The NDICEA model: a supporting tool for nitrogen management in arable farming

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Abstract

Nitrogen use efficiency is an important item in organic farming. Modelling nitrogen dynamics can help to understand the impact of alternative agronomic practices and thus assist in decision making. In three examples in the Netherlands, the role of the NDICEA model is demonstrated. It is concluded that NDICEA is an easy to use and helpful tool for optimizing nitrogen efficiency and minimizing losses.

Introduction

Nutrient management is a key factor in organic agriculture. For some nutrients a balance approach will do, but for nitrogen this is not sufficient. Availability and crop demand should be synchronized as close as possible for optimal efficiency and minimal losses. Because of the number and complexity of processes involved, a model approach can be useful. In this paper we present aspects of the use of the NDICEA model in optimizing nitrogen management by means of three examples.

Methods and results of the three examples

For the description and interpretation of the nitrogen dynamics in different situations we used the NDICEA model (Nitrogen Dynamics In Crop rotations in Ecological Agriculture, Burgt *et al.*, 2006a). This model describes soil water dynamics, nitrogen mineralization and inorganic nitrogen dynamics in relation to weather and crop demand. Crop yields are used as input, making the model target-oriented which is distinctive from most other nitrogen models (Kersebaum et al., 2007). The model includes a two-layer soil model and calculations are based on time steps of one week. NDICEA has been used in the Netherlands by farm advisory services (Burgt *et al.*, 2006b) and in research (Cuijpers & Hospers-Brands, 2009) and in the UK for analysing nitrogen dynamics in organic crop rotations (Burgt *et al.*, 2006c).

In two of the following examples the model was used as decision support tool in arable farming, one on tactical and one on strategic level. The third case is connected to strategic questions in nitrogen use efficiency and is derived from a research project.

For these three examples, all agronomic data relevant for NDICEA on soil and soil water, fertilization, crop and green manures were gathered. This was done for at least three years: the year in which measurements took place, and the foregoing two years. The model performance was checked by soil inorganic nitrogen measurements, three or more per season, and expressed as RMSE (Wallach & Goffinet, 1989) for measured and simulated soil mineral nitrogen. If the RMSE was beneath 20 kg N ha^{-1} model performance is considered to be acceptable (Burgt, 2006a)

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First example: tactical decision in practice of arable farming

At the biodynamic farm 'Loverendale' (51°.34'34 N, 3°.34' 55 E) the nitrogen dynamics of six fields are modelled. At the field 'Iepenoord' the crop sequence was 2007 barley (whole plant silage) and Italian ryegrass green manure; 2008 potato and black radish/vetch green manure; 2009 beetroot. Last manure application took place in August 2007, 25 tons per hectare of cattle deep litter manure. The farmer feels unsure about the beetroot crop: does it need additional fertilizer to realize the expected yield of 50 tons per hectare?

The simulated and measured level of soil inorganic N is given in figure 1. In this figure, weather data up to march 2009 are from a nearby meteo station; the rest of the 2009 weather data are average regional data.

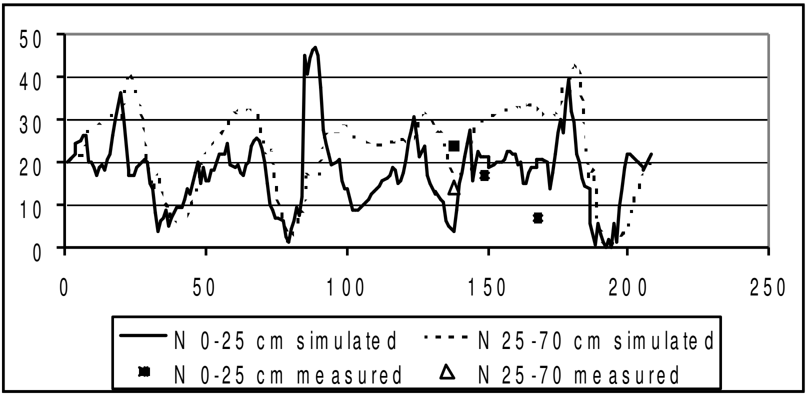

Figure 1: Simulated (lines) and measured (labels) soil inorganic nitrogen. X-axis: week number, 0 = 1 January 2006. Y-axis : kg ha^{-1} .

The simulation of the nitrogen dynamics of this field is adequate (RMSE = 12,6 ; n = 4). The other five fields had comparable results (not shown, RMSE's between 4,0 and 21,0). The simulation of the 2008 beetroot crop, yield 70 tons ha^{-1} (not shown), indicates a calculated shortage of 40 kg ha^{-1} nitrogen. The predicted available nitrogen in an 'average' year allows a reasonable yield, and this crop has shown in 2008 the potential for a higher yield, even when the NDICEA simulation showed a nitrogen shortage. The calculated shortage could be explained by a deeper root system than modelled or by a lower nitrogen content of the crop or the crop residues. Both possibilities could be checked in future. This information made the farmer decide to reject an additional fertilizer application.

Second example: strategic decision in practice of arable farming.

The organic arable farm 'Tongelaar' (51°.42'.57 N , 5°.46'.37 E) is considering the presence of winter wheat in the rotation. Weed control and nitrogen efficiency might be improved by the replacement of winter wheat by green manure in autumn/winter followed by spring wheat. Nitrogen measurements and NDICEA simulations were available from four fields with winter wheat (P1, P2, P5 and P9). The simulation was sufficiently accurate (RMSE of the four fields together was 12,5; n=12).

Based on this information a simulation was done, replacing a winter wheat crop by a green manure crop followed by spring wheat. The farmer assumed that winter and summer wheat yield would be equal and that the black radish/vetch crop would produce 2200 kg dry matter ha^{-1}. N content of the cathcrop was 82 kg ha^{-1}. The simulations shows that leaching was reduced but the reduction in N losses was much lower than 82 kg ha^{-1} for several reasons. Part of the catch crop N-content (26 kg) is fixed by the Vetch, not extracted from the soil. The increased N-release after incorporation of the catch crop increases soil inorganic N level and enhances both denitrification and leaching. After the grain harvest, soil N level is higher in case of spring wheat, increasing the risk of leaching after the main crop. Based on this information, the farmer has decided to change his rotation in favour of spring wheat: less weed problems, less leaching, higher N availability with potentially higher yield or increased protein content, closed green cover of the field during winter and additional organic matter application to the soil.

Third example: strategic design of crop sequence; research project.

To assess nitrogen use efficiency in courgette cultivation, a comparison study is done at the organic farm of Rozendaal in Strijen (51°,45'.24 N , 4°,29'.49 E). Three precrop/fertilizer treatments were studied. 1: Precrop cabbage, autumn ploughing, courgette crop with 120 kg N-total in Vinasse as pre-planting fertilizer. 2: Precrop grassclover, spring ploughing, no fertilizer. 3: Precrop grassclover, spring rotary cultivation, no fertilizer. Soil mineral N was monitored five times, two of which at two depths. The treatments were modelled, resulting in RMSE 8,8 , 15,5 and 10,6 for the treatments respectively (n=7 for each treatment). Results are shown in figure 2.

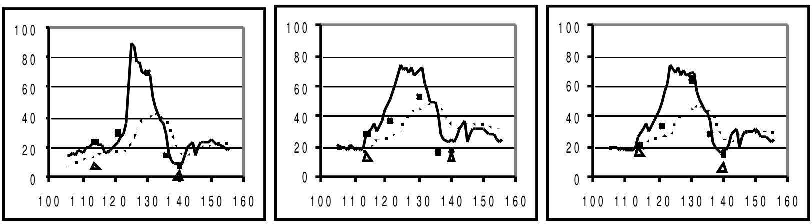

Figure 2: Simulated (lines) and measured (labels) soil inorganic nitrogen. X-axis: week number, 105 = 1 January 2008. Y-axis : kg ha^{-1} . Treatments: 1 (left), 2 (middle), 3 (right). Solid line and squares: 0-30 cm, simulated and measured. Dotted line and triangles: 30-60 cm, simulated and measured.

Courgette yield of the three treatments were 33107, 27907 and 32847 kg ha^{-1} respectively with an obviously lower yield for grassclover and ploughing (treatment 2). Precrop cabbage and 120 kg N fertilizer (treatment 1) resulted in the same yield as precrop grassclover without fertilizer and with rotary cultivation (treatment 3). The difference between ploughing and rotary cultivation is not accurately simulated in the modelled nitrogen mineralization, simply because soil cultivation is no variable in the model. The measurements in mineral N tend to show a lower level in case of ploughing. This is reasonable: the decomposable material is brought deeper in the soil and is less mixed with the soil compared to rotary cultivation, so mineralization could have been be hampered.

It was concluded that grassclover precrop can save fertilizer application, and that the type of soil cultivation is of mayor importance for the next crop, whether this was due to the nitrogen dynamics or to the soil structure. Based on these results the farmer decided to combine treatment 1 and 3 to optimize the cultivation of courgette following grassclover and rotary cultivation, using an limited fertilizer gift.

Discussion

The use of NDICEA is relatively simple: it can be downloaded from the internet for free, and all information needed to model a field or rotation can be acquired in a talk with the farmer or can be estimated (Burgt, 2006a). The only exception are mineral N measurements needed for validation. In all three examples presented, the simulations of soil mineral nitrogen matched sufficiently with the measurements. No calibrations or changes in the default model parameters were needed, indicating that the default model parameters are adequate for these circumstances. Nevertheless a check with at least four soil inorganic N measurements, spread over a growing season, should be part of the procedure before the model can be used as decision support tool.

The use of a dynamic model is interesting, not only because of the many processes it unites, but also because it reveals effects both short-term and long-term effects of an interference (Christiansen *et al*., 2006). In the second example discussed above it became clear that less leaching in short terms might be followed by more leaching and other losses later. This also plays a role in the third example: with grassclover as precrop the production can do without fertilizer, but after harvest leaching of nitrogen is much higher in case of the grassclover precrop.

Conclusions

In the three cases presented, decision making is supported by the outcome of the NDICEA model calculations. The simulations add information to what was known already. Except for additional soil mineral N measurements, all data needed as input for the model can be deduced from the farmer in spoken form, making the use easy.

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