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Developing and testing an algorithm for site-specific N fertilization of winter oilseed rape

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ABSTRACT

Winter oilseed rape (WOSR) is a major crop in Germany, combining economic benefits with a high value in crop rotation, but it still lacks agronomically sound concepts for site-specific nitrogen (N) fertilization. Since ecological challenges resulting from high optimal N rates and a low N harvest index are approaching on WOSR cropping systems, optimizing N fertilization becomes crucial. Recent studies showed the importance of taking autumnal N uptake into account when estimating optimal N rates for WOSR, thus autumnal N is pivotal in the algorithm that is introduced in this study. The algorithm was parameterized by using data from site-specific N fertilization trials and optimized to reduce N fertilizer amounts. Afterwards it was tested on different commercial farms in northern Germany. The autumnal N uptake was estimated using hyperspectral reflection measurements gained from tractor-mounted devices, and the data was processed to N application maps used for the N application in spring. In addition, a uniform optimal fertilization and a uniform application of average N rates calculated by the algorithm were applied to provide control treatments. Yield, N balance and economic net-revenue were evaluated for each treatment. Yields from site-specific fertilization were slightly lower (0.06 t/ha) than from uniform optimal treatment but 0.22 t/ha higher than from the uniform application of the site-specific N amount (not significant in both cases). The N balance was significantly lower when fertilizing site-specifically instead of applying uniform optimal N rate, while the net-revenues were slightly higher.

1. Introduction

Winter oilseed rape (WOSR) is a major crop in Germany, especially in the northern and northeastern regions. Despite its value in crop rotations (often being the only non-cereal crop), ecological challenges are approaching on WOSR cropping systems. The economically optimal N fertilization rates in WOSR are high, often exceeding 200 kg N/ha (Henke et al., 2009), while the N offtake by the seeds remains low (120 kg N/ha on a three-year average) (Sieling et al., 1998), so the N harvest index of WOSR is low (Malagoli et al., 2005). Consequently, recent studies (Henke et al., 2007) showed WOSR to be a major contributor to surpluses of N balance in cropping systems. In Germany, the N balance surplus is legally limited to a three-year-average of 60 kg N/ha (Anonymous, 2006). In addition the EU-"Renewable Energy Directive" requires a calculation of greenhouse-gas-balances for WOSR that is used for biofuels and N fertilization proves to be pivotal for these calculations (Pahlmann et al., 2013). Thus, optimizing N fertilization is crucial to WOSR cropping systems. Henke et al. (2009) studied the impact of soil and canopy factors on economically optimal N doses in winter oilseed rape in a two-year trial on different sites in Germany. While neither soil mineral N at the start of spring growth nor canopy N uptake in spring showed a significant correlation to the optimal N fertilization rates in their study, the canopy N uptake in autumn proved to be a good indicator to adjust N fertilization. They found that optimal N rate (i.e. the N rate that maximizes the net-revenue) in a certain year at a specific location ($U_{opt}(year, loc)$)[2] could be described as a function of the actual autumnal canopy N uptake ($U_{up}(year, loc)$):

$$U_{opt}(year, loc) = a_{loc} + b \cdot U_{up}(year, loc) \quad (1)$$

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[2] To avoid confusion between a site-specific view and an approach that treats the whole field uniformly, a simple nomenclature is used: Whenever nitrogen (uptake, rates, etc.) is treated uniformly within a field this is indicated by "*U*" (e.g. U_{opt} = uniform optimal N rate, U_{up} = average N uptake of the whole field). On the other hand, "*N*" indicates a site-specific approach, specific to every subarea of the field (e.g. N_{opt} = optimal N rate for the actual subarea, N_{up} = N uptake of the actual subarea).

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The intercept of this function (a_{loc}) was specific to the trial location while the slope ($b = -0.7$) did not interact with the location, thus it was identical for all locations in their study. Both parameters did not interact with the year. These findings were confirmed by Sieling and Kage (2011) who continued and extended the trial series for two more years and included more locations. While Henke et al. (2009) and Sieling and Kage (2011) found a strong relationship between spring U_{opt} and autumnal U_{up}, the intercept (that varies between different locations) cannot be easily derived from the yield or other parameters for practical N recommendations. Thus Henke et al. (2009) concluded autumnal U_{up} should be used for relative adaption of N fertilization although lacking the possibility to give absolute recommendations. Nevertheless, for purposes of practical use by farmers, i.e. estimating *ex-ante* optimal spring N rates using information available to farmers, they suggest to start with the official regional recommendations and adapt fertilization by taking into account (by a factor of $b = -0.7$) the difference of the actual U_{up} and an assumed overall average U_{up} of 50 kg N/ha, derived from the average value of a series of measurements in northern Germany over several years and sites. Henke (2007) proposed site-specific N fertilization to be the next step in optimizing N fertilization of WOSR.

The literature lacks published, well described algorithms for variable rate N application in WOSR. While there are different concepts for wheat, none of these can be adopted to WOSR directly. The main methods used in wheat are in-season N adjustments. In-season adjustments can be performed using optical sensing combined with fertilization algorithms (Raun et al., 2002) or plant N-status at calibration ramps (Raun et al., 2008). Another approach is using crop models (Link et al., 2008) to predict the optimal site specific N rate. For WOSR those concepts are hardly adoptable. In WOSR, the first spring N dressing is applied directly at the start of the vegetation period and the second dressing follows shortly after the first. A third dressing, if any, is very low and combined with measures for plant-protection. Thus, N fertilization of WOSR is almost completed before in-season measurements (e.g. measuring calibration ramps) can contribute information to the decision process. Model based strategies sound promising, but naturally they need an existing crop-model first. Although different WOSR models had been developed (Habekotté, 1997; Gabrielle et al., 1998), Diepenbrock (2000) stated that none of these predict biomass and yield with satisfying precision.

The aim of the present study is to develop and parameterize a site-specific N fertilization algorithm draft that is based on spatial variable WOSR N uptake. Afterwards, the parameterized algorithm is tested on commercial farms in a on-farm research field trial with respect to yields, economic revenue and N balance.

2. Conceptual design of an algorithm for site-specific N fertilization in WOSR

As mentioned above, Henke et al. (2009) found a strong relationship between the autumnal canopy N uptake and the optimal N rate. Used as an indicator, N uptake in autumn was superior to N uptake in early spring. Thus, for site-specific N fertilization of WOSR an adoption of the findings of Henke et al. (2009), taking autumnal N uptake into account, seems the most promising approach. For site-specific purposes, the concept of Henke et al. (2009) (see Section 1) needs to be generalized by substituting the unknown intercept by another fixed point on the regression line. Since there is a linear relationship between U_{up} and U_{opt} at a given location, the average U_{up} and U_{opt} can be used as a fixed point. Calculating the average (for convenience only a single location is examined, omitting the index "$_{loc}$") results in:

$$\frac{\sum_{year=1}^{M} U_{opt_{year}}}{M} = a + b \cdot \frac{\sum_{year=1}^{M} U_{up_{year}}}{M} \tag{2}$$

$$\overline{U_{opt}} = a + b \cdot \overline{U_{up}} \tag{3}$$

$$a = \overline{U_{opt}} - b \cdot \overline{U_{up}} \tag{4}$$

where $\overline{U_{opt}}$ is the average (by years) optimal uniformly applied spring N rate and $\overline{U_{up}}$ the corresponding average autumnal N uptake. The parameter a and b are the same regression coefficients introduced in Eq. (1). So the U_{opt} in Eq. (1) can be expressed as:

$$U_{opt}(year) = \overline{U_{opt}} + b \cdot \left(U_{up}(year) - \overline{U_{up}}\right) \tag{5}$$

When assuming the local recommendations for uniform fertilization (U_{rec}) being the optimal total spring N rate in the average of all years and assuming the mean autumnal U_{up} to be 50 kg N/ha, Eq. (5) is identical to the practical implementation suggested by Henke et al. (2009) and Sieling and Kage (2011):

$$U_{opt}(year) = U_{rec} - 0.7 \cdot \left(U_{up}(year) - 50\right) \tag{6}$$

Since there are non-destructive methods for measuring the amounts of N taken up by a WOSR canopy using hyperspectral reflectance measurements (Müller et al., 2008), it is possible to evaluate site-specific N uptake (N_{up}) for every subarea (A_{sub}) of a field. Thus the question arises if it is possible to use the N_{up} estimated by the use of sensor technique for site-specific N fertilization of WOSR. For these purposes, the concept introduced needs to be adapted. The algorithm of Henke et al. (2009) and Sieling and Kage (2011) adapts N fertilization to the variation caused by year-effects. To show this more clearly, Eq. (5) is expanded to a more explicit notation in Eq. (7). Our hypothesis is, that in analogy to adapting N fertilization to the variation caused by year-effects, fertilization can be adapted to variations caused by differences between subareas (Eq. (8)):

$$U_{opt}(year) = \frac{\sum_{year=1}^{M} U_{opt_{year}}}{M} + b \cdot \left(U_{up}(year) - \frac{\sum_{year=1}^{M} U_{up_{year}}}{M}\right) \tag{7}$$

$$N_{opt}(A_{sub}) = \frac{\sum_{A_{sub}=1}^{n} N_{opt_{A_{sub}}}}{n} + c \cdot \left(N_{up}(A_{sub}) - \frac{\sum_{A_{sub}=1}^{n} N_{up_{A_{sub}}}}{n}\right) \tag{8}$$

where $N_{up}(A_{sub})$ and $N_{opt}(A_{sub})$ are the N uptake and optimal N rate of a subarea while $\left(\sum_{A_{sub}=1}^{n} N_{opt_{A_{sub}}}\right)/n$ and $\left(\sum_{A_{sub}=1}^{n} N_{up_{A_{sub}}}\right)/n$ are the average values for the whole field.

3. Materials and methods

3.1. Parameterization of the algorithm

Eq. (8) shows a draft of an algorithm for site-specific N fertilization of WOSR depending on site-specific N-uptake. For convenience, abbreviations are introduced, expressing Eq. (8) as:

$$N_{opt} = \overline{N_{opt}} + c \cdot \left(N_{up} - \overline{N_{up}}\right) \tag{9}$$

The site-specific optimal N fertilization for a given subarea of a field (N_{opt}) depends on the measured autumnal N uptake at this subarea (N_{up}), the average N uptake of all subareas ($\overline{N_{up}}$) and the average N_{opt} of all subareas ($\overline{N_{opt}}$) and a slope c. While N_{up} and $\overline{N_{up}}$ can be measured, c and $\overline{N_{opt}}$ must be parameterized.

The parameterization was performed on a dataset collected from two years of a field trial, located in northern Germany on the Hohenschulen Experimental Station (University of Kiel). The regional climate is humid. The long-term (1981–2010) precipitation average is 778 mm containing 390 mm in the April to September period and the average air temperature is 8.9 °C (Deutscher Wetterdienst, 2013).