A Geostatistical Analysis of the Spatial Variation of Soil Mineral Nitrogen and Potentially Available Nitrogen Within an Arable Field

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Abstract. The technology for site-specific applications of nitrogen (N) fertilizer has exposed a gap in our knowledge about the spatial variation of soil mineral N, and that which will become available during the growing season within arable fields. Spring mineral N and potentially available N were measured in an arable field together with gravimetric water content, loss on ignition, crop yield, percentages of sand, silt, and clay, and elevation to describe their spatial variation geostatistically. The areas with a larger clay content had larger values of mineral N, potentially available N, loss on ignition and gravimetric water content, and the converse was true for the areas with more sandy soil. The results suggest that the spatial relations between mineral N and loss on ignition, gravimetric water content, soil texture, elevation and crop yield, and between potentially available N and loss on ignition and silt content could be used to indicate their spatial patterns. Variable-rate nitrogen fertilizer application would be feasible in this field because of the spatial structure and the magnitude of variation of mineral N and potentially available N.

Keywords: soil mineral N, potentially available N, within-field variation, geostatistics

Introduction

Where water and other nutrients are not limiting, nitrogen (N) is the nutrient that has the largest effect, in general, on the growth and yield of cereal crops (MAFF, 2000; Gabrielle et al., 2001). There has been much interest in variable-rate application of N fertilizer because of the environmental (Hergert and Ferguson, 1997) and financial benefits that can accrue (Østergaard, 1997). To benefit from this technology, the spatial variation of N supply within fields must be known in order to adjust fertilizer rates accordingly.

During the growing season, cereals use several sources of N, such as that from fertilizer inputs, existing soil mineral N (nitrate and ammonium) and that released through the breakdown of organic matter in the soil (mineralization). During periods when release of N through mineralization exceeds plant uptake, residual mineral N accumulates, which is then available for plant uptake and susceptible to losses. Measurement of mineral N (usually nitrate) that has accumulated in soil before planting or at a specific time during the crop’s growing season can be used to guide N fertilizer recommendations. These pre-planting or pre-side dress tests have been used widely in the
United States and Europe (Keeney, 1982; Mengel, 1991). Such 'snapshot' measurements of mineral N give only a partial view of the soil N status because 97–99% of N occurs in an organic form in the soil organic matter (Bundy and Meisinger, 1994).

Whilst there is no standard technique for predicting the N that will be released from the breakdown of organic matter, it has been suggested that chemical and biological indices can provide a relative indication of potentially available N (PAN) (Bundy and Meisinger, 1994). We do not attempt to review the literature that describes potential indices of soil N supply here, but refer readers to the following reviews (Jarvis et al., 1996; Stockdale et al., 1997; Bhogal et al., 1999).

The government’s recommendations for calculating N supply (MAFF, 2000) suggest that it is necessary to account for soil mineral N (to maximum rooting depth), total crop N content and mineralizable N (MAFF, 2000).

To determine soil mineral N and PAN is costly because sampling and laboratory analyses are not readily automated. Soil properties such as the particle size fractions and loss on ignition (LOI) are less variable through time and so if they can be related to soil N supply they might provide a more economic alternative for describing its spatial variation. Such relations might also provide a basis to guide targeted sampling to determine soil N supply directly at a few well-selected sites during the growing season to determine fertilizer requirements.

Information about soil N supply usually derives from sampling and it is likely to be sparse in relation to the area to be managed by the farmer (Oliver, 1999). As the precision farmer wants to manage continuous tracts of land, reliable predictions at places between the sampling sites are needed. Geostatistical methods (Webster and Oliver, 2001) provide the tools to describe spatial variation quantitatively and for optimal prediction. The variogram describes the spatial correlation structure in the variables examined and will identify those that have similar spatial patterns. Provided that the data are spatially correlated, the parameters of the variogram model can be used with the data to predict at the unsampled locations by kriging. It provides unbiased predictions with known and minimal errors. If regional trend accounts for most of the spatially structured variation, trend surface analysis (TSA) can be used for prediction. This is a form of multiple regression in which the predictors are the spatial coordinates.

The character of the field scale variation of mineral N and PAN and the factors that contribute to this spatial variation have not been well documented. This is a significant gap in our understanding. There are few examples of within-field investigations of PAN (Robertson et al., 1993; Cambardella et al., 1994; Mahmoudjafari et al., 1997) and mineral N (Mary et al., 2001; Dampney et al., 1997; Simmelsgaard and Djurhuus, 1997).

The aim of this study was to measure soil mineral N and PAN in the spring, together with gravimetric water content (GWC), LOI, sand, silt and clay contents, crop yield from the previous growing season, and elevation to gain insight into their spatial variation and to assess the feasibility of variable rate N fertilizer applications.

Experimental site and materials and methods

The study site, Cashmore field at Silsoe Research Institute near Bedford, England, has been described previously by Lark et al. (1998). Seven soil series have been mapped in