Development of Intensive Nitrogen Management Strategies for Winter Barley (*Hordeum vulgare* L) in the mid-Atlantic Region

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Crop and Soil Environmental Sciences

ABSTRACT

Winter barley (*Hordeum vulgare* L.) production in the mid-Atlantic region occupies a substantial amount of arable land. Variable levels of winter and spring precipitation can result in N loss. The objectives of this study were to determine the optimum rate and timing of N fertilization and develop predictors of optimum N rates. An uptake study was conducted to determine N uptake of winter barley with respect to growth stage. Various N rate combinations at growth stages (GS) 25 and GS 30 were evaluated over twenty locations and three cropping seasons, to determine the application regime required to optimize grain yields at each site. Predictor variables at GS 25 and GS 30 were evaluated to predict optimum N rates. The N uptake study indicated an increased N uptake at GS 25 and GS 30. Yields from plots receiving no spring N varied from 1400 to 7530 kg ha\(^{-1}\), at various sites, indicating a yield response of barley to residual N. Optimum N rates over locations varied from 0 to 136 kg N ha\(^{-1}\), suggesting a need to diagnose site-specific N requirements. Plant tissue tests at GS 30 were the best predictor of GS 30 optimum N rates with a critical level of 3.5% N in plant tissue above which no
economic response to applied N would be expected. GS 25 tiller density was the best predictor of optimum GS 25 N rates in 1994-1995. This season was climatically atypical thus this method must be evaluated further.
Dedication

To my mother, Margaret T. Pridgen,
who always valued my accomplishments in life much more than I did.

My sole regret is that she is here in spirit only to share
our latest accomplishment.
Acknowledgements

I am very grateful to my major professor Dr. Mark Alley who, although always kind and supportive, managed to coax and challenge this aging student to levels of achievement I considered not possible. Thanks to Dr. Dan Brann for some gentle arm twisting in encouraging me down this path, and for very helpful advice during my research. I also appreciate the advice and encouragement of Dr. Dave Martens whom I greatly respect. I greatly appreciate the interest and advice of Dr. Carl Griffey regarding the varietal selections of this project and suggestions regarding my curriculum and future vocation. I would like to acknowledge Mr. Ron Mulford with the University of Maryland for conducting the field research at the Maryland location.

I am very grateful for the hard work of Mr. Jim Hammons who always brought an attitude of organization, dedication and optimism to the field. Many thanks to Mr. Marvin Martz for his many hours of assistance with this research and for our friendship, cemented by our mutual dedication to the field of agriculture. I would also like to acknowledge my friend Mike Jones for some critical and timely help during harvest. Thanks also to Ms. Rhonda Schrader for her assistance in preparing numerous tables and reports relating to
this project. I am very grateful to all the cooperating producers for their assistance and support of this research.

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Chapter I

Introduction

OVERVIEW

Barley (*Hordeum vulgare* L.) is an important winter cereal in the mid-Atlantic region of the United States. Approximately 41,000 hectares of arable land are utilized for growing winter barley in Virginia (Bass and Lawson, 1993) which ranks fourth in Virginia in percentage of crop land use, following corn, soybeans and wheat.

Fertilizer N applied prior to expected crop uptake is subject to leaching and denitrification losses. Application of excessive N results in lodging, and possibly lower grain yields of reduced quality. Under application of N reduces grain yield, grain quality and producer profit per hectare. Development of a field specific method to determine optimum rates and proper timing of spring fertilizer N applications on winter barley could have significant economic and environmental benefits in the humid mid-Atlantic region.

Concern for non-point source nitrate loading of surface waters has dictated the implementation of more intensive agricultural management practices to reduce the potential of fertilizer nitrogen reaching surface waters. The majority of Virginia winter small grain production lies in the eastern Piedmont and Coastal Plain regions. The close
proximity of these regions to streams which terminate at the Chesapeake Bay has increased the concerns related to excessive N application and the effect of soil nitrate loading on this estuary. To exacerbate this effect, the soils in the Coastal Plain region are typically coarser textured sandy-loams and loamy-sands, with relatively high percolation rates which increase the potential of nitrate leaching. Soil characteristics coupled with relatively high winter and early spring precipitation rates, increases the potential for leaching losses of late fall or early spring applied N.

An estimated 40% of the N in the total nutrient load in the Chesapeake Bay originates from area croplands (Camacho, 1992). Agricultural best management practices (BMP's) recently implemented have reduced agricultural nitrate loadings of tributaries feeding the bay, but more precise nutrient management practices are required to reduce nitrate to target levels by the year 2000.
CONTEXT OF PRESENT RESEARCH

Nitrogen recommendations for cereals in Virginia are based upon yield expectations associated with the productivity rating of the soil series (Simpson et al, 1993). Soil characteristics considered include water-holding capacity, cation exchange capacity, and soil organic matter. Historic yield data for a particular field, when available, are also considered in the recommendation. Soil N levels are not typically considered, either for possible carryover or potentially mineralizable soil N. Historically, the potential value of residual soil N sources from a preceding crop have been considered insignificant. A recent study with winter wheat in Virginia, however, identified March levels of soil profile mineral N as great as 237 kg N ha\(^{-1}\) (Scharf and Alley, 1994) indicating that residual mineral N can significantly contribute to yields of winter cereals, and should be budgeted in spring fertilizer-N recommendations.

The obvious initial approach to quantify plant-available N in the spring prior to fertilizer N application is to assess extractable soil ammonium (NH\(_4^+\)) and nitrate (NO\(_3^-\)) in the soil profile. Soil samples are traditionally taken from the top 15 cm of the soil profile. However, winter cereals establish root systems well beyond 15 cm during late fall and early winter, and NH\(_4^+\) and NO\(_3^-\) determinations from a traditional 15 cm soil sample would potentially underestimate soil mineral N available to barley. Varying soil textures, particularly across the different Virginia physiographic regions in which winter barley is
grown, also contribute to possibly erroneous predictions. Jolley and Pierre (1977), for example, found widely varying soil NO₃ levels due to soil variation in percolation rates within different soils. In addition, early spring precipitation can result in many soils being at or near field capacity, encouraging leaching and denitrification (Bundy and Malone, 1988). Deeper soil profile sampling has been suggested as a method to determine total plant-available N, but calibrating these measurements over a wide variation of soil series and climatic events has not proven to be an accurate predictor of supplemental spring fertilizer N in humid regions (Fox and Piekielek, 1978).

The objective of optimizing N use efficiency of winter barley is achieved when available soil profile N matches plant N uptake. The challenge of balancing soil labile N with plant N requirements is in synchronizing peak N availability periods with peak plant N usage periods. As outlined previously, the amount of plant-available soil N, although variable, typically declines in early spring due to climatic factors. Conversely, the typical N usage of winter cereals escalates during spring as rapid growth occurs. Consequently, available soil N assessment and additional N fertilization need to match plant N uptake. Little information is available regarding the N uptake pattern of winter barley in the mid-Atlantic region. From an N fertility perspective, a relative N uptake pattern would be useful in predicting seasonal needs of N for winter barley. Baethgen and Alley (1989) developed N uptake curves for winter wheat in Virginia which identified two periods of increased N uptake following growth stage (GS) 25 and GS 30, respectively (Zadoks et.
al., 1974). Carreck and Christian (1991) working with malting barley varieties in Europe, developed similar uptake curves but did not notice a pronounced rate increase of N uptake between GS 25 and GS 30. This slight difference could of course be due to numerous environmental and genetic factors. Actual N uptake patterns for winter barley in the mid-Atlantic are needed.

The effect of spring N application timing on winter cereals is well understood. Nitrogen applications in late winter increase survival rates of fall tillers and increase the number of fertile tillers per plant (Walker and Matthews, 1991). Tiller growth and development at GS 25 requires adequate soil N levels. The period of most rapid growth of winter barley is during stem elongation at GS 31 to GS 37. Work with winter wheat in Virginia indicates a strong yield response to a second N application at GS 30 (Baethgen and Alley, 1989; Scharf and Alley, 1993). Fertilizer N application, if required, could possibly be more efficiently utilized by winter barley if split between GS 25 and GS 30.

Plant tissue analysis has emerged as an important diagnostic tool to correct nutrient deficiencies in crop plants. Initial studies examined crop plant mineral composition in relation to corresponding mineral fertilizer applications. Subsequent research established nutrient concentration levels at specific plant developmental growth stages which defined "zones" of mineral concentrations deemed deficient, sufficient or toxic (Melsted et. al. 1969; Bates, 1971). Dow and Roberts (1982) acknowledged the accuracy of plant analysis
as a measure of in-season nutrient sufficiency, but indicated that climatic variations, nutrient interactions, and to a lesser extent varietal variation may influence plant nutrient sufficiency levels. Considering site-specific nutrient recommendations, many factors should be included which relate to the soil-plant nutrient balance and ultimate crop yield. Soil test levels can be used to indicate adequate levels of soil phosphorous, calcium and potassium and plant available nitrogen could possibly be monitored via plant tissue analysis and amended in-season. Fox and Piekelek (1984) infer that plant tissue analysis may be a useful tool for N recommendations where soil nitrate analyses are variable. Scharf et. al. (1993), using a tissue N testing model applied to producer situations, demonstrated the power of an in-season tissue testing procedure in predicting site-specific economically optimum N application rates. It would seem that an in-season, tissue-based monitoring system for winter barley in humid climates could be of value in predicting optimum spring fertilizer N rates.

Plant tissue testing, although valuable in determining plant N requirements, is time consuming and could delay timely fertilizer N application. The recent emergence of hand held chlorophyll meters has increased interest regarding the use of these meters for in-field prediction of plant nitrogen needs. The SPAD - 502 (Minolta Camera Co., Ltd., Japan) is a portable chlorophyll meter that has been used to evaluate N sufficiency in crop plants. The SPAD - 502 meter is a non-destructive meter which measures the amount of light absorbance in the 650 nm range, and a light attenuation coefficient is determined by
sequentially directing a second infrared beam through the leaf. This measurement reflects the amount of absorbed light in the 650 nm range and the transmitted light in the 950 nm infrared range (Inada, 1963). This reading is directly related to the chlorophyll level of the plant tissue (Takabe and Yoneyama, 1989).

Some studies have indicated success predicting nitrogen needs in certain plants using chlorophyll meters (Takabe and Motomatsu, 1987; Wood et. al., 1992). Other studies have shown inconsistent correlations between leaf chlorophyll levels and tissue nitrogen levels due to genotypic or environmental differences. Monje and Bugbee (1992), found that light scattering properties inside the leaf membrane contributed to the inaccuracy of the SPAD readings at certain chlorophyll levels. In a Virginia study, significant differences were observed between SPAD readings and actual chlorophyll levels among samples of the same species grown under different environmental conditions (Campbell et. al., 1990). Leaf thickness has recently been proposed as a factor which may influence light scattering properties within the leaf. Since scattering of light is a function of leaf density and thickness (Sestak, 1985), adjustments to meter readings based on these factors could improve the correlation of chlorophyll meter readings to actual tissue N levels. Peng et. al. (1993), in a study involving rice plants, adjusted the SPAD - 502 readings for specific leaf weight, the dry weight of the leaf per unit area of the leaf surface. This adjustment resulted in a much better correlation between chlorophyll meter readings and tissue nitrogen levels. Specific leaf weight measurements, however, are time
consuming, requiring drying of the plant tissue and precise weighing and leaf area
measurement. A mechanical thickness measuring system could possibly be incorporated
within the meter to aid in determining plant N status.
REFERENCES


Chapter II

Nitrogen Fertilization of Winter Barley

In the mid-Atlantic Region

ABSTRACT

Winter and early spring precipitation in the humid mid-Atlantic region enhances nitrogen loss from heavily fertilized fields cropped to winter barley (*Hordeum vulgare* L.). More precise timing of N application coinciding with plant N requirements could reduce loss of soil N and optimize grain yields. The objectives of this study were to develop a N uptake pattern of winter barley and determine optimum N rates for each location at growth stage (GS) 25 and GS 30. During the 1994-1995 season, cumulative barley plant N uptake was determined for various time periods throughout the season. Nitrogen rate and timing studies, evaluating yield response to different GS 25 and GS 30 N applications, were conducted over three seasons at twenty locations. The N uptake study indicated an uptake of 35 kg N ha⁻¹ at GS 25 with a subsequent increase of approximately 70 kg N ha⁻¹ at GS 30. Grain yields from the N rate and timing studies varied from 1400 to 9620 kg ha⁻¹. Grain yields from sites receiving no spring applied N varied from 1400 to 7530 kg ha⁻¹ indicating that residual N may persist through winter.
and influence barley grain yields. Sixteen of the twenty locations showed positive yield responses to GS 30 applied N. All or a portion of applied spring N should be delayed until GS 30, the period of peak plant N uptake. Residual N at some locations contributed significantly to grain yield, indicating a need to determine plant N status at GS 25 and GS 30 and adjust N applications accordingly.
INTRODUCTION

Nitrogen is one of the major yield enhancing components in cereal production. N is also one of the most difficult nutrients to manage because crop response varies by soil type, climate and residual levels. N-use efficiency is estimated to be 50 to 60% worldwide (Abrol et al., 1984). Nitrogen is utilized by winter barley (*Hordeum vulgare* L.) in either the nitrate or ammonium form (Amon, 1937). Some workers have suggested that ammonium N sources may be more efficiently used by cereals (Leyshon et al., 1980; Spratt and Gasser, 1970). Nitrate is the most abundant N ion in warm, moist well-oxygenated soils; therefore, it does not appear practical to manipulate the N source in production systems, particularly in humid, temperate climates.

Winter barley seedlings obtain N from the soil solution once embryonic N sources have been exhausted. Adequate early N is required to stimulate root establishment and initial shoot growth. Initial fall tillering in winter barley has been observed within the first three weeks of growth (Cannell, 1969), thus adequate soil N levels are required to promote the initiation and development of fall tillers in winter barley (Garcia Del Moral et al., 1984; Needham and Boyd, 1976). N requirements are low during the semi-dormant winter phase but increase during early spring. Nitrogen applications in early spring increase the survival rate of fall tillers and increase the number of fertile tillers per plant.
(Walker and Matthews, 1991). Dry matter yields, number of heads per plant, and grain N content is decreased when N is limiting (Pearson et al., 1989).

Nitrogen nutrition of winter barley in the mid-Atlantic region has traditionally relied on a pre-plant application of N followed by a single subsequent N application the following spring. Higher yield potentials and environmental concerns are strong reasons for examining N recommendations for winter barley grown in the mid-Atlantic region. Newer cultivars of winter barley are available which have higher yield potentials than previous varieties. Average yield of winter barley in Virginia, for example, has increased from 1560 kg ha\(^{-1}\) in 1963 to 4200 kg ha\(^{-1}\) in 1992 (Bass and Lawson, 1993). Newer varieties grown under intensive management practices have produced 8000 kg ha\(^{-1}\). Higher yields from these modern varieties require additional N, although increasing environmental concerns for excess nitrate loading of surface and sub-surface waters dictate more intensive management of applied N.

Winter and early spring precipitation rates in humid climates enhance N leaching. Spring N applications must match the time of fertilizer N utilization to reduce potential leaching. Few studies exist relating N rates and timing to winter barley yields in humid climates. However, several recent European studies indicate variable responses to split-spring N application regimes. Conry and Dunne (1993), in Ireland, observed a positive yield response to N applications in both March and April, probably at GS 25 and GS 30,
respectively. Other studies indicate a larger yield response to April applied N and no significant improvement in yields with earlier N applications (Penny et al., 1986; Widdowson et al., 1986). Considering different varietal and climatic factors, a N uptake pattern for barley grown in the mid-Atlantic region would be useful in predicting the optimum timing of spring N applications. Baethgen and Alley (1989), in Virginia studies with winter wheat, developed N uptake curves which indicated increases in N uptake at growth stage (GS) 25 and GS 30, respectively (Zadoks et. al., 1974). Physiologically, this agrees with accepted growth patterns in cereals which indicate that early spring N applications stimulate tiller formation and shoot growth, and subsequent applications promote fertile tillers and increased grain yield (Spiertz and Devos, 1983).

The importance of N rate and timing are critical to optimize winter barley grain yields and concurrently, reduce the environmental impact of excess N loading. The objectives of this study were (i) to develop an N uptake pattern for winter barley in the mid-Atlantic region, and (ii) to determine the optimum GS 25 and GS 30 N rates for winter barley in a humid environment.

MATERIALS AND METHODS

The N uptake study was conducted at the Kentland Research Farm, Virginia Tech in 1994-1995. A 7.5 X 75 m strip of 'Nomini' barley was divided into three 7.5 X 25 m
blocks. N treatments consisted of 28 kg N ha$^{-1}$ at planting followed by 64 kg N ha$^{-1}$ at GS 25 and 64 kg N ha$^{-1}$ at GS 30. From establishment to harvest, whole plant tissue samples were taken periodically from each of the three blocks. The samples were dried and ground to pass a 40-mesh sieve. Samples were then bottle ground and mixed by sealing tissue in glass bottles with stainless steel rods of various diameters. The bottles were then rotated horizontally on a conveyor belt for 12 hours. The samples were then dried to a constant weight, and analyzed by micro Kjehldahl analysis by Quik Chem Method No. 13-107-06-2-13 (Lachat Instruments, Milwaukee WI), using a Quik Chem Automated Ion Analyzer. All samples were digested and analyzed in duplicate. N uptake was calculated in kg N ha$^{-1}$ for each sample and plotted against the appropriate sampling time.

N rate and timing experiments were conducted over three growing seasons, 1992 through 1995, at physiographic regions in which winter barley is currently grown (Table 1) in Virginia and Maryland. Locations 7, 12, 17, and 18 in Maryland were at the Poplar Hill Research Station, University of Maryland. Locations 8, 9, 13, 14, 19, and 20, in Virginia, were at the Kentland Research farm, Virginia Tech. The remaining locations were producer fields in the Coastal Plain and Valley regions of Virginia. The site/year locations, varieties, and corresponding soil series are summarized in Table 1. All site selections were based on barley variety, uniformity of soil type, and stand.

The experimental design was comprised of 4.5 X 5 m plots in randomized
<table>
<thead>
<tr>
<th>Location Number</th>
<th>Year</th>
<th>Cultivar</th>
<th>Soil series and texture</th>
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<tr>
<td>1</td>
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<td>Nomini</td>
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complete block design with four replications. Treatments consisted of factorial combinations of GS 25 application rates of 0, 34, 68, and 102 kg N ha\(^{-1}\), and subsequent GS 30 applications of 0, 34, 68, 102, and 136 kg N ha\(^{-1}\). Treatments at location 7 in Maryland in 1995 were factorial combinations of GS 25 applications of 0, 95, and 190 kg N ha\(^{-1}\) followed by 0, 95, and 190 kg N ha\(^{-1}\) at GS 30.

Urea - NH\(_4\)NO\(_3\) (30% N) solution was used as the N source in all treatments except the 1993 and 1994 Maryland experiments where granular NH\(_4\)NO\(_3\) was the N source. The N solution was applied using either a CO\(_2\)-pressurized, backpack sprayer or a tractor mounted, diaphragm pump, boom sprayer. Both sprayers were equipped with the appropriate Tee Jet "raindrop" flat fan spray nozzles to deliver the correct N rate ha\(^{-1}\). Ground speed was controlled via metronome-timed walking speed with the backpack sprayers for each N rate. Rate calibration for the tractor sprayer applied plots was obtained by calibrating a timed flow rate with a measured speed determined by stopwatch timing over a measured 15.25 m course for each N rate. The granular ammonium nitrate applications were premeasured for each plot, then uniformly hand broadcast over the appropriate plot.

The plant growth regulator ethephon, (2-chloroethyl) phosphonic acid, was applied to all experiments at a rate of 280 g ha\(^{-1}\) to reduce lodging. Ethephon was applied at GS 43-45, prior to head emergence in approximately 175 L water ha\(^{-1}\) using either a
pressurized CO₂ backpack sprayer or a tractor mounted boom sprayer previously described.

Plots were mechanically harvested using a Hege 140 plot combine. Wet grain yields were measured and moisture readings taken using a Dickey John- Grain Analysis Computer. Yields were adjusted to 135g kg⁻¹ moisture content.

Analysis of variance was used to determine if significant differences existed between treatments at each site. For sites that exhibited treatment responses, GS 30 N rates were regressed against yields for each GS 25 N rate. Optimum N rates were calculated for each GS 25 N rate from the regression equation using current prices for barley and N. Thus, for each site four optimum N rates were determined corresponding to each GS 25 N rate; three optimum N rates were derived from the 1995 Maryland experiment.

Least squares estimated profit-response surfaces were generated for each location. Estimated profit on the response surface is a function of the GS 25 and GS 30 N rate combination. Profit was defined as current barley grain price multiplied by grain yield, less N cost, less a constant $371.00 ha⁻¹ to cover other variable costs. The GS 25 N rate corresponding to the point of highest economic return on the response surface was determined as the economic optimum GS 25 N rate. All statistical computations were
performed using SAS (SAS Institute, Cary, NC). Least squares response surfaces were
generated using Sigma Plot software (Jandel Scientific, San Rafael, CA).

RESULTS AND DISCUSSION

Climatic conditions varied considerably over the three cropping seasons. The
winters of 1992 - 1993 and 1993 - 1994 were generally colder and more severe compared
to the relatively mild 1994 - 1995 season. Precipitation for the late winter and early spring
of 1995 was much lower than 1993 and 1994 (Table 2). The 1995 barley was shorter with
more rigid stems that were more resistant to lodging. Weather conditions were generally
conducive to good barley growth with the exception of locations 5 and 6 in 1994-1995.
Barley plants at locations 5 and 6 in 1995, grown on coarse textured soils, suffered
drought stress in late spring resulting in depressed growth and relatively low yields. Heavy
winter precipitation and extreme temperature fluctuations at locations 17 and 18 also
depressed growth and grain yields in 1993.

The results of the 1994 - 1995 barley N uptake study are shown in Figure 1. The
mild fall temperatures and adequate precipitation encouraged good early fall growth, and
N uptake. Approximately 80 kg N ha⁻¹ was taken up by barley plants prior to December.
Twenty-eight kg N ha⁻¹ applied prior to planting constituted the only fall - winter applied
Table 2. Precipitation in the Virginia Coastal Plain for the 1992 through 1995 barley growing seasons.

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</tr>
<tr>
<td>Nov</td>
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<td>9.6</td>
<td>8.4</td>
</tr>
<tr>
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<td>8.9</td>
</tr>
<tr>
<td>Feb</td>
<td>5.9</td>
<td>11.9</td>
<td>5.4</td>
<td>8.1</td>
</tr>
<tr>
<td>Mar</td>
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<td>23.2</td>
<td>8.6</td>
<td>9.9</td>
</tr>
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<td>4.0</td>
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<td>7.5</td>
</tr>
<tr>
<td>May</td>
<td>11.5</td>
<td>8.0</td>
<td>10.8</td>
<td>10.2</td>
</tr>
<tr>
<td>Jun</td>
<td>7.5</td>
<td>5.7</td>
<td>10.4</td>
<td>9.4</td>
</tr>
</tbody>
</table>
Fig. 1. Nomin barley N uptake pattern for 1994-1995, Hayter loam soil, Valley region.
N, thus these plants effectively scavenged nearly 50 kg N ha\(^{-1}\) prior to the high precipitation late winter and early spring season. The use of barley in a winter rotation could be a very effective N trap, reducing the amount of mineral N exposed to leaching loss. Nitrogen uptake did not significantly increase again until February. During February to late March, N uptake increased approximately 35 kg N ha\(^{-1}\), indicating an increased demand for available N in early spring. It is interesting to note however, that GS 25 for winter barley in this physiographic region of Virginia, usually occurs in late February or early March, and though Baethgen and Alley (1989) documented increased N uptake of winter wheat at this period, it is possible that winter barley may require N earlier. The more probable reasons for early spring N uptake however were the very well developed late fall plants coupled with a relatively mild late winter which encouraged earlier spring plant growth. The most rapid increase of N uptake was from late March to mid April, confirming earlier work that post GS 30, during the stem extension phase, marks both the period of most vigorous plant growth and highest rate of N uptake. N uptake increased approximately 70 kg N ha\(^{-1}\) during this 18 day period, averaging approximately 3.9 kg N ha\(^{-1}\) day\(^{-1}\).

Grain yields varied widely between treatments, sites, and years. Yields ranged from 1400 to 9620 kg ha\(^{-1}\) in 1992 - 1993, 3550 to 8550 kg ha\(^{-1}\) in 1993 - 1994, and from 1610 to 8480 kg ha\(^{-1}\) in 1994 - 1995. Depressed yields at locations 5 and 6 in 1994 - 1995 and at locations 17 and 18 in 1992 - 1993, were due to climatic events as discussed
previously, and did not reflect N limiting conditions. Grain yields of 7200 kg ha\(^{-1}\) were measured at location 8 with no spring N applications, indicating a high level of residual N. This experiment was conducted on a deep Hayter loam where potentially high levels of mineralizable N could be expected. Location 15 however produced yields of 5800 kg ha\(^{-1}\) on a loam soil in the Coastal Plain with no spring-applied N. These significant levels of residual N may be available to winter barley in the spring even on coarse textured soils following heavy winter precipitation. Over sites and years grain yields of plants receiving no spring N ranged from 1400 kg ha\(^{-1}\) to 7530 kg ha\(^{-1}\), indicating a need to identify sites with appreciable levels of residual N and adjust spring N applications accordingly.

Grain yield response at each site was evaluated by regressing yield against GS 30 N treatments for each GS 25 N treatment. Sixteen of twenty locations exhibited a positive yield response to GS 30 N applications. Examples of grain yields plotted against GS 30 N treatments for each GS 25 treatment are shown in Figures 2 and 3. Figure 2 represents a N responsive site versus Figure 3 which is typical of a site that did not respond to GS 30 N treatments. Locations 1, 8, 19, and 20 showed no significant yield response to any GS 30 N application even when no GS 25 N was applied. It is important to note that of the four non-responsive sites, locations 8, 19, and 20 were grown on the Hayter loam which contained approximately 2.5% organic matter and thus a high level of potentially mineralizable N. In addition, these locations do not represent the physiographic soil regions in which the majority of barley acreage in Virginia is grown. Location 1 was
Figure 2. Callao barley yield response to GS 30 N application for each GS 25 N rate at location 15 grown on a Kempsville loam. Yields at this location are responsive to GS 30 N applications for all GS 25 N treatments.
Figure 3. Callao barley yield response to GS 30 N applications for each GS 25 N rate at location 8 grown on a Hayter loam. Yields at this location were not responsive to GS 30 N applications.
located in the coastal plain region but obviously retained a large amount of labile mineral N as evidenced by very excessive fall growth in comparison to the other sites. Residual N may vary over years and sites, however the majority of locations exhibited positive responses to GS 30 N applications.

Optimizing yields in a production system infers maximizing yield with minimal inputs. For the purpose of this paper, optimum yield is considered in terms of a single variable, applied N, in which the economic value of the grain unit produced equals the last corresponding added unit of applied N. Careful attention was taken, regarding experimental sites, to insure that applied N was the sole limiting producer-controlled input. Uncontrollable inputs such as precipitation and temperature were disregarded. Optimum GS 30 N rates were calculated for each GS 25 N rate at each location and summarized in Table 3. An optimum N rate greater than zero indicates a significant positive response to applied GS 30 N. Optimum GS 30 N rates varied widely, indicating large differences in residual N, either applied or retained as available N from a prior crop.

Economic response surfaces were generated for each location indicating the economic return for each GS 25 X GS 30 N rate combination. An example of these response surfaces is shown in Figure 4. The point of peak economic return for each response surface was determined and the associated optimum GS 25 N rate was calculated for each site and summarized in Table 4. GS 25 optimum N rates varied considerably over...
Table 3. Optimum GS 30 N rates (kg ha\(^{-1}\)) for respective GS 25 N treatments for each location.

<table>
<thead>
<tr>
<th>Location</th>
<th>0 kg N ha(^{-1})</th>
<th>34 kg N ha(^{-1})</th>
<th>68 kg N ha(^{-1})</th>
<th>102 kg N ha(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>121</td>
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<td>0</td>
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<tr>
<td>3</td>
<td>84</td>
<td>74</td>
<td>73</td>
<td>47</td>
</tr>
<tr>
<td>4</td>
<td>79</td>
<td>80</td>
<td>69</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>64</td>
<td>63</td>
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</tr>
<tr>
<td>6</td>
<td>96</td>
<td>43</td>
<td>42</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>58</td>
<td>—</td>
<td>66(^{\dagger})</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>73</td>
<td>54</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>116</td>
<td>134</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
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<td>19</td>
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<td>0</td>
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<tr>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^{\dagger}\) This GS 25 N treatment at location 7 was 51 kg N ha\(^{-1}\).
Figure 4. Least squares response surface estimating economic return for each GS 25 X GS 30 N rate combination. These surfaces were generated for each location and used to determine optimum GS 25 N rates.
Table 4. Optimum GS 25 N rates for each location determined from estimated profit response surfaces.

<table>
<thead>
<tr>
<th>Location</th>
<th>Optimum GS 25 N rate kg ha$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
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<tr>
<td>3</td>
<td>45</td>
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<td>5</td>
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<td>65</td>
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<td>7</td>
<td>100</td>
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<tr>
<td>9</td>
<td>35</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
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<td>11</td>
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<td>100</td>
</tr>
<tr>
<td>19</td>
<td>25</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>
locations, sites, and years. The optimum GS 25 N rates were particularly high for 1993-1994 locations compared to other seasons. High late-winter and early-spring precipitation levels during 1993 - 1994 probably increased N leaching losses, particularly on the loam and sandy loam soils at locations 10 and 11. Locations 13 and 14 however, grown on the Hayter loam, also required high GS 25 N rates, though in other years this soil required much less early spring applied N to produce optimum yields. Clearly, crop rotations, climatic conditions and cultural practices should be taken into consideration to evaluate GS 25 N needs for winter barley.

A split-application regime for winter barley in the mid-Atlantic region appears to be a more economically advantageous alternative to the traditional practice of a single spring N application. Residual N available to winter barley in the spring is quite variable, dictating the need to assess plant N needs prior to both GS 25 and GS 30 to optimize yields, and more closely match the barley N uptake pattern.
REFERENCES


Penny, A., F. V. Widdowson, and J. F. Jenkyn. 1986. Results from experiments on winter barley measuring the effects of amount and timing of nitrogen and some other factors on the yield and nitrogen content of the grain. I. Agric. Sci. 106:537-549.


Chapter III

Predicting Optimum Nitrogen Rates for Winter Barley
in the mid-Atlantic Region

ABSTRACT

Previous studies with winter barley in the mid-Atlantic region indicate that residual
N may persist through winter and early spring at levels sufficient to influence grain yields.
The objective of this study was to evaluate a number of diagnostic variables at growth
stage (GS) 25 and GS 30 for use in predicting optimum GS 25 and GS 30 N rates.
Optimum GS 25 and GS 30 N rates were determined for each of twenty locations over
three cropping seasons. These optimum N rates were regressed against the appropriate GS
25 and GS 30 predictor variables. Late-winter soil mineral N levels were not useful in
predicting optimum GS 25 N rates. Tiller density at GS 25 appeared to be the best
predictor of optimum GS 25 N rates ($r^2 = 0.67$); however, this model was tested in a
climatically atypical season, and should be reevaluated in a more normal season. SPAD-
502 chlorophyll meter readings and SPAD readings plus leaf thickness values were not
reliable predictors of GS 30 optimum N rates. Percent N in plant tissue at GS 30 was the
best predictor of GS 30 optimum N rates ($r^2 = 0.65$), indicating a level of 3.5% N in plant
tissue above which no economic response to applied N would be expected. Plant tissue
testing at GS 30 coupled with a reliable GS 25 tiller density model appear to be the best
predictive system for determining split-spring N applications for winter barley.
INTRODUCTION

Optimum total spring N rates in the field studies (Chapter II) varied from 0 to 136 kg ha\textsuperscript{-1} indicating that residual N varies over sites and years. More accurate fertility recommendations could be made if a field-specific system was developed to quantify residual N in winter barley production systems. Since nitrate (NO\textsubscript{3}\textsuperscript{-}) exists as the predominant plant available form of N in well-aerated, warm, moist soils, recent focus on residual N determination in humid regions has relied on soil profile NO\textsubscript{3}\textsuperscript{-} levels.

Several studies in humid regions have identified soil profile NO\textsubscript{3}\textsuperscript{-} that has been retained from a previous cropping sequence (Jolley and Pierre, 1977; Linville and Smith, 1971; Scharf and Alley, 1993). However few studies have successfully predicted current crop N needs from soil NO\textsubscript{3}\textsuperscript{-} levels. Bundy and Malone (1988), in a humid region in Wisconsin, measured corn yield response to residual soil profile NO\textsubscript{3}\textsuperscript{-} and determined a critical level of 150 kg ha\textsuperscript{-1} profile NO\textsubscript{3}\textsuperscript{-} above which no additional yield response to applied N was measured. Baethgen and Alley (1989) in studies with winter wheat in Virginia, developed pre-topdress, site-specific spring N application rates based on soil profile NO\textsubscript{3}\textsuperscript{-} levels.

Nitrogen uptake data from the previous chapter indicated an increase in N uptake in the spring at growth stage (GS) 25 and GS 30. Consequently, N rate predictors should coincide with these plant developmental stages in order to be most effective.
Early spring applications of N, if needed, have been shown to increase fall tiller survival and increase shoot growth (Spiertz and DeVos, 1983). Tiller counts, taken at GS 25, could possibly be a useful predictor of N status of winter barley. Scharf and Alley (1993), successfully used tiller density at GS 25 to predict optimum winter wheat N applications, and identified a critical tiller number at which no applied GS 25 N was required if a subsequent GS 30 application was anticipated. Their study also found that soil profile NO$_3^-$ at GS 25 was the best predictor of a single spring N application regime.

Winter cereals at GS 30, prior to stem elongation, are beginning the period of most rapid growth. The largest percentage of plant N uptake occurs during this period (Baethgen and Alley, 1989; Carreck and Christian, 1991; Pridgen et al., 1995 unpublished data). Therefore, predictors would be useful at this stage to determine N status of winter barley and project future N needs. Spring soil mineral N levels have been used with success on certain crops to predict plant N needs (Blackmer et al., 1989; Fox and Piekielek, 1978). Increased quantities of precipitation during winter and early spring in the mid-Atlantic region, however, encourage leaching and denitrification losses (Jolley and Pierre, 1977). Predicting crop N requirements from soil NO$_3^-$ levels in this region also is more difficult because of variable percolation rates.

Tissue N testing is currently used in assessing crop N status. Plant tissue testing commonly has been used to establish N sufficiency ranges above which no positive yield
response is obtained to additional applied N (Donahue and Brann, 1984; Melsted et al, 1969). Few investigators have successfully used plant tissue tests to predict optimum N rates. Roth et al. (1989), determined optimum N rates for winter wheat using whole plant Kjeldahl - N concentrations at several specific plant growth stages. A recent study with winter wheat in Virginia concluded that N applications based on plant tissue N at GS 30 were economically superior to conventional N recommendation practices (Scharf et al., 1993).

Plant tissue testing, although valuable as a plant N diagnostic tool, is time consuming, because of sampling, drying, and laboratory analysis. These requirements can delay timely fertilizer N application. Recently developed, portable chlorophyll meters may offer a quick, in-field measurement of crop N status because leaf chlorophyll levels have been shown to be correlated to leaf N levels (Takabe et al., 1990). Piekielek and Fox (1992) using a SPAD - 502 chlorophyll (Minolta Camera Co., Ltd., Japan) established critical N sufficiency SPAD readings for corn. Other studies, however, suggest that genotypic or environmental variations reduce the utility of the SPAD - 502 meter in determining leaf chlorophyll and N levels (Campbell et al., 1990; Monje and Bugbee, 1992). A recent rice study determined that correcting the SPAD readings for specific leaf weight, the dry weight of the leaf per unit area of live leaf surface, improved the ability of the meter to predict leaf N concentration, but, specific leaf weight measurements require accurate measurements of leaf area and dry leaf weight, thus limiting the chlorophyll meter
as a means of rapid plant N assessment. However, leaf thickness can be rapidly measured with a caliper and might improve the in-field plant N assessment of the SPAD - 502 meter. The objectives of this study were: (i) to determine if soil mineral N levels could be used to predict optimum N rates under a single spring N application regime, (ii) to evaluate GS 25 tiller counts and GS 30 plant tissue tests, and GS 30 SPAD - 502 readings and leaf thickness measurements as predictors of optimum N rates at GS 25 and GS 30, respectively.

MATERIALS AND METHODS

Experimental sites, years, locations, barley varieties, and soil types were identical to the companion paper and are summarized in Table 1. Fertilizer N treatments, rates, and schedules were also identical.

Composite soil sample cores were taken at GS 25 on each site at interval depths of 15, 30, 60, and 90 cm prior to GS 25 N applications. The samples were dried, ground, and extracted with 2M KCL (Keeney and Nelson, 1982), then centrifuged. Nitrate content of the extract was determined with a Lachat automated ion analyzer which quantitatively reduces the nitrate to nitrite via cadmium reduction. The nitrite was then analyzed colorimetrically using Quikchem Method No. 12-107-04-1-B (Lachat Instruments, Milwaukee, WI.). Ammonium levels were determined with the same instrument using the
salicylate method, Quikchem method No. 12-107-06-2-A. Nitrate and ammonium contents of the soil samples were converted to kg mineral N ha⁻¹ using average bulk density measurements of each soil series.

In 1995, average tiller density at each location was determined by counting all tillers with two or more fully developed leaves from 8 random 1m row-lengths per site, and computing tiller number m⁻² based on average row width measurements taken from the specific site.

Plant tissue samples were taken at each location at GS 30. One plot from each GS 25 N rate, for each replication, was sampled by removing all above ground tissue from two 0.9 m row lengths from each plot. The samples were dried and ground to pass a 40 mesh sieve. Samples were then bottle ground and mixed by sealing tissue in cylindrical glass bottles with stainless steel rods of various diameters. The bottles were rotated horizontally on a conveyor belt for 12 hours. Samples were then redried and analyzed by micro-Kjehldahl analysis on a Lachat automated ion analyzer, Quik Chem Method No. 13-107-06-2-B. Eight SPAD - 502 chlorophyll meter readings were also taken at GS 30 from each GS 25 treatment, and treatment averages computed for each site. In 1994-1995, leaf thickness measurements were made on each leaf subjected to SPAD meter analysis using a digital machinist caliper.
All plots were rated for lodging at physiologically maturity using the Belgium scale (Moes and Stobbe, 1991), and harvested with a Hege 140 plot combine. Wet grain yields were measured and moisture readings taken using a Dickey John Grain Analysis Computer. Yields were adjusted to 135 g kg⁻¹ moisture content.

Optimum GS 25 and GS 30 N rates, from Table 2 and Table 3, were regressed against several predictor variables: GS 25 optimum N rates vs. GS 25 tiller density, GS 30 optimum N rates vs. plant tissue N content, SPAD - 502 meter readings, and SPAD readings plus leaf thickness measurements. Optimum GS 25 N rates were also regressed against GS 25 mineral N levels for a single spring rate prediction. All statistical computations were performed using SAS (SAS Institute, Cary, NC) and Sigma Plot software (Jandel Scientific, San Rafael, CA).

RESULTS AND DISCUSSION

Tiller counts were taken at locations 1 through 9 in 1995, and regressed against optimum GS 25 N rates given in Table 4. The results of this relationship are shown in Figure 5. The data from locations 5 and 8 were definite outliers from the relationship in Figure 5 and were not included in the summary regression relationship. Plants at location 5 were severely drought stressed and tiller growth was reduced. Location 8 retained high levels of residual N as indicated by tissue N content and tiller counts over 1900 tillers m⁻².
Figure 5. Optimum GS 25 N rate vs. average tiller density 1995.

\[ y = 147.8 - 0.068 \text{ (tiller m}^{-2}\text{)} \]

\[ r^2 = 0.67 \]
However economic analysis indicated that 50 kg N ha\(^{-1}\) were required to optimize yields at location 8. The relationship between tiller density and optimum GS 25 N rate was good (r\(^2\) = 0.67), however these results should be viewed with caution. Climatically, 1994-1995 was an atypical year, with adequate fall precipitation and mild winter conditions encouraging fall-winter tiller development. Prior work with winter wheat in Virginia (Scharf and Alley, 1993) identified a critical tiller density at GS 25 of 1000 tillers m\(^{-2}\) above which no economic response to applied GS 25 N was expected. Although barley tiller density may average higher than wheat, a critical GS 25 barley tiller density of 2000 tillers m\(^{-2}\) is suprising. Increased barley tillering rate would be expected since barley matures faster than winter wheat, however it would not be prudent to assume that the 1994-1995 tiller counts are indicative of normal barley tillering since this season was unusual.

Cumulative nitrate N and mineral N (NO\(_3\) and NH\(_4\)) were regressed against optimum GS 25 N rates determined from the least squares response surfaces summarized in Table 4, for all 1993-1994 and 1994-1995 locations except location 12, at which reliable soil samples were not available. Soil N levels were not useful in predicting optimum GS 25 N rates. The regression results of optimum GS 25 N rate predictor variables are summarized in Table 5.

Percentage of N in plant tissue related well to optimum GS 30 N rates in 1992-1993 and 1993-1994. The data from these years, graphed in Fig. 6a, indicate a critical level
Table 5. Regression relationships between optimum GS 25 N rates and potential predictor variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Regression equation</th>
<th>$r^2$</th>
<th>P- value</th>
</tr>
</thead>
<tbody>
<tr>
<td>tiller density</td>
<td>$y = 147.8 - 0.068(\text{tiller m}^{-2})$</td>
<td>0.67</td>
<td>0.03</td>
</tr>
<tr>
<td>nitrate to 30 cm</td>
<td>---</td>
<td>0.01</td>
<td>NS</td>
</tr>
<tr>
<td>nitrate to 60 cm</td>
<td>---</td>
<td>0.19</td>
<td>NS</td>
</tr>
<tr>
<td>mineral N$^\dagger$ to 30 cm</td>
<td>---</td>
<td>0.11</td>
<td>NS</td>
</tr>
<tr>
<td>mineral N to 60 cm</td>
<td>---</td>
<td>0.05</td>
<td>NS</td>
</tr>
</tbody>
</table>

$^\dagger$ mineral N = nitrate + ammonium
Fig. 6. Optimum GS 30 N rates vs % N in barley tissue at GS 30.

of approximately 3.5 % N in plant tissue, above which no economic response to applied GS 30 N would be expected. When combined with 1994-1995 data however, the relationship between GS 30 optimum N rates and %N in tissue changed significantly, Fig. 6b. The slope of the regression line changed substantially, and plotted data exhibited much more scatter around the regression line. Some sites in 1994-1995 with plant tissue N approaching levels of 4.0% required up to 70 kg ha\(^{-1}\) of GS 30 applied N to optimize yields. More importantly, the combined data suggest a critical GS 30 tissue N level of approximately 4.0%, and the data scatter lowered the \(r^2\) value to 0.45, greatly reducing the accuracy of this relationship as a predictor of spring N rates. The dry early spring of 1995 allowed barley plants to utilize significantly more N than in prior seasons, without suffering yield reductions due to lodging. The relationship derived from the 1992-1993 and 1993-1994 data should be a more accurate predictor of optimum GS 30 N rates in more typical seasons.

SPAD-502 chlorophyll meter readings taken in 1992-1993 and 1993-1994 were not useful in predicting optimum GS 30 N rates, on either an individual or combined year basis. In 1994-1995, SPAD meter values alone and combined with leaf thickness measurements were evaluated as predictors of optimum GS 30 N rates. Although climatic departure of the 1994-1995 season from the prior two seasons has been discussed, we thought it useful to compare all GS 30 N rate predictor values during 1994-1995 as possible future N rate predictors. Data from locations 5 and 8 were disregarded in these comparisons since, as previously discussed, these locations exhibited unusual responses to
applied N. The 1994-1995 SPAD readings regressed against optimum GS 30 N rates are shown in Figure 7. This model does not explain a very high percentage of the variation ($r^2 = 0.34$), however, the regression response is significant ($p = 0.003$) indicating that SPAD values do describe a portion of the GS 30 response to applied N. In Figure 8 leaf thickness was added as an additional variable to the regression model as a possible predictor of GS 30 applied N. This did improve the ability of the SPAD - 502 meter to predict applied GS 30 N, but still did not describe the majority of the variation ($r^2 = 0.44$).

The statistical results of the GS 30 N predictor variables for 1994-1995 are summarized in Table 6. Though 1994-1995 was an atypical season, the SPAD meter plus leaf thickness values equalled the tissue N test in predicting GS 30 N rates in this season. It would not be prudent, however, to include these results in a recommendation system, since this season was a climatic anomaly, and the correlation is not strong enough to conclude a solid predictive relationship between SPAD readings and leaf thickness versus optimum GS 30 N rates. SPAD readings were regressed against % N in tissue to test the possibility of using the SPAD meter as a proxy for estimating GS 30 N requirements. The regression was significant but the correlation of these variables was poor ($r^2 = 0.25$).

Scharf and Alley (1993) evaluated the economics of N use with various predictive models on winter wheat using least squares estimated profit response surfaces generated for various experimental sites. The studies were done to determine if N recommendations
Fig. 7. Optimum GS 30 N rate vs. GS 30 SPAD values for selected sites in 1994-1995.
$Z = 374.1 - 10.9(\text{SPAD}) + 554(\text{thickness})$

$r^2 = 0.44$

Fig. 8. Optimum GS 30 N rate vs. SPAD values and leaf thickness for selected sites in 1994-1995.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Regression equation</th>
<th>$r^2$</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>% N in plant tissue</td>
<td>$y = 184 - 41(% \text{ N in tissue})$</td>
<td>0.42</td>
<td>0.001</td>
</tr>
<tr>
<td>SPAD values</td>
<td>$y = 408 - 8.3(\text{SPAD reading})$</td>
<td>0.34</td>
<td>0.003</td>
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based on tiller density and GS 30 tissue tests generated superior economic returns versus traditional single spring N rate application systems. The economic response surfaces from the previous chapter were used to evaluate the predictor variables for winter barley. Returns for each predictor model versus traditional N management practices are summarized in Tables 7 and 8. In Table 7, a homogenous single application regime, a homogenous split application regime, and a homogenous GS 25 N rate plus GS 30 tissue test based model are compared for the 1992-1993 and 1993-1994 season. Locations 17 and 18 were not included since reliable tissue samples were not available for those sites. The average economic return over 9 sites did not differ significantly between the three separate management practices. Locations 10, 19, and 20 however, required substantially less GS 30 N to optimize yields compared to other locations. Location 10 required 100 kg N ha\(^{-1}\) at GS 25 to maximize returns ha\(^{-1}\), indicating a need for predicting optimum GS 25 N rates. Locations 19 and 20 however, required no GS 30 applied N to optimize yields, thus the tissue test based system proved superior in identifying non-responsive sites to GS 30 applied N; returns per hectare were $25 ha\(^{-1}\) and $53 ha\(^{-1}\) greater than traditional management systems. Though average return did not differ between different management practices, several individual locations did benefit from GS 30 tissue tests.

In Table 8, the two traditional N management systems were compared with tiller counts to predict optimum GS 25 and either GS 30 tissue N levels or SPAD plus leaf thickness values to predict subsequent GS 30 N rates for the 1994-1995 data only. The

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averages: 183 198 205 64 55

\(^{1}\)Estimated profit calculations based on grain price of $0.09 kg\(^{-1}\), applied N cost of $0.48 kg\(^{-1}\), and production costs of $371.00 ha\(^{-1}\).
Table 8. Estimated profit\(^1\) as a function of different spring N management practices during 1994-1995.

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\(^{1}\)Estimated profit calculations based on grain price of $0.09 kg\(^{-1}\), applied N cost of $0.48 kg\(^{-1}\), and production costs of $371.00 ha\(^{-1}\).
single spring N application system was economically inferior to the split application programs which returned on average $27 \text{ ha}^{-1}$ more. Barley plants at location 5 were severely drought stressed and did not respond to spring N applications. Location 8 had high levels of residual N and although yields were high, no significant response to applied spring N was observed. When locations 5 and 8 were disregarded, the return of the split-N application models over the single application practice increased to approximately $70 \text{ ha}^{-1}$. The negative economic returns from location 6 were also due to yield loss from moisture stress. Neither GS 30 tissue or GS 30 SPAD readings plus leaf thickness based N rates, performed significantly better than the homogenous split-N regime. The GS 30 tissue N levels versus GS 30 optimum N rates in 1994-1995 lacked the statistical power of results obtained in the previous two experimental seasons. SPAD readings coupled with leaf thickness values did improve the chlorophyll meter's ability to predict optimum GS 30 N rates, however this model still did not perform significantly better than 1994-1995 tissue tests.

Sites at which residual N is expected, could benefit economically from methods to determine winter barley N status and predict spring N application rates. Tiller counts at GS 25 appear to be the most powerful predictor of optimum GS 25 N rates. These experiments, unfortunately, evaluated tiller density in a climatically atypical season, therefore, results from this year should be viewed with caution. Tiller counts can probably be used to determine early spring N needs of winter barley, but this method should be evaluated over more typical growing seasons before implementation. The 1992-1993,
1993-1994 data relating % tissue N to optimum GS 30 N rates appear to be the best prediction of GS 30 N rates in a split-application regime. In typical seasons, 3.5% N or above measured in barley tissue at GS 30 indicates that no economic response to applied N will occur. Split spring-N applications will generally produce a higher economic return than single spring-N applications. Therefore, GS 30 tissue testing should probably be coupled with a reliable GS 25 tiller density based N rate to optimize barley yields. SPAD-502 chlorophyll meter readings plus leaf thickness measurements possibly offer a quick estimate of plant N status but should be evaluated during a more typical growing season.
REFERENCES


Chapter IV

Summary and Conclusions

Winter barley production in the mid-Atlantic region occupies a substantial amount of arable land. New barley cultivars have the capacity for much greater yields than traditional varieties. Nutrient requirements, particularly nitrogen, will increase as grain yields ha\(^{-1}\) increase. Winter and spring precipitation in this humid region increases the potential for N loss through leaching, elevating environmental concerns of N loading to surface and ground waters. Also yields can be reduced when N is lost from the root zone. The traditional N management practice for winter barley consists of a small application at planting with a single subsequent spring N application. Nitrogen use would be optimized if the rate and timing of applied fertilizer N were matched more closely with plant requirements.

Prior work with winter wheat in Virginia indicated an increase of spring N uptake at GS 25 and GS 30. The current N uptake study with winter barley indicated a similar response. An increase in N uptake was observed slightly prior to GS 25 and peak uptake occurred during the stem extension period following GS 30. N applications, if required, would be more effectively utilized if timed to coincide with these growth stages.

Barley N rate and timing experiments over three seasons were used to evaluate
grain yield response to different N applications split between GS 25 and GS 30. The majority of locations were responsive to GS 30 N applications confirming the need to delay a portion or all the applied N. High yields were measured at several locations that received no applied spring N, indicating that residual N can persist through winter and early spring at levels which impact grain yields.

Optimum GS 25 and GS 30 N rates, determined for each location, indicated the amount of applied N required to maximize the economic return for that respective site. Optimum N rates varied considerably between sites and years, thus development of site-specific methods to optimize N rates are needed.

Soil nitrate and ammonium levels and GS 25 tiller densities were evaluated as predictors of optimum GS 25 N rates, both in a single and split spring N application system. Soil N levels were not useful in determining optimum GS 25 N rates. Tiller density was a good predictor of optimum N rates in a split N application system, however, this variable was evaluated in a climatically unusual season. Tiller density appears to be the best GS 25 optimum N rate predictor but should be studied further before recommending its use in a production system.

Whole plant tissue samples, SPAD-502 chlorophyll meter readings, and SPAD-502 readings plus leaf thickness measurements were evaluated at GS 30 as possible GS 30
optimum N rate predictors. Percent N in plant tissue consistently was the best overall estimate of GS 30 plant N status. However, when results from the first two years of experiments were combined with the third season's data, the relationship between % N in tissue and optimum N rates changed substantially. Since the third season was climatically atypical we decided that the final year's data should be disregarded in a recommendation system. SPAD readings were not useful in predicting optimum GS 30 N rates. Leaf thickness measurements were coupled with SPAD readings in the last experimental season only, thus this system should be evaluated further over more normal conditions.

Winter barley responds positively to N applications where GS 30 N is inadequate. High grain yields from some sites receiving no spring N indicates the presence of residual N which contributes significantly to grain yields. Economic returns are maximized if required N is split applied at GS 25 and GS 30. The best optimum GS 30 N rate predictor is % N in plant tissue at GS 30. Early spring tiller density appears to be the best indicator of optimum GS 25 N rates, however evaluation of this relationship over a more normal season is required.
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APPENDIX B

TREATMENT MEAN YIELDS, TEST WEIGHTS

AND LODGING INDICES
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\(\dagger\)GS 25 = Zadoks growth stage 25 (spring greenup)  
GS 30 = Zadoks growth stage 30 (pre-jointing)
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\(^{\dagger}\)GS 25 = Zadoks growth stage 25 (spring greenup)  
GS 30 = Zadoks growth stage 30 (pre-jointing)
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GS 30 = Zadoks growth stage 30 (pre-jointing)
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GS 30 = Zadoks growth stage 30 (pre-jointing)
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\(^t\)GS 25 = Zadoks growth stage 25 (spring greenup)
GS 30 = Zadoks growth stage 30 (pre-jointing)
Treatment mean yields, test weights, and lodging indices at location 7.

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\(^t\)GS 25 = Zadoks growth stage 25 (spring greenup) 
GS 30 = Zadoks growth stage 30 (pre-jointing)
### Treatment mean yields, test weights, and lodging indices at location 8.

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GS 30 = Zadoks growth stage 30 (pre-jointing)
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*GS 30 = Zadoks growth stage 30 (pre-jointing)*
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GS 30 = Zadoks growth stage 30 (pre-jointing)
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GS 30 = Zadoks growth stage 30 (pre-jointing)
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GS 30 = Zadoks growth stage 30 (pre-jointing)
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†GS 25 = Zadoks growth stage 25 (spring greenup)
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*GS 25 = Zadoks growth stage 25 (spring greenup)*
*GS 30 = Zadoks growth stage 30 (pre-jointing)*
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\(^\dagger\)GS 25 = Zadoks growth stage 25 (spring greenup)
GS 30 = Zadoks growth stage 30 (pre-jointing)
APPENDIX C

SOIL MINERAL N LEVELS MEASURED IN

LATE JANUARY - EARLY FEBRUARY
Soil mineral N measured in late January - early February

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¹NA = data not available
APPENDIX D

BARLEY YIELD RESPONSE TO GS 30 N

APPLICATIONS FOR EACH GS 25 N RATE
Grain yield (kg ha$^{-1}$) vs. N (kg ha$^{-1}$) applied at GS 30

**Location 11**

- N at GS 25
  - 0 kg N ha$^{-1}$ (●)
  - 34 kg N ha$^{-1}$ (□)
  - 68 kg N ha$^{-1}$ (▼)
  - 102 kg N ha$^{-1}$ (◆)

N (kg ha$^{-1}$) applied at GS 30
Grain Yield (kg ha⁻¹) vs. N (kg ha⁻¹) applied at GS 30 for Location 18.

- 0 kg N ha⁻¹
- 30 kg N ha⁻¹
- 60 kg N ha⁻¹
- 90 kg N ha⁻¹

N at GS 25
APPENDIX E

RESPONSE SURFACES DESCRIBING ESTIMATED PROFIT AS A FUNCTION OF N APPLICATION RATE AT GS 25 AND GS 30
Equations for estimated profit ($ ha\(^{-1}\)) quadratic response surfaces (N rates in kg ha\(^{-1}\)).

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Location 9

N Applied at GS 25 (kg ha⁻¹)

N Applied at GS 30 (kg ha⁻¹)

Dollars ha⁻¹
APPENDIX F

GS 30 TISSUE N CONCENTRATION, SPAD METER READINGS,
AND LEAF THICKNESS VALUES FOR EACH LOCATION
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† Tissue data not available for locations 17 and 18
GS 30 tissue N concentration, SPAD meter readings, and leaf thickness values for each location.

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Vita

The author was born in Burlington, North Carolina in 1957. At six months of age his family returned to Tazewell, Virginia, where he grew up on the family beef cattle and sheep farm. After graduating from Tazewell High School in 1975, he enrolled at Virginia Tech as an undergraduate in the Department of Animal Science. After receiving his Bachelor of Science degree in Animal Science in the spring of 1979, he worked for numerous farm supply firms in Southwest Virginia, including Southern States Cooperative, Inc., Christiansburg Fuel and Supply, Inc., and New River Farm Center. In the fall of 1993 he enrolled as a graduate student in the Crop and Soil Environmental Science department in pursuit of a Master of Science degree, under the direction of Dr. Mark Alley.