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# Sustainable meat and milk production from grasslands

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# A new approach to N fertiliser advice on grassland in the Netherlands

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## Abstract

Advice on the nitrogen (N) fertilisation of grassland is usually based on the N supply of the soil (SNS). Generally, a higher SNS results in advice for lower N fertilisation rate. Recent research showed that the recommended N fertiliser rate can deviate by more than 60 kg $ha^{-}$ $y^{-1}$ from the optimum. Historic and recent grassland field trial data are, therefore, re-analysed to improve the accuracy of optimum fertiliser rates. Since 1950, over 250 trials were carried out on 140 different locations, resulting in a database with about 10,000 records. The main soil types were sand (46%), clay (21%), river clay (4%) and peat (28%). Analysis showed that the SNS increased over time and that the apparent nitrogen recovery (ANR) was constant over N doses varying between 0-350 kg $ha^{-1}$ $y^{-1}$. However ANR varied considerably between sites and years. We used machine learning algorithms (random forest models) to estimate the ANR in response to soil, weather and management. Initial results showed that it was possible to accurately distinguish fields with ANR.

**Keywords:** soil N delivery, ANR, N fertiliser, random forest

## Introduction

In the Dutch advisory system, the soil N supply (SNS) is based on the quantity of total N in the top 10 cm of a soil profile. It is derived from a statistical relationship between the annual N-uptake of unfertilised plots and the total N content of soils based on long-term series of field trials (Hassink, 1995, 1996) and some more recent field trials. The SNS, therefore, gives an indirect estimation of the real N-mineralisation in soil. Nowadays, it is important to use fertilisers (and manures) efficiently to prevent negative environmental effects while maximising N uptake. Thus, the question if SNS is sufficiently accurate enough to meet future targets for efficient fertilisation is important. A recent desk study (Ros and Van Eekeren, 2016) showed that the annual recommended N fertilisation rate can deviate by more than 60 kg N $ha^{-1}$ $y^{-1}$ from the optimum according to the Dutch N recommendation system (Anonymous, 2017). We have, therefore, investigated the background of this deviation and how SNS, apparent N recovery (ANR) and N fertiliser rate are related. A first analysis of field trial data from 1950 - 2015 (unpublished results) shows large variation in the ANR. The ANR varied considerably between sites, years and soil types with small dependency on N fertiliser rate. Furthermore, ANR decreased with SNS, with a strong soil type effect.

To optimise the fertiliser efficiency, it is important to be able to predict which fields have a high ANR while accounting for actual fertiliser management, soil properties and weather conditions. If we are able to make such a prediction, the farmer can use his restricted amount of nitrogen (by law) more efficiently, resulting in higher yields and more protein in the herbage. To predict which fields have the highest ANR, we analysed available grassland field trial data in the Netherlands using an innovative data driven approach (machine learning).

## Materials and methods

Almost all available Dutch field trial data (> 250) over the last decades were collected, including soil properties, grass properties (ryegrass, age), groundwater table (Gt), weather data (rainfall, temperature, radiation during growth and close to fertilisation dates), and nutrient management (timing, dose and fertiliser type). Focusing on N fertiliser trials, 5,224 annual experiments have been selected with N doses varying between 30 and 900 kg N $ha^{-1}$ (excluding the zero fertilised plots). From this dataset a subset (5,224 records) with seasonal yields and fertiliser rates below 1000 kg N $ha^{-1}$ $y^{-1}$ were selected to evaluate the factors controlling ANR. The resulting database subset contained field trial data from 1941, 1942 and the period 1959 up to 2014. The main soil types included sand (40%), clay (34%), river clay (3%) and peat (22%). About 23% of the data had N fertiliser levels above 400 kg $ha^{-1}$ $yr^{-1}$. There were 342 location by year combinations and 3,450 location by year by treatment combinations.

We studied the possibility of predicting ANR of individual fields using random forest (RF) algorithms; RFs are an ensemble learning method for classification and regression. It operates by constructing a multitude of decision trees at training time and outputting the class, that is the mode of the classes (classification) or mean prediction (regression) of the individual trees (Witten and Frank, 2005). The advantage of RF over decision trees is that it prevents overfitting to the training set.

## Results

The effects of the most important soil, weather and management factors on the ANR (based on all trial data before 1998, about 90% of the data; the calibration set) are shown in Figure 1. The Gt, fertiliser type, DM yield (DMY), and fertiliser rate were the most dominant factors controlling ANR. Validating the model on all field experiments after 1998 showed that the ANR can be predicted quite satisfactorily ($R^2$ = 0.76). Restricting the prediction model to the top 10 most relevant factors did not strongly reduce model performance ($R^2$ = 0.74). In-depth analysis of the forest floor (analysing the cross validated feature contribution

of individual factors) confirmed the impact of Gt, DMY, precipitation on fertiliser date and the number of high rainfall events. ANR increased almost linearly with DMY, whereas N rate showed almost no effect within the range of common N fertilisation doses. Low Gt generally resulted in lower ANR, with a maximum effect of almost 10%. At low N fertilisation doses (< 100 kg $ha^{-1}$), the ANR was slightly (max

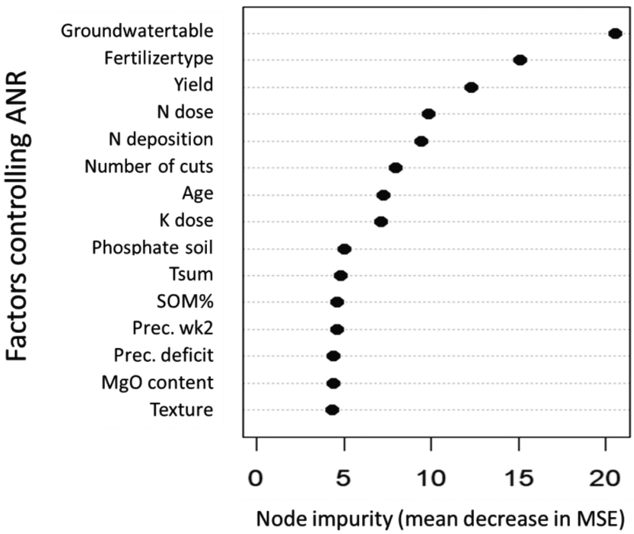


Figure 1. The 15 most important factors of the RF model controlling ANR (impurity is measured by residual sum of squares; node impurity refers to total decrease in MSE on the variable, averaged over all trees).

5%) higher. The Gt and DMY had the strongest effect. Using this reduced training set for the validation set (trials after 1998) resulted in $R^2$ of 75%. For practical implementation in fertiliser recommendation systems, we distinguish five possible soil classes with different N fertiliser recoveries (Table 1). Validating the trained RF model on the field experiments from last decade (after 1998) allowed us to predict the ANR class correctly for 67% of the included field experiments. In approximately 30%, the ANR was over or underestimated by 20%. This approach is thus very promising and can, in principle, be used as selection criteria to distribute N fertiliser over fields.

Table 1. Predicted versus actual ANR for the field trial data 1998 - 2014 (10% of the subset).

| Predicted ANR | Actual ANR | | | | |
|---|---|---|---|---|---|
| | < 0.2 | 0.2 - 0.4 | 0.4 - 0.6 | 0.6 - 0.8 | > 0.8 |
| > 0.8 | 0 | 0 | 0 | 7.2 | 7.8 |
| 0.6 - 0.8 | 0 | 0 | 4.2 | 23.4 | 0.6 |
| 0.4 - 0.6 | 0 | 1.2 | 31.7 | 7.2 | 0.6 |
| 0.2 - 0.4 | 0 | 3.6 | 6.6 | 0 | 0 |
| < 0.2 | 0.6 | 4.2 | 0 | 1.2 | 0 |

We tested this approach also on individual cuts. The results were improved and weather parameters became more dominant. This, in principle, gives opportunities for more weather related fertiliser management, but it needs further investigation.

Before implementing this concept, further testing is needed, including evaluation in practice, to check if this approach is workable for farmers. In addition, the question arises if ANR and SNS can be used at the same time, since SNS indicates an optimum of N fertiliser above the natural soil delivery, and ANR predicts where N is most effective.

## Conclusion

Prediction of the ANR for classification of individual fields has potential. Based on random forest analysis of a large historical database of field trials results, including soil and weather data, we were able to predict the ANR for 67% of the annual field trials correctly. In principle, it is now possible to allocate N fertiliser to fields with the highest ANR.

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