In-season assessment of plant nitrogen status for perennial ryegrass seed production using remote sensing

M.D. Flowers, J.M. Hart, W.C. Young III, C.J. Garbacik, M.E. Mellbye, T.B. Silberstein, and N. Anderson

Department of Crop and Soil Science
Oregon State University
109 Crop Science Building
Corvallis, OR 97331

Abstract:

The high nitrogen (N) fertilizer rates applied to perennial ryegrass combined with the winter rainfall pattern in western Oregon may result in reduced profitability for producers and N loss to the environment. Plant tissue testing to determine the in-season plant N status may improve N management. However, tissue testing can be costly, time consuming, and difficult for growers to adopt. A possible solution to these problems is remote sensing. The objective of this study was to determine if remote sensing in the form of aerial images could be used to assess the in-season plant N status of perennial ryegrass. Research was conducted at four sites in 2007, 2008, and 2009. Strong relationships were found between spectral measurements and both whole-plant N concentration (r^2 = 0.46) and N uptake (r^2 = 0.61) across site-years. Additionally, critical values obtained from these relationships were similar to those found through tissue testing, indicating that spectral measurements may be used to replace tissue tests to assess in-season plant N status of perennial ryegrass.

Introduction:

Growers in the Willamette valley region of Oregon rely on yield goal estimates and experience to formulate spring nitrogen (N) rates. However using this approach, N rates may be insufficient or excessive in any given year. Thus, improved methods that optimize spring N rates are required.

Soil based approaches have been unsuccessful in perennial ryegrass (Hart et al., 2006). A plant based approach, in-season tissue testing, has shown some promise. However, tissue tests have several limitations. They are relatively expensive, difficult, and time consuming to obtain when considering the number of samples required to accurately describe the within field spatial variability found in most Willamette valley fields.

Remote sensing in the form of aerial photographs or an on-the-go sensor might offer a solution to these limitations. Reflectance in the visible and near infrared (NIR) spectrum can be related to chlorophyll, N concentration, biomass, and vigor of plants (Gates et al., 1965; Knipling, 1970).

Thus, similar to tissue tests, remote sensing may be related to whole-plant N concentration or N uptake.

In 2006, a research project was initiated to examine the use of remote sensing to assess the in-season N status of perennial ryegrass for seed production. Specifically, we wanted to determine if spectral measurements from aerial images could assess the plant N status of perennial ryegrass.

Materials and Methods:

Site and Agronomic Description

Research was conducted at the Hyslop Crop Science Farm near Corvallis, Oregon in 2007 through 2009. In 2008, research was also conducted at an additional on-farm location (Macpherson Farm) located near Peoria, Oregon. In 2007 and 2008 at Hyslop, a randomized complete block design with 21 N treatments and four replications was used. Nitrogen treatments were arranged in a factorial design with three fall N rates (0, 45, and 90 kg N ha^{-1}) and seven spring N rates (0, 45, 90, 135, 180, 225, and 270 kg N ha^{-1}). In 2009 at Hyslop a randomized complete block design with seven spring N treatments (0, 45, 90, 135, 180, 225, and 270 kg N ha^{-1}) and 12 replications was used. At the Macpherson site, a randomized block design with three N treatments and three replications was used. Nitrogen treatments consisted of a control (0 kg N ha^{-1}), a fall application of 0 kg N ha^{-1} followed by 202 kg N ha^{-1} in the spring, or a fall application of 45 kg N ha^{-1} followed by 157 kg N ha^{-1} in the spring.

Urea (46-0-0) was used as the N source for all applications. Treatments at each site were sampled in April to determine in-season plant N status. Samples were collected from one-foot sections of adjacent rows by clipping all plant tissue above the soil surface. Samples were analyzed for dry biomass and whole-plant N concentration. Nitrogen uptake for each treatment was calculated by multiplying dry biomass by whole-plant N concentration.

At maturity, treatments were swathed, allowed to dry, and combined. Seed was weighed and a bulk sample was taken for cleaning. Clean seed yield for each treatment was determined using the cleanout percentage from the bulk sample.

Aerial Images

Aerial images of each site were obtained in conjunction with the April tissue samples. Aerial images consisted of four spectral bands; blue (400-500 nm), green (500-600 nm), red (600-700 nm) and NIR (700-900 nm). The procedure described by Flowers et al. (2001) was used to derive spectral reflectance values for each band using ERDAS Imagine software (ERDAS, 2006). In addition to examining the reflectance from individual bands, the normalized difference vegetation index (NDVI; Yang and Anderson, 1999) was calculated and analyzed.

Reflectance values from the individual bands and the spectral index NDVI were compared to the whole-plant N concentration and N uptake values determined from the plant tissue samples.

The relationship between whole-plant N concentration and N uptake with the NIR band and NDVI was examined across sites using a non-linear procedure in SAS (SAS, 2002). A high N reference approach (Blackmer and Schepers, 1995) was also examined by determining the relative NIR or NDVI values for each treatment using the mean NIR or NDVI values from the highest N rate treatment.

Results and Discussion:

To examine the spectral measurements across site-years the Hyslop 2009 dataset was removed due to its unusually high whole-plant N concentrations and small N uptake values that resulted from poor plant growth in the spring. At the remaining three sites, differences in whole-plant N concentration across site-years could be accounted for using a high N fertilizer reference approach (Fig. 1a). In addition, the linear plateau model determined a critical whole-plant N concentration value of 36 g kg^{-1}. This critical value is higher than that determined by the tissue testing analysis (data not shown) and previous studies (Young et al., 1998 and Rowarth et al., 1998). However, the difference among critical values is not likely to be the largest problem with implementation of this approach. The need to use a high N fertilizer reference strip is likely to be a much greater obstacle to grower adoption.

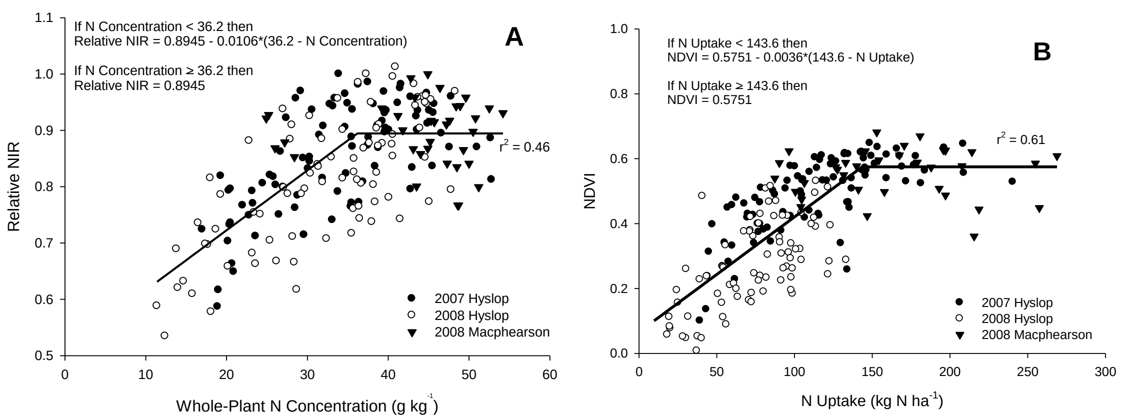

Figure 1. Relationship between nitrogen (N) uptake and relative near infrared (NIR) values (A) or the normalized difference vegetation index (NDVI; B) at three sites in 2007 and 2008.

Unlike the results for whole-plant N concentration, NDVI was able to account for differences in N uptake across site-years without the use of a high N fertilizer reference (Fig 1b). This enhances the appeal of using spectral measurements or sensor readings and may increase grower adoption of such techniques. In addition, the critical value determined by the linear plateau model is 144 kg N ha^{-1}. This is similar to the critical N uptake value of 158 kg N ha^{-1} determined by the analysis of the tissue tests (data not shown). Thus, both the plant tissue samples and spectral measurements are providing the same information in regards to N uptake.

Conclusion:

Perhaps our most important finding was a strong relationship between NDVI and N uptake across site-years (Fig. 1b). This relationship does not depend on the use of a high N reference and also has a critical value very close to that determined by the analysis of the tissue tests (data not shown).

Our results are very promising and indicate that spectral measurements from aerial images can directly replace sampling for in-season assessment of N status of perennial ryegrass. This could have a major impact in improving the management of N fertilizer in perennial ryegrass grown for seed. Future research should focus on developing and validating a robust model for predicting spring N fertilizer rate as well as examining the many commercial sensor platforms available for producers.

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