Modelling nitrogen dynamics after growing winter oilseed rape in different cropping systems

Johannes Henke, Ulf Boettcher, Klaus Sieling, Henning Kage

Institute of Crop Science and Plant Breeding, Christian-Albrechts University, Hermann-Rodewald-Str. 9, 24118 Kiel, Germany Email: henke@pflanzenbau.uni-kiel.de

Abstract

In Germany the acreage grown with winter oilseed rape (OSR) increased in the last decades because of its profitability, the beneficial value as preceding crop for cereals, and the opportunity to grow OSR for biofuel production on set-aside. OSR demands high levels of nitrogen (N) fertilizer often exceeding 200 kg N ha^{-1} to achieve maximum yields. However, N offtake by the seeds is comparatively low leading to high positive N balances. There are also significant N losses from the plant before harvest due to leaf abscission. Additionally, the early harvest potentially enhances high mineralization of both crop residues and soil N in the favourable structured soil after harvest. The subsequent winter wheat crop normally takes up 20 - 25 kg N ha^{-1}. As a result soil mineral N content (SMN) can increase during autumn and large amounts of nitrate are likely to be leached with percolation water. However, there are several well known agronomic opportunities like minimum tillage and catch crop growing to reduce nitrate leaching after growing OSR.

The aim of our study is to quantify the effects of several agronomic strategies on nitrate leaching losses after OSR by combining an experimental and a modelling approach.

The experiment is a field trial with different tillage operations (mouldboard ploughing vs. conservation tillage) and different succeeding crops (winter wheat, spring oats, catch crop). The model was constructed from several existing and newly designed modules, all based on an object oriented class library called HUME. Modules for calculating the N dynamics including nitrate leaching, crop residue decomposition, tillage operations, and N uptake by the crops following OSR were thereby coupled to a system simulation model.

First results of the leaching period 2005/2006 show that nitrate leaching during winter was only marginally affected by the amount of crop residues of OSR. N mineralization after OSR therefore originates mainly from the soil mineral N pool which was highly influenced by the intensity of tillage in autumn. The results indicate that catch crops have a high potential to reduce the SMN pool in autumn because of N uptake up to 60 kg N ha^{-1} before winter. The model was used to extrapolate the experimental results to different soil and weather conditions.

Key words: Oilseed rape, modelling, nitrogen leaching, tillage, catch crop

Introduction

Winter oilseed rape (OSR) became in Germany a more and more important crop in the last decades because of its profitability, the beneficial value as preceding crop for cereals and the opportunity to grow OSR for biofuel production on set-aside. Its high demand on nitrogen (N) fertilizer and the comparatively low N offtake by the seed lead to large N surpluses on the crop scale. Significant N losses from the plant before harvest due to leaf abscission (Malagoli et al. 2005) and additionally the early harvest time allow a high mineralization potential of both crop residues and soil N in the favourable structured soil after OSR harvest. In consequence soil mineral N content (SMN) can increase during autumn and large amounts of nitrate are likely to be leached with percolation water. However, there are several well known agronomic opportunities to reduce nitrate leaching after growing OSR. First of all reduced tillage depth after harvest has the potential to minimize N release because of diminished soil disturbance (Huetsch & Mengel 1992). Secondary, changes in the crop rotation associated with the introduction of catch crops and spring cereals are appropriate to decrease SMN during autumn and consequently to reduce the risk of nitrate leaching after OSR (Justes et al. 1999). Several model approaches deal with N dynamics after OSR harvest especially in terms of crop residue decomposition (Nicolardot et al. 2001). The aim of the presented paper is to analyse the N dynamics after growing OSR combining a field trial and a model approach. Data from a field experiment were used for the analyses in the given paper. Furthermore scenario calculations were carried out to quantify potential leaching losses during the leaching period under hypothetical soil and weather conditions to derive functional relationships between cropping system, site characteristics and nitrate leaching potentials.

Material and Methods

The experimental data presented here originate from a field trial established in autumn 2003 on a pseudogleyic sandy loam at the Hohenschulen Experimental Station of the University of Kiel, located in NW Germany 15 km west of Kiel (Schleswig-Holstein). The climate can be described as humid. Total rainfall averages 750 mm annually at the experimental site, with ca. 400 mm received during April-September, the main growing season, and ca. 350 mm during October-March. The trial based on different treatments after OSR and was designed as a split-plot design with three replications as blocks, tillage and following crop as main plots and nitrogen fertilizer rate as subplots. In treatments 1 and 2 winter wheat as the typical subsequent crop was grown following OSR but tillage differed (plough vs. minimum tillage). In treatment 3 phacelia

(*Phacelia tanacetifolia*) was sown as a catch crop after OSR harvest following a cultivator tillage operation. Tillage depth was performed at a depth of 10 cm using a compact disc cultivator, at 20 cm using a cultivator and at 30 cm using a plough. The amount of fertilizer N for OSR was 200 kg N ha^{-1} and was applied as calcium ammonium nitrate with 27 % N. Fungicides and other crop management factors not involving the treatments (e. g. herbicides, sowing date) were handled in accordance with the farmers' normal practice. At maturity total number of OSR plants, dry matter of stems and pods and corresponding C and N concentrations were determined (C/N-Analyser Vario MAX, CN Elementar Analysesysteme). In the subsequent winter wheat total above-ground dry matter and N concentration were measured at the end of autumn growth and start of spring growth. In phacelia total above-ground dry matter and N concentration was quantified fortnightly from emergence to end of autumn growth. N concentrations were determined using near infrared spectrometry (NIRS 5000, Foss). Soil mineral nitrogen (NO_3-N plus NH_4-N: SMN) and gravimetric water content were monthly assessed if there was no snow or frost. Four cores per plot, averaged to one sample, were taken to 90 cm in 30 cm horizons. Additionally soil samples (0-30 cm) were taken fortnightly in treatment 3 in autumn.

The water transport model calculates soil water movement by using the water content based a formulation of the Richard's equation. Relationships between soil water diffusivity and the volumetric water content are described by the functions of van Genuchten (1980). Potential evapotranspiration is calculated using the Penman-Monteith equation. In order to consider delayed water influx into the soil a submodel of snow accumulation is introduced. Mineralisation of crop residues and soil organic matter is estimated by a simplified modification of the model of Verberne et al. (1990) with four organic carbon pools C_i, soil organic matter C_{som}, microbial biomass C_{biom}, easily decomposable crop residues C_{dpm} and more resistant crop residues C_{rpm}. All these pools have fixed C/N rations and decompose by first order kinetic processes. Abiotic limitations of temperature, soil water content, and shortage of SMN affecting the decomposition processes are considered in the model. The impact of tillage operations on soil N dynamics is included within the mineralisation submodel by a factor which boosts the decomposition rates in the tilled soil layers. This boosting factor is decaying over time according to a first order kinetic. Each time tillage operations are carried out crop residues are buried into the soil and the four carbon pools are equally redistributed within the tilled soil layer. In well-aerated soils the concentration of ammonium is usually very low compared to nitrate. Therefore only nitrate N is considered by the model. Nitrate transport in the soil profile is calculated by a numerical solution of the convection-dispersion equation. The initial condition for this equation was the measured nitrate concentration from 0 to 90 cm which was determined in a spatial resolution of 30 cm. N flow at 120 cm soil depth was defined as N loss due to leaching. Crop N uptake of wheat and phacelia is calculated using a proper function fitted to the experimental data. For winter wheat the expolinear growth curve and for Phacelia the logistic growth curve was chosen to describe autumn growth. A base temperature of 3 °C was assumed. Similar procedures are used to fit measured data of leaf area index, crop height and crop dry matter. The above algorithms were implemented as sub-models within the HUME modelling environment (Kage & Stützel 1999).

Results

After harvest 2005 70 kg N ha^{-1} in OSR residues was remained on the field in the different treatments. N losses due to leaf fall were about 30 kg N ha^{-1}. The residues were buried into the soil according the different tillage operations. Because of a C/N ratio of about 60 the incorporation of the residues caused a nitrogen immobilisation. After tillage SMN raised remarkably depending on tillage intensity and depth because of mineralization of soil N (Fig. 1).

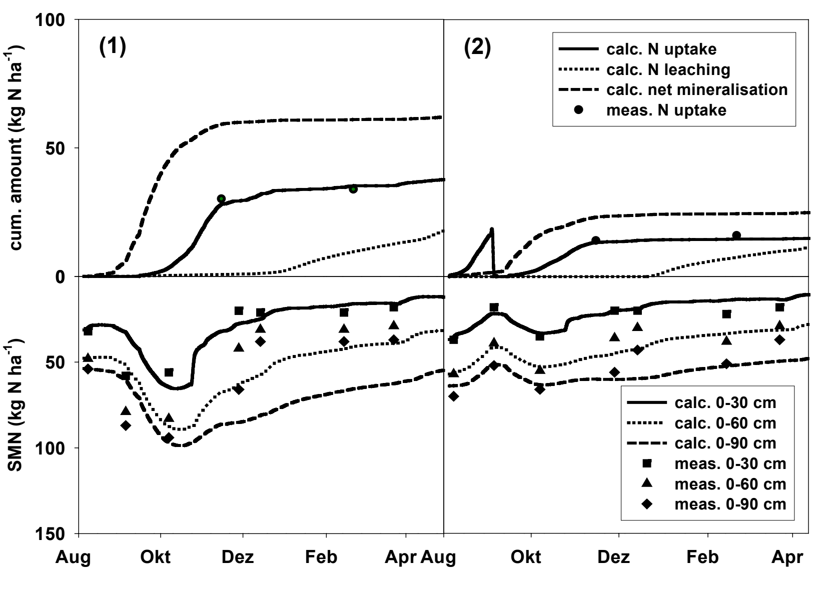

Fig. 1: N dynamics in the treatment 'winter wheat conventional tillage' (1) and 'winter wheat minimum tillage' (2) after OSR in the leaching period 2005/2006 at 'Hohenschulen'

Calculated net mineralization was highest in the treatment 'winter wheat conventional tillage' followed by 'winter wheat minimum tillage' and 'catch crop' (Tab. 1) depending on the intensity and depth of tillage operations. N uptake until the end of autumn growth differed clearly between the tillage treatments. N uptake in the ploughed plots was on average twice compared to the minimum tillage plots.

Due to the early sowing compared to wheat and the quite high N mineralization after the cultivator tillage N uptake of the catch crop was highest. Estimated nitrogen leaching using the simulation model decreased in the order 'winter wheat conventional tillage', 'winter wheat minimum tillage' and 'catch crop' (Tab.1).

Tab. 1: Key data of N dynamics after OSR in all treatments in the leaching period 2005/2006 at 'Hohenschulen'

	'Winter wheat conventional tillage'	'Winter wheat minimum tillage'	'Catch crop'
N uptake at end of autumn growth (kg N ha^{-1}) measured	30	14	57
SMN at end of autumn growth (kg N ha^{-1}) measured	66	56	36
Cumulative net mineralization (kg N ha^{-1}) calculated	62	25	35
Cumulative N leaching (kg N ha^{-1}) calculated	18	14	7

In the leaching period 2005/2006 the amount of rainfall was about 100 mm lower than the long-term average of 442 mm and consequently also the amount of percolation water and the nitrate leaching in all three treatments. Sieling (2000) reported on average measured N leaching of 58 kg N ha^{-1} under wheat following OSR from 1991 to 1997 at the same location. Also the high N uptake of winter wheat, especially in the treatment 'conventional tillage', decreased the N pool at the risk to be leached in this percolation period.

Long-term scenario calculations using weather data and soil parameters of the locations 'Hohenschulen' (1992-2006), 'Hannover-Herrenhausen'(1971-1995) and 'Guelzow' (1996-2005) were made to estimate the long-term probability of N losses for alternative soil and climatic conditions. We used a sandy soil (Hannover-Herrenhausen) and a more continental location (Guelzow) with less rainfall. These locations represent important regions for OSR cropping in northern Germany. In all scenario calculations N leaching was lowest in the 'catch crop' treatment and highest in the 'winter wheat conventional tillage' treatment. Although the amount of N leaching was quite low, the EU drinking water limit of 50 mg NO_3 l^{-1} was exceeded in all treatments.

Table 2 summarizes the main characteristics of the scenario calculations.

Location	Simulation period	Soil	N leaching (kg N ha^{-1}) (conc. mg NO_3 l^{-1})		
			Winter wheat conventional tillage	Winter wheat minimum tillage	Catch crop
Hohenschulen	1992-2006	Sandy loam	47 (104)	31 (73)	26 (82)
Hannover-Herrenhausen	1971-1995	Sand	39 (112)	26 (83)	20 (83)
Guelzow	1996-2005	Sandy loam	36 (117)	25 (87)	24 (100)

Discussion

Considering the EU drinking water limit of 50 mg NO_3 l^{-1} N management after OSR need to be improved because N leaching is highest after OSR compared with winter wheat and winter barley (Sieling 2000). Our results show that shallow tillage operations has the potential to reduce N leaching because of diminishing mineralization of soil borne N compared to the ploughed treatment (Huetsch & Mengel 1992). Most effective in terms of a reduction in N leaching was the treatment 'catch crop'. Phacelia had the largest N uptake in autumn due to the early tillage operation and corresponding N mineralisation. This agrees with the results Justes et al. (1999) who report about a markedly reduction of SMN due to growing a catch crop of radish or OSR volunteers. They also found an N immobilization effect of about 20 kg N ha^{-1} after incorporating OSR residues into the soil but this effect was smaller compared to the catch crop. Multi year simulation of N leaching at the three locations, representing large areas of OSR cropping in northern Germany, lead to the conclusion that the probability of N leaching is highest in the ploughed treatment with winter wheat as subsequent crop followed by the 'minimum tillage' and the 'catch crop' treatment. However, growing a catch crop is associated with additional seed cost and the abandonment of the typical subsequent winter wheat crop and therefore unattractive for farmers if there is no compensation. Costs saving conservation tillage is already a quite common practice after OSR but it is only effective in preventing N leaching if the tillage depth is reduced.

Acknowledgement

The authors thank Dr. R.-R. Schulz for providing the weather and soil data of the Guelzow experimental station.

References

Huetsch, B. & Mengel, K. 1992. Effect of long-term ploughing and direct drilling on the distribution and leaching of mineral nitrogen in a loamy and a sandy soil. European Journal of Agronomy 1, 213-219.

Justes, E., Mary, B. & Nicolardot, B. 1999. Comparing the effectiveness of radish cover crop, oilseed rape volunteers and oilseed rape residues incorporation for reducing nitrate leaching. Nutrient Cycling in Agroecosystems 55, 207-220.

Kage, H. & Stützel H. 1999. HUME: an object oriented component library for generic modular modelling of dynamic systems. In Modelling Cropping Systems, ESA conference, Lleida June 1999 (Eds C. S. M. Donatelli, F. Villalobos & J. M. Villar), pp. 299-300: Lleida, Spain: European Society of Agronomy.

Malagoli, P., Laine, P., Rossato, L. & Qurry, A. 2005. Dynamics of Nitrogen Uptake and Mobilization in Field-grown Winter Oilseed Rape (Brassica napus) from Stem Extension to Harvest I. Global N Flows between Vegetative and Reproductive Tissues in Relation to Leaf Fall and their Residual N. Annals of Botany 95, 853-861.

Mueller, T., Jensen, L. S., Magid, J. & Nielsen, N. E. 1997. Temporal variation of C and N turnover in soil after oilseed rape straw incorporation in the field: simulations with the soil-plant-atmosphere model DAISY. Ecological modelling 99, 247-262.

Nicolardot, B., Recous, S. & Mary, B. 2001. Simulation of C and N mineralization during crop residue decomposition: A simple dynamic model based on the C:N ratio of the residues. Plant and Soil 228. 83-103.

Sieling, K. (2000). Untersuchungen zu den Auswirkungen unterschiedlicher Produktionssysteme auf einige Parameter des N-Haushalts von Boden und Pflanze. Habilitationsschrift, Universität Kiel. Schriftenreihe des Instituts für Pflanzenbau und Pflanzenzüchtung der Agrarwissenschaftlichen Fakultät der CAU, Bd. 16.

Verberne, E. L. J., Hassink, J., De Willigen, P., Groot, J. J. R., & J.A., V. V. (1990). Modelling organic matter dynamics in different soils. Neth. J. agric. Sci. 38, 221-238.

Van Genuchten, M. T. (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J. 44: 892-898.