finding precision farming solutions for small-scale farms is essential. Also, 2/3 of EU agricultural holdings in 2016 were smaller than 5 ha in size (Eurostat, 2018). Such pilot fields are represented in Thessaly (Greece) and the results will be usable by farmers (& comparable to other small-scale systems in EU-27 countries).

Unmanned aerial vehicles (UAV) are platforms suitable for monitoring fields of small to medium size and provide a number of possibilities and benefits for farmers. Among them are crop monitoring (high-resolution data on plant health), nutrient management (application of fertilizer according to the actual needs or even the individual needs of the plants) and yield mapping (data on the yield at different parts of the field) (Montgomery *et al.*, 2020). Purchase and the operational knowledge costs and the time needed to acquire and process the remote sensing data are considered some of the major drawbacks of UAV technology (Hunt and Daughtry, 2018). Even though precision fertilization methodologies and monitoring of the vegetation condition have been advanced, crop N-status quantification and fertilization support based on remote sensing imagery is still not fully standardized (Bergera *et al.*, 2022). The reliability of image data provided by a UAV platform to non-destructively diagnose N status in wheat and to guide in-season VR-N has been provided by recent studies (Argento *et al.*, 2021; Zhang *et al.*, 2022) but few studies dealing with VR-N in small-scale farming systems and new sensing technologies are in the literature.

The novelty of this work is that except for the optimization of the N fertilization efficiency, and the fact that this is the first official VR-N application in wheat crop in Greece, the proposed strategy does not require expensive equipment, is friendly to use and it could be utilized by farmers and consultants. The objectives of the study were (i) to test an algorithm (Holland and Schepers, 2010) to calculate VR-N with near real time data which was basically created to incorporate sensor retrieved real time data and (ii) to increase knowledge on how data derived from a UAV platform representing temporal and spatial variability of crops can support VR-N application in durum wheat in small fields of about 3–4 ha under Mediterranean conditions.

## Materials and methods

### *Site characteristics and field management*

Two commercial fields which are located in the south-east part of Larissa Prefecture, (Region of Thessaly) central Greece, under different agroclimatic zones were selected for this study in the growing season 2022–2023 (Figure 1). Field A in Agrokipio, (39°25'26.36"N, 22°42'16.93"E) occupies an area of 4.1 ha (altitude 140 m a.s.l.) and Field B in Ano Vasilika (39°19'53.86"N, 22°34'0.63"E) occupies an area of 2.9 ha (altitude 277 m a.s.l.). The Köppen–Geiger climate type in the region of Field A is a combination of cold semi-arid with dry and hot summers (BSk/Csa) and in the region of Field B a Mediterranean climate with dry, hot summers (Csa) (Beck *et al.*, 2018). Field A exhibits variable slopes, with the dominant category being from 0.1 to 5%, whereas, Field B exhibits greater slopes, which in many areas exceeds 10%. The soil in Field A is classified in the order of Cambisols and in Field B in the order of Calcisols (WRB, 2015). Wheat sowing was performed on 18 November 2022 in Field A (cv Simeto) and on 21 November 2022 in Field B (cv Monastir) and 300 kg/ha of seeds were used in both fields. Field A has been managed to oregano for the past 3 years under no tillage. Tillage operations included conventional ploughing (0.25 m), field cultivating (heavy type) and disking were performed prior to wheat sowing. In Field B the preceding crops

were wheat, lentils and wheat in crop rotation under conventional tillage operations (ploughing, field cultivating - heavy type).

The soils of the fields were moderately fine-textured clay-loam (Field A) or fine-textured clayey (Field B) with a slightly alkaline ( $pH_{1:1}$  8.0) or medium alkaline soil reaction ( $pH_{1:1}$  8.2) and  $CaCO_3$  content of 11.8% and 27.1% respectively. The soils in both fields were deficient ( $<10.0$  mg P/(kg soil)) in available phosphorous (P Olsen). Soil electrical conductivity (EC  $<1.00$  mS/cm at 25 °C), soil organic matter (approx. 1.5%) and total soil N (0.1–0.2%) were low in both fields. The farmer in Field A applied preplant fertilizer uniformly (Nutriphos 16–20–0) at a rate of 200 kg/ha on 15 November 2022 and at Field B applied preplant fertilizer uniformly (Slowtec 12–18–3) on 18 November 2022, at 220 kg/ha to provide adequate N supply during early season under P and K sufficiency. The growing season of 2023 was relatively dry and at middle-heading (BBCH 55) (Meier *et al.*, 2009) wheat in Field A, received 20 mm of irrigation through a ‘travelling gun’ irrigation system on 27 March 2023. No irrigation was applied in Field B. Phytosanitary operations were performed whenever necessary to control broad-leaved weeds.

#### Experimental design N management and data collection

Each field was divided into six equivalent in size zones and the experimental design used was completely randomized. Half of the zones, received a uniform top dressing of granular ammonium nitrate ( $NH_4NO_3$ , 34.5–0–0) at the rate of 343 kg/ha (UR-N) when plants were at the mid-tillering (BBCH 25) stage (usual practice and rates of Greek wheat producers) whereas, the rest zones received VR-N, using a two-disc fertilizer spreader, with a controlled doser (Rauch Axis M/H 30.2). At harvest (on 22 June 2023 in field A and on 30 June 2023 in field B, BBCH 92-93), total above-ground biomass (TBY), 1000 grains weight (TGW), grain yield (GY), grains/m<sup>2</sup>, harvest index (HI) (ratio between grain dry weight and total dry weight), grain protein content GPC (%) and N grain yield (NGY) (g/m<sup>2</sup>) were determined as the averages of 3 subsamples (each of 1 m<sup>2</sup> sampling area) within each of the 6 zones. GY was converted into t/ha at 13% humidity. The N concentration of the grain dry matter was determined by the Kjeldahl method. Residual nitrate N was also determined after wheat harvest.

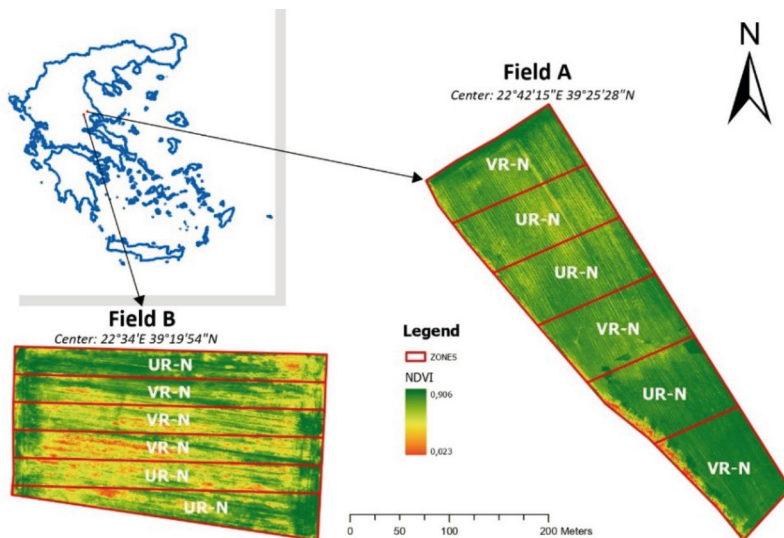


Figure 1. Location of the study site in Larissa Prefecture (Greece) and delineated zones of uniform (UR-N) in season N fertilization and variable-rate N application (VR-N) of fields (A, B). NDVI index refers to BBCH 25 (mid tillering) (20 February 2023).

### *Low-altitude remote sensing data and VR-N calculation*

Two days before in season N application high resolution multispectral image data were taken (near real time data) with the UAV DJI Phantom 4 Multispectral RTK. The UAV flights took place from 10:00 am to 12:00 pm on sunny days with low wind conditions. Using the software DJI GS Pro the flight altitude was set at 120 m (6.4 cm pixel resolution). This altitude provides a balance between image resolution and coverage. Image overlap was determined for 80% front and side, to ensure sufficient redundancy for accurate photogrammetric reconstruction. Flying speed was 5 m/s to minimize motion blur while maintaining efficient coverage. UAV imagery was proceeded with DJI Terra software to generate Normalized Difference Vegetation Index (NDVI) for each field. Holland and Schepers (2010) developed an algorithm to calculate N application rates using a reference value of NDVI reflectance of the crop. The NDVI reference value was determined by the 'virtual strip approach' for the use of multispectral sensors (Holland and Schepers, 2011). Based on this approach, a portion (one strip) of the existing crop that represented the range in crop vigour within the field selected from the entire field NDVI values, and then statistically identified plants that are deemed to be non-N limiting by selecting the 95-percentile cumulative value from the histogram of NDVI values. The virtual strip approach has been applied for VR-N applications in wheat, cotton and corn cultivations demonstrating significant reductions in N fertilization (Evangelou *et al.*, 2020; Stamatiadis *et al.*, 2018, 2020). The algorithm by Holland and Schepers (2010) was applied for each pixel of the captured images to calculate the VR-N doses for each field and to create fertilizer prescription maps using ArcGIS software (ArcGIS Desktop: Release 10, ESRI, Redlands, CA, USA).

## **Results**

N fertilizer application rates were reduced in the VR-N treatments by 20% and 50%, depending on the field. In Field A, 170 kg/ha of fertilizer N was applied on average which is half (50%) of the fertilizer N dose applied by the farmer in the UR-N treatment (Table 1). Total biomass yield (TBV) in both fields showed no significant difference between the VR-N and the UR-N treatment and ranged from 13.9 t/ha (Field B, VR-N) to 16.1 t/ha (Field A, UR-N). In Field B 20% less fertilizer was applied in the VR-N zones. GY showed significant difference between the two fertilizer treatments and was on average 17.4% lower in the VR-N compared to UR-N treatment whereas, in Field A GY showed no significant difference between the two fertilizer treatments. Correspondingly, TGW after harvest was significantly lower in the VR-N treatment compared to UR-N treatment in Field B. Grains/m<sup>2</sup> and HI showed no significant difference between the VR-N and the UR-N treatments in both fields. The grain protein content (GPC) varied from 11.9% (Field A) to 12.4% (Field B) in the VR-N zones, while in the UR-N zones from 13.8% (Field A) to 11.6% (Field B). NGY and residual soil NO<sub>3</sub>-N showed also no significant difference between the VR-N and the UR-N treatments. The content of residual soil NO<sub>3</sub>-N in the VR-N zones was lower than that in the UR-N zones (significantly 36% lower in field A and 14% lower in field B).

## **Discussion**

The current study deals with the performance comparison of VR-N in wheat with UR-N and introduces a method to determine the N rates as well. For the latter, an algorithm was applied to NDVI images of the wheat canopy captured two days prior to fertilization. One of the benefits of using this algorithm is that information for estimating wheat N requirements is not based on soil or plant tissue analyses, but on the plant's own response to incident radiation, which includes any variations both spatially within the boundaries of a field and temporally from year to year. The use of the algorithm in combination with aerial images and smart fertilizer spreaders could make the variable rate applications of fertilizers very easy process for farm managers and consultants. As far as the performance comparison between the two treatments, the results proved that VR-N

Table 1. N fertilizer applied, yield and N related parameters and residual soil NO<sub>3</sub>-N at the crop harvest in Larissa Thessaly Central Greece for the 2022-2023 growing season.

Field	N fertilization (kg/ha)	TBY (t/ha)	GY (t/ha)	TGW (g)	Grains/m <sup>2</sup>	HI (%)	GPC (%)	NGY (g/m <sup>2</sup> )	Soil NO <sub>3</sub> -N (kg/ha <sup>1</sup> )
A	VR-N: 170*	15.4	5.49	56.3	11511	34.6	11.9	10.1	16.8b
	UR-N: 343	16.1	6.35	51.7	13361	39.3	13.8	13.9	26.3a
B	VR-N: 280	13.9	5.42b	43.6b	13518	38.9	12.4	10.8	14.6
	UR-N: 343	15.5	6.56a	49.5a	14548	45.0	11.6	12.2	16.9

Averages of zones. Means with different lower case letters are significantly different at  $p < 0.05$  (Tukey). Means with no letters are not significantly different.

application reduced the total N application without any yield loss in one of the two pilot fields (Field A) confirming results of other studies for small-to-medium-sized wheat agricultural systems (Argento *et al.*, 2021; Stamatiadis *et al.*, 2018; Wang *et al.*, 2019). GYs were in the range of 5.42–6.56 t/ha and were comparable in two fields. However, similar GYs in the VR-N zones resulted from much higher on average N fertilizer application (additional 110 kg/ha) in Field B as compared to Field A. In Field A, underlying soil properties but also pedoclimatic conditions may have favored high soil N-mineralization rate during the vegetation period which led to a good grain filling and higher TGW in the VR-N treatment (Table 1). Moreover, in Field B, GY and TGW in the VR-N treatment were significantly lower compared to UR-N treatment. These results may be attributed to high fluctuations of the relief of the topography and the greater slopes (reaching 15%) in Field B which affects water movement in soil, erosion of topsoil, and deposition. In steeper slopes reduced water retention and higher erosion rates, result in thinner and less fertile soils (Zhang *et al.*, 2021). Moreover, soil in Field B belongs in the order of Calcisols enriched with free calcium carbonate (CaCO<sub>3</sub>=27.1%), which may be rather problematic under certain conditions for wheat crop production (i.e., limited availability of P and some of the trace elements such as Fe, Zn and Cu). Application method of N did not significantly affected number of grains m<sup>-2</sup>, HI, and NGY in both fields. GPC (11.6–13.8%) was relatively lower compared to GPC that obtained by Stamatiadis *et al.* (2018) in the same region, under three N treatments including VR-N, for durum wheat Simeto cultivar which has medium tillering ability and responds well to N fertilization. Residual soil NO<sub>3</sub>-N in the VR-N zones was lower than in the UR-N zones (significantly lower in Field A) suggesting that VR-N technology can potentially reduce the risk for groundwater pollution and therefore can protect environmental resources as described also by other researchers (Zhao *et al.*, 2007). An economic balance between the cost of fertilizer and the gain from the sale of the grain to the mill would offer better insight as to how VR-N technology could be adopted by farmers. However, this is a simplified measure for financial gain (marginal return) because the cost to obtain prescription maps or costs for the technology and the machinery is not taken into account. Our results revealed that under less favorable conditions (i.e. high slopes like Field B) this financial gain from VR-N compare to yield losses is not significant (data not shown).

## Conclusions

VR-N has the potential to reduce fertilizer inputs without considerable yield loss. The results of this study indicated that the implementation of site-specific N fertilization using VR-N technology

reduced average N application compared to the conventional uniform fertilization strategy. Site conditions can play an important role in the effectiveness of VR-N, which should be considered in future applications. VR-N technology did not affect yield more in the field than primary soil properties, pedoclimatic and other management conditions by the farmer were more favourable (Field A). Application method of N did not significantly affect yield components (except TGW in Field B), HI, and GPC in both fields. VR-N may reduce the potential of groundwater pollution as the residual soil  $\text{NO}_3^-$ -N in the VR-N zones was lower than in the UR-N zones. The future plans of this study is to develop a friendly user application that will apply the algorithm to aerial images that users will be allowed to upload and to export automatically prescription maps for VR-N. A holistic approach to estimate gains for adapting VR-N technology would include economic and environmental parameters.

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