Vincent, C.D. and P.J. Gregory. 1989. Effects of temperature on the development and growth of winter wheat roots. I. Controlled glasshouse studies of temperature, nitrogen, and irradiance. Plant and Soil 119:87-97.

Warrington, I.J. and R.A. Norton. 1991. An evaluation of plant growth and development under various daily quantum integral. J. Amer. Soc. Hort. Sci. 116:544-551.

JOURNAL OF PLANT NUTRITION, 16(5), 781-796 (1993)

DETERMINATION OF WHEAT NITROGEN STATUS WITH A HAND-HELD CHLOROPHYLL METER: INFLUENCE OF MANAGEMENT PRACTICES

D. W. Reeves
USDA-ARS National Soil Dynamics Laboratory, P. O. Box 3439, Auburn, Alabama 36831-3439

P. L. Mask, C. W. Wood, and D. P. Delaney
Agronomy and Soils Department, Auburn University, Alabama 36849-5412

ABSTRACT: The nitrogen (N) status of wheat at specific growth stages has potential in predicting yield goals and supplemental N fertilizer requirements but there is a need for a simple and reliable method for field determihation of wheat (*Triticum aestivum* L.) N status under different management schemes. This field study was conducted for two seasons (1989-90 and 1990-91) on a Norfolk sl (fine-loamy, siliceous thermic Typic Kandiudults) in east-central Alabama. Treatment variables were tillage, fungicide and N rate. Tillage treatments were disk/harrow or paraplow. Fungicide treatments were no fungicide or propiconazole (Tilt®) applied at Feekes growth stage (GS) 8. Nitrogen rates were a 0-N control and 45, 90, 134, or 179 kg N/ha applied in a two-way split with 22.5 kg N/ha applied at planting and the remainder applied in mid-February. Whole plant samples at GS 3 and 5, and flag leaf samples at GS 10.51 were analyzed for N; a hand-held meter was used to measure chlorophyll concentrations at these sampling times also. The most consistent yield response was to fungicide, especially at higher N rates, with increases ranging from 15 to 62%. Paraplowing

1. Contribution of USDA-ARS in cooperation with the Alabama Agricultural Experiment Station. This research was supported by the Alabama Farmer's Federation Wheat and Feed Grain Check-Off Program.

also affected grain yield response to N application. Leaf chlorophyll meter readings were significantly correlated to tissue N concentration and grain yield. The best predictor of grain yield was N uptake at GS 5, however, multiple regression models that included chlorophyll meter readings and dry matter at GS 5 were comparable to N uptake as predictors of yield. Chlorophyll meter readings have potential to be combined with other simple measurements, *e.g.*, dry matter determination and/or soil nitrate tests, to develop quick and reliable methods for predicting N fertilizer requirements for winter wheat.

INTRODUCTION

Researchers have long sought a reliable, easy to use method for determining the N status of wheat and relating it to N fertilizer requirement. Methods tried, with varying degrees of success, include measurements of stem nitrate (Roth et al., 1989), N uptake (Alley et al., 1986), and tissue N at various stages of growth (Hargrove et al., 1983; Donohue and Brann, 1984; Roth et al., 1989). In England, concentrations of chlorophyll *a* in 5-week old spring barley (*Hordeum vulgare* L.) was correlated to grain yield (Batey, 1984). All these methodologies, with the exception of stem nitrate, must be done in the laboratory, as opposed to the field. In Japan, measurement of leaf greenness, as an indicator of chlorophyll concentration, is widely used to determine N status and fertilizer requirements of rice (*Oryza sativa* L.) (Takebe and Yoneyama, 1989).

Recently, hand-held meters that rapidly determine leaf chlorophyll have become available in the United States. One commercial meter, the SPAD-502® Chlorophyll Meter[2] (Minolta Camera Co., Ltd., Japan), utilizes technology that has proven effective in determining the N status of rice (Kitagawa et al., 1987; Takebe et al., 1990; Turner and Jund, 1991), corn (*Zea mays* L.) (Schepers et al., 1990; Wood et al., 1992a; Piekielek and Fox, 1992), and cotton (*Gossypium hirsutum* L.) (Wood et al., 1992b). Chlorophyll meter readings with this instrument are instantaneous and involve no destructive sampling. If these meters can reliably determine wheat N status, expensive and time consuming laboratory procedures for monitoring tissue N in wheat could be avoided. There have been no published reports relating chlorophyll concentrations or chlorophyll meter readings to N status of wheat.

Nitrogen utilization, as well as yield, of wheat is affected by management practices. Two critical management factors for improving wheat N response and yield, especially on Coastal Plain soils in humid regions, are deep tillage (Karlen and Gooden, 1987; Reeves et al., 1991), and protection from fungal pathogens (Roth and Marshall, 1987; Morris et al., 1989).

The objectives of this study were: i) to determine the feasibility of using a hand-held chlorophyll meter to monitor N status of wheat; ii) to determine the influence of management factors on wheat yield, response to N fertilizer, and chlorophyll meter readings; and iii) to compare tissue N and chlorophyll meter readings as to their usefulness for predicting wheat yield under various management systems.

MATERIALS AND METHODS

This study was conducted for two growing seasons (1989-90 and 1990-91) at the E. V. Smith Research Center of the Alabama Agricultural Experiment Station in east-central Alabama. The soil is a Norfolk sl (fine-loamy, siliceous, thermic Typic Kandiudults). Initial soil pH was 6.1. Soil test values were: 47 mg/kg P, 71 mg/kg K, 88 mg/kg Mg, and 375 mg/kg Ca. On 10/18/89, an application of 33 kg/ha S, 110 kg/ha K, and 1.8 kg/ha B was made to the site. On 11/14/90, 86 kg/ha K, 22 kg/ha Mg, 44 kg/ha S, and 26 kg/ha P was applied to the site. Wheat, cultivar 'Saluda', was seeded at a rate of 134 kg/ha on 11/21/89 and 11/15/90 using a drill width of 17 cm. Plot size was 2.75-m wide by 6-m long.

The experimental design was a split plot with four replications. Tillage treatments were main plots. Factorial arrangements of N application rates and fungicide treatments were subplots. Tillage treatments were disk//harrow or paraplowing to a depth of 40 cm. Fungicide treatments were no fungicide or an application of 293 mL/ha propiconazole (Tilt®) at Feekes growth stage (GS) 8 (Feekes, 1941). Nitrogen rates were 0, 45, 90, 134, and 179 kg/ha. With the exception of the 0-N control, N was applied in a two-way split, with 22.5 kg N/ha

2. Mention of a trademark or proprietary product or vendor does not constitute a guarantee or warranty of the product by the USDA or Alabama Agricultural Experiment Station and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

applied at planting and the remainder applied in mid February of each year. Nitrogen as NH_4NO_3 was broadcast by hand.

Whole plant samples, 0.3 m from each of 4 drill rows per plot, for N analysis and dry weight were taken at GS 3 and GS 5. Flag leaf samples from 30 plants at GS 10.51 were taken from each plot for N analysis. Total N in plant tissue was analyzed with a LECO CHN-600 analyzer[2]. Leaf chlorophyll meter readings, 30 per plot, with a Minolta SPAD-502® Chlorophyll Meter were taken from flag leaves at GS 10.51 in 1990 and 1991. In 1991, these readings were also taken from the upper-most expanded leaves at GS 3 and GS 5. The meter reads in dimensionless units called SPADs (an acronym for Soil Plant Analysis Development) which are proportional to the concentration of chlorophyll in the leaf. Grain yield was determined by harvesting the center 1.25 m of each plot with a plot combine. Grain yields were adjusted to a moisture content of 130 g/kg. Yield data are presented as relative yield, as a per cent of the maximum yielding plot for that year. Maximum grain yield was 3647 kg/ha in 1990 and 2077 kg/ha in 1991.

Analysis of variance indicated significant interactions for year, tillage, and fungicide effects on most variables, therefore the data were analyzed and are presented separately by year, and tillage and fungicide combinations. Multiple regression procedures with stepwise elimination of nonsignificant independent variables were used to determine relationships among variables. Terms were eliminated from models if they were nonsignificant at the 0.10 level of significance.

RESULTS AND DISCUSSION

Yield response to N fertilizer was curvilinear both years for all fungicide and tillage combinations (Fig. 1). Maximum yield in 1991 was only 57% of that in 1990. Climatological data offers no explanation for the decreased yields in 1991 (Fig. 2). Poor wheat yields throughout the state in 1991 were attributed to scab head blight (*Fusarium* spp.) (P. L. Mask, extension grain specialist, personal observation). The higher yield potential in 1990 resulted in a better response to N fertilizer and N fertilizer rate accounting for more variation in yield in 1990 than in 1991.

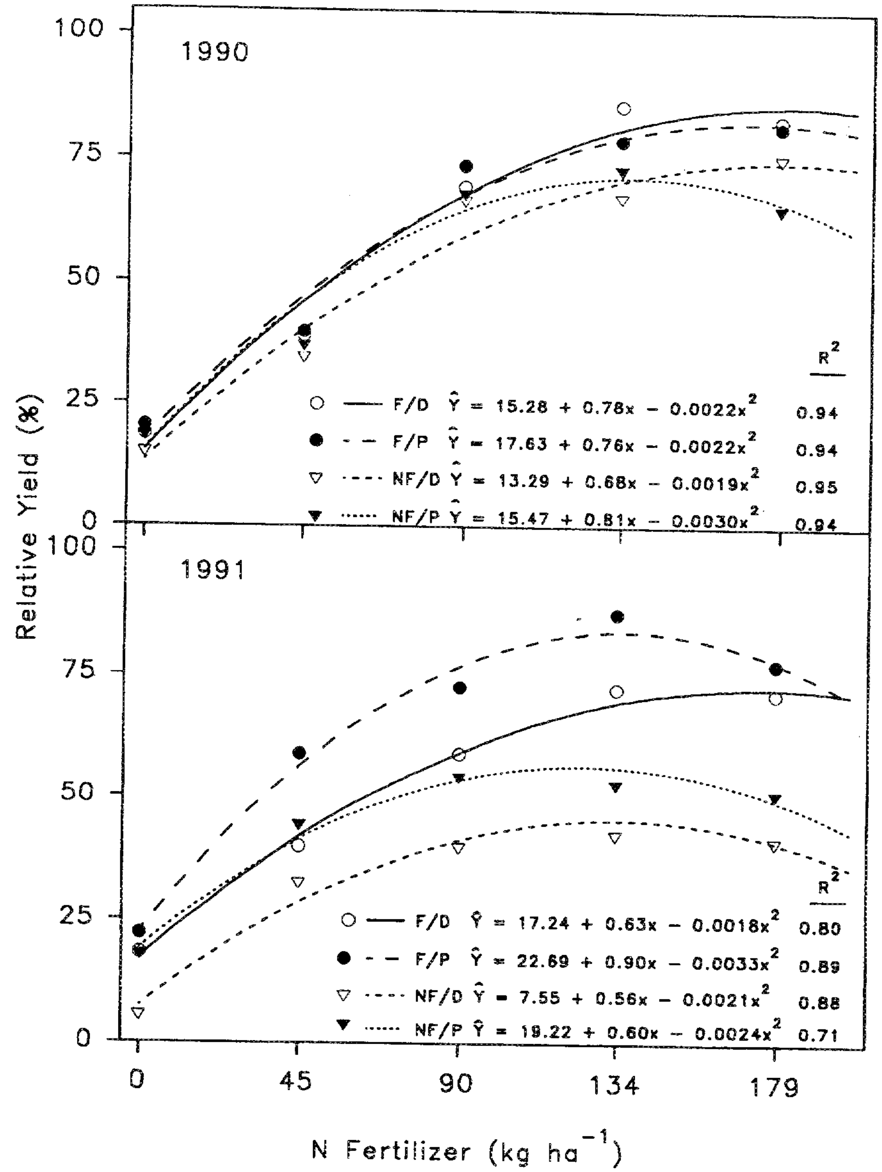

FIGURE 1. Wheat Grain Yield Response to N Fertilizer as Affected by Tillage and Fungicide in 1990 and 1991. Relative Yield Expressed as a Per Cent of Maximum Yield (3647 kg ha^{-1} in 1990 and 2077 kg ha^{-1} in 1991). F= fungicide, NF= no fungicide, D= disk, and P= paraplow.

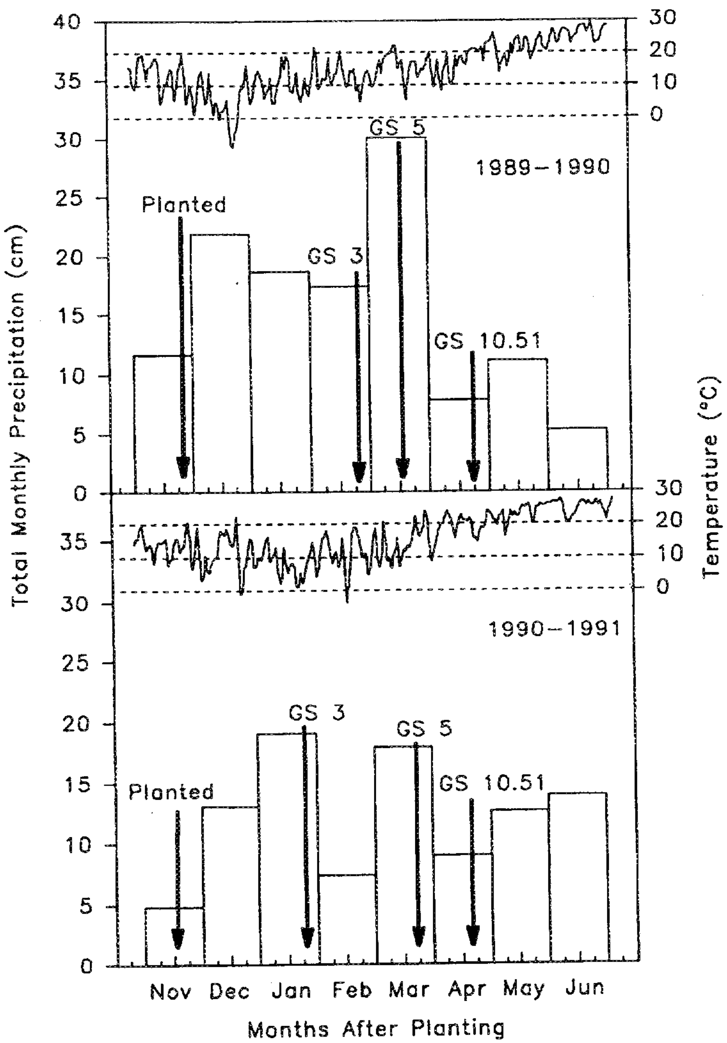

FIGURE 2. Average Daily Temperature and Monthly Rainfall During 1990 and 1991 Growing Season.

Management factors, *i.e.*, fungicide and tillage, affected grain yield response to N fertilizer (Fig. 1). In 1990, response to N was less without fungicide. Paraplowing without fungicide application reduced yields at N rates greater than 134 kg/ha. In 1991, deep tillage with fungicide resulted in the greatest response to N. Yield response to N was poorest with disk tillage and no fungicide. These results agree with other research. Morris et al. (1989) found that fungicide increased wheat yield response to high N rates which were split applied. Karlen and Gooden (1987) reported that deep tillage, *i.e.*, moldboard plowing, increased yield compared to disking on Coastal Plain soils in South Carolina.

There was a wide variation in the ability of plant parameters to account for variation in yield. In 1990, plant tissue N concentration and N uptake (the product of dry matter production per unit area and tissue N concentration) at GS 5 were the parameters that offered the best prediction of yield (Table 1). In 1991, variation in yield was better accounted for by N uptake than tissue N concentration at GS 5 (Table 2). The ability of tissue N concentration at GS 5 to account for yield variation was especially reduced when fungicide was not used as evidenced by the low R^2 for these treatments at GS 5 in 1991. The linear slope component of the model was also reduced in treatments with no fungicide compared to fungicide treatments in 1991. Roth et al. (1989) reported that tissue N concentration at GS 3 through 6 was a better predictor of N fertilizer response by wheat than N uptake in Pennsylvania. They cited variation in dry matter as influenced by environmental conditions as the cause of the decreased predictive ability of N uptake on yield. In our study, variation due to management factors as well as yearly environmental influences affected the relative ability of tissue N concentration versus N uptake at GS 5 to predict yield.

Both tissue N concentration and N uptake at GS 3 were inconsistent in their ability to account for variation in yield (Tables 1 and 2). These parameters at this growth stage were not as good predictors as at GS 5. This is in agreement with results reported by Roth et al. (1989).

Flag leaf N concentration at GS 10.51 was not as good a predictor of grain yield as N concentration or N uptake at GS 5 in 1990 or 1991. Our results differ from those reported by Hargrove et al. (1983). In their study, flag-leaf N concentration at GS 10.5 correlated with grain yield had a higher r value (0.47) than tissue N concentration at GS 10 or GS 3.

TABLE 1

Relationships Between Several Plant Parameters and Wheat Grain Yield in 1990. Relative Yield Expressed as a Per Cent of Maximum Yield (3647 kg ha^{-1}).

Parameter	GS	Fungicide-Tillage	Model	R^2
Tissue N (g kg^{-1})	3	fungicide-disk	Y= - 4.42 + 1.47x	0.57
		fungicide-paraplow	Y= - 32.11 + 2.01x	0.82
		none-disk	Y= - 8.89 + 1.43x	0.63
		none-paraplow	Y= - 21.71 + 1.67x	0.85
	5	fungicide-disk	Y= - 20.53 + 22.88x - 0.961x^2	0.87
		fungicide-paraplow	Y= - 85.46 + 47.08 - 3.169x^2	0.91
		none-disk	Y= - 124.84 + 76.87x - 7.737x^2	0.89
		none-paraplow	Y= - 104.38 + 57.65x - 4.753x^2	0.80
	10.51	fungicide-disk	Y= - 311.03 + 182.16x -20.950x^2	0.76
		fungicide-paraplow	Y= 33.02 + 27.57x	0.49
		none-disk	Y= 47.80 + 29.61x	0.62
		none-paraplow	Y= 53.27 + 32.56x	0.60
N uptake (kg ha^{-1})	3	fungicide-disk	Y= - 3.85 + 4.22x	0.72
		fungicide-paraplow	Y= - 22.73 + 6.16x - 0.090x^2	0.71
		none-disk	Y= 0.33 + 2.55x	0.63
		none-paraplow	Y= - 12.48 + 5.51x -0.093x^2	0.69
	5	fungicide-disk	Y= - 1.35 + 2.79x - 0.022x^2	0.83
		fungicide-paraplow	Y= 2.44 + 2.30x -0.016x^2	0.86
		none-disk	Y= - 3.54 + 3.06x - 0.031x^2	0.84
		none-paraplow	Y= - 4.68 + 2.56x - 0.021x^2	0.87
Leaf chlorophyll (SPAD)	10.51	fungicide-disk	Y= - 90.59 + 4.10x	0.66
		fungicide-paraplow	Y= - 155.67 + 5.93x	0.67
		none-disk	Y= - 385.80 + 20.54X - 0.230X^2	0.87
		none-paraplow	Y= - 1105.67 + 59.26X - 0.747X^2	0.71

Leaf chlorophyll meter readings of flag leaves at GS 10.51 accounted for 66 to 87% of the variation in grain yield, dependent on management factors, in 1990 (Table 1). In 1991, meter readings accounted for 34 to 70% of the variation in grain yield (Table 2). The coefficients of multiple determination (R^2) for the relationships between leaf chlorophyll meter reading and yield were on average better than those for the relationships between tissue N concentration and yield at this growth stage for both years.

As with tissue N concentration and N uptake, meter readings taken at GS 3 were not effective predictors of grain yield (Table 2). This growth stage appears to be too early for practical prediction of grain yield response based on any parameter used in this study.

Leaf chlorophyll meter readings at GS 5 were not as good a predictor of grain yield as N uptake or tissue N concentration (Table 2). In both years, N uptake was a good predictor of grain yield, accounting for, on average, 85% of the variation in yield. Since N uptake is dependent on dry matter yield as well as tissue N concentration, comparison of N uptake to leaf chlorophyll meter readings is biased unless dry matter is also used as a component in a model with leaf chlorophyll meter readings. When this was done, R^2 values ranged from 0.74 to 0.87 at GS 5 (Table 2). These R^2 values compare very favorably to those obtained by regressing yield against N uptake. In one case (no fungicide and paraplowing) dry matter alone accounted for 74% of the variation in yield and chlorophyll meter reading was not a significant component of the model. For this particular management factor combination, N uptake accounted for 77% of the variation in yield as opposed to only 36% accounted for by tissue N concentration at GS 5. Thus, in one case, dry matter production was more critical in improving the ability to account for yield variation than either leaf chlorophyll or tissue N concentration.

Flag leaf chlorophyll meter readings were significantly correlated to tissue N concentration in 1990 (Fig. 3) and 1991 (Fig. 4). Tissue N values ranged from 24.7 to 46.4 g/kg in 1990 and from 26.4 to 42.7 g/kg in 1991. Hargrove et al. (1983) reported that flag leaf N concentrations of from 35 to 40 g/kg were sufficient to obtain maximum wheat grain yields. This range of flag leaf tissue N concentration would correspond to a range of chlorophyll meter readings from 37 to 42 SPAD units (Figures 3 and 4). There was a wider range of flag leaf tissue N

TABLE 2

Relationships Between Several Plant Parameters and Wheat Grain Yield in 1991. Relative Yield Expressed as a Per Cent of Maximum Yield (2077 kg ha^{-1}).

Parameter	GS	Fungicide-Tillage	Model	R^2
Tissue N (g kg^{-1})	3	fungicide-disk	Y= - 143.70 + 6.04x	0.53
		fungicide-paraplow	Y= - 172.96 + 6.56x	0.35
		none-disk	Y= - 70.63 +3.16x	ns
		none-paraplow	Y= - 786.25 + 46.78x - 0.654x^2	0.45
	5	fungicide-disk	Y= - 169.97 + 13.40x - 0.187x^2	0.76
		fungicide-paraplow	Y= - 170.93 + 15.05x - 0.222x^2	0.79
		none-disk	Y= - 91.58 + 7.86x - 0.115x^2	0.55
		none-paraplow	Y= 11.77 + 1.170x	0.36
	10.51	fungicide-disk	Y= - 88.77 + 3.92x	0.38
		fungicide-paraplow	Y= - 49.07 + 3.367x	0.44
		none-disk	Y= - 26.71 + 1.77x	0.37
		none-paraplow	Y= - 8.10 + 1.53x	0.34
N uptake (kg ha^{-1})	3	fungicide-disk	Y= - 33.63 + 6.59x - 0.105x^2	0.67
		fungicide-paraplow	Y= 29.58 + 1.24x	0.24
		none-disk	Y= 13.49 + 0.99x	0.51
		none-paraplow	Y= - 35.34 + 5.07x - 0.072x^2	0.66
	5	fungicide-disk	Y= - 6.65 + 2.06x - 0.012x^2	0.86
		fungicide-paraplow	Y= - 5.18 + 2.12xx - 0.012x^2	0.89
		none-disk	Y= - 3.31 + 1.55x - 0.012x^2	0.87
		none-paraplow	Y= - 3.38 + 1.50x - 0.009x^2	0.77
Leaf Chlorophyll (SPAD)	3	fungicide-disk	----------	ns
		fungicide-paraplow	Y= 294.74 - 7.76x	0.27
		none-disk	----------	ns
		none-paraplow	Y= 198.32 - 5.18x	0.31
	5	fungicide-disk	Y= - 111.51 + 4.59x	0.68
		fungicide-paraplow	Y= - 84.63 + 3.96x	0.62
		none-disk	Y= - 663.36 + 36.02x - 0.461x^2	0.43
		none-paraplow	Y= - 327.53 + 18.29x - 0.219x^2	0.58
	10.51	fungicide-disk	Y= - 147.75 + 4.88x	0.70
		fungicide-paraplow	Y= - 148.92 + 5.25x	0.60
		none-disk	Y= - 140.68 + 4.09x	0.59
		none-paraplow	Y= - 76.18 + 2.99x	0.34
Leaf chlorophyll (SPAD) and Dry Matter (DM) (kg ha^{-1})	3	fungicide-disk	Y= - 42.37 + 0.248 DM - 0.00014 DM^2	0.56
		fungicide-paraplow	Y= 228.62 + 0.034 DM - 6.405 SPAD	0.34
		none-disk	Y= - 12.99 + 0.121 DM - 6.4x10^{-5} DM^2	0.40
		none-paraplow	Y= 190.90 + 0.146 DM - 6.5x10^{-5} DM^2 - 7.31 SPAD	0.71
	5	fungicide-disk	Y= - 24.68 + 0.027 DM + 0.0305 SPAD^2	0.79
		fungicide-paraplow	Y= - 85.12 + 0.059 DM - 1.0x10^{-5} DM^2 + 2.241 SPAD	0.83
		none-disk	Y= - 333.51 + 0.055 DM - 1.5x10^{-5} DM^2 + 17.051 SPAD - 0.221 SPAD^2	0.87
		none-paraplow	Y= - 24.74 + 0.059 DM - 1.0x10^{-5} DM^2	0.74

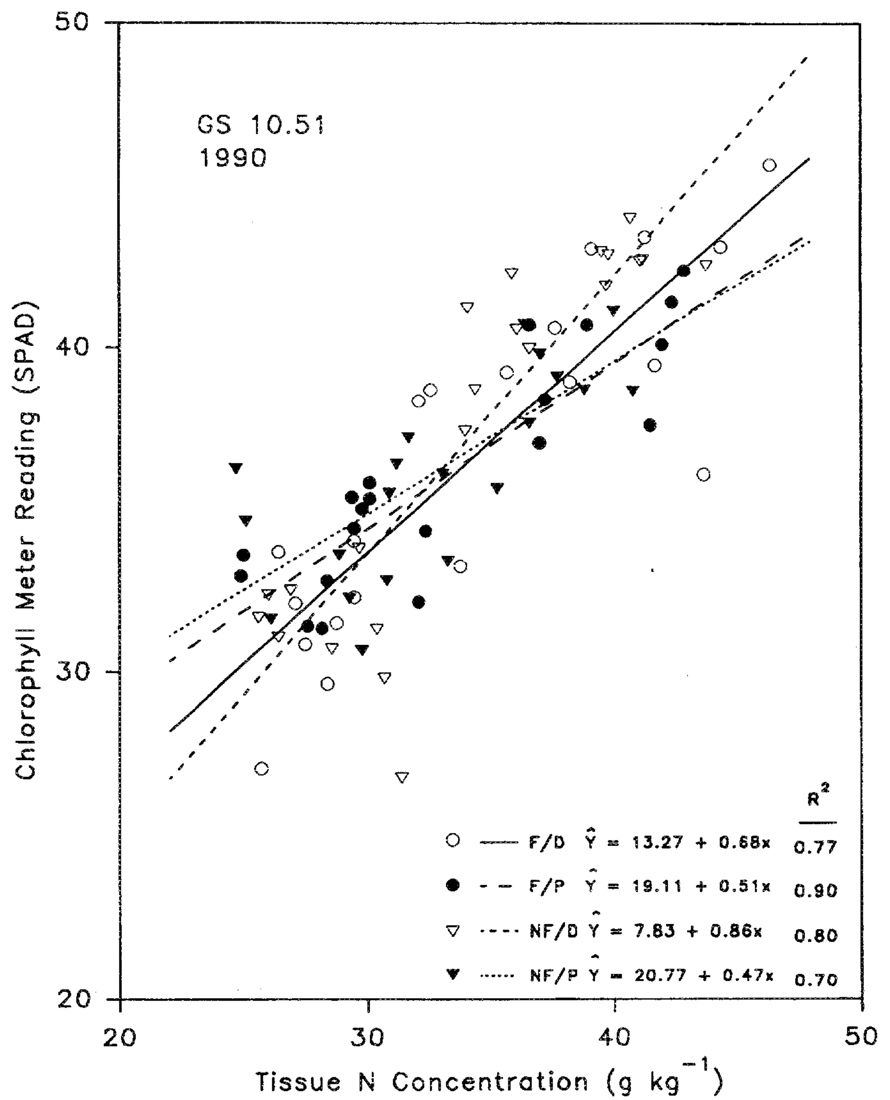

FIGURE 3. Relationship Between Leaf Chlorophyll Meter Readings (SPAD Units) and Tissue N Concentration of Wheat Flag Leaves at GS 10.51 in 1990. F= fungicide, NF= no fungicide, D= disk, and P= paraplow.

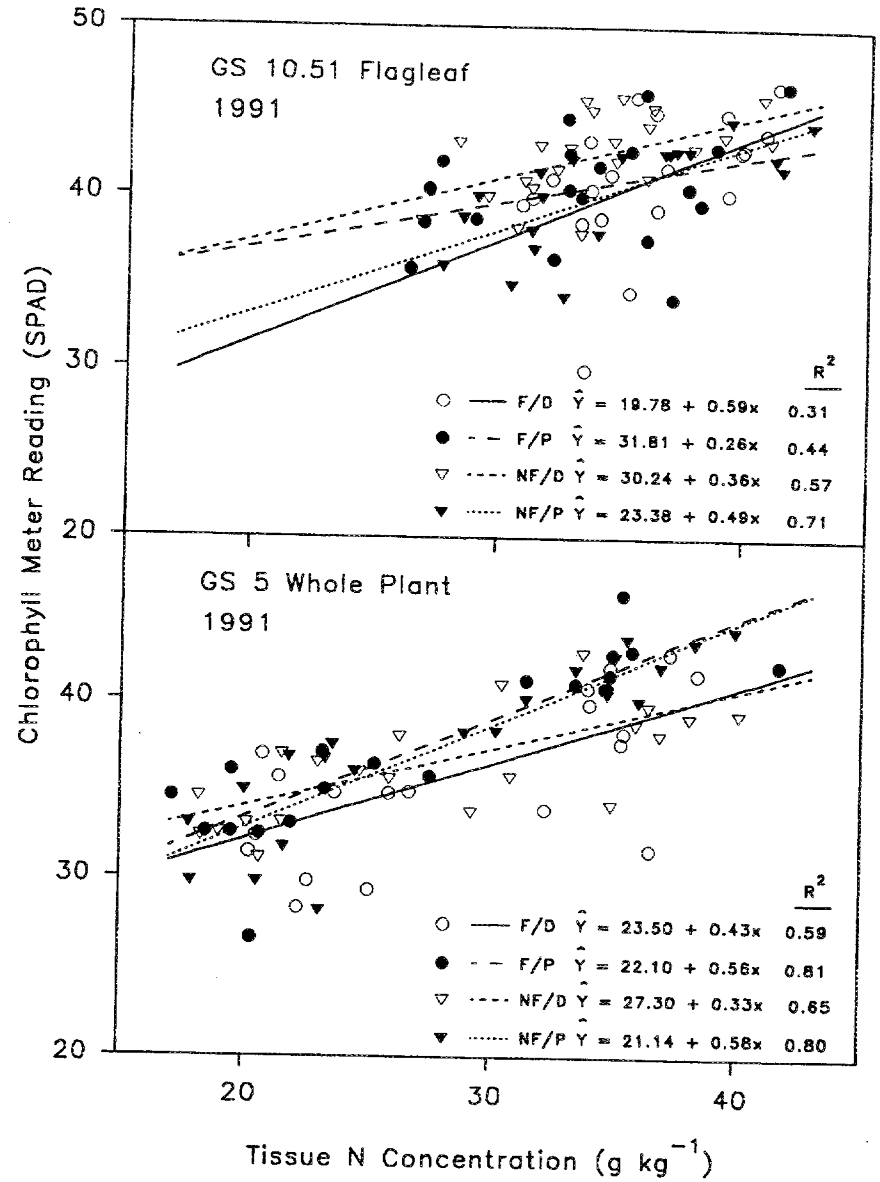

FIGURE 4. Relationships Between Leaf Chlorophyll Meter Readings (SPAD Units) and Tissue N Concentration of Wheat at GS 5 and GS 10.51 in 1991. No Relationship Found at GS 3. F= fungicide, NF= no fungicide, D= disk, and P= paraplow.

values in 1990 than 1991 and better relationships between meter readings and flag leaf tissue N in 1990 than in 1991. In 1990, intercepts and linear slopes of regressions for disked treatments were greater than those of paraplowed treatments (Fig. 3).

Relationships between leaf chlorophyll meter readings and tissue N leaf concentrations at GS 5 were better than those at GS 10.51 in 1991 (Fig. 4). Also, regression models for paraplowed treatments had steeper slopes than those of disked treatments at GS 5. Roth et al. (1989) reported that a tissue N concentration of 35.0 g/kg at GS 5 produced 90% of wheat maximum yield in tests in Pennsylvania. This would correspond to a meter reading of about 37 to 41 SPAD units, dependent on management treatment (Fig. 4).

The relative effectiveness of parameters to account for variations in yield at GS 5 is encouraging since N fertilizer applied shortly after this growth stage can effectively meet the N requirement of wheat (Alley et al., 1986). Although chlorophyll meter readings at GS 5 were not as good a predictor of grain yield as N uptake, the combination of dry matter and leaf chlorophyll meter readings resulted in models that accounted for an average of 81% (averaged over management factors) of the variation in yield. This was comparable to that accounted for by N uptake (85%).

Dry matter and chlorophyll meter readings can be done quickly and without special equipment as opposed to the substantial time and equipment required to analyze for plant tissue N. Our results show that chlorophyll meters have potential for determining N requirement of wheat. The simplicity and ease of use of this tool could be combined with other simple measurements, *e.g.*, dry matter determination and/or soil nitrate tests, to develop improved quick and reliable methods for predicting N fertilizer requirements for winter wheat. Further research over a wide range of soil and climate conditions needs to be conducted to determine the simplest but most comprehensively reliable method for applying this technology to wheat.

REFERENCES:

Alley, M. M., W. E. Baethgen, and D. E. Brann. 1986. Determining N needs for maximum economic wheat yields in humid regions. 18p. IN: Maximum

Wheat Yield Research Systems Workshop. Denver, CO. Mar. 5-7, 1986. Potash & Phosphate Institute and Foundation for Agronomic Research, Norcross, GA.

Batey, T. 1984. Plant growth and composition as predictors of nitrogen requirements, pp. 227-232. IN: The Nitrogen Requirement of Cereals. Ministry of Agriculture, Fisheries, and Food Reference Book 385. Her Majesty's Stationery Office, London, UK.

Donahue, S. J. and D. E. Brann. 1984. Optimum N concentration in winter wheat grown in the coastal plain region of Virginia. Commun. Soil Sci. Plant Anal. 15:651-661.

Feekes, W. 1941. De Tarwe en haar milieu. Vers. XVII Tech. Tarwe Comm. Groningen, 560-1.

Hargrove, W. L., J. T. Touchton, and J. W. Johnson. 1983. Previous crop influence on fertilizer nitrogen requirements for double-cropped wheat. Agron. J. 75:855-859.

Karlen, D. L. and D. T. Gooden. 1987. Tillage systems for wheat production in the Southeastern Coastal Plains. Agron. J. 79:582-587.

Kitagawa, Y., K. Okayama, and T. Hirokawa. 1987. Determination of leaf colour in rice cv. Koshihikari plants with a chlorophyll meter. Bull. Toyama Agric. Res. Cen. 1:1-7.

Morris, C. F., D. L. Ferguson, and G. M. Paulsen. 1989. Nitrogen fertilizer management with foliar fungicide and growth regulator for hard winter wheat production. Appl. Agric. Res. 4:135-140.

Piekielek, W. P. and R. H. Fox. 1992. Use of a chlorophyll meter to predict sidedress nitrogen requirements for maize. Agron. J. 84:59-65.

Reeves, D. W., P. L. Mask, and D. P. Delaney. 1991. Tillage and N management effects on wheat yield, N status, and leaf chlorophyll, p. 299. IN: Agronomy Abstracts. American Society of Agronomy, Madison, WI.

Roth, G. W. and H. G. Marshall. 1987. Effects of timing of nitrogen fertilization and fungicide on soft red winter wheat. Agron. J. 79:197-200.

Roth, G. W., R. H. Fox, and H. G. Marshall. 1989. Plant tissue tests for predicting nitrogen fertilizer requirements of winter wheat. Agron. J. 81:502-507.

Schepers, J. S., D. D. Francis, and C. Clausen. 1990. Techniques to evaluate N status of corn. p. 280. IN: Agronomy abstracts. American Society of Agronomy, Madison, WI.

Takebe, M., and T. Yoneyama. 1989. Measurement of leaf color scores and its implication to nitrogen nutrition of rice plants. Japan Agric. Res. Q. 23: 86-93.

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

Turner, F. T. and M. F. Jund. 1991. Chlorophyll meter to predict nitrogen topdress requirement for semidwarf rice. Agron. J. 83:926-928.

Wood, C. W., D. W. Reeves, R. R. Duffield, and K. L. Edmisten. 1992a. Field chlorophyll measurements for evaluation of corn nitrogen status. J. Plant Nutri. 15::487-500.

Wood, C. W., P. W. Tracy, D. W. Reeves, and K. L. Edmisten. 1992b. Determination of cotton nitrogen status with a hand-held chlorophyll meter. J. Plant Nutri. 14:1435-1448.

JOURNAL OF PLANT NUTRITION, 16(5), 797-812 (1993)

UREA TRANSFORMATION AND THE ADAPTABILITY OF THREE LEAFY VEGETABLES TO UREA AS A SOURCE OF NITROGEN IN HYDROPONIC CULTURE

Jian Luo, Zhaohuang Lian and Xiaolong Yan[1]

Department of Soils and Agrochemistry, South China Agricultural University, Guangzhou 510642, China

ABSTRACT : Substitution of urea for commonly used nitrate fertilizers in hydroponic culture of vegetables would not only avoid excessive accumulation of nitrate in plants but would also reduce the cost of production. This substitution, however, might have adverse effects, such as a dramatic decrease in solution pH, reduced nutrient uptake and possibly urea toxicity *per se.* Differences in adaptability to urea were found among three species of leafy vegetables, *Ipomoea aquatica* Fossk., *Lactuca sativa* L. and *Brassica chinensis* L. *I. aquatica* showed the best adaptability, growing normally with urea as the sole nitrogen source in spite of the dramatic pH decrease in the nutrient solution. It was further found that *I. aquatica* had significantly lower urease activity in the roots than the other two species when urea was supplied to the solution. Tolerance of low pH and avoidance of urea toxicity may be possible mechanisms of *I. aquatica*'s adaptability to urea application in hydroponic culture.

[1] Corresponding author.