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Crop modelling based analysis of site-specific production limitations of winter oilseed rape in northern Germany

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ABSTRACT

Winter oilseed rape production is typically characterised by low nitrogen (N) use efficiency. Defining site-specific fertiliser strategies based on field trials and crop modelling may help to improve the ecological efficiency of this crop. However, no model has been evaluated for winter oilseed rape that simulates the growth of the plant as limited by the interaction of water and N. In this study, the APSIM canola model which was originally developed for the temperate regions of Australia, was adapted for conditions in Germany and tested against measured data (total biomass, grain yield, leaf area index, N-uptake and soil mineral N) at three sites near Göttingen (northern Germany). In the second part of the study, the evaluated model was used in a simulation experiment to explore site-specific climate and soil related production limitations to match fertiliser rates to yield targets. Historical weather data from four sites across northern Germany and a fertile loamy soil with different rooting depths, implicating different plant available water capacities, were used. Model results showed large differences in yield (up to 1000 kg ha^{-1}) and N-balance (>30 kg ha^{-1}) for 200 kg N-fertiliser rate ha^{-1} between restricted (50 cm) and unrestricted rooting depths. Simulated yields for such high N-fertiliser rate were lower for sites with continental climate than for sites close to the coast, reflecting different rainfall patterns. Results indicate that water supply plays a critical role when maintaining high N use efficiency and reaching simultaneously grain yields of 4000 kg ha^{-1}.

1. Introduction

The average yields of winter oilseed rape (*Brassica napus* L.) have reached 4000 kg ha^{-1} in many northern states in Germany since 2000 with the most favourable sites regularly yielding above 5000 kg ha^{-1} (Statistisches Bundesamt, 2014). Under optimal growing conditions (optimal nutrient and water supply, absence of pest and diseases, no weeds) a potential grain yield of 6500 kg ha^{-1} has been suggested by Berry and Spink (2006). However, under rainfed conditions winter oilseed rape production in Germany is frequently affected by water stress, indicated by national yields below 3000 kg ha^{-1} in years with a dry spring period as observed in 2003 and 2011 (Statistisches Bundesamt, 2014). Indeed, oilseed rape is a water demanding crop (Gerbens-Leenes et al., 2009) with studies showing that >300 mm of water must be available from flowering to maturity to support high yields of more than 4000 kg ha^{-1} (Berry and Spink, 2006; Rathke et al., 2006). Available soil moisture at flowering is therefore critical to support the crop under conditions where rainfall is limited. Shallow, sandy or constrained soils with low plant available water capacity (PAWC) therefore have a limited ability to buffer a crop during periods of low rainfall, and it is on these soil types that yields are most severely limited.

Another limiting factor in oilseed rape production is that N-application is restricted by the EU Nitrate Directive in Germany to limit average annual N-balance (N applied minus N removed by harvest) to a three year average of 60 kg ha^{-1}. N-balance measured after winter oilseed rape usually exceeds this limit, and is frequently above 100 kg ha^{-1} (Henke et al., 2007). Large surpluses arise due to typical fertiliser rates in the range of 160 to 200 kg N ha^{-1} in spring. A low harvest index (HI; ratio harvested organ/total biomass) of oilseed rape, typically 0.3, and N harvest index (NHI; ratio N in harvested organ/N in total biomass) of 0.6–0.7 result in a large proportion of the applied N remaining in straw residues on the field. The following crop, commonly winter wheat, is not able to take up the mineralising N in autumn. Despite this overall trend, the N-balance for the same N-fertiliser rate can differ strongly from site to site (Sieling and Kage, 2010), when factors,

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which are largely beyond the scope of management, such as water supply, solar radiation and temperature, limit growth. Matching fertiliser application rates to site-specific attainable yield may help to adapt management practices and improve the N-balance.

In the last twenty years, field trials have been widely conducted in Germany to define site-specific best management practices by setting targets for site-specific yield and improved N use efficiency (Lickfett, 1993; Henke et al., 2008a, 2008b; Rathke et al., 2006). However, field trials are expensive and time consuming and, more importantly, results and also N-response curves statistically derived from these trials are difficult to extrapolate to other sites and years due to the complex nature of the interaction between crop physiology, N-uptake and distribution, temperature driven growth duration, intercepted radiation and water supply (rainfall amount, distribution and storage in the soil) (Henke et al., 2007; Schulte auf'm Erley et al., 2011). For other crops, mechanistic plant growth models have been successfully used to develop complementary insights into soil and climate specific fertiliser practices (e.g. for wheat: Asseng et al., 2000).

During the 1990s, few models for oilseed rape have been developed in Europe and Australia. However, so far, no model has been evaluated for simulating the growth of rainfed oilseed rape limited by N. For example, the respective LINTUL version developed by Habekotté (1997a–1997c) takes only solar radiation and temperature into account and assumes optimal conditions for growth where water and N are not limiting. It further ignores the autumn and winter development phases of winter oilseed rape. A second example is that of the CERES-Maize model adapted for winter oilseed rape in France, but only tested for non-water stressed plants (Gabrielle et al., 1998). For Mediterranean conditions in Italy, a winter oilseed rape model was adapted within the DSSAT framework (Deligios et al., 2013). For conditions in Australia, a canola model was incorporated into APSIM (Robertson et al., 1999) and mainly used to assess temperature effects on plant phenology (Farre et al., 2002). Both models – DSSAT rapeseed and APSIM canola – were developed for warmer climates than the growing conditions of central and northern Europe. Although both models have not been tested for crop N-uptake, they make use of intensively tested modules for soil N and water dynamics, which make them suitable as a basis for model development and adaptation.

Against this background, this study aimed to (1) collect rainfed field trial data from multiple sites and years to (2) adapt the existing APSIM canola model for winter oilseed rape production in Germany and (3) to evaluate the performance of the calibrated model in terms of total biomass, grain yield, leaf area index (LAI), N-uptake and soil mineral N (SMN) dynamics against these field trial data and (4) explore the scope for site-specific N-management in northern Germany for improving the productivity (represented by yield) and reducing the risk of exceeding the N-balance.

2. Materials and methods

2.1. Field experiments

Data for the calibration and the evaluation of the model derived from N-rate × variety field trials conducted at Reinshof in 2010/2011, at Rosdorf in 2012/2013 (Lower Saxony, Germany, University of Göttingen) and a at third experimental site, at Harste in 2006–2012 (Institute of Sugar Beet Research). These three sites are located in the vicinity of Göttingen. The region is located in the transition between maritime and continental climate. Average annual precipitation is 637 mm and average daily temperature is 9.17 °C (Figs. 1 and 2). Daily weather data (including solar radiation, maximum and minimum temperature and rainfall) were obtained from the German weather service station in Göttingen around one km

Fig. 1. Map of Germany presenting the selected sites: Magdeburg (1), Göttingen (2), Bad Salzuflen (3) and Leck (4).

from the Reinshof field trial and five km from the trial at Rosdorf. For Harste, meteorological data were taken from a nearby weather station (Wetterstation Göttingen, 2014).

2.1.1. Reinshof

The soil was a Pseudogley with organic carbon content (OC; 0–10 cm) of 1.8% (Table 1). Soil texture was a clayey silt and the pH value was 7 (0.01 M $CaCl_2$; VDLUFA, 1991). Phosphorus (P; 7 mg 100 g^{-1} soil; CAL method), potassium (K; 12 mg 100 g^{-1} soil; CAL method) and magnesium (Mg; 9 mg 100 g^{-1} soil; $CaCl_2$ method) were measured at field trial start and found in sufficient supply (VDLUFA, 1991). The field trial was carried out from 08/2010 to 07/2011. In this study we used data from a factorial experiment with four replicates of three hybrids (cvv. PR46W31, PR46W20, PR46W26) and three N-levels (0, 100, 200 kg ha^{-1}). N-fertiliser was applied in two equally split doses at recommencement of growth after winter dormancy in spring and four weeks later. The crop was shown on 20/08/2010 at a planting density of 50 plants m^{-2}. Soil characterisation including hydrological properties needed to parameterise the soil water balance model in APSIM were taken from Jung (2003) with an assumed rooting depth of 150 cm. SMN (0–90 cm) was low with 30 kg ha^{-1} before sowing (N_{min} method, Wehrmann and Scharpf, 1979). Aboveground residues of the preceding wheat crop were removed. 40 kg ha^{-1} of sulphur (S) were applied as Kieserite on 08/02/2011. Biomass production, N-uptake and SMN were recorded before winter, after winter, at flowering and at harvest (including grain yield and N-uptake). The main phenological development stages were monitored according to the BBCH scale (Lancashire et al., 1991). All biomass values from the field trial, same for Rosdorf and Harste, were presented as dry weight.

2.1.2. Rosdorf

The soil was a Pseudogley with OC (0–15 cm) of 1.7% (Table 1). Soil texture was a clayey silt and the pH value was 6.5 (0.01 M $CaCl_2$). The nutrient status (5 mg P 100 g^{-1} soil (CAL method), 10 mg K 100 g^{-1} soil (CAL method), 6 mg Mg 100 g^{-1} soil ($CaCl_2$ method) was tested prior to sowing and found in sufficient supply (VDLUFA, 1991). The field trial was conducted from 08/2012 to 08/2013. The hybrid Visby and the variety line Adriana were tested with three N-levels (0, 100, 200 kg ha^{-1}; replicates = 4). N-fertiliser was applied in two equally split doses at recommencement of