60. Comparing methods for determination of N uptake in winter wheat

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Abstract

Local and current soil nitrogen (N) mineralisation should guide supplemental N rates. To facilitate this, methods for rapid assessment of crop N uptake (kg N/ha) were tested in five winter wheat (*Triticum aestivum* L.) trials in Sweden, around GS39. Four types of measurements were done: leaf sensors, handheld canopy sensors, multispectral drone cameras, and other, manual methods. Several options were found to be simple and accurate enough (mean absolute error <5 kg N/ha) for practical use by farmers and advisors. The best results were obtained when leaf and canopy measurements were combined.

Keywords: drone**,** mineralisation, proximal sensor, reflectance, transmittance, zero-plots

Introduction

In variable rate application (VRA) of nitrogen (N), the N rate is often increased or decreased in relation to a field average rate, using tractor-borne crop reflectance sensors or remote sensing-based decision support systems. Therefore, it is crucial to correctly determine the field average N requirement, both for optimising return of inputs and for reducing risk for nutrient loss (Delin and Stenberg, 2014). As a service to farmers, both the Swedish Board of Agriculture and some Swedish advisory organizations do regular measurements with a handheld Yara N-Sensor (Yara, Oslo, Norway) to assess the total N content in the above-ground biomass (N uptake) in plots without added N (zero-plots) in farmers' fields, so that the average supplementary N rate can be adapted to current and local soil N mineralisation.

Measures of N uptake within the season have been shown to be efficient in prediction of optimum N rate (Link *et al.*, 2005). There are many alternatives available to collect such data, both sensors and simple manual methods may be useful (Ferguson, 2018; Padilla *et al.*, 2018). However, there is a lack of information on the performance of such methods, as well as simple instructions on how to calculate the N uptake from the measurements. The requirement of a functional method is that it is judged cost-effective and easy for the users, and that it is accurate enough to be meaningful for N rate correction. Available methods and crop sensors collect inferential data, i.e. they do not directly measure the N uptake. Instead, the measurements must be translated into N uptake using empirical relationships.

Current recommendations in Sweden are based on the assumption that the total N uptake in the crop canopy in zero-plots reflects the soil N mineralization (Engström and Lindén, 2009). The current recommendation by Yara is to decrease (or increase) the N rate by 10 kg/ha for each 5 kg/ha of increase (or decrease) of the N uptake.

One way to rapidly assess N uptake in zero-plots is to use a combination of a leaf sensor and a canopy sensor, where the leaf sensor gives a proxy for N concentration in above-ground biomass (an intensive variable) and the canopy sensor gives a proxy for the amount of biomass per unit ground area (an extensive variable). This has been proposed by e.g., Blackert (2018), who calibrated N uptake prediction models based on a combination of a handheld crop canopy reflectance sensor, the GreenSeeker (Trimble, Westminster, CO, USA) and a leaf transmittance sensor, the N tester (Yara, Oslo, Norway).

There are also more simple methods, such as crop height measurement or crop cutting and weighing, which can be interesting alternatives. In winter oilseed rape the fresh weight is used to assess N uptake (Swedish Board of Agriculture, 2023), and that practice could be tested also in winter wheat. The aim of this study was to investigate and compare performance of alternative methods and instruments for rapid assessment of N uptake in zero-plots, and in crop canopies with normal N fertilisation or with a non-limiting N rate (max-plots) in winter wheat (*Triticum aestivum* L.) at the end of stem elongation, around growth stage GS39 (Zadoks *et al.*, 1974).

Materials and methods

Measurements in field trials

Measurements were made in five winter wheat field trials across southern Sweden (Figure 1) at GS37–41 in 2024. There was one cultivar per trial and four replicates of different N rates – three of the N rates were included in this study (0, 70 and 250 kg N/ha). As reference, crop canopy N uptake (kg N/ha) was determined from the biomass and N concentration of cut samples of 0.5 m^2. Measurements were made with the following methods (Figure 2):

1. Handheld leaf transmittance sensors: SPAD 502Plus (Konica-Minolta, Japan), Yara N-tester and Dualex Scientific (Metos, Austria).
2. Handheld crop canopy reflectance sensors: RapidSCAN CS-45 (Holland Scientific Inc., USA) and GreenSeeker . The former registers reflectance values in three bands: red, rededge (RE), and near infrared (NIR), while the latter only provides a calculated vegetation index (VI): NDVI. In addition, Yara provided cultivar-corrected N-sensor data for the measured trial plots (their proprietary SN index, which is an estimate of the N uptake based on two RE bands) (Reusch, 2006).
3. Drone-borne multispectral cameras: MAIA (Eoptis Srl, Italy) and Micasense RedEdge (AgEagle Aerial Systems, USA). The former has nine bands that are consistent with the Sentinel-2 satellite, while the latter has five bands, in the visible to NIR-region in the electromagnetic spectrum.
4. Other tools: A mobile phone app (Canopeo) (Patrignani and Ochsner, 2015) for assessing crop coverage, a ruler for crop height, a Platemeter for crop biomass (normally used in grassland), and scissors for fresh weight sampling.

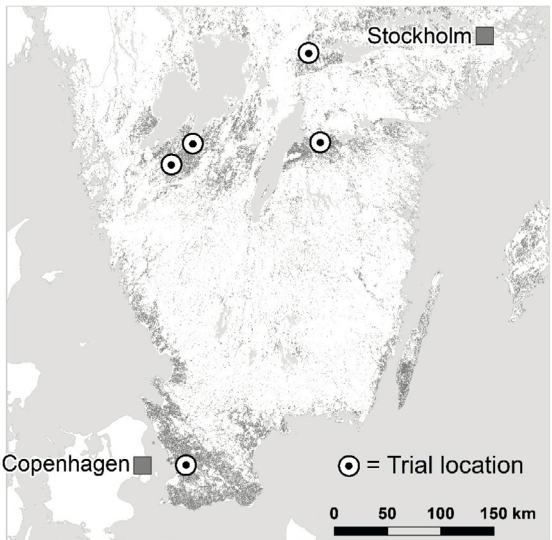

Figure 1. Location of the field trials in southern Sweden. Agricultural land is dark grey.

Figure 2. Equipment used in 2024. (a) Dualex, (b) SPAD, (c) N-tester, (d) RapidScan, (e) GreenSeeker, (f) Canopeo, (g) ruler, (h) platemeter, (i) drones, two different sensors, and (j) cut crop samples for determination of fresh weight and N uptake.

The following VIs were computed from band reflectance values of the RapidSCAN, and the drone cameras: NDRE, NDVI, MSAVI2, and for the latter also ChlI, GRDI, EVI and $d_{74}r_6$. A description of these VIs can be found in e.g., Piikki *et al.* (2022). Median values of the four repetitions per trial and treatment were computed for all variables and models of two types: linear regressions and multivariate adaptive regression splines (Hastie *et al.*, 2009) were evaluated by their mean absolute error (MAE) in a leave-one-trial-out cross-validation. MAE was calculated for all treatments together and for each treatment alone. Single measurements; pairwise combinations of a leaf measurement (1) and a canopy measurement (2–4) were tested.

Results

The N uptake (mean ± standard deviation of five trials) in zero-plots, normal-plots and max-plots were 31±9, 78±25 and 144±35 kg N/ha, respectively. Many of the methods had relatively similar validation statistics (Figure 3). Some drone camera indices, handheld sensor measurements, and also simple methods such as the fresh weight of a cut sample worked well alone. Leaf clip sensors alone did not work as good, but when combined with other methods they often improved the validation statistics. In the evaluation of all plots together, the best leaf sensor was Dualex Flav (a flavonol index) with MAE=14 kg N/ha. The best canopy sensor was the Yara SN-index, MAE=10 kg N ha^1, while the Micasense RedEdge NDRE or ChlI index was about equally accurate, MAE=11 kg N/ha. The N uptake assessments were improved by combining a leaf sensor (an intensive measurement) with a canopy sensor (an extensive measurement), as exemplified in Figure 4a and c, where the Dualex sensor combined with fresh weight, or an index from a drone camera improves the predictions in left-out trials substantially. In general, absolute prediction errors were smaller in zero-plots (Figures

3 and 4). The number of prediction models with MAE≤10 kg N/ha was 66 in zero-plots, 13 in normal-plots and 5 in max-plots (Fig. 3).

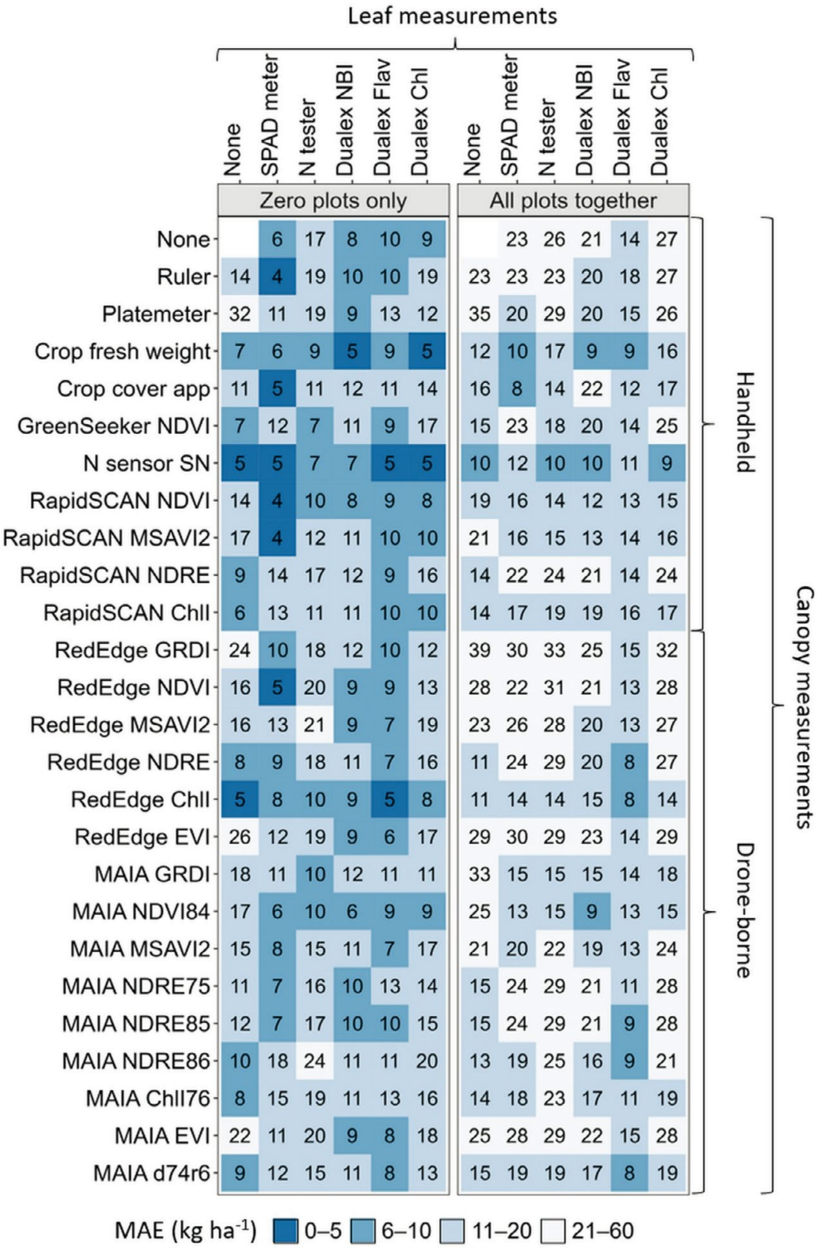

Figure 3. Mean absolute errors (MAE, kg/ha) in the leave-one-trial-out cross-validation. Results for the best of two models (linear regression and multivariate adaptive regression splines) are presented. Models were parameterized using all treatments (fertilisation before measurement: 0, 70 and 250 kg N/ha) and evaluation was done for zero-plots only and for the three treatments together.

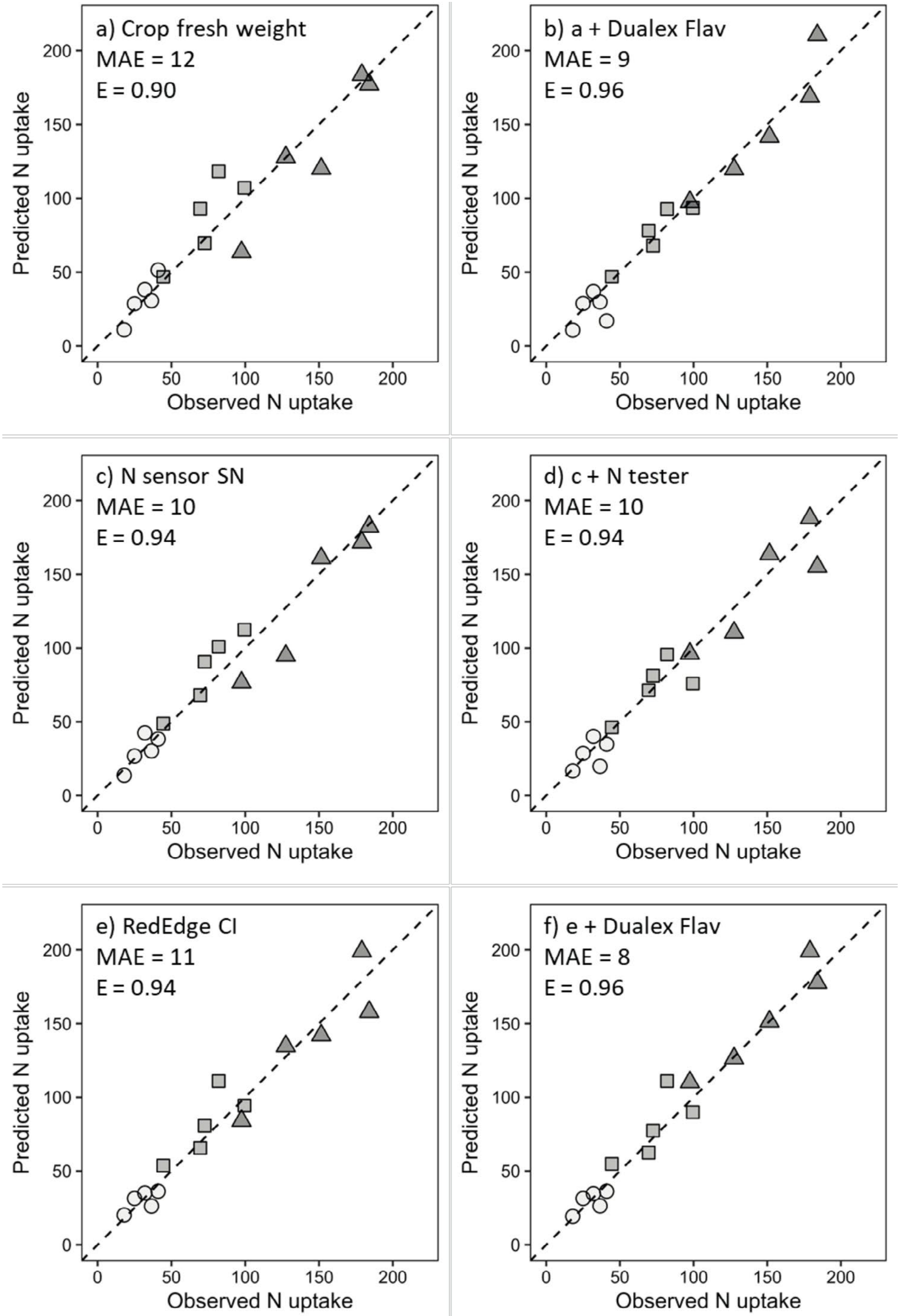

Figure 4. Predicted versus observed N uptake (kg N/ha) for three different canopy measurements (a, c and e) and these canopy measurements in combination with a leaf measurement (b, d and f). MAE, mean absolute error; E, Nash–Sutcliffe modelling efficiency (both based on all treatments).

Discussion

The results show that there are multiple options for rapid assessment of N uptake that are both simple and deemed accurate enough for practical use by farmers and advisors. Thus, the use of zero-plots can be further promoted as a technique to assess soil N supply for fields or management zones. This is useful information that allows taking current-year soil N mineralization into account when deciding supplemental N rates in winter wheat. The present study shows how different methods relate to each other by providing comparable results analysed in the same way. It is conceivable that advisory organisations can invest in more expensive equipment (e.g. various hand-held sensors and multispectral cameras mounted on drones) while farmers may prefer simpler methods, such as height measurement, cutting crop+weighing.

The drone-borne VIs differ in how well they perform (especially in dense crop canopies), and GRDI, which is based only on visible bands, gives the largest errors (both drone cameras). Model performance is much improved if one choose a camera with RE and NIR bands compared to a simple RGB camera, which may not work well enough for the measurements to be useful in practice. Model performance was often improved when canopy measurements were combined with leaf measurements, and especially the Dualex Flav, often improved the N-uptake predictions. In the collected data, there was a negative correlation between N uptake and Dualex Flav. This is likely due to the fact that the leaf content of polyphenolics (including flavonoids) decrease, with the increased application of N in wheat (Cartelata *et al.,* 2005).

Since satellite data has been increasingly used in practical crop cultivation via systems such as CropSAT (Dataväxt, Grästorp, Sweden) and Atfarm (Yara), it is also of great interest to know how well hand sensor measurements can be transferred to satellite data, this will also be evaluated in the project. However, more data from several years are necessary to obtain useful and stable models. Therefore, two more years are planned (2025 and 2026) with the same methodology. The models that are considered useful will become freely available at www.slu.se.

Conclusions

This evaluation of methods for rapid assessment of N uptake in practice (i.e. validated across different sites) showed that there is a number of suitable and fast methods for determining N uptake in winter wheat – from cheaper, perhaps more suitable for farmers, to more advanced methods for advisory services. Combinations of one leaf sensor and one canopy sensor were generally better than using either sensor type alone, and errors were generally smaller in zero-plots than in denser (less N deficient) winter wheat stands.

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