Grain Yield Response to N Fertilizer Across Landscape Positions

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Introduction

The successful implementation of variable rate nitrogen fertilization hinges on the ability of agronomists to accurately predict crop nitrogen requirements across both soil landscapes and growing seasons. The ability of the agronomic community to accurately predict differences in crop nitrogen requirements depends on our knowledge of soil nitrogen dynamics and how these dynamics vary within a field and ultimately how soil nitrogen supply affects both fertilizer requirements and crop yield. This purpose of this paper is to describe the effect that landscape position and growing season have on soil nitrogen availability and, as a consequence, how these factors affect both fertilizer nitrogen requirements and crop yield.

Crop response to N-fertilization

Soil testing laboratories have traditionally relied on an additive approach for making fertilizer recommendations. Predictions of fertilizer requirements are based on spring mineral nitrogen content, expected net mineralization, and crop demand. This method tends to be inaccurate, due mainly to our inability accurately assess nitrogen mineralization over a growing season (Rice and Havalin, 1994). Mineral nitrogen supply, during the growing season, is dependent upon several factors within the nitrogen cycle, each of which is regulated by a variety of environmental processes. The inherent inaccuracy of additive approach would most likely be magnified when used to make fertilizer predictions for variable rate fertilization. Changes in the soil environment, as it relates to both crop growth and nitrogen supply, across the landscape results in differences in the demand for nitrogen fertilizer. The following sections discuss some of the variables that will ultimately influence N fertilizer requirements for variable rate fertilization.

Crop demand for nitrogen

Crop yields vary across the landscape; this is one of the underlying premises of variable rate fertilization. One of the philosophies of variable rate fertilization is that if crop yields vary across the landscape, so should nitrogen fertilizer rates. The three factors that regulate the amount of nitrogen taken up by the crop are grain yield, harvest index, and grain protein content. It is obvious that areas within a field with greater yields will require more nitrogen, therefore the effect that field position has on yield is a variable which must be predicted. The use of landscape position as an indicator of yield potential is one such approach, generally crop yield is related to landscape position. It is often expected that crop yield increases downslope, however, the relationship between crop yield and landscape position is not always that straight forward. Several researchers have noted an increase in crop yield from upper to lower landscape positions (Spratt and McIver, 1972; Hanna et al., 1982), while other researchers have noted the opposite trend (Colvin et al., 1991; Popoff, 1994; Wibawa et al., 1993). As a consequence the amount of nitrogen taken up by the crop is not necessarily reflected by landscape position. The amount of nitrogen taken up by a wheat crop grown at Hepburn in 1997 is shown below (Figure 1). At Hepburn in 1997 the control that landscape exerted on crop growth resulted in increased yields downslope As a consequence of this increase in yield downslope, N uptake increased downslope.

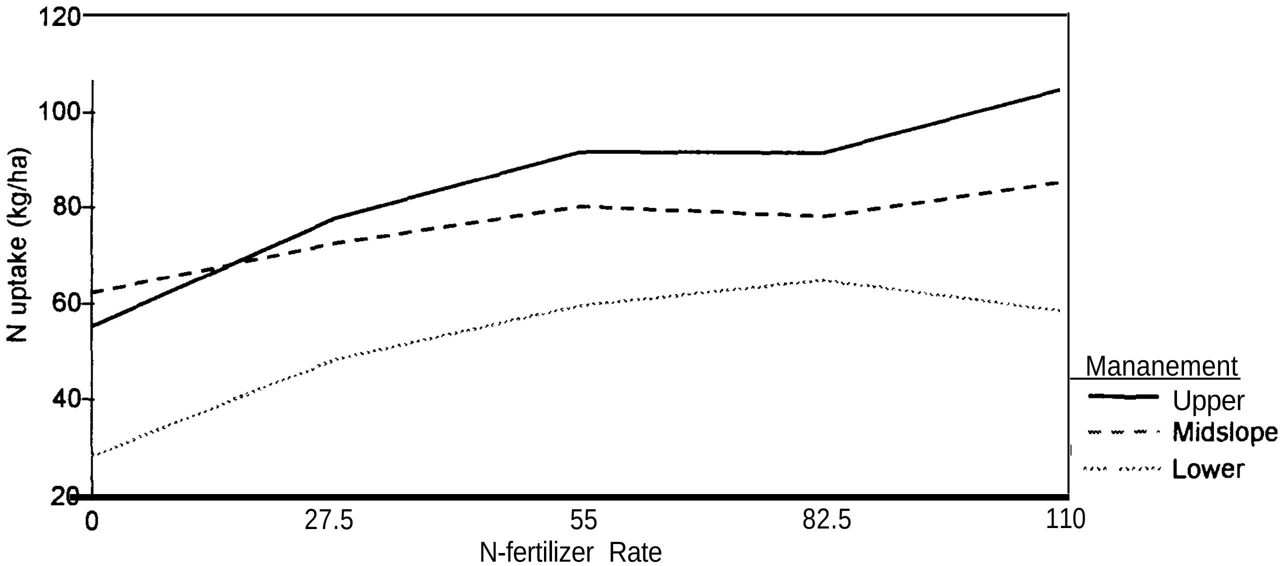

Figure 1: Nitrogen Uptake: Hepburn 1997

Nitrogen availability and it's effect on nitrogen fertilizer requirements

The use of spring nitrogen for variable rate fertilization requires an understanding of the relationship between mineral nitrogen and landscape position. Although soil mineral nitrogen is subject to a variety of processes (mineralization, immobilization, denitrification, leaching, etc.), increased levels of mineral nitrogen in lower landscape positions has been documented (Stevenson et al., 1996, Malo and Worcester, 1975, and Ayres et al, 1985). Stevenson et al. (1996) and Malo and Worcester (1975) attributed the increase in mineral nitrogen downslope to maximum erosion and poor moisture conditions in the shoulder positions and deposition of organic matter and better moisture conditions in lower slope positions. Ayres et al. (1985) attributed these differences to the translocation of materials downslope.

In an attempt to quantify the nitrogen supplying power of the soil a balance sheet method has been used by various researchers (Rice and Havlin, 1994; Huggins and Pan, 1993). Both studies describe the amount of available nitrogen, and hence the amount of fertilizer required, as the net sum of the various components of the nitrogen cycle. The relevant components of the nitrogen cycle are: mineralization, immobilization, volatilization, denitrification, and deep leaching. The net sum of these components is regulated by: the amount and quality of substrate (Bonde and Roswall, 1987), pH, aeration, soil physical and chemical properties, and soil moisture and temperature regimes (Schepers and Meisinger, 1994). Since these components are intimately related to each other, and also, since each component varies both spatially and temporally, the effect landscape has on nitrogen availability is not straightforward.

Mineralizable N is related to organic matter, which in turn, is related to landscape position (Fiez et al., 1994). Both Qian and Schoenau (1995) and Goovaerts and Chiang (1993) found that nitrogen mineralization was explained by the amount of oxidizable carbon, which in turn was related to moisture content. Furthermore, Qian and Schoenau (1995) noted that the differences in mineralizable nitrogen across the landscape were consistent with differences in both organic carbon and total nitrogen across the landscape. It is mineralizable nitrogen that is responsible for significant differences in the amount of nitrogen supplied by the soil for crop growth (Cabrera et al., 1994) therefore differences in nitrogen mineralization across the landscape will ultimately have an effect on crop growth. This correlation between nitrogen supplying power and organic carbon content, as previously noted, provides the possibility to map nitrogen supplying power based on organic matter content (Cahn et al., 1994; Fiez et al., 1994).

Conversion of organic nitrogen into plant available nitrogen (mineralization), is also regulated by temperature and moisture (Van der Paauw, 1966, as cited in Wander et al., 1995). As was previously mentioned, soil moisture and temperature are both influenced by landscape position, therefore, the control landscape exerts on these two parameters ultimately effects the nitrogen supply power of the soil. Optimum moisture conditions for nitrogen mineralization have been found to be in the range of -0.01 to - 0.03 MPa (Myers et al., 1982; Doe1 et al., 1990) and mineralization has been found to cease at water contents below -0.30 MPa (Doe1 et al., 1990). Temperature also has a profound effect on mineralization rates; rates have been found to double for each 10°C increase in temperature from 0 to 35°C (Stanford et al., 1975; Campbell et al., 1981).

Although adequate moisture is necessary for mineralization, excess moisture can result in gaseous losses of nitrogen via denitrification. Pennock et al. (1992) found that denitrification losses of nitrogen were centered in depressional areas of the field, and they speculated that the high rates were associated with the anaerobic conditions prevalent in the lower depressional areas of the field. Parkin (1993) also found that denitrification rates were related to landscape position; denitrification rates were found to vary from 8.3 $\mu g\ N \cdot kg^{-1} \cdot day^{-1}$ in the shoulder position to 70.5 $N \cdot kg^{-1} \cdot day^{-1}$ in pothole positions. The author attributed the difference in rates to differences in soil moisture content, organic carbon, soil morphology and mineral nitrogen content across the field. Elliott (1990) also noted a relationship between landscape position and denitrification, where regardless of cropping system, denitrification rates were significantly higher in lower landscape positions as compared to upper level landscape positions. The author concluded that differences in denitrification were due primarily to differences in moisture content across the landscape. Spatial differences in denitrification are attenuated, however, over the growing season. Van Kessel et al. (1993) and Elliott (1990) observed a decrease in the spatial variability of denitrification as differences in moisture content converged across the landscape through the growing season.

Plant nitrogen uptake may also be limited by soil physical properties, erosion, and the phosphorus status of the soil. Pan and Hopkins (1991) noted that erosion resulted in limited plant nitrogen uptake, and that compact soil layers and subsoil phosphorus deficiencies resulted in restricted root development, which further limited plant nitrogen uptake.

It is obvious that the amount of soil made available to the crop for any given year or landscape positions is not straight forward. This ambiguity in nitrogen supply necessitates the utilization of a risk based approach to fertilization, that is, fertilization should be based on the probability of a certain set of growing conditions occurring in a given year. This probability based approach is likely more important in the context of variable rate fertilization. In constant rate fertilization the factors that control net mineralization across a landscape then to 'average themselves out' across a field. At the management unit scale the factors that affect nitrogen fertilizer requirements are more sensitive to growing season conditions. The effect that spatial averaging has on fertilizer requirements is covered in the next section.

Developing a fertilizer recommendation – constant rate fertilization

Traditionally fields are treated as a single entity; that is fertilizer requirements are calculated as the average requirement for an entire field. Determination of these fertilizer requirements is based on fertilizer response curves developed in traditional small plot yield trials. Given the fertilizer response, which is an integration of all the controlling factors of the nitrogen cycle and the spring mineral nitrogen levels, soil testing laboratories are able to prescribe a fertilizer recommendation. This method of developing fertilizer recommendations relies on the fact that spring mineral nitrogen levels are a reasonable indicator of nitrogen availability across the landscape over a growing season (Nyborg et al., 1976 as cited in Campbell et al., 1994). These recommendations are unique to soil zone, expected growing season precipitation, and expected yield. With these inputs considered fertilizer required is the sum of spring N levels and the point on the fertilizer response curve that corresponds to a given yield and fertilizer rate.

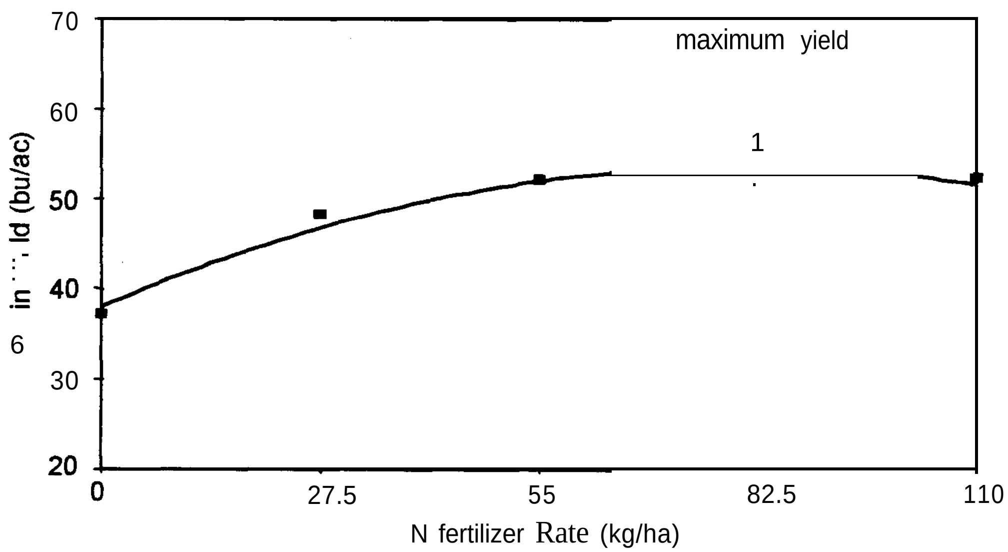

Figure 1: Average fertilizer response curve: Hepburn 1997

Fertilizer recommendations are, on average, accurate in determining the proper fertilization rate for a given field. For example, in a wetter than average year, crop production may be limited in lower landscape positions, but growing conditions are excellent in the upper landscape positions, therefore fertilizer is utilized efficiently in the mid and upper landscape positions, but is underutilized, with respect to grain yield, in the lower landscape positions. Conversely, in a drier than average year, fertilizer N may be under utilized in the dry upper landscape positions, but may be used efficiently in the mid and lower landscape positions. This example shows that fertilizer recommendations for constant fertilization is successful, because differences in the landscape are attenuated by the spatial averaging effect that an average fertilizer rate has on both soil variability and growing season conditions. Therefore, the 'dressings will be appropriate to the average conditions of the area where the trials were' (Cooke, p113, 1972)

Variable rate fertilization

The biggest problem with making a fertilizer recommendation is that the integration of all the factors that control soil N supply and plant growth vary across the landscape. The amount of nitrogen required to produce a unit of grain (UNR) also varies (Fiez et al., 1994). Given that plant growth, soil N supply, and UNR vary across the landscape, crop response to N fertilization will also vary across the landscape. These differences in crop response to N fertilization must be considered when developing N fertilizer predictions for variable rate fertilization. Conventional fertilization relies on a single, or average response curve, to determine fertilizer requirements. Since the fertilizer response curves vary between management units, development of successful fertilizer prescriptions will require a more thorough understanding of the relationships between spring N and soil moisture, expected mineralization, and expected crop yield. Figure 3 demonstrates that differences in crop response to nitrogen fertilization existed in Hepburn for the 1997 growing year. As mentioned earlier, these differences in fertilizer response curves between management is due to differences in both crop yield and the nitrogen supply power of the soil.

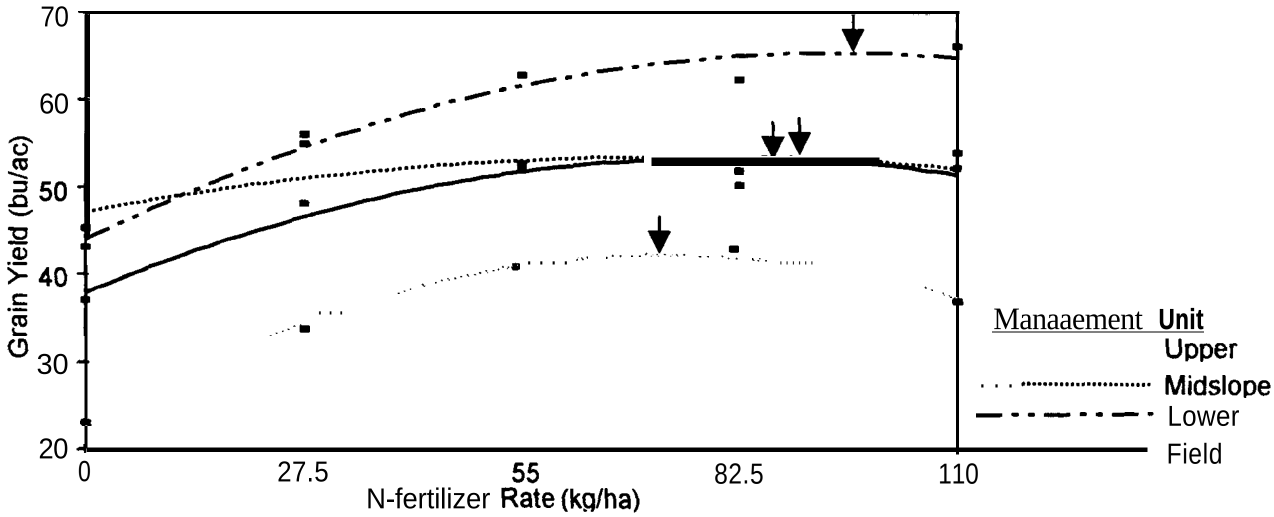

Figure 2: Fertilizer response curves at the management unit level (arrows represent maximum yield for each management unit.

Consideration must also be given to the temporal stability of the factors which control yield across the landscape. It has been shown that not only do the yield regulating factors differ between management units, but also between growing seasons. Management of this variability across growing seasons will require an understanding of the stochastic nature of the variability, such that temporal variations can be accounted for on the basis of temperature and precipitation probabilities. Once sufficient data has been accumulated a method similar to that used by soil testing labs for accounting for precipitation probabilities could be utilized.

Summary

Predicting nitrogen fertilizer rates for variable rate fertilization provides a new challenge, yield potential, nitrogen uptake, and nitrogen supplied from the soil vary across the landscape. Therefore, the accurate assessment of nitrogen fertilizer requirements depends our ability to account for these differences. Ultimately reliable fertilizer predictions should be based on a stochastic model that incorporates the probability of occurrence of different growing season conditions. Unique to each growing season condition would be a probability of occurrence and a set of nitrogen recommendations for each defined management unit. The success of this database will rely on continued research into crop response to nitrogen fertilizer across the landscape.

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