**Research Proposal**

Submitted To

Oklahoma State University

Department of Plant and Soil Sciences

**In season prediction of Nitrogen Use Efficiency and Grain**

**Protein in winter Wheat (Triticum aestivum L.)**

**and Corn (Zea mays L.)**

Natasha E. Macnack

Graduate Student

Fall 2010

Department of Plant & Soil Sciences

Oklahoma State University

Introduction

Environmental and economic demands make it necessary for farmers to adopt management systems that improve Nitrogen Use Efficiency (NUE). As the costs for manufacturing N fertilizers increase it becomes increasingly important to monitor the effectiveness with which N is used by wheat and other crops. Nitrogen Use Efficiency is a term used to indicate the grain production per unit of available Nitrogen in the soil (Moll *et al*. 1982). In other words, the nitrogen use efficiency implicates fertilizer recovery in a production system.

Raun and Johnson (1999) note that N fertilizer losses due to gaseous plant emission, soil denitrification, surface runoff, volatilization and leaching are main contributors to the low NUE in cereal grain production worldwide. In essence, loss of N occurs when fertilizer N is applied in excess of what the crop needs. This in turn raises environmental issues and unjustifiable additional expenses for farmers. The year to year variability in the nitrogen balance and the changes in yield response cause variability in nitrogen use efficiency. Producers tend to apply the same amount of nitrogen year after year without considering this variability.

Precision agriculture practices now create the possibility to apply N fertilizer more precisely, matching the variable plant needs across the landscape (Raun et al. 1999).

Oklahoma State University research on N management focuses on using optical sensors in red and near infrared bands for yield prediction and incorporate that information in an algorithm to estimate the fertilizer need (Raun et al. 2005).

This algorithm uses the predicted yield potential (YP0) and an estimated response index (RI) to predict the yield potential when N is applied (YPN). The fertilizer recommendation is then determined by dividing the difference in grain N uptake of YPN and YP0 by an estimated use efficiency (Raun *et al.* 2005).

Grain protein in cereal grains is receiving increased attention because of premiums being paid to producers. Protein is a very important quality component of cereal grains and an important attribute in the market place. Woolfolk et al. (2002) stated that the protein goal of wheat depends on the type or the use of wheat. Bread flour, certain foods and animal feeds require a high protein content (12-16%), while for soft red winter wheat low protein contents ranging from 8-11% are favored (Woolfolk et al. 2002; Hunter and Stanford, 1973).

Research in Colorado has shown that grain protein content is a reliable indicator to determine if nitrogen was limiting for the production of wheat (Goos et al. 2008). Nitrogen is a critical component of protein as it is part of the basic structure of amino acids (Brown, 2000).

If N supply remains constant, increased yield usually results in a decrease in protein content due to the use of N by larger biomass (Gauer et al. 1992, Campbell et al. 1977, Clarke et al. 1990)

Cassman et al. (1992) notes that the complexity of N fertilizer management in wheat results from considerable differences of grain yield and grain protein responses to Nitrogen supply.

According to Cassman et al. (1992) factors such as plant dry matter, accumulation of nitrogen, partitioning of dry matter and nitrogen between vegetative biomass and grain determine grain yield and N concentration or grain protein.

Working with sensors has become increasingly important in agricultural production.

Wright et al. (2003) notes that the grain protein content or the nitrogen status of crops can be effectively evaluated by using crop spectral reflectance. Work by Stone et al. (1996) showed a high correlation between plant nitrogen spectral index (PNSI) and the total Nitrogen uptake of wheat forage.

This study was proposed to investigate whether NUE and grain protein of winter wheat could be predicted mid season using Greenseeker and SPAD-502 readings and by evaluating previous NDVI readings.

literature review

**Importance of NUE**

When discussing efficient nitrogen fertilization and crop development, NUE is an important topic. Various definitions can be found for NUE. Nielsen, (2006) defines it as the relative balance between the amount of fertilizer N taken up and used by the crop versus the amount of fertilizer N lost. Van Sanford and MacKown (1986) define NUE as grain dry weight or grain nitrogen as a function of N supply. In essence NUE measures fertilizer N recovery in plants and a high NUE is preferable. Moll et al. (1982) states that the efficiency of uptake and the efficiency with which the N absorbed is utilized to produce grain, are the two primary components of N use efficiency. The effectiveness in which crops use N fertilizer is becoming an increasingly important issue as N fertilizers prices rise.

**Factors affecting NUE**

The world cereal grain NUE is estimated at about 33%, with NUE’s of 42 and 29% in developed and developing countries, respectively (Raun and Johnson 1999). Several factors influence Nitrogen Use Efficiency. Nielsen (2006) mentions the health of the crop and the combination of the frequency and severity of nitrogen loss as the two major factors that affect the nitrogen use efficiency. Many 15N recovery experiments have reported losses of fertilizer N in cereal production from 20 to 50%. These losses are combined effects of denitrification, volatilization and or leaching (Raun and Johnson 1999, Francis et al., 1993, Olson and Swallow, 1984, Karlen et al., 1996, Wienhold et al., 1995; Sanchez and Blackmer, 1988). Francis et al. (1993) also mentions loss through the plant canopy as a cause of nitrogen loss, while Fageria and Baligar (1995) list surface runoff as another process that causes loss of N.

*Plant losses*

A loss of N through above ground biomass is a significant factor that has to be taken into account when discussing the plant-soil Nitrogen cycle. Yet, not until recently have scientists documented that cereal plants release Nitrogen from above ground biomass, mainly as NH3 (Raun and Johnson 1999, Francis et al., 1993, Harper et al., 1987).

Francis et al. (1993) notes that most plant losses occur after anthesis and are greater at higher levels of soil Nitrogen.

N fertilizer recovery studies utilizing isotopic techniques suggests that apparent N losses from aboveground biomass or plant tissue ranged from 45 to 81 kg N ha-1(Francis et al, 1993).

Various studies have been conducted to determine post-anthesis N loss from foliage of different crops. Daigger et al. (1976) found losses for wheat ranging from 25 to 80 kg N ha-1. Stutte and Weiland (1978) report an estimated loss of at least 45 kg N ha-1 for soybean over the growing season.

*Leaching*

Nitrogen applied in excess of the plants need could result in the downward movement of nitrate into the groundwater, where it becomes a concern to the environment. According to Holland and Schepers (2010) groundwater used for irrigation and drinking water had already exceeded the safe drinking water standard of 10 mg per liter of nitrate, by the mid- 70s. Barry et al. (1993) marks the leaching of nitrate as a fundamental component of the total N mass balance.

*Denitrification*

The conversion of nitrate-N (NO3-N) to gaseous forms of N occurs under anaerobic conditions by autotrophic bacteria. These conditions mainly occur when the soil is flooded or severely compacted (Malhi et al., 2001). The denitrification process is influenced by various soil properties such as pH, soil water content and temperature (Davis et al., 2003, Pu et al., 1999).

Eichner (1990) also lists a number of management practices that affect the occurrence and rate of denitrification such as type of fertilizer, the rate and technique and the time of application,.

Gaseous losses due to denitrification from applied fertilizer have been reported to be 9.5% in winter wheat (Raun et al., 1999, Aulakh et al., 1982). Adding plant residues to the soil increases the loss of N through denitrification (Pu et al., 1999). Aulakh et al. (1984) notes that the addition of straw to the soil as mulch or by incorporating it, can result in a twofold increase in gaseous N loss.

*Surface run off and Volatilization*

When urea fertilizers are applied to the soil surface without incorporation, losses of N as ammonia (NH3) can be more than 40% (Raun and Johnson, 1999; Fowler and Brydon, 1989; Hargrove et al., 1977). Volatilization increases with increasing soil and air temperature and high wind speeds. This means that applying urea in cool, wet conditions would reduce loss through volatilization. Annual run off N losses of 11.9, 18.3 and 198 kg N ha-1 were reported for grassland, upland rice fields and potato fields in China (Zhu and Chen, 2002; Peng et al. 1995).

**Improving NUE**

Raun and Johnson (1999) list several management practices that can result in increased NUE. These management or production practices tackle the environmental conditions that cause N losses. The NUE of fertilizer N in winter wheat decreases with increasing N levels and varies due to several factors such as year, site and preceding crops (Sieling et al., 1998; Fischbeck et al., 1992; Johnston et al., 1994). Bertic et al. (2007) found that nitrogen efficiency varied with growing year. Hatfield and Prueger (2004) note that the NUE of a crop depends on its response to nitrogen- and soil water supply.

Blankenau et al. (2002) found that increased N availability to the crop at critical growth stages could increase the NUE. Zhu and Chen (2002) list a number of management practices for China that could improve the use efficiency of nitrogen fertilizer such as optimizing the application rate, deep placement of fertilizer, match the N application with the crops demand and use of nitrification inhibitors and controlled release N fertilizers.

**Precision sensing and NUE**

Developments in crop canopy sensing technology have increased the possibility to use remote sensing instruments in N management (Li et al., 2009). Work by Raun et al. (2001) has shown that yield potential could be successfully estimated using mid season canopy reflectance measurements registering the Normalized Difference Vegetative Index (NDVI). Continued research resulted in further improvement of this work where the in season estimated yield (INSEY) was modified by dividing a single NDVI measurement by the growing degree days, where GDD> 0 (Raun et al., 2005; Raun et al., 2002). The sensor – based in season N prediction algorithm used at the Oklahoma State University employs the predicted yield potential without additional N (YP0) and an estimated response index (RI) to predict the yield potential when N is non-limiting (YPN) (Raun et al. 2002). The grain N uptake without additional N (PNGYP0) and the grain uptake with added N (PNGYPN) are then calculated. Consequently the recommended N rate is then calculated by subtracting PNGYP0 from PNGYPN and dividing it by an assumed nitrogen use efficiency level (Raun et al., 2005; Li et al., 2009)

**Grain Protein**

The quality of wheat is mainly judged according to the grain protein content. The premium paid to producers has farmers striving for maximum grain protein levels (Wright et al., 2003). According to Kramer (1978) the protein content of wheat grains approximately ranges from 8 to 20%. Nitrogen is critical in the synthesis of amino acids which are the building blocks of all protein (Brown, 2000). Shewry (2007) reports protein percentages of 5.8-7.7% for rice on a dry weight basis (as cited by Champagne et al. 2004), 8-15% for barley (Shewry, 1993) and 9-11% for corn (Zuber and Darrah, 1987).

**Factors affecting Grain protein**

Research has shown that grain protein levels are mainly affected by N availability (Woolfolk et al., 2002; Daigger et al., 1976). In other words the availability of nitrogen is critical to achieve optimum protein levels.

Cassman et al. (1992) stresses the importance of time of fertilization as an influential factor on yield goal and grain protein content. Split application increases the efficiency with which the crop utilizes applied fertilizer (Woolfolk et al., 2002, Boman et al., 1995, Mascangi and Sabbe, 1991). According to Ellen and Spiertz (1980) nitrogen availibilty late in the season increases grain protein and yield. Gauer et al. (1992) noted that applying higher N rates to increase the grain protein content is relatively inefficient, especially under dry soil conditions. Nitrogen addition early in the season in excess of what the plant needs to achieve a projected yield goal is also inefficient in raising the protein content (Cassman et al., 1992). Work by Wright et al. (2003) has shown that midseason N application at anthesis increased grain protein content by 0.3-0.4% in Hard Red Spring wheat.

Besides N fertilization and time of application, protein concentrations in wheat are also affected by variety, fertility, water and temperature (Wright et al., 2003, Terman et al., 1969, Stark et al., 2001).

**Precision sensing and Grain protein**

Research has found that remote sensing could be an effective tool to evaluate the nitrogen status over large areas and manage the protein content in wheat (Wright et al., 2004; Filela et al., 1995; Westcott, 1998). Remote sensing has been used by various researchers to estimate different crop parameters such as leaf chlorophyll (Wright et al., 2004; Thomas and Gausman, 1977; Curran et al., 1991; Munden et al., 1994), leaf area index (LAI) (Wright et al., 2004; Asrar et al., 1985), plant greenness (Wright et al., 2004; Pinter et al., 1987), total dry-matter accumulation (Wright et al., 2004; Tucker, 1981) and many more crop properties.

Several other crop parameters such as protein, moisture, fat and oil have been measured by using near-infrared diffuse reflectance spectrophotometry (Stone et al., 1996; Wetzel, 1983). Work by Fox et al. (2001) has shown that chlorophyll measurements at the one-fourth milk line growth stage (MLGS) was a good indicator of N concentrations in corn.

Other research has shown that there is also high correlation between field chlorophyll measurements and N concentrations in corn at V10 using the SPAD-502 chlorophyll meter (Stone et al., 1996; Wood et al., 1992).

**Objective**

The objective of this study is to determine if NUE and grain protein can be predicted using in season Greenseeker NDVI and SPAD-502 chlorophyll meter readings.

**Materials and Methods**

Three winter wheat field experiments were established to evaluate NUE, grain protein, and N uptake as a function of rate and timing. These experiments are located at Lake Carl Blackwell, Lahoma and Hennessey. The experimental site at Lake Carl Blackwell is on a Port silt loam; fine-silty, mixed, thermic Cumulic Haplustolls. The experimental site at Lahoma is located on a Grant silt loam;   fine-silty, mixed, superactive, thermic Udic Argiustolls and the site at Hennesey is located on a  Bethany silt loam;  fine, mixed, superactive, thermic Paleustoll. All sites were planted in the fall of 2010 using a 3 meter Kincaid drill with a row spacing of 15.24 centimeter. The planting dates and wheat varieties are as follow: the site at Lake Carl Blackwell was planted on September 29, 2010 with ‘Centerfield’; the Hennessey site was planted on October 1, 2010 with ‘Centerfield’ and the Lahoma site was planted on October 6, 2010 using ‘OK Bullet’. Plots are 6.096 m long and 3.048 m feet wide. The treatment structure is a randomized block design with four replications and 14 treatments (figures 1, 2 and 3). Treatment 2 through treatment 14 all received a pre-plant treatment with Urea Ammonium Nitrate (28-0-0) (N-P-K) ranging from 28kg/ha to 227 kg/ha. The UAN was applied with an ATV sprayer with a 3m boom. Treatments 4, 5, 6, 7, 8 and 9 received an additional top dress treatment at rates of 28, 57, 85, 113 and 142 kg N ha-1. Greenseeker and SPAD- 502 readings will be collected at Feekes 3, 4, 5 and 7. At maturity, plots will be harvested using a Massey Ferguson 8XP self propelled combine. A grain subsample from each plot will be collected for total nitrogen analysis using a LECO Truspec CN dry combustion analyzer (Schepers et al., 1989).

Nitrogen Use Efficiency will be calculated by using the formula [(Grain N uptake treated- Grain N uptake check)/N rate applied]. Sensor readings collected at all stages, combined with the use of climatological data available via the Mesonet (Oklahoma mesonet) will be evaluated for their use in predicting NUE and final grain protein contents. Various indices using a combination of sensors will also be developed and evaluated for predicting protein, NUE, and final yield.

Statistical analysis will be done using SAS (SAS institute, 2003)

*Figure 1: Treatment structure for the LCB site Figure 2: Treatment structure for the Lahoma site*



**

*Figure 3: Treatment structure for the Hennessey site*

**References**

Asrar, G., E. T. Kanemasu, and M. Yoshida. 1985. Estimates of leaf area index

from spectral reflectance of wheat under different cultural practices and solar

angle. *Remote Sensing of Environment* *17:1-11.*

Aulakh, M. S., D. A. Rennie, and E. A. Paul. 1982. Gaseous nitrogen losses from cropped and

summer fallowed soils. *Can. J. Soil Sci. 62: 187-195.*

Aulakh, M. S., D. A. Rennie, and E. A. Paul. 1984.The influence of plant residues on

denitrification rates in conventional and zero tilled soils. *Soil Sci. Soc. Am. J. 48: 790-794*

Barry, D. A., J. D. Goorahoo and M.J. Goss. 1993. Estimation of Nitrate Concentration in

Groundwater using a whole farm Nitrogen Budget. J. Environ. Qual. 22: 767-775

Bertic, B., Z. Loncaric, V. Vukadinovic, Z. Vukobratovic. 2007. Winter wheat yield

responses to mineral fertilization. *Cereal Research Communications* 35: 245-248

Blankenau, K., Olfs H. W., and H. Kuhlmann. 2002. Strategies to improve the use efficiency of

mineral fertilizer nitrogen applied to winter wheat. *Journal of Agronomy and Crop Science 188, 146-154.*

Boman, R.K., R. L. Westerman, W. R. Raun and M. E. Jojola. 1995. Time of nitrogen

application: Effects on winter wheat and residual soil nitrate. *Soil Sc. Soc. Am. J. 59:*

*1364-1369.*

Brown, B. 2000. Nitrogen Management for hard wheat protein enhancement. *University of*

*Idaho Winter Commodity school proceedings.*

Campbell, C. A., Cameron, D. R., Nicholaichuk, W. and H. R. Davidson. 1977.Effect of

fertilizer N and soil moisture on growth, N content, and moisture use by spring wheat. *Can. J. Soil Sci. 57: 289-310*

Cassman, K.G., D.C. Bryant, A. E. Fulton and L.F. Jackson. 1992*.* Nitrogen supply of effects of

dry matter and nitrogen to grain of irrigated wheat*. Crop Sci. 32: 1251-1258*

Clarke, J. M., Campbell, C. A., Cutforth H. W., De Pauw, R. M. and G. E. Wilkleman. 1990.

Nitrogen and phosphorus uptake, translocation, and utilization efficiency of wheat in relation to environment and cultivar yield and protein levels. *Can. J. Plant Sci. 70: 965-977.*

Curran, P. J., R. L.Dungan, B. A. Macler, and S. E. Plummer. 1991. The Effect of

Red Leaf Pigment on the Relationship between Red Edge and Chlorophyll

Concentration. *Remote Sensing of Environment* 35:69-76.

Davis, R.L, J.J Patton, R.K Teal, Y. Tang, M.T. Humphreys, J. Mosali, K. Girma, J.W Lawles,

S.M. Moges, A. Malapati, J. Si, H. Zhang, S. Deng, G.V Johnson, R.W. Mullen and W.R.

Raun. 2003. Nitrogen Balance in the Magruder Plots Following 109 years in continuous Winter Wheat. *J. of Plant nutrition 26: 1561-1580*

Daigger, L. A., D. H. Sander and G. A. Peterson. 1976. Nitrogen content of winter wheat during

growth and maturation. *Agron. J. 68: 815-818*

Eichner, M.J. 1990*.* Nitrous oxide emission from fertilized soils: summary of available data. *J.*

*Environ. Qual. 19, 272-280.*

Ellen, J., and J.H.J. Spiertz. 1980. Effects of rate and timing of nitrogen dressings on grain yield

formation of winter wheat. *Fert. Res. 1:177-190.*

Fageria, N. K., and V. C. Baligar. 2005. Enhancing Nitrogen Use Efficiency in crop plants.

*Advances in Agronomy* 88: 97–185.

Filella, I., L. Serrano, J. Serra and J. Peñuelas 1995. Evaluating wheat nitrogen status with

canopy reflectance indices and discriminate analysis. *Crop Sci. 35: 1400-1405*

Fischbeck, G., J. Dennert, R.Müller. 1992. Untersuchungen zur Verwertung des Stickstoffes in

der oberirdischen Biomasse von Winterweizen-Feldbeständen beiunterschiedlicher Hö he

und Verteilung der mineralischen Düngung. *Bayerisches Landwirtschaftliches Jahrbuch*

69: 131-148.

Fowler, D. B., and J. Brydon. 1989. No- till winter wheat production on the Canadian prairies:

placement of urea and ammonium nitrate fertilizers. *Agron. J. 81: 518-524.*

Fox, R. M., W. P. Piekielek and K. E. Macneal. 2001.Comparison of Late-season diagnostic

tests for predicting nitrogen status of corn*. Agron. J. 93: 590-597.*

Francis D. D, J. S Schepers and M. F. Vigil. 1993. Post-Anthesis Nitrogen Loss from Corn.

*Agron J. 85: 659-663.*

FreemanK. W, W. R. Raun, G. V. Johnson,R. W. Mullen, M. L. Stone, and J. B. Solie. 2003.

Late- season prediction of wheat grain yield and grain protein. *Communications in soil science and plant analysis 34: 1837-1852*

Gauer, L. E., C. A.Grant, D. T. Gehl, and L. D. Bailey. 1992. Effects of nitrogen fertilization on

grain protein content, nitrogen uptake, and nitrogen use efficiency of six spring wheat

(Triticum aestivum L.) cultivars, in relation to estimated moisture supply. *Can. J. Plant*

*Sci. 72:235 241.*

Goos R. J., D. G Westfall and A. E Ludwick. 2008. Grain protein content and N Needs.

Colorado State University extension paper.

Hargrove, W. L., D. E. Kissel, and L. B. Fenn. 1977. Field measurements of ammonia

volatilization from surface applications of ammonium salts to a calcareous soil. *Agron. J.*

*69: 473-476.*

Harper, L. A., R. R. Sharpe, G. W. Langdale, and J. E. Giddens. 1987. Nitrogen cycling in a

wheat crop: soil, plant and aerial nitrogen transport. *Agron. J. 79: 965-973.*

Hatfield J. L and J. H Prueger. 2004. Nitrogen Over-use, Under-use, and Efficiency.

*Proceedings of the 4th International Crop Science Congress.*

Holland K.H and J.S Schepers. 2010. Derivation of a variable Application Model for In- Season

Fertilization of Corn. *Agron J. 102: 1415-1424.*

Hunter, A. S., and G. Stanford. 1973. Proteincontent of winter wheat in relation to rate and time

of nitrogen fertilizer application. *Agron. J. 65: 772-774.*

Johnston, A. E., J. McEwen, P. W. Lane, M. V. Hewitt, P. R. Poulton, and D. P. Yeoman.

1994. Effects of one to six year old ryegrass-clover leys on soil nitrogen and on the

subsequent yields and fertilizer nitrogen requirements of the arable sequence winter wheat, potatoes, winter wheat, winter beans (*Vicia faba*) grown on a sandy loam soil. *Journal of Agricultural Science*, *Cambridge* 122: 73-89.

Karlen, D. L., P. G. Hunt, and T. A. Matheny. 1996. Fertilizer 15nitrogen recovery by corn,

wheat, and cotton grown with and without pre-plant tillage on Norfolk Loamy sand.

*Crop. Sci. 36: 975-981.*

Kramer Th. 1979. Environmental and genetic variation for protein content in winter wheat

(Tricticum Aestivum L.). *Euphytica 28: 209-218.*

Li F., Y. Miao, F. Zhang, Z. Cui, R. Li, X. Chen, H. Zhang, J. Schroder, W.R. Raun, L. Jia.

2009*.* In- season optical sensing improves Nitrogen-Use Efficiency for winter wheat. *Soil Sci. Soc. Am. J. 73: 1566-1574*

Malhi, S.S., C. A. Grant, A. M Johnston and K. S. Gill. 2001. Nitrogen fertilization management

for no-till cereal production in the Canadian Great Plain: a review. *Soil & Tillage*

*research, 60: 101-122*

Mascangi, H. J., Jr., and W. E. Sabbe. 1991. Late spring nitrogen application on a poorly drained

soil. *J. Plant Nutr. 14: 1091-1103.*

Moll, R.H, E.J Kamprath and W.A Jackson. 1982. Analysis and Interpretation of factors which

contribute to efficiency of Nitrogen Utilization. *Agron J. 74: 562- 564.*

Munden, R., P. J. Curran, and J. A. Catt. 1994. The relationship between red edge

and chlorophyll concentration in the Broadbalk Winter Wheat Experiment at

Rothamsted. *International Journal of Remote Sensing* *15:705-709.*

Nielsen, R. L. 2006. N Loss mechanisms and Nitrogen Use Efficiency. *Purdue Nitrogen*

*Management Workshops.*

Olson, R. V., and C. W Swallow. 1984. Fate of labeled nitrogen fertilizer applied to winter wheat

for five years. *Soil Sci. Soc. Am. J. 48: 583-586.*

Peng L., Wan JZ and Yu CZ. 1995. Nutrient losses in soils on Loess Plateau. *Pedosphere 5: 83–*

*92*

Pinter, P. J., G. Zipoli, G. Maracchi, and R. J. Reginato. 1987. Influence of topography

and sensor view angles on NIR/Red ratio and greenness vegetation

indices of Wheat. *International Journal of Remote Sensing* *8:953-957.*

Pu, G., P. G. Saffigna, W. M. Strong. 1999. Potential for denitrification is cereal soils of

northern Australia after legume or grass-legume pasture. *Soil Biol. and Biochemistry 31: 667-675*

Raun, W. R and G.V Johnson. 1999. Review and interpretation Improving Nitrogen Use

Efficiency for Cereal Production. *Agron J. 91: 357-363.*

Raun, W. R., G. V. Johnson, M. L. Stone, J. B. Solie, E. V. Lukina, W. E. Thomason and J. S.

Schepers. 2001*.* In- season prediction of potential grain yield in winter wheat using canopy reflectance. *Agron. J. 93: 131-138*

Raun W. R., J. B. Solie, G.V. Johson, M.L. Stone, R. W. Mullen, K. W. Freeman, W. E.

Thomason and E. V. Lukina. 2002. Improving Nitrogen Use Efficiency in cereal grain production with optical sensing and variable rate application*. Agron. J. 94: 815-820.*

Raun W. R, J.B. Solie, M. L. Stone, K.L. Martin, K. W Freeman, R. W. Mullen, H. Zhang, J.S.

Schepers and G.V. Johnson. 2005. Optical Sensor- Based Algorithm for Crop Nitrogen Fertilization. *Communications in Soil Science and Plant Analysis 36: 2759-2781.*

Sanchez, C. A., and A. M. Blackmer. 1988.Recovery of anhydrous ammonia- derived nitrogen-

15 during three years of corn production in Iowa. *Agron. J. 80: 102-108.*

SAS Institute. 2003. SAS/STAT User’s Guide: Release 9.1 ed. SAS Inst., Cary, NC.

Schepers, J. S., D.D. Francis, and M.T. Thompson. 1989. Simultaneous determination of

total C, total N and 15N on soil and plant material. *Commun. Soil Sci. Plant Anal. 20: 949-959.*

Shewry P. R. 2007. Improving the protein content and compostion of cereal grain. *Journal of*

*Cereal Science 46: 239-250.*

Sieling K., H. Schroder, M. Finck, H. Hanus. 1998*.* Yield, N uptake, and apparent N-use

efficiency of winter wheat and winter barley grown in different cropping systems. *Journal of Agricultural Science, Cambridge 131: 375-387*

Stark J.,E. Souzza, B. Brown and J. Windes 2001. Irrigation and nitrogen management systems

for enhancing hard spring wheat protein. American Society of Agronomy Annual

Meetings. Charlotte, North Carolina. Available at http: [http://www.cals.uidaho.edu/swidaho/Nutrient%20Management/ASA%20protein%20presentatns/2001ASAStark1/sld001.htm](https://mail.okstate.edu/owa/redir.aspx?C=8947e290740d400d8dd76ec92ad76131&URL=http%3a%2f%2fwww.cals.uidaho.edu%2fswidaho%2fNutrient%2520Management%2fASA%2520protein%2520presentatns%2f2001ASAStark1%2fsld001.htm)

Stone M. L, J.B Solie, W.R Raun, R.W Whitney, S.L Taylor, J.D. Ringer. 1996*.* Use of spectral

for correcting in- season fertilizer nitrogen deficiencies in winter wheat*. Transactions of the ASAE. 39: 1623-1631.*

Stutte, C. A. and R. T Weiland. 1978.Gaseous nitrogen loss and transpiration of several crop

and weed species. *Crop Science 18: 887-889*

Terman, G. L., R. E. Ramig, A. F. Dreier and R. A. Olson. 1969. Yield- protein relationships in

wheat grain as affected by nitrogen and water. *Agron. J. 61: 755-759.*

Thomas J. R. and H. W. Gausman. 1977. Leaf reflectance vs leaf chlorophyll and carotenoid

concentrations for eight crops. *Agronomy Journal 69: 799-802.*

Tucker, C. J. 1979. Red and Photographic Infrared Linear Combinations for Monitoring

Vegetation. *Remote Sensing of Environment* *8:127-150.*

Van Sanford, D. A. and C. T. MacKown. 1986. Variation in nitrogen use efficiency among soft

red winter wheat genotypes. *Theor Appl Genet 72: 158-163.*

Westcott, M., 1998. How to get a higher spring wheat protein more efficiently. *Montana State*

*University Extension Publication MT9806.*

Wetzel, D. L. 1983. Near- infrared reflectance analysis. *Anal. Chem. 55: 1165A-1176A.*

Wienhold, B. J., T. P. Trooien, and G. A. Reichman. 1995. Yield and nitrogen use efficiency of

irrigated corn in the northern great plains. *Agron. J. 87: 842-846.*

Wood, C. W., D. W Reeves, R. R. Duffield, and K. L. Edmisten. 1992. Field chlorophyll

measurements for evaluation of corn nitrogen status. *J.* *of Plant Nutr. 15: 487-500.*

Woolfolk C.W., W. R. Raun, G.V. Johnson, W. E. Thomasen, R.W. Mullen, K. J. Wynn and

K.W. Freeman 2002.Influence of late season Foliar nitrogen applications on yield and

grain nitrogen in winter wheat*. Agron J. 94: 429-434.*

Wright, D. L., G.L. Ritchie, V.P. Rasmussen, R.D. Ramsey and D.J. Baker. 2003.

Managing Grain Protein in Wheat Using Remote Sensing. *Online Journal of Space*

*Communication. Vol. 3.* (unpaginated).

Wright D. L, V. P Rasmussen, R. D Ramsey and D. J. Baker. 2004.Canopy reflectance

estimation of wheat nitrogen content for grain protein management. *GIS and Remote Sensing 41: 287-300.*

Zhu Z. L. and D. L. Chen. 2002. Nitrogen fertilizer use in China- Contributions to food

production, impacts on the environment and best management strategies. *Nutrient Cycling in Agroecosystems 63: 117-127.*