DETECTING SPATIALLY VARIABLE CORN NITROGEN NEEDS USING GREEN REFLECTANCE FROM 35MM PHOTOGRAPHS

Jared Williams, Newell Kitchen*, and Peter Scharf
University of Missouri, Columbia, Missouri
*USDA Agriculture Research Service, Columbia, Missouri

Abstract

Rising fertilizer costs and environmental concerns are reasons producers are looking to decrease nitrogen (N) fertilizer rates. This study investigated the use of relative green reflectance from 35 mm aerial photographs to detect spatially variable corn [*Zea mays* L.] N needs for developing variable rate fertilizer maps. Photographs were taken at three different growth stages (V7, V11, R3) at altitudes from 3,000 to 5,500 ft for two Missouri fields representing alluvial and deep loess soil types. Nitrogen was applied in strips across the field at early vegetative (about V5) stage ranging from 0 to 250 lbs/acre in 50 lbs increments. Relative green reflectance were developed using a ratio of the green reflectance values of the 0 and 250 lbs/acre N fertilizer treatments. Optimal N rates were calculated using a quadratic plateau with yield as a function of N fertilizer rates. Relative green reflectance and optimal N rates were correlated for both sites but not for all growth stages. Areas that had high apparent soil electrical conductivity (soil EC_a) showed a strong correlation between relative reflectance and optimal N rates with r^2 values as high as 0.76. These results will be used to explore the potential for aerial images to detect corn N status, explain soil type (soil EC_a) and crop color interactions, and develop in-season variable N fertilizer maps.

Introduction

The hypoxic zone that has formed over a large portion of the Louisiana coastal shelf is the result, in part, of N from the Mississippi River. Increased N levels in the Mississippi River have been associated with management of agricultural lands including increasing N fertilizer rates over the past four decades (CAST, 1999). Many N management programs recommend an application of N to non-leguminous crops at rates that are expected to supply most all crop N needs resulting in poor producing areas of fields being over fertilized. Additionally, N fertilizer is inexpensive and over fertilization has little adverse effects on many crops and so the inclination of many producers is to apply a rate that will "insure" N is not limiting. Recent environmental and economic developments suggest an increase in fossil fuel prices will cause N fertilizer production costs to increase. Consequently producers will have more incentive to implement cost saving N management practices.

A potential solution to help reduce costs and the negative environmental impact of N fertilizer is implementing management practices using variable-rate N fertilizer to match site-specific crop N needs. The challenge with variable-rate strategies is determining procedures and measurements that best determines or assesses crop N needs. Crop canopy greenness and soil EC_a are proposed measurements that could be used for developing variable N application maps.

Crop canopy greenness is a measurement of the amount of light reflected from the green visible band. Crop canopy greenness differences are a result of chlorophyll content in the leaves that are strongly related to the N health of the plant (Gausman et al., 1973 and Thomas and Gausman, 1977). As chlorophyll content in the leaf increases the more green light is reflected and the darker green the leaf becomes (Thomas and Oerther, 1972). Under N deficiency conditions, chlorophyll content is sub-optimal which causes a decrease in green reflectance therefore linking chlorophyll content to light reflectance (Al-abbas et al., 1974; Thomas and Gausman, 1977; Maas and Dunlap, 1989; Walburg et al., 1982; Hinzman et al., 1986; Takebe et al., 1990; Blackmer et al., 1994).

Tools have been developed to measure differences in crop canopy greenness and assign digital values based on brightness. McMurtrey et al. (1994) used an integrate sphere radiometer to measure green reflectance of a corn crop canopy and showed that spectral separation existed between N sufficient and N deficient corn plants in the green (0.55 Φm) band. Blackmer et al. (1994) measured green reflectance using a Hunter Tristimulus Colorimeter of four corn hybrids and was able to distinguish between the N sufficient and N deficient areas for each hybrid with the green band. Crop canopy greenness measurements can also be acquired by taking aerial images with a film-based camera and scanning those images. Crop canopy greenness measured from aerial photography can be used for creating in-season variable rate N fertilizer maps. Blackmer et al. (1996) digitalized aerial color photographs and generated digital counts for the green band of the image. The green digital counts were related to late season N stress in corn. Studies have also shown that aerial photographs provided a better indication of crop N deficiency than chlorophyll meters and allow for evaluation of the entire field at a relatively low cost (Blackmer and Schepers 1996).

Crop canopy measurements to determine plant N need indirectly express soil characteristics that affect the availability of N. Apparent soil EC_a may aid crop canopy measurements in accurately developing variable-rate N fertilizer maps. Soil EC_a is a measurement of soil salinity, volumetric water content, the porosity of the soil, soil temperature, and soil texture (McNeill, 1992). Fritz et al., (1999) studied soil EC_a and reported that it accurately predicted soil NO_3-N concentrations and gravimetric water contents, but suggested that further studies are needed to confirm these results. A better understanding of these interactions can help researchers in understanding when and how much N fertilizer should be applied to a crop.

This study has two objectives to help develop variable-rate N fertilizer maps with the potential of reducing the amount of N fertilizer applied to corn crops. The study (1) evaluated crop color greenness extracted from aerial photographs to detect corn crop N health; and (2) determined if soil EC_a can enhance the accuracy of variable-rate N fertilizer maps based on green relative reflectance

Materials and Methods

Research was initiated in 2000, located in two major row-crop areas of Southeast and West-central Missouri representing substantially different soil types. Soils in Southeast Missouri (Aeric Fluvaquent) are alluvial soils of the northern end of the Mississippi River delta and soils in West-central Missouri (Typic Argiudolls) are formed either in deep loess or Missouri River alluvium. The southeast part of the state receives higher temperatures and more precipitation than the West-central area.

Experimental plots were strips six rows (15 ft) wide and running the width or half the width of the field. Typically, the plot length was 1300 ft or longer. Fields were specifically selected for the purpose of having the plots traverse a range of micro-environments (soil type, landscape position, slope, aspect, hydrology). Treatments were designed by using N fertilizer rates and arranging them in a randomized complete block design with three or four replications. Nitrogen fertilizer rates for pre-plant application were rates of 0 or 250 lbs N/acre. Some treatments received an early side-dress (V5) N fertilizer application ranging from 50 to 250 lbs N/acre in increments of 50 lbs N/acre.

Aerial photographs were taken two to three times during the growing season at early vegetative (V7), late vegetative (V11), and reproductive growth stages (R3). Photographs were taken as close to solar noon as possible. Aerial targets or ground control points (GCP) were constructed and laid out at the corners of the sites. Photographs were taken using an EOS ELAN II (Canon Inc., Tokyo, Japan) 35 mm camera with a Promaster Ultraviolet filter 4745/72mm (Photographic Research Organization Inc.) and Elite Chrome Extra Color 100 slide film (Eastman Kodak Co., Rochester, NY). The developed slides were scanned using a Sprint Scan 35 model CS-2700 (Polaroid Corp., Cambridge, MA) slide scanner.

Digital images were registered and rectified using ENVI 3.4 software (Research System Inc., Boulder, CO). The aerial targets were used as GCPs where the target UTM coordinates acquired by either a real-time kinematic global positioning system (RTK GPS) or a differential global positioning system (DGPS) was used to register and then rectify the images. Soil pixels were removed from the images by using k-means unsupervised classification. An unsupervised classification was used instead of a supervised classification because of the tediousness of designating training cells. The images were overlaid with 65 ft grid polygons and green band pixel values extracted and averaged together for individual polygons.

Soil EC_a data were collected using the Geonic EM38 (Mississauga, Ontario, Canada). Data for each field was gathered within the same day in order to maintain similar conditions across the field. The sensor was operated in the vertical dipolar mode, providing an effective measurement depth of approximately 5 ft. Soil EC_a data were collected using a mobile system including an all-terrain vehicle, a wooden trailer for carrying the EM38, a RTK GPS, and a computer for data acquisition (Kitchen et al., 1996). Data were acquired along transects ranging from 16.5 to 33 ft apart at 1-s intervals which correspond to a measurement every 6.5 to 10 ft along transects. A laptop computer on the ATV merged data with geographical coordinates from the RTK GPS that was later used to krig a 65 ft grid and produce soil EC_a maps.

A Gleaner R42 (AGCO Corp., Duluth, GA) combine equipped with a four-row corn header was used to harvest the center four rows of each six-row treatment. Yield data were collected using an Ag Leader Yield Monitor 2000 (Ag Leader Technology, Ames IA). A RTK GPS was used to obtain geographical coordinates and a laptop computer in the combine merged the yield data and coordinates. Cells where recorded yield were questionable because of end rows or other harvesting problems were removed from the data. The data for each site were kriged on a 65 ft grid and mapped.

Statistical procedures for this research were performed using SAS 8.0 software (SAS Inst., Cary, NC). Optimal N rates were determined as the beginning point of the plateau of a quadratic plateau model with yield as a function of N rate. Corn grain price ($2.00/bushel) and N fertilizer costs ($0.25/lbs) were considered in the model, thus making this an "economic optimal" analysis. Relative green reflectance was calculated by dividing the green digital value from the control fertilizer strip (0 lbs N/ acre) by the non-limiting strip (250 lbs N/ acre at planting). Least squares differences linear regression was used to determine correlation between optimal N rate and relative green reflectance.

Results and Discussion

Optimal N rates for the West-central Missouri field ranged from 43 to 184 lbs N/acre with a mean of 107 lbs N/acre and a standard deviation of 30 lbs N/acre. The optimal N rates for the Southeast Missouri field ranged from 42 to 213 lbs N/acre with a mean of 113 lbs N/acre and a standard deviation of 46 lbs N/acre. Producers of both theses areas commonly apply between 200 and 225 lbs N/acre, which is on average much more than the average need for these two fields. If these fields are representative of other corn fields in this area these results suggest that farmers are over applying N fertilizer and as a result they are not achieving maximum economic value and possible increasing pollution.

Relationships were established between optimal N rates and relative green reflectance for both V11 and R3 growth stages of the Southeast Missouri site but with low r^2 values (Fig. 1 and Table 1). The West-central Missouri site only showed a relationship at the V7 growth stage but with very low r^2 value (Fig. 1 and Table 1). Variable rate N fertilizer maps could be developed from these results by predicting fertilizer rates according to the relative green reflectance of the crop. These maps could be used as a bases for a remedial N fertilizer application. Southeast Missouri uses irrigation to supplement rainfall and the irrigation system could be used to apply liquid N fertilizer at any corn growth stage. The West-central Missouri site is non-irrigated and the corn would be too tall for conventional N fertilizer side-dress after the V7 growth stage, although a late season N fertilizer application would be possible with a high clearance vehicle.

Many obstacles exist in implementing the use of relative green reflectance for developing in-season variable-rate N fertilizer maps. Few producers use side-dress management practices, and those that do apply N fertilizer at or before the V5 growth stage. The V5 growth stage is too early in the growing season to accurately predict N need by relative green reflectance. Producers would have to wait until the V6 growth stage (at the earliest) and be furthered delayed with the additional time for processing the images. The waiting time for N recommendations will be reduced as the image processing technology is further developed, but producers will still be reluctant to wait until the V6 growth stage because of the narrow time window left to apply N before the corn is too tall for conventional side-dress (Bausch and Duke, 1996; Scharf and Lory, 2000).

The low r^2 values and non-significant relationships could be a result of the photographic quality of the images. An attempt was made to eliminate soil pixels from the images, but the resolution of the images hampered the ability to completely eliminate all soil pixels. Pixel resolutions for the images ranged between 0.5 and 1.4 ft. These resolutions were probably too coarse resulting in many plant pixels mixed with soil and shadows being included in the data analysis. Higher resolution will remedy this problem and could be accomplished by using a large sized film and a camera with higher resolution capabilities.

Precipitation and the large area of research field (approximately 20 acres, 120 x 800 yds) created additional problems when analyzing the results. The research fields were composed of many different soil types and landscape attributes which interact differently with N based on precipitation received during the cropping season. A solution to this problem is to understand how soil type and landscape attributes might be affecting plant available N under the weather conditions of the growing season. Soil EC_a may provide insight into soil and some landscape effects on soil mineral N and N losses with different precipitation conditions. High soil EC_a is often associated with high cation exchange capacity or high clay content and potentially, high denitrification, but low leaching. Precipitation amounts for West-central Missouri were low to normal from April to June and high during July and early August. Data for this site and for each growth stage was separated into low, medium, and high soil EC_a categories. The data were statistical examined according to category using a regression model with optimal N rate a function of relative green reflectance (Fig. 2). The only relationships between optimal N rate and relative green reflectance were in the high soil EC_a areas of the field (Table 2). The reason why only high soil EC_a areas had a relationship between optimal N rate and relative green reflectance could be because of plant stand variability but further studies will need to be conducted.

Conclusions

Relative green reflectance show potential to be used for variable rate N fertilizer mapping but significant obstacles will need to be overcome before implementation of this technology. Farmers will have to be convinced to wait until the V7 corn growth stage or later to apply side-dressed N fertilizer. Images taken with high-resolution capable cameras maybe needed to accurately separate soil and plant pixels in the imagery. Soil and landscape measurements, such as soil EC_a, may offer opportunities to classify relative green reflectance to predict optimal N rate. Environmentally, relative green reflectance used for variable rate N fertilizer mapping has potential to reduce the amount of N applied to agricultural fields and as a result lower N levels in the Mississippi River.

References

Al-abbas, A.H., R. Barr, J.D. Hall, F.L. Crane, and M.F. Baumgardner. 1974. Spectra of normal and nutrient-deficient maize leaves. Agron. J. 66:16-20.

Bausch, W.C. and H.R. Duke. 1996. Remote sensing of plant nitrogen status in corn. Trans. ASAE 39:1869-1875.

Blackmer T.M., J.S. Schepers, and G.E. Varvel. 1994. Light reflectance compared with other nitrogen stress measurements in corn leaves. Agron. J. 86:934-938.

Blackmer T.M. and J.S. Schepers. 1996. Aerial photography to detect nitrogen stress in corn. J. Plant Physiol. 148:440-444.

Blackmer T.M., J.S. Schepers, G.E. Varvel, and G.E. Meyer. 1996. Analysis of aerial photography for nitrogen stress within corn fields. Agron. J. 88:729-733.

Council for Agricultural Science and Technology. 1999. Gulf of Mexico Hypoxia: Land and Sean Interactions. CAST.

Fritz, R.M., D.D. Malo, T.E. Schumacher, D.E. Clay, and C.G. Carlson. 1999. Field comparison of two soil electrical conductivity measurement systems. p. 1211-1217. *In* P.C. Robert, R.H. Rust, and W.E. Larson (ed.) Proc. 4th Intl. Conf. on Precision Agriculture, St. Paul, MN. 19-22 July 1998. ASA, CSSA, and SSSA, Madison, WI.

Gausman H.W., W.A. Allen, C.L. Wiegand, D.E. Escobar, R.R. Rodriguez, and A.J. Richardson. 1973. The leaf mesophylls of twenty crops, their light spectra, and optical and geometrical parameters. USDA Tech. Bull. No. 1465. Gov. Print. Office, Washington, D.C.: USDA.

Hinzman, L.D., M.E. Bauer, and C.S.T. Daughtry. 1986. Effects of nitrogen fertilization on growth and reflectance characteristics of winter wheat. Remote Sens. Environ. 19:47-61.

Kitchen, N.R., K.A. Sudduth, and S.T. Drummond. 1996. Mapping of sand deposition from 1993 Midwest floods with electromagnetic induction measurements. J. Soil and Water Cons. 51:336-340.

Maas, S.J. and J.R. Dunlap. 1989. Reflectance, transmittance, and absorptance of light by normal, etiolated, and albino corn leaves. Agron. J. 81:105-110.

McMurtrey, J.E., III, E.W. Chappelle, M.S. Kim, J.J. Meisinger, and L.A. Corp. 1994. Distinguishing nitrogen fertilization levels in field corn with actively induced flourescence and passive reflectance measurements. Remote Sens. Environ. 47:36-44.

McNeill, J.D. 1992. Rapid, accurate mapping of soil salinity by electromagnetic ground conductivity meters. In: Advances in Measurements of Soil Physical Properties: Bringing Theory Into Practice. Spec Publ. 30, SSSA, Madison, WI, pp. 209-229

Scharf, Peter C. and John A. Lory. 2000. Calibration of remotely sensed corn color to predict nitrogen need. In Proc. 5th Intl. Conf. on Precision Agriculture, paper 165. CD format only. American Society of Agronomy, Madison, WI.

Takebe, M., T. Yoneyama, K. Inada, and T. Murakami. 1990. Spectral reflectance of rice canopy for estimating crop nitrogen status. Plant soil 122:295-297.

Thomas, J.R. and H.W. Gausman. 1977. Leaf reflectance vs. leaf chlorophyll and carotenoid concentration for eight crops. Agron. J. 69:799-802.

Thomas, J.R. and G.F. Oerther. 1972. Estimating nitrogen content of sweet pepper leaves by reflectance measurements. Agron. J. 64:11-13.

Walburg, G.M. M.E. Bauer, C.S.T. Daughtry, and T.L. Housley. 1982. Effects of nitrogen nutrition on the growth, yield, and reflectance characteristics of corn canopies. Agron. J. 74:677-683.

Fig. 1. 2000 optimal N rates for corn in response to relative green reflectance (lines drawn when F-test is significant).

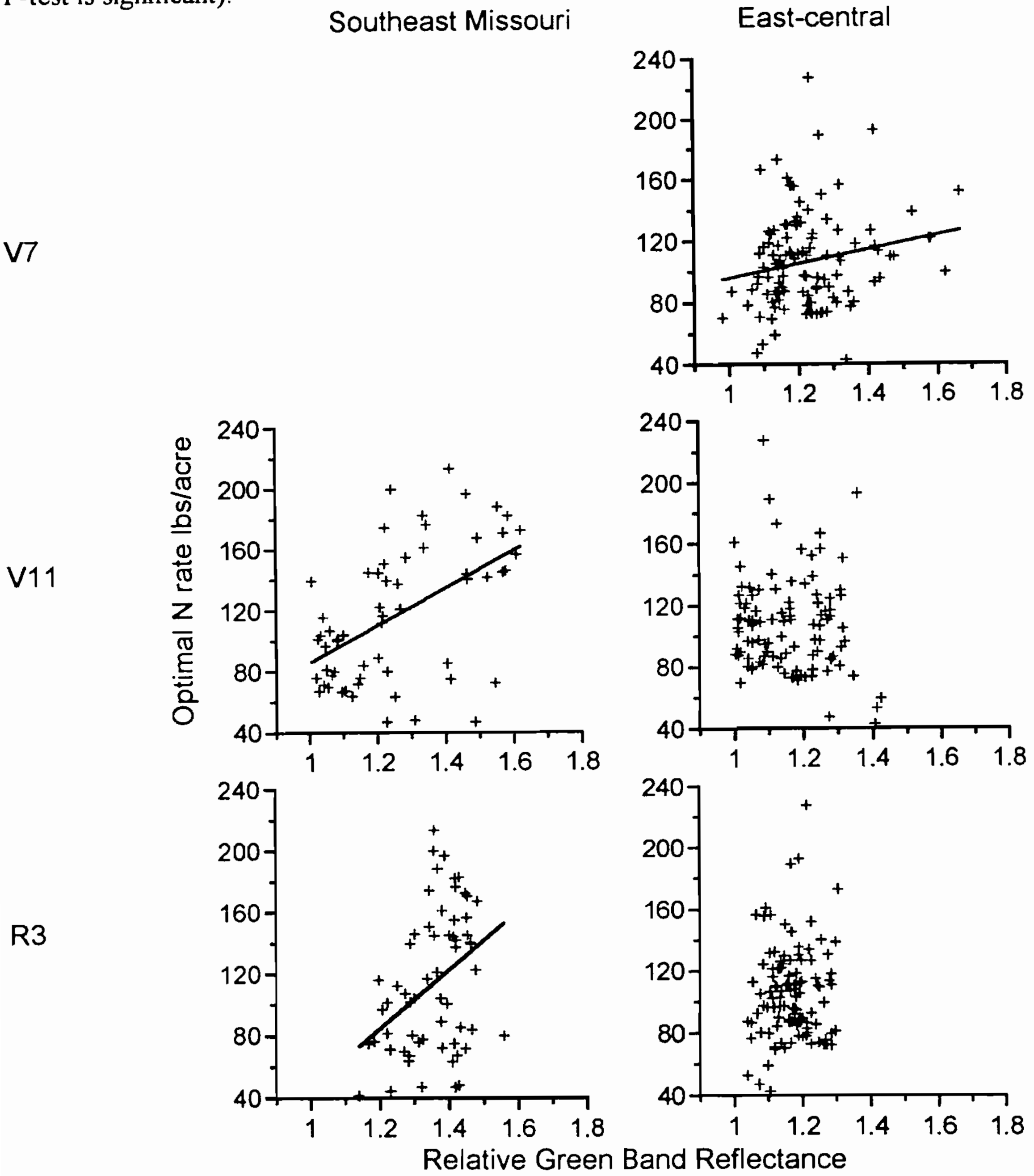

Table 1. Significant (F-test P0.05) regression analysis parameters for optimal N rate as a function of relative green reflectance.

Site	Growth Stage	r^2 value	Pr>|t|
East central Missouri	V7	0.044	0.0319
Southeast Missouri	V11	0.267	<.0001
Southeast Missouri	R3	0.078	0.0320

Fig. 2. Central-east Missouri 2000 optimal N rates as a function of relative green reflectance and classed as low, medium, and high soil EC_a.

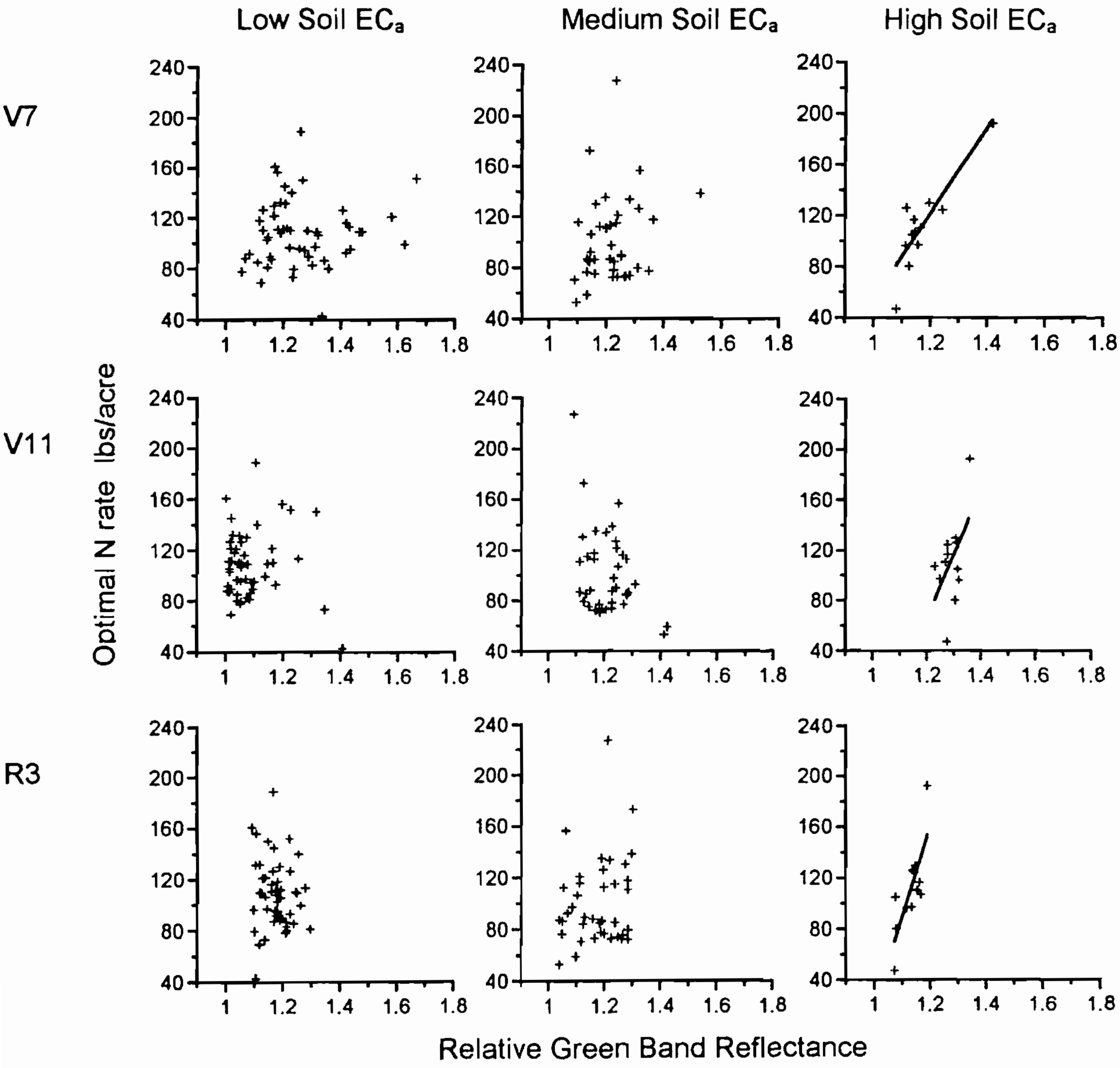

Table 2. Significant (f-test P#0.05) regression analysis parameters for high soil EC_a optimal N rate as a function of relative green reflectance.

Site	Growth Stage	r^2 value	Pr>|t|
East central Missouri	V7	0.621	0.0023
East central Missouri	V11	0.265	0.0866*
East central Missouri	R3	0.760	0.0002

*Significant at an alpha of 0.10

PROCEEDINGS OF THE

THIRTY-FIRST
NORTH CENTRAL
EXTENSION-INDUSTRY
SOIL FERTILITY CONFERENCE

Volume 17

November 14-15, 2001
Holiday Inn University Park
Des Moines, IA

Program Chair:
Keith Reid
Ontario Ministry of Ag, Food & Rural Affairs
581 Huron Street
Stratford, Ontario N5A 5T8
519/271-9269

Published by:
Potash & Phosphate Institute
772 – 22nd Avenue South
Brookings, SD 57006
605/692-6280