A soil and weather dependent estimator of the soil's capacity to supply nitrogen

Ros G.H.[1], Bussink D.W.[1] and Reijneveld J.A.[2]
[1]*Nutrient Management Institute, Binnenhaven 5, 6709 PD Wageningen, the Netherlands;* [2]*BLGG AgroXpertus, Binnenhaven 5, 6709 PD Wageningen, the Netherlands*

Abstract

The ability of soils to meet nitrogen (N) requirements of grass via mineralization of organic matter is of economic and environmental importance to farmers and society. Soil N mineralization is controlled by soil organic matter dynamics and regulated by water availability and temperature. In the Netherlands, the soil N supply in grasslands is estimated by a statistical model relating N supply to the total amount of N present in soil. We showed that a single N index is insufficient to predict the contribution of N mineralization at field scale, limiting the farmer's possibilities to optimize yields and N-use efficiency. Based on experimental data, we integrated routine soil and climatic parameters in simple empirical models explaining more than 50% of the variation in annual N supply. Combining this information with recent organic manure applications, national fertilizer regulations and optimum N dose-response relationships we showed that the net N efficiency of farming systems can be improved, both on field and farm scale. The developed algorithms are implemented in Dutch advisory systems and will boost the efficiency of N fertilizers.

Keywords: soil N supply, growing season, weather dependency

Introduction

The protein content of grasslands in the Netherlands has decreased from 207 g protein kg^{-1} dry matter in 1996 to around 150 g kg^{-1} nowadays. This decrease has been attributed to the tightening of manure policies, fertilizer use and, consequently, a decrease in the capacity of soils to supply N. Simultaneously, sustainable livestock production systems are increasingly reliant on on-farm production of high quality forages. This requires accurate knowledge of soil N supply (SNS) in order to use the limited amounts of manure and fertilizer optimally. SNS is sensitive to factors controlling the mineralisation potential (e.g. soil properties, geohydrology and manure history) and to environmental conditions. Measuring SNS within the growing season, however, is very laborious, and a more holistic approach is required, which involves the use of combined N indices together with weather data (Dessureault-Rompre *et al.*, 2010; Luce *et al.*, 2011; Ros, 2011). This paper summarizes the results of a 4 year programme entitled 'A novel method in agricultural N management: Unravelling the mystery of natural N release in soils to the benefit of farming and environment' focusing on the integration of routine soil and climatic parameters in the forecast of SNS during the growing season. Currently this approach is implemented in agricultural advisory systems of the main agricultural laboratory of the Netherlands.

Materials and methods

Using a meta-analysis approach, we evaluated the predictive value of most common soil tests (extracting a specific labile N fraction) developed over the last 100 years (using 2,068 observations from 218 papers). The mean correlation coefficient for each soil test was calculated using fixed-effect or random-effect models as implemented in METAWIN 2.0 (Rosenberg *et al.*, 2000). The current approach in the Netherlands (using total N in soil as an estimator of SNS during the season) has been assessed by evaluation of 470 field experiments (227 sand, 98 clay and 145 peat soils) that have been performed during 1960 to 2014.

Based on the collected data, we designed a holistic empirical model combining relevant soil properties with climatic data. The potential soil N supply (under controlled environmental conditions) was quantified using either a combination of soil properties indicative for the labile N pool in soil or a direct approach using Near-infrared reflectance spectroscopy (measuring anaerobic NH_4 production over 14 days at 40 °C). Daily rainfall, evaporation and temperature were derived from nearby weather stations. They were used to correct the potential N supply for the effect of environmental conditions. This correction was made using dimensionless scaling functions for soil water and temperature effects, and mineralization flushes due to rewetting, all derived from published laboratory experiments.

The integrated empirical model was subsequently evaluated on a set of incubation and field experiments, including most relevant soil types in the Netherlands. The mineralisation of N was determined in 100 soils using a classic aerobic incubation assay over a period of 20 weeks. Relevant soil properties were determined, including different kinds of extractable soil organic matter fractions. The mineralisation of N in 44 grassland experiments was determined by the N uptake of unfertilized plots (performed over different years and sites).

Results and discussion

The N uptake in unfertilised mineral grassland soils increased with soil organic matter and total N levels, indicating that these soil properties have some potential to estimate the capacity of soils to supply N. Nevertheless, the statistical power of these models was quite low (Figure 1) showing that uncertainty remains above the 50 kg N ha^{-1}. Variation among years was substantial but not related to changes in manure policies, suggesting that weather conditions are the main factor responsible for strong variability among years. A mean prediction error of 50 to 100 kg N ha^{-1} shows that a direct approach (using one soil test to estimate soil N supply) is not suitable for optimisation of fertiliser management in practice.

The meta-analysis showed that all soil tests were positively related to the potential of soils to supply N. Nevertheless, none of them explained more of the variation in N supply than total N, suggesting that the relationship between both is likely to depend on their mutual relationship with soil organic matter (SOM) (Ros, 2011). It seems evident that an increase in SOM levels increases the capacity of soils to supply N, because there is more substrate available for mineralisation. Similarly, an increase in

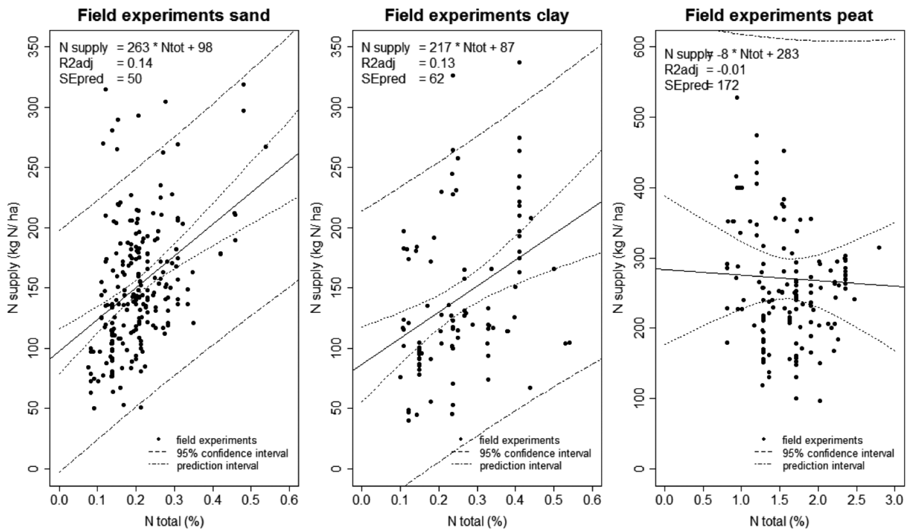

Figure 1. Observed N uptake (or soil N supply) in unfertilised grasslands from field experiments on sand, clay and peat soils (data from experiments performed in 1960 to 2014).

N mineralization rates may increase the levels of depolymerized and recalcitrant by-products; products that have been identified as the main constituents of soil test extractable N. Predictions of SNS were significantly lower for field experiments (R^2<20%) compared to measurements under controlled conditions (R^2>40%). Unfortunately, regression coefficients strongly suggest that the holy grail of an extractable and bioavailable organic matter fraction is likely to remain elusive (Andrén *et al.*, 2008). The variation in regression coefficients might be related to the idiosyncratic response of soil test N and SNS to, for example, a change in climatic conditions and manure history, but these aspects have not yet been investigated. Furthermore, the use of soil tests in sustainable fertiliser programmes requires a more holistic approach accounting for differences in soil organic matter levels (and quality), texture and weather.

Combining soil properties reflecting the soil organic matter content on the one hand, and soil texture on the other resulted in the best estimate of the SNS under controlled environmental conditions (R^2 >0.75). The uncertainty was in most cases smaller than 40 kg N ha^{-1}, giving a more robust and reliable estimate of the SNS than the current Dutch N recommendation system. Similar findings were shown for experiments performed under variable conditions for soil moisture (not shown). Accounting for the variable weather conditions in field experiments had a substantial effect on predicted N supply: annual differences could vary between -20 and +80 kg N ha^{-1} over the period 1960 to 2011. Use of this holistic approach reduced the prediction uncertainty in field experiments by about 10 to 30%: the mean standard error of prediction could be reduced from 30 kg N ha^{-1} down to 10 kg N ha^{-1}.

Conclusions

The meta-analysis and the assessment of the Dutch SNS concept show that the current black-box approach consisting of the evaluation of regression statistics is oversimplified, hampering the search for a reliable and robust estimate of soil N supply. As shown, great progress can be made using a more holistic approach integrating soil properties and weather conditions.

References

Andrén O., Kirchmann H., Kätterer T., Magid J., Paul E.A. and Coleman D.C. (2008) Visions of a more precise soil biology. *European Journal of Soil Science* 59, 380-390.

Dessureault-Rompre J., Zebarth B.J., Burton D.L., Sharifi M., Cooper J.M. and Grant C.A. (2010) Relationships among mineralizable soil nitrogen, soil properties, and climatic indices. *Soil Science Society of America Journal* 74, 1218-1227.

Ros G.H. (2011) *Predicting soil nitrogen supply. Relevance of extractable soil organic matter fractions*. PhD thesis Wageningen University, the Netherlands, 248 pp. Available at: http://edepot.wur.nl/168954.

Rosenberg M.S., Adams D.C. and Gurevitch J. (2000) *MetaWin. Statistical software for meta-analysis*. Version 2.0. Sinauer Associates, Inc., Sunderland, MA, USA.

St Luce M., Whalen J.K., Ziadi N. and Zebarth B.J. (2011) Nitrogen dynamics and indices to predict soil nitrogen supply in humid temperate soils. *Advances in Agronomy* 112, 55-102.