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INFLUENCE OF NITROGEN APPLICATION RATE ON
SUGARBEET (BETA VULGARIS L.) YIELD AND QUALITY
ALONG WITH WEED EMERGENCE AND GROWTH

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Amy Emma Guza

has been accepted towards fulfillment
of the requirements for the

M.S. degree in Crop and Soil Sciences

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INFLUENCE OF NITROGEN APPLICATION RATE ON SUGARBEET (*Beta vulgaris* L.) YIELD AND QUALITY ALONG WITH WEED EMERGENCE AND GROWTH

By

Amy Emma Guza

A THESIS

**Submitted to
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ABSTRACT

INFLUENCE OF NITROGEN APPLICATION RATE ON SUGARBEET (*Beta vulgaris* L.) YIELD AND QUALITY ALONG WITH WEED EMERGENCE AND GROWTH

By

Amy Emma Guza

Field studies were conducted to determine optimum nitrogen (N) application rates for sugarbeet (*Beta vulgaris* L.). Linear plateau, quadratic plateau, and quadratic models were used to determine optimum N application rates based on yield, grower payment, recoverable white sucrose (RWSA), and return. Economic optimum N rates based on grower payment and RWSA are insensitive to changes in sugar and N prices. Based on economic return, optimum N rates within a range of 135 kg N ha⁻¹ plus or minus 15 kg N ha⁻¹ was sufficient for sugarbeet production. Three out of 14 sugarbeet field sites were non-responsive to N fertilizer. In two of three non-responsive sites, OM was greater than 4%; suggesting that organic matter (OM) may assist in predicting non-responsive sites.

Field and greenhouse studies were conducted to investigate the effect of preplant broadcast incorporated urea ammonium nitrate (UAN 28%) on early season weed emergence and growth. Emergence of common lambsquarters and ladythumb smartweed increased as N increased in the early seeding dates in 2003 and 2004. Emergence of giant foxtail increased as available N increased in the early N application dates in 2003 and 2004. Total weed biomass increased as available N increased at all weed seeding dates in 2003 and in two of three seeding dates in 2004. Reducing available N in the weed germination and rooting zone will reduce weed emergence and the growth and competitiveness of weeds in sugarbeets.

This thesis is dedicated to my grandma Guza. She has been an inspiration to me through her love and compassion whether I lived next door or hours away.

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KEY TO SYMBOLS OR ABBREVIATIONS

ABUTH	Velvetleaf
AMARE	Redroot pigweed
ANOVA	Analysis of variance
ANST	Amino sugar-N test
CHEAL	common lambsquarters
CJP	Clear juice purity
EONR	Economic optimum N rate
INST	Illinois nitrogen soil test
OM	Organic matter
PEONR	Payment economic optimum N rate
POLPY	Ladysthumb smartweed
PPNT	Preplant nitrate test
PSNT	Presidedress nitrate test
R^2	Coefficient of determination
REONR	RWSA economic optimum N rate
RONR	RWSA optimum N rate
RWSA	Recoverable white sucrose
SAS	Statistical Analysis System
SETFA	Giant foxtail
VLFR	Very low fluence response
YEONR	Yield economic optimum N rate
YONR	Yield optimum N rate
UAN	Urea ammonium nitrate

CHAPTER 1

USING DIAGNOSTIC SOIL TESTS TO DETERMINE THE OPTIMUM RATE OF NITROGEN APPLICATION FOR SUGARBEET (*Beta vulgaris* L.)

INTRODUCTION

Nitrogen (N) recommendations for sugarbeet (*Beta vulgaris* L.) need reassessment for current crop production practices. In the past, Michigan growers typically planted sugarbeets after dry beans (*Phaseolus vulgaris* L.); however, as dry bean acres decline (Kleweno and Matthews, 2003), more growers are planting sugarbeet after corn (*Zea mays* L.). Current N recommendations for sugarbeet in Michigan are based on yield goal and previous crop (Warncke et al., 2004). With respect to these recommendations, many sugarbeet fields are over fertilized with N because the recommendations lack consideration for soil N. A soil test that can quantify the amount of N that is available at the beginning of the growing season and/or the amount of N that will become available to the sugarbeet crop during the growing season may assist growers in making N management decisions that maximize their payments.

Sugarbeet yield is important to Michigan growers because yield with an adjustment for sugar content is the basis for grower payments. However, Michigan Sugar Company is investigating potential changes in grower payments from being weighted towards yield (amount of sugarbeets produced) to a payment that focuses more on quality (amount of sugar produced). In other regions where sugarbeets are grown, grower payment is based on recoverable white sucrose per acre (RWSA) (Adams et al., 1983; Franzen, 2003), which is

defined as the actual amount of raw sugar produced for the consumer. RWSA is important because it encompasses sugar content, clear juice purity (CJP), and yield. A grower may focus N applications to produce a high yielding crop, but sugar content and CJP may be reduced. Sugarbeets with low sugar content and CJP reduce the efficiency of the factory in extracting sugar. Therefore, growers should apply N to achieve not only optimum yields, but also greatest sugar content and CJP. If Michigan grower payments are weighted more towards the amount of actual sugar produced (RWSA), sugarbeet producers may be more likely to adjust their N application rates to optimize RWSA, not yield.

Physiology and Nitrogen Uptake

Nitrogen is the most important nutrient supplied to sugarbeet in fertilizers because few mineral soils contain sufficient N in available form as nitrate (NO_3^-) or ammonium (NH_4^+), for maximum growth (Draycott, 1996). During the growing season, sugarbeets have a rapid initial phase of N uptake followed by a phase of either slower but maintained uptake or no further uptake (Armstrong et al., 1986). The rapid initial phase of uptake is where the greatest amount of N must be available to meet crop demand. Typically, this phase begins when sugarbeet plants have four to five leaves and diminishes following canopy closure. Nitrogen benefits the crop during this growing period because N increases leaf expansion and leaf area, and subsequently increases the amount of solar radiation intercepted by the leaves (Milford et al., 1985b). In contrast, too little N retards

leaf growth (Milford et al., 1988) and thereby reduces intercepted solar radiation and yield.

Sugarbeet uses N preferentially from the upper 0.30 m of soil; however, the crop can recover N from depths greater than 1.35 m (Zinati et al., 2001). Late in the growing season, N is needed to sustain the growth of storage roots and new leaves. Ideally, the crop obtains late season N as it is remobilized during senescence of older leaves. If N remains in the soil because of over fertilization or late season mineralization of organic N, sugarbeets will preferentially use soil N over N remobilized within the plant. Because of this preference for soil N, N can be taken up in excess of what is required and ultimately results in reduced sugar content and CJP. When CJP decreases, sugar extraction becomes more difficult. This is why some sugar companies base grower payments on sugar and impurities. For example, when the N supply during late summer and autumn is abundant, the crop can take up over 400 kg N ha⁻¹ (Draycott, 1996). This luxury consumption results in less N mobilized from older leaves, the older leaves are retained longer, and large, late-formed leaves are produced. When soil is over fertilized with N, sugarbeet plants partition biomass mainly to shoot growth, and as a result, root yield and sugar content decrease.

As with other crops, foliage color in sugarbeet changes in response to N supply. In other crops where foliage determines yield; there is a direct relationship between the N content of the crop (the greenness of the crop) and yield (Scott and Jaggard, 1993). In contrast, in sugarbeet, there is no direct

relationship between N uptake, as evidenced by the greenness of the foliage, and sugar yield. For instance, Lamb et al. (2001) stated that sugarbeet quality increased when N deficiency occurred six weeks prior to harvest.

In the United Kingdom, it is thought that a sugarbeet crop needs to take up a total of approximately 200 kg ha⁻¹ of fertilizer plus soil N to maximize yield and sugar quality. However, few mineral soils provide more than about 60 kg N ha⁻¹ each year as inorganic N remaining from the previous crop or mineralization of organic N (Draycott, 1996). In Minnesota, depending on the depth of sampling, the sum of measured soil NO₃⁻-N plus fertilizer N should be 112 or 135 kg N ha⁻¹ (Lamb et al., 2001). One can then estimate that 65 to 88 kg ha⁻¹ of mineralized soil or residual N is used by a sugarbeet crop in Minnesota, which is slightly more than the 60 kg N ha⁻¹ that Draycott (1996) suggested.

Environmental Issues

Reduced sugar content and increased sugar impurities are two concerns related to the over application of N. Environmental concerns such as N leaching into ground water and gaseous losses of N into the atmosphere can also increase as N rates increase. Roth and Fox (1990) found that reducing N fertilizer and manure application rates to economically optimum levels could minimize the potential for nitrate contamination in water resources. But even at economic optimum fertilizer rates, N can be lost through leaching and denitrification before crop uptake (Armstrong et al., 1986; Roth and Fox, 1990). Other researchers also stress the environmental importance of applying optimal

N to maximize yield and reduce the risk of off-site contamination of ground water (Aldrich, 1984; Draycott, 1993; Hallberg, 1986; Jolley and Pierre, 1977; Keeney, 1986; Magdoff et al., 1990; Oberle and Keeney, 1990; Schepers et al., 1986; Scott and Jaggard, 1993). Though sugarbeet is one of the most effective scavengers of N, leaving only a small concentration of N in the soil at harvest (Draycott, 1993), preplant and early season N applications to sugarbeets are subject to loss depending on the temperature and amount of precipitation that occur after application (Carter et al., 1974; Hallberg, 1986; Jolley and Pierre, 1977; Oberle and Keeney, 1990; Poulson 1994; Sander et al., 1994; Schepers et al., 1986).

Economic Optimum N Rates

In Montana, sugarbeet payments are ultimately based on recoverable sucrose production; therefore, the economically appropriate fertilization rate should be related to the response of recoverable sucrose to fertilizer, not the response of root yield to fertilizer (Adams et al., 1983). Unlike Montana, recoverable sucrose is not currently considered in Michigan grower payments. Michigan payments are based on yield with an adjustment for sugar. If the grower's sugar content is above the company average sugar content, then a premium is paid to the grower; when the grower's sugar content is below the company average, then the grower's payment is reduced.

The economic optimum N rate (EONR) is defined as the quantity of fertilizer that will result in the maximum net return (Black, 1993), and return is

calculated as the payment the grower receives less the cost of N. For most crops, models of yield response to applied N are then fit with mathematical functions that estimate the quantity of fertilizer that returns the maximum net profit given crop and N prices. This is appropriate when yield is the only factor that determines payment. When payment is a combination of several factors, monetary return must be used to assess the EONR with response curves. The yield optimizing N rate (YONR) is the amount of N required to maximize yield without regard to economic return. The recoverable white sucrose optimum N rate (RONR) is the amount of N required to maximize RWSA without regard to economic return.

In studies by Adams et al. (1983) and Carter et al. (1976), where payments are based on RWSA, recoverable sucrose was maximized at N application rates that were less than what was needed to maximize root yield. The RONR was found to be approximately 35 to 90 kg N ha⁻¹ less than YONR (Adams et al., 1983; Carter et al., 1976; Sims, 2004). In these instances, it would be economically favorable to apply less N (saving on N cost) and optimize RWSA. The EONR, in this case, would be less than RONR because it would take into account the cost of N. In any growing region, sugarbeet N recommendations should be focused on creating the greatest return. How this is achieved is dependent upon how many factors are involved in the payment formula.

Nitrogen Recommendations for Sugarbeet

Nitrogen fertilizer recommendations should consider all potential sources of available N, as well as crop sequences, soil properties, fertilizer management, and climatic effects to estimate crop fertilizer N need (Carter et al., 1976; Meisinger, 1984). The most widely used method of recommending N is to use a factor multiplied by the expected yield, which ignores any variability in available soil N (Blumenthal, 2002; Carter et al., 1976; Mortvedt et al., 1996; Warncke et al., 2004). If the estimated yield potential is too high, or root yield is limited because of insect damage, disease, poor stands, other nutrient deficiencies, or adverse climatic factors, then the recommended N rate will be greater than necessary, may reduce the amount of sucrose produced (Carter et al., 1976), and subsequently, the net return from applying N.

In some soils in the upper Midwest in United States, large amounts of residual N are present, and sugar yield is maximized without additional fertilizer (Winter, 1984). In some situations, only small amounts of additional fertilizer can cause a rapid decline in sugar percentage by increasing water retention in the tap root and CJP by increasing the concentration of amino compounds caused by excessive uptake of nitrate late in the season (Winter, 1984). Broadbent (1984) and Stanford (1982) reported that in many cases, mineralizable N is sufficient to supply a considerable portion of the crop need.

Sugarbeet N recommendations are complex and vary among the different sugarbeet production regions. Michigan State University fertilizer N recommendations for sugarbeet are formulated by multiplying the yield goal by 2

kg N metric ton⁻¹, and if corn was the previous crop, then an additional 34 kg N ha⁻¹ is suggested (Warncke et al., 2004). The adjustment for corn as a previous crop was made because most research on which N recommendations were based was conducted in fields where dry bean was the previous crop. Additionally, Christenson and Butt (1998) found that more N was needed after corn to offset the legume N credit that was built into the recommendations. Some Michigan growers have also observed that more N was needed when corn was the previous crop compared to a previous bean crop.

Sugarbeet N recommendations in Nebraska and Colorado are based on yield goal, but N credits are given based on soil parameters (Blumenthal, 2002; Mortvedt et al., 1996). For example, Blumenthal (2002) and Mortvedt et al. (1996) include organic matter and residual soil N.

In other sugarbeet growing regions, yield goal is omitted from the N recommendations. In these instances, a maximum N application rate is suggested, and N credits are subtracted from the suggested rate based on soil tests. The University of Minnesota (Lamb et al., 2001) and North Dakota State University (Franzen, 2003) recommend a total of 112 kg N ha⁻¹; this includes soil NO₃⁻-N measured in the top 0.60 m of soil plus fertilizer N. When soil NO₃⁻-N is measured to a depth of 1.2 m, the sum of soil NO₃⁻-N plus fertilizer N is suggested to be 135 kg N ha⁻¹ in Minnesota (Lamb et al., 2001) and 146 kg N ha⁻¹ in North Dakota (Franzen, 2003). In both Minnesota and North Dakota, deeper sampling is encouraged because sugarbeets can recover N at deeper depths, and because this region has less precipitation than Michigan, there is

less N lost from the soil profile over winter. The climate is drier in the winter and spring in Nebraska, Colorado, Minnesota, and North Dakota where more residual soil N is found. Therefore, use of residual soil N in N recommendations is more favorable in these states compared to Michigan because Michigan has a wetter climate where little residual soil N is found in the spring.

Nitrogen Soil Tests

Nutrient requirements for optimal yields are commonly determined by soil analysis (Draycott, 1993). Nitrogen applications for sugarbeet need to be planned to increase the early growth of the leaf canopy and to maintain it throughout the growing season until harvest, but to avoid excess N that will decrease root quality (Draycott, 1996). Nitrogen soil tests have been developed to refine N recommendations for corn; however, tests such as the preplant nitrate test (PPNT) and presidedress nitrate test (PSNT) have not been widely investigated for use in sugarbeet production in Michigan. The Illinois nitrogen soil test (INST) has not been investigated for use in any sugarbeet production region in the United States.

Soil Nitrate Testing ,

In Minnesota (Lamb et al., 2001) and North Dakota (Franzen, 2003) N fertilizer recommendations for sugarbeet are based on the PPNT. Soil samples are collected to a depth of 0.60 m (or deeper) in the spring prior to planting to quantify the soil NO_3^- -N concentration. In essence, the PPNT measures residual N from the previous year, which is then used as a N credit that is subtracted from

the maximum N recommendation of 112 kg N ha⁻¹. The PPNT is used in a similar manner for corn (Bundy et al., 1999; Bundy and Malone; 1988; Schmitt and Randall, 1994; Vitosh et al., 1990).

The PPNT was developed for corn N recommendations where the NO₃⁻-N concentration in the surface 0.60 m of soil is measured in the spring prior to planting (Schmitt and Randall, 1994). As with sugarbeet, a residual N credit is determined and often subtracted from the maximum N recommendation (Bundy et al., 1999; Bundy and Malone, 1988; Vitosh et al., 1990).

The PSNT was developed by Magdoff et al. (1984) to provide accurate fertilizer N recommendations for corn that are based on anticipated effects of manure and crop management. With the PSNT, NO₃⁻-N is measured in a 0.30 m soil sample collected just prior to the period of rapid corn growth (at corn height between 0.15 to 0.30 m). Nitrogen fertilizer is then applied to make up the difference between what it is believed the soil can supply and the recommended N rate (Magdoff, 1991).

The PSNT is effective for corn production. However, sugarbeet is a high maintenance crop that requires aggressive management in the spring. Growers have little time to soil sample, await PSNT results, and apply N fertilizer. If they use the PSNT, growers may risk applying N later than the optimum timing for sugarbeet, which is at the two to four leaf stage, because of delayed testing and unfavorable weather conditions for application. The PSNT is not currently used in deriving sugarbeet N recommendations in any sugarbeet growing region.

Illinois Nitrogen Soil Test (INST)

Soil testing for nitrate using the PPNT and the PSNT are considered the best options for identifying sites where corn yield does not respond to additional N fertilization (Khan et al., 2001). Because the PPNT and PSNT do not always predict fields where corn does not respond to fertilizer N, the INST was developed.

The INST is a modified version of the amino sugar-N test (ASNT). Khan et al. (2001) reported that the ASNT differentiated sites that were responsive to N fertilization from those that were non-responsive to N fertilization. Non-responsive soils had a greater quantity of amino sugar-N, and mineralization was accompanied by a net decrease in amino sugar-N (Khan et al., 2001). The ANST and INST will also recover exchangeable NH_4 . Thus, results of the ANST or INST may be influenced by recent fertilizer or manure applications (Khan et al., 2001).

It has been suggested for corn production that a soil sample collected to a depth of 0.30 m with an INST value greater than 250 mg N kg^{-1} will be non-responsive to additional N fertilizer (Anonymous, 2002). While the amino sugar-N fraction is a labile source of soil N, it is more stable than an inorganic form such as NO_3^- -N because it is not as susceptible to leaching and other nitrous losses (Sawyer et al., 2003).

The time of soil sampling is less critical with the INST because it is less dependent on N transformations and is less variable than the PPNT or the PSNT (Khan et al., 2001). However, Hoeft et al. (2002) found that INST values were

3.5 to 12.6% greater in the spring compared to fall because of microbial decomposition of crop residues during mild winters. Hoefft et al. (2002) advised that soils should be sampled in the fall after harvest to reduce the risk of a type II error where a responsive soil could be erroneously identified as a non-responsive soil, based on greater INST values from spring sampling.

The ability of the INST to detect sites where corn is non-responsive to N fertilization varies. Sawyer et al. (2003) found the INST to correctly identify corn responsiveness to N at one of seven site years. All seven sites were identified by the INST to be non-responsive sites, when actually; six sites were responsive (type II error). Hoefft et al. (2002) also reported that out of 15 sites, the INST predicted four responsive sites as non-responsive sites. Because the INST can incorrectly identify responsive sites, growers may be reluctant to use the INST to predict sites that are non-responsive to N fertilizer.

The INST may have the ability to predict sugarbeet sites that are non-responsive to N fertilization by establishing a critical threshold value similar to that of corn (250 mg N kg^{-1}). Potentially, this value could be determined for sugarbeet crops in different regions to assist the N recommendations by predicting sites that would be non-responsive to additions of N fertilizer. This is especially important in sugarbeet growing regions where N fertilizer is applied when it is not necessary, and return to the grower would then be reduced because of the cost of the fertilizer that was not needed. During a time when N costs are rising, it is increasingly important to accurately detect sites that do not require N. Therefore, the INST may be a valuable resource to growers to assist

them in maximizing yield and quality of sugar produced and in turn, maximizing their net profit.

OBJECTIVES

The objectives of this study were to: (1) quantify the economic optimum N rate for sugarbeets grown in a sequence with corn, soybean (*Glycine max*, L.), or dry bean, (2) assess the validity of the current sugarbeet N recommendations, and (3) evaluate the INST and other soil tests to predict N responsiveness in sugarbeet.

MATERIALS AND METHODS

Plot Design and Treatments

Five sites each in 2002 and 2003, and four sites in 2004 were selected in the Saginaw Valley and Thumb sugarbeet production regions in Michigan (Table 1.1). Each year, two sites were located at the Saginaw Valley Bean and Beet Farm; one site had a previous crop of corn, and the other had a previous crop of dry beans. The remaining sites were located in sugarbeet grower fields and had previous crops of corn, soybeans, or dry beans (Table 1.2).

Plots were 4.6 m wide and 15.2 m long. Sugarbeet variety Hilleleshög E-17¹ was planted in 2002 and 2003, and Beta 5451² in 2004 in 0.76 m rows at a

¹ Syngenta Seed Co., Longmont, CO

² BetaSeed, Inc. Shakopee, MN

rate of 129,100 seeds ha^{-1} . No starter fertilizer was applied in 2002. In 2003 and 2004, starter fertilizer was applied in all plots at a rate of 150 kg ha^{-1} of 0-15-38 plus 1.5% Mn and 0.2% S. Nitrogen treatments were applied in a randomized complete block design with four replications. Nitrogen rates ranged from 0 to 238 kg ha^{-1} in 34 kg ha^{-1} increments in 2002 and 0 to 225 kg ha^{-1} in 45 kg ha^{-1} increments in 2003 and 2004. All plots received 34 or 45 kg N ha^{-1} as urea at planting with the exception of the control plots (0 kg N ha^{-1} applied). The remaining amount of N, as urea, to complete the treatment was knifed in at sidedress when sugarbeet plants had two to four true leaves. Approximately two months after planting, sugarbeets were thinned to approximately 62,000 plants ha^{-1} in 2002 and approximately 90,400 plants ha^{-1} in 2003 and 2004. Weed and disease control measures were carried out according to normal production practices. Sugarbeets were machine harvested from the middle 9.1 m in each of the center two rows in late October through early November each year. Harvested roots were analyzed for sucrose content and CJP by the Michigan Sugar Company. Planting, sidedress fertilization, and harvest dates are given in Table 1.2.

Soil Sampling

Preplant soil samples were collected to depths of 0 to 0.15, 0 to 0.30, 0.30 to 0.60, and 0.60 to 0.90 m in each replication. All soil samples were air-dried, ground, sieved through a 2 mm sieve, and mixed thoroughly to ensure homogeneity. Dried and ground soil samples were stored in plastic bags.

Organic matter (OM), pH, Olsen-P or Bray 1-P, exchangeable K, Ca, and Mg (Brown, 1998) were measured on the 0 to 0.15 m soil samples. Measured soil fertility parameters along with the soil taxonomic classification for each site are provided in Table 1.3. Samples collected at depths of 0 to 0.30, 0.30 to 0.60, and 0.60 to 0.90 m were analyzed to determine NO_3^- -N (Brown, 1998) and NH_4^+ -N (Keeney and Nelson, 1982). The INST was analyzed on 0 to 0.30 m samples with procedures provided in Appendix A, and details provided in Appendix B.

Statistical Analysis

Equations

The following are equations that were used to calculate parameters prior to data analysis:

RWSA, grower payment and economic return

$$\text{RWSA (kg ha}^{-1}\text{)} = (\text{yield}^1 * ((\text{sucrose content} * 18.4) - 22) * (1 - (60 / (\text{CJP} - 35)))) / 0.4$$

$$\text{Grower payment}^2 (\$ \text{ ha}^{-1}) = \text{yield}^1 * (35 - (35 * (0.0599 * (18.685 - \% \text{ sucrose content}))))$$

$$\text{Economic return}^3 (\$ \text{ ha}^{-1}) = \text{grower payment} - (0.66 * \text{N rate})$$

Relative payment and relative return

Relative payment and relative return are used to assess payment or return across locations. Relative payment for a given location was calculated as the

¹ Yield is expressed in tons of beets produced per acre.

² Grower payment is calculated based on the 2003 Michigan Sugar Company payment formula.

³ Economic return is based on a N cost of \$0.66 kg⁻¹.

payment at each N rate divided by the greatest payment at a given N rate at that location and multiplied by 100. Each location had a relative payment of 100%, and the remaining treatments were less than 100% depending on the payment at each N rate. The other locations were calculated similarly.

$$\text{Relative payment (\%)} = (\text{payment} / \text{greatest payment}) \times 100$$

$$\text{Relative return (\%)} = (\text{return} / \text{greatest return}) \times 100$$

Response of yield and RWSA to N fertilization

Response of yield (or RWSA) to N fertilization was calculated at each location using the optimum and check plot (0 kg N ha⁻¹ applied) yields at that location.

$$\text{Yield Response (\%)} = ((\text{Optimum Yield} - \text{Check Plot Yield}) / \text{Check Plot Yield}) \times 100$$

$$\text{RWSA Response (\%)} = ((\text{Optimum RWSA} - \text{Check Plot RWSA}) / \text{Check Plot RWSA}) \times 100$$

Determination of Optimum N Rates

To determine optimum N rates at each location to maximize yield, RWSA, grower payment, relative payment, and relative return, PROC NLIN in SAS was used to calculate optimum N rates using linear plateau, quadratic plateau, and quadratic models (SAS Institute, 1999). The models for yield, RWSA, grower payment, relative payment, and relative return at each location were chosen based on R² values and graphically, by plotting the data and models to view which model best fit the data. The greater the R² value, the better the model fit

the data. The optimum N rates were located at the join points of the linear plateau and quadratic plateau models and the maximum of the quadratic model. When response models would not converge on the data, ANOVA was used to verify non-responsive sites; in that a nonsignificant ANOVA verified that N rate had no effect on yield.

Economic Optimum N Rates

Economic optimum N rates were determined based on the models chosen for RWSA, payment, and return at each location. The EONR was the point where RWSA and payment most exceeded the total cost of N. The EONR for RWSA or payment was based on the greatest distance between RWSA or payment (based on the model) and the cost of N. If the model that best fit the data was the linear plateau model, then the EONR is equal to the optimum N rate because the greatest distance between the cost of N and the model is at that point. Figure 1.1 illustrates of this concept. If the quadratic plateau or quadratic model best fit the data, then the EONR was calculated using the model parameters, by comparing the tangent of the curve to cost of N (Black, 1993). The EONR is where the tangent of the curve equals the slope of the cost of N (Black, 1993), this is the point at which RWSA or return most exceeds the cost of N.

Economic optimum N rates using the linear plateau model

$$EONR = ONR$$

Economic optimum N rates using quadratic plateau or quadratic models

$$REONR^1 = ((ratio^\dagger - b^\ddagger) / (2 * c^\ddagger))$$

$$PEONR^2 = ((N \text{ cost} - b^\ddagger) / (2 * c^\ddagger))$$

It is important to consider if potential changes in N cost could affect N recommendations in sugarbeet based on the current grower payment formula. Therefore, four N prices of \$0.44, 0.55, 0.66, and 0.77 ha⁻¹ were evaluated to determine if EONR substantially changed with changes in N cost. If grower payment were based on RWSA, different price ratios of the cost of N to the price of sugar as 1:1 (\$0.10 N : \$0.10 sugar), 2:1 (\$0.20 N : \$0.10 sugar), 3:1 (\$0.30 N : \$0.10 sugar), and 4:1 (\$0.40 N : \$0.10 sugar) were used in calculating the EONR to determine if differences in cost of N and price of sugar would affect N recommendations if RWSA were to be used for future grower payments.

When combining data across all sites, EONR is calculated for relative return based on the current payment plan to compensate for large differences in absolute return for various sites. Relative payment is expressed in percentages; therefore, EONR for combined data cannot be calculated using a response model that fits the relative payment data. Thus, relative return is calculated because it factors in the cost of N. The EONR for relative return is the optimum N rate, regardless of the model used (linear plateau, quadratic plateau,

¹ REONR = RWSA Economic Optimum N Rate

² PEONR = Payment Economic Optimum N Rate

[†] The ratio is defined as the cost of N to the price of sugar.

[‡] The letters b and c represent parameters in the model.

or quadratic), because the cost of N is already factored in the calculation.

RESULTS AND DISCUSSION

Determination of Optimum N Rates

For all locations, data showing sugarbeet yield, sugar, CJP, and RWSA are provided in Tables 1.4 through 1.17. Graphical representation of sugarbeet yield, RWSA, and payment at each N rate is provided in Figures 1.2 through 1.15. Tables 1.18 through 1.20 show the response model, model parameters, R^2 values, and the respective optimum N rates for each location to achieve maximum sugarbeet yield, RWSA, and payment. At locations 2002-3, 2002-5 and 2003-3, response models did not fit the data; therefore, sugarbeets on these sites were declared non-responsive to N fertilization.

Optimum N rates for yield, RWSA, and payment at each location were within 20 kg ha⁻¹ at the following locations: 2002-1, 2002-2, 2003-3, 2002-5, 2003-1, 2003-2, 2003-3, 2003-4, and 2004-5 (Table 1.21). At locations 2002-6, 2004-1, and 2004-6, YONR was at least 20 kg ha⁻¹ less than RONR and PONR. While at location 2003-5, YONR was at least 20 kg ha⁻¹ greater than RONR and PONR. At location 2004-2, YONR was 11 kg ha⁻¹ greater than PONR and 14 kg ha⁻¹ less than RONR.

The differences between RONR and PONR were less than or equal to 10 kg ha⁻¹ at all locations except 2003-5, 2004-2, and 2004-6, where the differences were 13, 25, and 13 kg ha⁻¹, respectively (Table 1.21). Unlike past research where RONR was less than YONR (Adams et al., 1983; Carter et al., 1976; and

Sims, 2004), YONR was not always the greatest N rate at a location; the YONR was greatest at five locations (2002-1, 2003-1, 2003-2, 2003-4, and 2003-5), RONR at two locations (2004-1 and 2004-2), and PONR at four locations (2002-2, 2002-6, 2004-5, and 2004-6). At locations 2002-3, 2002-5, and 2003-3, the RONR, PONR, and YONR were 0 kg N ha⁻¹. Therefore, the concern of over fertilization when fertilizing at the YONR may not be as great as anticipated because there are locations where the RONR and PONR exceeded the YONR.

The optimum N rate for the two locations in 2002 and one location in 2003 was 0 kg N ha⁻¹, meaning these sites were non-responsive to additional N fertilizer. Disregarding the non-responsive sites, YONR ranged from 94 to 181 kg N ha⁻¹, RONR ranged from 98 to 167 kg N ha⁻¹, and PONR ranged from 103 to 169 kg N ha⁻¹. Overall, YONR had a larger range than did either RONR or PONR.

Nitrogen recommendations may change if the formula for grower payment changes from being focused on primarily yield with an adjustment for sugar to a quality payment. So it is important to understand if or how PONR and RONR differ. When fertilizing to solely maximize parameters such as yield, RWSA, or payment, cost of N is disregarded.

Determination of Economic Optimum N Rates

Economic optimum N rates based on the current payment formula with a N cost of \$0.66 kg⁻¹ are shown in Table 1.21. If cost of N were to change within the range of \$0.44 kg⁻¹ to \$0.77 kg⁻¹, the maximum difference in optimum N rates

is small (6 kg N ha^{-1}) (Table 1.22). EONR is relatively insensitive to the different prices of N; thus, changes in yield at the EONR for various prices are small (Table 1.22).

Economic optimum N rates for RWSA are important to consider, as potential changes in the payment plan may focus on RWSA. The impact of various N:sugar price ratios on EONRs are minimal. Table 1.21 provides the EONR and associated yield when N:RWSA price ratio is 3:1 (\$0.66 N:\$0.22 sugar). Results from evaluating different price ratios for RWSA ranging from 1:1 to 4:1 are shown in Table 1.23; with the greatest difference in N rates across different price ratios is 14 kg N ha^{-1} . Because the EONR at different price ratios is relatively unaltered, yield is also unaltered (maximum difference is 0.9 Mg ha^{-1}).

A comparison of EONR calculated based on RWSA at a price ratio of 3:1, and payment at a N price of $\$0.66 \text{ kg}^{-1}$ is provided in Table 1.21. Economic N rates for RWSA and payment were within 17 kg N ha^{-1} , with an average difference of 5.4 kg N ha^{-1} . Although the REONRs and PEONRs are similar (within 17 kg N ha^{-1}), the REONRs are less than the PEONRs at 6 of the 14 locations. Because the difference between the N rates for RWSA and payment at each location are relatively small, the difference in yield is also small (within 1 Mg ha^{-1}). Yield may be compromised, but of more importance, return is maximized when fertilizing at the EONR. RWSA could potentially be used to calculate payment without drastic changes to return or N recommendations.

Relative Return

By combining all locations, the locations represent a subset of the entire population. When all locations are combined, the EONR could be determined that reliably fits all the data. By calculating relative return, all locations are placed on the same scale. The optimum N rate of relative return is equal to the EONR. Combining all locations, relative return is shown across N rates in Figure 1.16. Models were fit to this data and are shown in Table 1.24. When all data is included, depending on the model (linear plateau, quadratic plateau, or quadratic), the EONRs for relative return range from 90 kg N ha⁻¹ for the linear plateau model to 160 kg N ha⁻¹ for the quadratic model.

Using all data (Figures 1.16 and 1.17), the EONR, using the linear plateau model, for relative return is 90 kg N ha⁻¹. This model plateaus at 94.1% relative return. With only the responsive sites, the optimum N rate for relative return is 97 kg N ha⁻¹ (linear plateau model); with a plateau at 95.7% relative return (Table 1.24). Despite similarities between N rates with all data and only the responsive sites, the R² value almost doubles when the non-responsive sites are removed from the data set (0.471 versus 0.721). The model does not fit as well when both non-responsive and responsive sites are used to fit the model because the non-responsive sites have a relative return of 100% at low N rates.

Relative return economic optimum N rates differ depending on which model is chosen (linear plateau, quadratic plateau, or quadratic). Using all the data, the linear plateau model is the best fit for the data based on the R² value 0.370 (Table 1.24). Generally, the quadratic plateau and quadratic models have

similar R^2 values (0.358 and 0.360, respectively) (Table 1.24). The linear plateau model also has the lowest EONR (90 kg N ha^{-1}), the quadratic plateau model has an EONR of 135 kg N ha^{-1} , and the quadratic model has the greatest EONR (160 kg N ha^{-1}) (Table 1.24).

If the EONR is based on the models, it is often difficult to pick one model over the other. Because the lowest EONR was with the linear plateau model, the risk of under fertilization may be the greatest with the linear plateau model. To assist in the decision on which N rate is best, the cost associated with under or over fertilization was evaluated (Table 1.28). All three models (linear plateau, quadratic plateau, and quadratic) were evaluated for all locations where soil NO_3^- -N was not considered, and with soil NO_3^- -N values at the 0 to 0.30 m depth and the 0 to 0.60 m depth.

The numbers used to generate Table 1.28 (along with Tables 1.29 and 1.30) were not based on relative return for the current payment plan, but by calculating RWSA response to N at a ratio of 3:1 ($\$0.66 \text{ kg}^{-1} \text{ N} : \$0.22 \text{ kg}^{-1} \text{ sugar}$). Relative return for current payment plan and RWSA response to N values are not the same; however, PONR and RONR are similar; thus, this discrepancy is irrelevant.

The optimum N rate for relative return over all locations, with the mean that was closest to zero (which minimized loss because of under or over fertilization) and the lowest standard deviation (least variability) was 135 kg N ha^{-1} (Table 1.28). If non-responsive sites could be predicted, 135 kg N ha^{-1} remains the optimum N rate.

Adding Preplant Profile Soil Nitrate to N Fertilization Rates

Preplant soil NO_3^- -N values were added to the EONR for RWSA and payment (Table 1.31) to determine if adding residual soil N at different depths would assist in predicting sites that are non-responsive to N. Nitrate-N values for the non-responsive sites were, on average, 22 kg N ha⁻¹ from the 0 to 0.30 m depth, 37 kg N ha⁻¹ from the 0 to 0.60 m depth, and 53 kg N ha⁻¹ from the 0 to 0.90 m depth. These values are less than the average EONR for responsive sites when NO_3^- -N is not added. The preplant profile NO_3^- -N values were unable to predict the non-responsive sites as the values for responsive and non-responsive sites were not drastically different. Sugarbeets on the non-responsive sites were attaining N from other sources than the NO_3^- -N in the top 0.90 m of soil.

Preplant soil N (NO_3^- -N) at depths of 0 to 0.30 m, 0 to 0.60 m, and 0 to 0.90 m was added to N fertilizer rates. These values were plotted with relative return (Figure 1.16) to determine if adding residual NO_3^- -N to the fertilizer N applied would improve the fit of the models with relative return and provide a clear idea of a N rate that could be used for recommendations. When NO_3^- -N was added to fertilizer N, the EONRs increased because the NO_3^- -N values shifted the EONRs to greater values (Tables 1.24 and 1.27). When preplant soil N was added to the N fertilizer rate, the R^2 value increased compared to the R^2 value with the N fertilizer rate alone for all sites. For example, the R^2 value for the linear plateau model for relative return for fertilizer N was 0.370 (Table 1.24) and increased to 0.453 when NO_3^- -N to a depth of 0 to 0.90 m was added to

fertilizer N (Table 1.27). When only responsive sites were considered, the addition of soil NO_3^- -N values did not greatly improve the fit of the response model as evidenced by similar R^2 values. For example, relative return R^2 values for fertilizer N with the linear plateau model (0.639 for N fertilizer only and 0.655 for N fertilizer and NO_3^- -N to a depth of 0 to 0.90 m) (Tables 1.24 and 1.27). Adding soil NO_3^- -N to predict optimum N rates would not improve N recommendations, nor would be economical (Table 1.30).

When soil NO_3^- -N values at the 0 to 0.30 m depth and the 0 to 0.60 m depths were analyzed at different N rates (Table 1.29), the mean and standard deviations were not improved over not sampling, and the cost of soil sampling and analysis, for example, \$13 ha^{-1} for soil sampling to 0.30 m and \$18 ha^{-1} for soil sampling to 0.60 m (\$5 ha^{-1} to analyze each 0.30 m sample and \$8 ha^{-1} for labor) would not be economically feasible compared to the optimum N rate of 135 kg N ha^{-1} without soil sampling.

It is often difficult and time consuming to soil sample to 0.90 m to test for preplant NO_3^- -N in Michigan. The information that could be gained from soil sampling may not be economical, as denitrification and leaching can remove a large portion of residual soil NO_3^- -N from the soil profile prior to planting. Because this method does not predict sites that are non-responsive to N fertilizer, there is a greater risk of over fertilization of these sites.

Model Development for N Recommendations

In an attempt to predict N rates in sugarbeets, another modeling approach was investigated. The model parameters were based on site characteristics (yield and previous crop) and soil properties (OM, INST, total N, total organic carbon, and preplant NO_3^- -N at depths of 0 to 0.30 m, 0 to 0.60 m, and 0 to 0.90 m) that were correlated to REONR and PEONR.

Correlation coefficients were determined for all parameters using PROC CORR in SAS (SAS Institute, 1999) (Table 1.32). Parameters significantly correlated to the RWSA economic optimum N rate (REONR) and payment economic optimum N rate were used as starting points for parameters that may produce a model that can predict economic optimum N rates. (PEONR) were used for determining significant equations for calculating optimum N rates in PROC REG (SAS Institute, 1999).

REONR and PEONR were significantly correlated ($\alpha = 0.10$) to previous crop, OM, INST, and preplant NO_3^- -N at the 0 to 0.30 and 0 to 0.90 m depths (Table 1.32). When the non-responsive sites were removed from the data set, there were no correlations between REONR or PEONR and any of the site parameters or soil properties (Table 1.33). The non-responsive sites were driving the significant relationships, and when removed, the correlations no longer existed. Relationships between OM and PEONR with all data (Figure 1.17a) and without non-responsive data (Figure 1.17b) illustrate the lack of significance when non-responsive sites are removed. Other soil test results,

such as preplant NO_3^- -N (Figure 1.18) and INST show similar trends (Figure 1.19).

The significant correlations prior to removal of the non-responsive values were used in PROC REG to develop an equation using the soil values that were significantly correlated to REONR or PEONR. The process used to analyze models using different parameters is provided in Appendix C. One of the statistically best models included yield and preplant NO_3^- -N (0-0.30 m, 0-0.60 m, and 0.90 m). This model included yield, but it would be difficult to predict the yield at the economic N rate; also, yield was not correlated to REONR ($P = 0.6424$) or PEONR ($P = 0.6465$) (Table 1.32). Other models included too many parameters. For example, to predict REONR, one of the best models included yield, OM, preplant NO_3^- -N (0-0.30 m, 0-0.60 m, and 0-0.90 m), and previous crop. This might be the best model, but it is the least practical because, in Michigan, it is difficult (but not impossible) for soil samples to be collected from a 0 to 0.90 m depth. One of the more practical models to predict REONR included OM and preplant NO_3^- -N (0-0.30 m), but when the non-responsive sites were removed from the data set, this model no longer predicted REONR (Figure 1.20). To predict PEONR, one of the best models included preplant NO_3^- -N at depths of 0-0.30 m, 0-0.60 m, and 0-0.90 m. This also no longer predicted PEONR after the non-responsive sites were removed (Figure 1.21). Therefore, the models that could have been used were unable to predict optimum N rates when non-responsive models were not included in the data set. The non-responsive sites

were driving the relationships between the site parameters and soil properties and the EONR.

Predicting Non-responsive Sites

Because non-responsive sites drive correlations, it may be possible to predict non-responsive sites when using one of the soil parameters where correlations existed for all data, but when non-responsive sites are removed from the data set, the correlation no longer exists (Table 1.33). In order to predict non-responsive sites, it was important to find relationships between soil properties and yield or RWSA. Thus, response of yield and RWSA to applied N was calculated for each location and was plotted against NO_3^- -N from a depth of 0 to 0.30 m (Figure 1.22), total N (Figure 1.23), OM from a depth of 0-0.15 m (Figure 1.24), and INST (Figure 1.25). The Cate-Nelson procedure (Cate and Nelson, 1971) was used to establish critical threshold values for NO_3^- -N from a depth of 0 to 0.30 m, total N, OM, and INST for yield and RWSA response. Typically, the threshold ranges were similar for yield and RWSA response.

For NO_3^- -N and total N, the Cate-Nelson procedure would not separate responsive sites from non-responsive sites, and the threshold ranges were narrow (4.38 to 5.04 mg kg⁻¹ for NO_3^- -N and 0.22 to 0.23% for total N). This is mainly because of large responses (greater than 100%) to N at locations 2004-1 and 2004-6. Organic matter had a critical threshold range of 3.63 to 4.05%, and

INST critical threshold range was 228 to 269 mg kg⁻¹. Both of these soil properties correctly identified two out of three non-responsive sites.

When NO₃⁻-N from a depth of 0 to 0.30 m (Figure 1.26), OM (Figure 1.27), and INST (Figure 1.28) were plotted against YONR and RONR, all three soil properties correctly predicted two out of three non-responsive sites based on critical threshold levels established by the Cate-Nelson procedure. The site that NO₃⁻-N from a depth of 0 to 0.30 m, OM, and INST did not predict was a type II error, not the type I errors reported by Hoefft et al. (2002) and Sawyer et al. (2003). Type I errors that predict responsive sites as being non-responsive result in under fertilization, and are often worse than type II errors that predict sites to be responsive when they are actually non-responsive. The threshold range for NO₃⁻-N was 6.24 to 7.66 mg kg⁻¹, and the critical threshold ranges for OM and INST did not change compared to the Cate-Nelson threshold ranges when plotted against yield and RWSA response (3.63 to 4.05% and 228 to 269 mg kg⁻¹, respectively).

The critical threshold range for the INST (228 to 269 mg kg⁻¹) is similar to the recommendation by the University of Illinois for corn; no N is needed when INST is greater than 250 mg kg⁻¹. Because OM and INST are significantly correlated (P = 0.0483) (Table 1.32), it would be more convenient to use OM to aid in prediction of non-responsive sites over the INST.

It is very difficult to predict sites that would not respond to N fertilizer, and there is no current soil test that can predict 100% of the non-responsive sites. However, OM is the best soil parameter that was evaluated to predict the non-

responsive sites. If OM is greater than 4%, it would be best to be conservative when applying N in sugarbeet; N should be applied such that the risk of over fertilization is minimized. More locations need to be studied to continue to verify this relationship.

Previous Crop and Residue Effects

It was observed in some locations where corn was the previous crop, the response to N at rates of 34 or 45 kg N ha⁻¹ was different from locations where the previous crop was beans. Visual differences were noted at locations that had both a previous crop of corn and soybean. The sugarbeets grown with a previous crop of corn were visually shorter than the sugarbeets with a previous crop of soybean, especially at the lower N rates (locations 2002-1 (Figure 1.2), 2003-1 (Figure 1.7), 2003-4 (Figure 1.10), 2004-1 (Figure 1.12), and 2004-5 (Figure 1.14)). However, not all sugarbeets where corn was the previous crop responded in this manner.

After studying the site information, it was determined that tillage may have interacted on the sugarbeet sites with previous corn crops. Sites that were moldboard plowed (2002-1, 2003-1, 2003-4, 2004-1, and 2004-5) had a low amount of crop residue visible on the soil surface, and sites that were chisel plowed visually had a greater amount of crop residue on the soil surface. Thus, it was important to assess whether yield or RWSA responses differed with the different tillage operations. At a given location, yield response (Figure 1.29a and RWSA response (Figure 1.29b) were similar. For example, at location 2002-1,

the yield response was 69% and the RWSA response was 64%. Most locations were below 80% response, where only two out of the six locations below 80% had large amounts of crop residue. Two locations had yield and RWSA responses above 100%, one had low residue and the other had high residue. A relationship between yield or RWSA response and the amount of residue associated was not related to tillage ($r = 0.23$).

CONCLUSIONS

The current N recommendation in Michigan is 90 to 112 kg N ha⁻¹ assuming a yield goal of 45 to 56 Mg ha⁻¹. Nitrogen recommendations for sugarbeet in Michigan should be adjusted to remove the equation that includes a factor multiplied by yield goal. Instead, values with guidelines should be used to choose a suitable N rate. On average, 135 kg N ha⁻¹ is the economically best rate for sugarbeet production. If a range of N rates is to be considered, it is best to apply 135 kg N ha⁻¹ plus or minus 15 kg N ha⁻¹. If non-responsive sites cannot be predicted, then applying 120 to 135 kg N ha⁻¹ is slightly better than 135 to 150 kg N ha⁻¹ because the 120 kg N ha⁻¹ application rate has a slightly lower standard deviation than 150 kg N ha⁻¹ (Table 1.28). While sugarbeets are sensitive to the over application of N, applying more N is generally less costly (Table 1.28) than under applying N.

For non-responsive sites, applying up to 80 kg N ha⁻¹ does not drastically change relative return. Thus, for sites with OM greater than 4%, a N recommendation of 80 kg N ha⁻¹ would reduce the potential for large economic

losses on soils that do not respond to N, but allows for cases where there may be small responses to N.

Adding preplant profile soil NO_3^- -N to fertilizer N could contribute to making N recommendations in Michigan, but is often not economical and would not aid in predicting non-responsive sites. This is more economical for climates that are drier, like Minnesota, where more residual N is found in the soil profile in the spring.

The Michigan Sugar Company is researching alternative payment plans to be weighted more on sugarbeet quality. EONR for payment is similar to EONR for RWSA. EONR for payment or RWSA are relatively insensitive to changes in the price of N or N:sugar price ratio, respectively; thus, any change made to the payment plan would not have a dramatic effect on sugarbeet N recommendations.

Out of 14 sites over three years, 21% of sugarbeet sites were non-responsive to N fertilizer. Currently, the best way to predict these sites is with OM or INST, even though both tests were only able to predict two out of the three non-responsive sites. Because OM is a routine soil test, using OM would be a more convenient method to identify potentially non-responsive sites. Further validation of the critical threshold range (3.63 to 4.05% OM) between OM and non-responsive sites is needed.

Soil tests like the INST and PPNT are difficult to use for Michigan sugarbeet recommendations. It is also difficult to choose an appropriate model or equation that included soil parameters that were correlated to the EONR.

When quantifying the EONR, despite visual differences between sugarbeet foliage in previous corn versus bean crops, previous crop did not play a major role in developing N recommendations. If the current sugarbeet recommendations were to change based on this research, yield goal and previous crop should not play a major factor in N recommendations.

It continues to be a challenge when deciding exactly how much N to apply to a sugarbeet crop. More field evaluations should be conducted to verify the relationship between N and OM, along with determining the guidelines for using a flat rate versus a range of N rates that a grower to apply to achieve the maximum return.

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Table 1.1. Location information.

Location[†]	County	Crossroads
2002 - 1	Saginaw	Thomas and Swan Creek
2002 - 2	Saginaw	Thomas and Swan Creek
2002 - 3	Gratiot	Bagley and M-46
2002 - 5	Saginaw	M-13 and Townline
2002 - 6	Saginaw	Baldwin and McGregor
2003 - 1	Saginaw	Thomas and Swan Creek
2003 - 2	Saginaw	Thomas and Swan Creek
2003 - 3	Gratiot	Harrison and E. Co. Line
2003 - 4	Gratiot	Wisner and Tyler
2003 - 5	Tuscola	Vassar and Hickey
2004 - 1	Saginaw	Thomas and Swan Creek
2004 - 2	Saginaw	Thomas and Swan Creek
2004 - 5	Saginaw	M-13 and Townline
2004 - 6	Saginaw	Westerveldt and Kochville

[†] The first four numbers in the location represent the year.

Table 1.2. Previous crop and dates of planting, sidedress fertilizer application, and harvest for sugarbeets grown in 2002-2004.

Location [†]	Previous Crop	Planting	Sidedress	Harvest
2002 - 1	Corn	15 April	22 May	14 October
2002 - 2	Dry Bean	15 April	22 May	14 October
2002 - 3	Dry Bean	23 May	27 June	13 October
2002 - 5	Soybean	11 April	25 May	15 October
2002 - 6	Corn	11 April	25 May	15 October
2003 - 1	Corn	28 April	2 June	14 October
2003 - 2	Dry Bean	28 April	2 June	14 October
2003 - 3	Soybean	29 April	3 June	30 October
2003 - 4	Corn	29 April	3 June	24 October
2003 - 5	Corn	30 April	2 June	9 November
2004 - 1	Corn	2 April	10 May	5 October
2004 - 2	Dry Bean	2 April	10 May	5 October
2004 - 5	Corn	12 April	10 May	26 October
2004 - 6	Corn	12 April	10 May	27 October

[†] The first four numbers in the location represent the year.

Table 1.3. Taxonomic classification and fertility parameters.

Location	Soil	Taxonomic Classification	P [†]	K	Ca	Mg	pH	OM
					ppm			%
2002 - 1	Misteguay silty clay loam	Fine, mixed, calcareous, mesic Aeric Endoaquept	22	264	4004	719	8.1	2.9
2002 - 2	Misteguay silty clay loam	Fine, mixed, calcareous, mesic Aeric Endoaquept	48	335	3618	880	8.0	3.1
2002 - 3	Parkhill loam	Fine-loamy, mixed, active, nonacid, mesic Mollic Endoaquept	39	215	3647	236	7.9	4.2
2002 - 5	Sloan silty clay loam	Fine-loamy, mixed, superactive, mesic Fluvaquentic Endoaquolls	32	155	1558	371	7.9	2.5
2002 - 6	Sloan silty clay loam	Fine-loamy, mixed, superactive, mesic Fluvaquentic Endoaquolls	32	147	2624	564	7.8	4.1
2003 - 1	Misteguay silty clay loam	Fine, mixed, calcareous, mesic Aeric Endoaquept	48	243	4129	839	8.2	3.1
2003 - 2	Misteguay silty clay loam	Fine, mixed, calcareous, mesic Aeric Endoaquept	66	238	3968	861	8.1	3.1
2003 - 3	Parkhill loam	Fine-loamy, mixed, active, nonacid, mesic Mollic Endoaquept	60	206	1793	290	6.5	3.3
2003 - 4	Parkhill loam	Fine-loamy, mixed, active, nonacid, mesic Mollic Endoaquept	173	330	1983	255	7.0	3.0
2003 - 5	Tappan loam	Fine-loamy, mixed, active, calcareous, mesic Typic Endoaquolls	77	205	2334	375	7.9	2.8
2004 - 1	Misteguay silty clay loam	Fine, mixed, calcareous, mesic Aeric Endoaquept	24	192	3212	608	8.0	3.6
2004 - 2	Misteguay silty clay loam	Fine, mixed, calcareous, mesic Aeric Endoaquept	31	183	3148	601	8.1	3.4
2004 - 5	Sloan silty clay loam	Fine-loamy, mixed, superactive, mesic Fluvaquentic Endoaquolls	44	107	1744	304	8.1	2.6
2004 - 6	Zilwaukee silty clay	Fine, mixed semiactive, calcareous, mesic Typic Endoaquolls	109	240	2507	428	8.0	3.2

[†] P values were determined by the Olsen-P soil test, except locations 2003-3 and 2003-4 where pH < 7.2, Bray-P test results are reported.

Table 1.4. Location 2002 - 1 ANOVA comparisons for yield, sugar, CJP, and RWSA at all N rates.

N Rate	Yield	Sugar	CJP	RWSA
kg ha ⁻¹	Mg ha ⁻¹	%	%	kg ha ⁻¹
0	32.4 d [†]	19.4 a	97.2 a	4392 d
34	37.1 cd	19.6 a	96.7 b	5039 cd
67	44.5 bc	19.6 a	96.5 bc	6024 bc
101	50.4 ab	19.6 ab	96.5 bc	6840 ab
134	51.9 ab	19.5 abc	96.4 bc	7010 ab
168	54.1 a	19.2 abc	96.4 bc	7186 ab
202	51.4 ab	19.3 bc	96.0 cd	6875 a
235	54.6 a	19.1 c	95.8 d	7085 a
CV (%)	13.4	1.42	0.37	14.3

[†] Within a column, means followed by the same letter are not significantly different ($\alpha = 0.10$).

Table 1.5. Location 2002 - 2 ANOVA comparisons for yield, sugar, CJP, and RWSA at all N rates.

N Rate	Yield	Sugar	CJP	RWSA
kg ha ⁻¹	Mg ha ⁻¹	%	%	kg ha ⁻¹
0	48.9 d [†]	20.1 ab	96.6 a	6863 b
34	59.8 c	20.5 a	96.3 ab	8453 a
67	63.5 abc	20.4 a	96.1 ab	8952 a
101	62.7 bc	20.4 a	96.1 ab	8810 a
134	66.9 ab	20.5 a	96.0 abc	9444 a
168	69.2 ab	20.2 ab	95.5 cd	9507 a
202	69.7 a	19.9 b	95.7 bcd	9481 a
235	64.0 abc	19.8 b	95.2 d	8653 a
CV (%)	9.0	1.63	0.51	10.2

[†] Within a column, means followed by the same letter are not significantly different ($\alpha = 0.10$).

Table 1.6. Location 2002 - 3 ANOVA comparisons for yield, sugar, CJP, and RWSA at all N rates.

N Rate	Yield	Sugar	CJP	RWSA
kg ha ⁻¹	Mg ha ⁻¹	%	%	kg ha ⁻¹
0	65.0 a [†]	17.6 a	93.7 a	7413 a
34	66.2 a	17.3 a	93.1 ab	7319 a
67	66.2 a	17.3 a	93.2 ab	7381 a
101	67.4 a	17.1 a	92.9 b	7365 a
134	68.2 a	16.5 b	92.7 bc	7131 ab
168	67.9 a	16.4 b	92.8 b	7056 ab
202	66.7 a	16.3 b	92.1 cd	6801 b
235	67.4 a	16.1 b	91.9 d	6732 b
CV (%)	3.7	2.95	0.51	4.7

[†] Within a column, means followed by the same letter are not significantly different ($\alpha = 0.10$).

Table 1.7. Location 2002 - 5 ANOVA comparisons for yield, sugar, CJP, and RWSA at all N rates.

N Rate	Yield	Sugar	CJP	RWSA
kg ha ⁻¹	Mg ha ⁻¹	%	%	kg ha ⁻¹
0	78.1 a [†]	17.9 a	93.7 a	9073 a
34	82.3 a	17.3 ab	92.9 a	9099 a
67	79.8 a	17.7 a	93.0 a	9050 a
101	79.8 a	16.7 bc	92.7 a	8408 a
134	77.1 a	16.7 bc	93.8 a	8387 a
168	80.0 a	16.3 c	93.3 a	8317 a
202	79.5 a	16.1 c	93.2 a	8164 a
235	82.5 a	16.3 c	93.1 a	8561 a
CV (%)	6.6	3.6	1.03	6.7

[†] Within a column, means followed by the same letter are not significantly different ($\alpha = 0.10$).

Table 1.8. Location 2002 - 6 ANOVA comparisons for yield, sugar, CJP, and RWSA at all N rates.

N Rate	Yield	Sugar	CJP	RWSA
kg ha ⁻¹	Mg ha ⁻¹	%	%	kg ha ⁻¹
0	44.2 d [†]	18.0 bcd	94.8 ab	5338 e
34	48.7 cd	18.4 ab	95.2 a	6046 de
67	54.3 bc	18.0 bcd	95.1 a	6597 bcd
101	61.3 ab	18.6 a	94.4 bc	7562 ab
134	54.1 bc	18.3 abc	94.5 bc	6567 cd
168	60.5 ab	18.2 abcd	94.2 c	7263 abc
202	65.0 a	17.8 d	94.9 ab	7692 a
235	59.3 ab	17.9 cd	94.3 c	6997 abcd
CV (%)	11.6	2.1	0.48	12

[†] Within a column, means followed by the same letter are not significantly different ($\alpha = 0.10$).

Table 1.9. Location 2003 - 1 ANOVA comparisons for yield, sugar, CJP, and RWSA at all N rates.

N Rate	Yield	Sugar	CJP	RWSA
kg ha ⁻¹	Mg ha ⁻¹	%	%	kg ha ⁻¹
0	33.1 b [†]	21.0 a	95.3 a	4702 b
45	32.4 b	20.9 a	95.4 a	4622 b
90	48.4 a	21.2 a	95.2 a	6988 a
134	48.7 a	21.3 a	95.4 a	7078 a
179	47.2 a	21.0 a	95.1 a	6714 a
224	49.4 a	20.7 a	94.9 a	6919 a
CV (%)	18.6	1.43	0.35	19.5

[†] Within a column, means followed by the same letter are not significantly different ($\alpha = 0.10$).

Table 1.10. Location 2003 - 2 ANOVA comparisons for yield, sugar, CJP, and RWSA at all N rates.

N Rate	Yield	Sugar	CJP	RWSA
kg ha ⁻¹	Mg ha ⁻¹	%	%	kg ha ⁻¹
0	37.5 c [†]	20.9 a	95.5 a	5347 d
45	41.5 c	21.0 a	95.8 a	5985 d
90	51.1 b	21.2 a	95.6 a	7422 bc
134	49.4 b	21.1 a	95.6 a	7138 c
179	58.8 a	20.7 a	95.5 a	8287 ab
224	58.8 a	21.0 a	95.4 a	8418 a
CV (%)	9.4	1.61	0.37	10.8

[†] Within a column, means followed by the same letter are not significantly different ($\alpha = 0.10$).

Table 1.11. Location 2003 - 3 ANOVA comparisons for yield, sugar, CJP, and RWSA at all N rates.

N Rate	Yield	Sugar	CJP	RWSA
kg ha ⁻¹	Mg ha ⁻¹	%	%	kg ha ⁻¹
0	49.2 a [†]	21.0 a	94.6 a	6946 a
45	48.2 a	21.2 a	94.7 a	6520 a
90	49.6 a	20.7 a	94.1 b	6793 a
134	51.1 a	20.5 a	93.7 bc	6897 a
179	47.7 a	19.9 a	93.2 c	6171 a
224	46.4 a	20.3 a	92.6 d	6066 a
CV (%)	9.4	3.03	0.42	8.5

[†] Within a column, means followed by the same letter are not significantly different ($\alpha = 0.10$).

Table 1.12. Location 2003 - 4 ANOVA comparisons for yield, sugar, CJP, and RWSA at all N rates.

N Rate	Yield	Sugar	CJP	RWSA
kg ha ⁻¹	Mg ha ⁻¹	%	%	kg ha ⁻¹
0	43.7 b [†]	20.3 a	94.9 a	5999 bc
45	42.5 b	20.2 a	94.7 a	5776 c
90	50.9 ab	21.5 a	94.5 a	7333 ab
134	57.6 a	21.5 a	94.0 a	8197 a
179	57.3 a	21.3 a	94.0 a	8062 a
224	57.1 a	21.6 a	93.8 a	8126 a
CV (%)	15.6	4.21	0.82	16.2

[†] Within a column, means followed by the same letter are not significantly different ($\alpha = 0.10$).

Table 1.13. Location 2003 - 5 ANOVA comparisons for yield, sugar, CJP, and RWSA at all N rates.

N Rate	Yield	Sugar	CJP	RWSA
kg ha ⁻¹	Mg ha ⁻¹	%	%	kg ha ⁻¹
0	42.5 c [†]	19.9 a	93.7 a	5435 a
45	46.9 bc	19.8 a	93.0 a	5996 a
90	54.6 ab	19.8 a	94.1 a	7115 a
134	55.8 a	20.5 a	93.7 a	7492 a
179	56.8 a	20.6 a	93.3 a	7627 a
224	56.8 a	20.3 a	93.9 a	7573 a
CV (%)	13.5	3.45	1.35	15

[†] Within a column, means followed by the same letter are not significantly different ($\alpha = 0.10$).

Table 1.14. Location 2004 - 1 ANOVA comparisons for yield, sugar, CJP, and RWSA at all N rates.

N Rate	Yield	Sugar	CJP	RWSA
kg ha⁻¹	Mg ha⁻¹	%	%	kg ha⁻¹
0	27.9 b [†]	18.8 d	92.3 a	3322 b
45	35.6 b	18.9 bcd	91.9 a	4235 b
90	70.9 a	19.6 a	91.8 a	8702 a
134	68.4 a	19.6 a	92.5 a	8565 a
179	69.4 a	19.0 bcd	92.5 a	8383 a
224	69.7 a	19.2 bc	91.8 a	8392 a
CV (%)	9.0	1.67	1.01	9.8

[†] Within a column, means followed by the same letter are not significantly different ($\alpha = 0.10$).

Table 1.15. Location 2004 - 2 ANOVA comparisons for yield, sugar, CJP, and RWSA at all N rates.

N Rate	Yield	Sugar	CJP	RWSA
kg ha⁻¹	Mg ha⁻¹	%	%	kg ha⁻¹
0	53.6 c [†]	19.1 a	91.5 a	6348 c
45	63.2 b	19.1 a	91.2 a	7449 b
90	74.8 a	19.4 a	90.4 a	8788 a
134	76.6 a	19.2 a	91.3 a	9102 a
179	76.3 a	18.8 a	90.1 a	8574 a
224	75.3 a	19.0 a	90.9 a	8701 a
CV (%)	5.2	2.26	1.4	6.5

[†] Within a column, means followed by the same letter are not significantly different ($\alpha = 0.10$).

Table 1.16. Location 2004 - 5 ANOVA comparisons for yield, sugar, CJP, and RWSA at all N rates.

N Rate	Yield	Sugar	CJP	RWSA
kg ha ⁻¹	Mg ha ⁻¹	%	%	kg ha ⁻¹
0	84.7 b [†]	18.3 a	93.0 a	9937 b
45	83.5 b	18.4 a	93.5 a	9915 b
90	98.6 a	18.8 a	93.4 a	12006 a
134	98.1 a	19.2 a	92.6 a	11964 a
179	96.8 a	18.8 a	92.6 a	11635 a
224	99.5 a	18.7 a	92.9 a	11904 a
CV (%)	7.4	2.95	0.6	5.6

[†] Within a column, means followed by the same letter are not significantly different ($\alpha = 0.10$).

Table 1.17. Location 2004 - 6 ANOVA comparisons for yield, sugar, CJP, and RWSA at all N rates.

N Rate	Yield	Sugar	CJP	RWSA
kg ha ⁻¹	Mg ha ⁻¹	%	%	kg ha ⁻¹
0	19.7 c [†]	18.0 c	93.4 a	2295 c
45	35.1 b	18.4 bc	93.4 a	4169 b
90	54.1 a	18.8 ab	93.2 a	6555 a
134	48.7 a	19.2 a	93.0 a	6004 a
179	58.0 a	18.8 ab	92.7 a	6955 a
224	58.3 a	18.7 ab	92.4 a	6898 a
CV (%)	16.4	2.66	0.66	17.3

[†] Within a column, means followed by the same letter are not significantly different ($\alpha = 0.10$).

Table 1.18. Models and optimum N rates for yield.

Location	Model [†]	Model Parameters			R ²	YONR [‡]	Yield [§]
		a	b	c			
						kg ha ⁻¹	Mg ha ⁻¹
2002 - 1	QP	31.2135	0.2457	-0.00068	0.651	181	53
2002 - 2	QP	50.1597	0.2435	-0.00088	0.546	139	67
2002 - 3	-	-	-	-	-	0	68
2002 - 5	-	-	-	-	-	0	80
2002 - 6	LP	39.9100	0.1369	-	0.205	101	62
2003 - 1	LP	30.1750	0.1717	-	0.487	106	48
2003 - 2	LP	36.5083	0.1522	-	0.491	126	56
2003 - 3	-	-	-	-	-	0	49
2003 - 4	LP	41.0576	0.1119	-	0.449	144	57
2003 - 5	QP	40.9532	0.1869	-0.00055	0.366	169	57
2004 - 1	LP	24.1307	0.4475	-	0.868	94	69
2004 - 2	QP	52.9161	0.3254	-0.00114	0.773	143	76
2004 - 5	LP	82.0375	0.1531	-	0.479	105	98
2004 - 6	LP	18.8526	0.3849	-	0.717	94	55

[†] QP = quadratic plateau model, LP = linear plateau model, and Quad = quadratic model

[‡] YONR = yield optimum N rate

[§] Yield at YONR

Table 1.19. Models and optimum N rates for RWSA.

Location	Model [†]	Model Parameters			R ²	RONR [‡]	RWSA [§]
		a	b	c			
						kg ha ⁻¹	kg ha ⁻¹
2002 - 1	QP	4248.8	34.0023	-0.1017	0.615	167	7091
2002 - 2	Quad	7096.0	32.0683	-0.1062	0.480	151	9517
2002 - 3	-	-	-	-	-	0	7150
2002 - 5	-	-	-	-	-	0	8569
2002 - 6	QP	5252.7	31.0755	-0.1248	0.176	125	7187
2003 - 1	LP	4294.2	25.3972	-	0.468	103	6904
2003 - 2	LP	5213.5	23.0611	-	0.491	119	7948
2003 - 3	-	-	-	-	-	0	6565
2003 - 4	LP	5600.3	18.2234	-	0.461	137	8094
2003 - 5	LP	5407.6	16.3594	-	0.406	134	7600
2004 - 1	QP	2906.9	76.1992	-0.2579	0.812	148	8536
2004 - 2	Quad	6320.9	34.3895	-0.1095	0.638	157	9021
2004 - 5	LP	9584.3	23.0056	-	0.648	98	11834
2004 - 6	QP	2201.8	59.4314	-0.1940	0.716	153	6753

[†] QP = quadratic plateau model, LP = linear plateau model, and Quad = quadratic model

[‡] RONR = RWSA optimum N rate

[§] Yield at RONR

Table 1.20. Models and optimum N rates for payment.

Location	Model [†]	Model Parameters			R ²	PONR [‡]	Payment [§]
		a	b	c		kg ha ⁻¹	\$ ha ⁻¹
2002 - 1	QP	1137.8	9.4015	-0.0277	0.638	169	1934
2002 - 2	Quad	1924.9	9.0169	-0.0292	0.522	154	2621
2002 - 3	-	-	-	-	-	0	2080
2002 - 5	-	-	-	-	-	0	2490
2002 - 6	QP	1463.2	8.7745	-0.0343	0.178	128	2025
2003 - 1	LP	1195.7	7.114	-	0.468	103	1929
2003 - 2	LP	1446.6	6.346	-	0.477	119	2206
2003 - 3	-	-	-	-	-	0	1887
2003 - 4	LP	1569.4	5.4532	-	0.475	139	2327
2003 - 5	LP	1544.5	5.2421	-	0.405	121	2181
2004 - 1	QP	860.4	23.0354	-0.0794	0.818	144	2532
2004 - 2	QP	1889.3	12.4753	-0.0470	0.703	132	2717
2004 - 5	LP	2784.9	6.3728	-	0.653	108	3473
2004 - 6	QP	647.3	16.3024	-0.0492	0.724	166	1997

[†] QP = quadratic plateau model, LP = linear plateau model, and Quad = quadratic model

[‡] PONR = payment optimum N rate

[§] Yield at PONR

Table 1.22. Economic optimum N rates and yields at different N prices for payment.

Location	EONR44 [†]	EONR55 [‡]	EONR66 [§]	EONR77 [¶]	YEONR44 [#]	YEONR55 ^{††}	YEONR66 ^{‡‡}	YEONR77 ^{§§}
	----- kg ha ⁻¹ -----				----- Mg ha ⁻¹ -----			
2002 - 1	162	160	158	156	53.2	53.1	53.1	53.0
2002 - 2	147	145	143	141	66.9	67.0	66.9	67.0
2002 - 3	0	0	0	0	68.0	68.0	68.0	68.0
2002 - 5	0	0	0	0	80.0	80.0	80.0	80.0
2002 - 6	121	120	118	117	61.6	61.6	61.6	61.6
2003 - 1	103	103	103	103	48.4	48.4	48.4	48.4
2003 - 2	119	119	119	119	55.7	55.7	55.7	55.7
2003 - 3	0	0	0	0	48.7	48.7	48.7	48.7
2003 - 4	139	139	139	139	57.1	57.1	57.1	57.1
2003 - 5	121	121	121	121	55.5	55.5	55.5	55.5
2004 - 1	142	142	141	140	69.2	69.2	69.2	69.2
2004 - 2	128	127	126	125	75.9	75.8	75.9	75.8
2004 - 5	108	108	108	108	98.1	98.1	98.1	98.1
2004 - 6	161	160	159	158	54.9	54.9	54.9	54.9

[†] Economic optimum N rate for payment at N price = \$0.44 kg⁻¹.

[‡] Economic optimum N rate for payment at N price = \$0.55 kg⁻¹.

[§] Economic optimum N rate for payment at N price = \$0.66 kg⁻¹.

[¶] Economic optimum N rate for payment at N price = \$0.77 kg⁻¹.

[#] Yield at the payment economic N rate at N price = \$0.44 kg⁻¹.

^{††} Yield at the payment economic N rate at N price = \$0.55 kg⁻¹.

^{‡‡} Yield at the payment economic N rate at N price = \$0.66 kg⁻¹.

^{§§} Yield at the payment economic N rate at N price = \$0.77 kg⁻¹.

Table 1.23. Economic optimum N rates and yields at different price ratios for RWSA.

Location	EONR1 [†]	EONR2 [‡]	EONR3 [§]	EONR4 [¶]	YEONR1 [#]	YEONR2 ^{††}	YEONR3 ^{##}	YEONR4 ^{§§}
	----- kg ha ⁻¹ -----				----- Mg ha ⁻¹ -----			
2002 - 1	162	157	152	148	53.2	53.0	52.9	52.7
2002 - 2	146	142	137	132	67.0	67.0	67.0	66.9
2002 - 3	0	0	0	0	68.0	68.0	68.0	68.0
2002 - 5	0	0	0	0	80.0	80.0	80.0	80.0
2002 - 6	120	116	112	108	61.6	61.6	61.6	61.6
2003 - 1	103	103	103	103	48.4	48.4	48.4	48.4
2003 - 2	119	119	119	119	55.7	55.7	55.7	55.7
2003 - 3	0	0	0	0	48.7	48.7	48.7	48.7
2003 - 4	137	137	137	137	57.1	57.1	57.1	57.1
2003 - 5	134	134	134	134	56.1	56.1	57.0	56.1
2004 - 1	146	144	142	140	69.2	69.2	69.2	69.2
2004 - 2	152	148	143	139	76.0	76.1	76.1	76.1
2004 - 5	98	98	98	98	98.1	98.1	98.1	98.1
2004 - 6	151	148	145	143	54.9	54.9	54.9	54.9

[†] Economic optimum N rate for RWSA at N:sugar price ratio of 1:1.

[‡] Economic optimum N rate for RWSA at N:sugar price ratio of 2:1.

[§] Economic optimum N rate for RWSA at N:sugar price ratio of 3:1.

[¶] Economic optimum N rate for RWSA at N:sugar price ratio of 4:1.

[#] Yield at the RWSA economic N rate at N:sugar price ratio of 1:1.

^{††} Yield at the RWSA economic N rate at N:sugar price ratio of 2:1.

^{##} Yield at the RWSA economic N rate at N:sugar price ratio of 3:1.

^{§§} Yield at the RWSA economic N rate at N:sugar price ratio of 4:1.

Table 1.24. Models and economic optimum fertilizer N rates for relative return.

Parameter	Model [†]	Model Parameters			R ²	EONR [§]	Plateau
		a	b	c			
<i>All Sites</i>						kg ha ⁻¹	%
Relative Return	LP	72.3000	0.2432	-	0.370	90	94.1
Relative Return	QP	72.1264	0.3300	-0.00122	0.358	135	94.3
Relative Return	Quad	72.6346	0.2918	-0.00091	0.360	160	96.0
<i>Responsive Sites Only[‡]</i>							
Relative Return	LP	64.4110	0.3240	-	0.639	97	95.7
Relative Return	QP	64.3157	0.4216	-0.00139	0.617	151	96.2
Relative Return	Quad	64.7739	0.3881	-0.00113	0.618	172	98.1

[†] QP = quadratic plateau model, LP = linear plateau model, and Quad = quadratic model

[‡] Without non-responsive sites (2002-3, 2002-5, and 2003-3).

[§] Relative return optimum N rate is equal to the economic optimum N rate.

Table 1.25. Models and economic optimum N rates for relative return for soil N (0 to 0.30 m) + fertilizer N.

Parameter	Model [†]	Model Parameters			R ²	EONR [§]	Plateau
		a	b	c			
<i>All Sites</i>						kg ha ⁻¹	%
Relative Return	LP	66.1890	0.2699	-	0.408	104	94.3
Relative Return	QP	62.9488	0.4476	-0.00160	0.398	140	94.3
Relative Return	Quad	65.4246	0.3541	-0.00101	0.398	175	96.5
<i>Responsive Sites Only[‡]</i>							
Relative Return	LP	58.4510	0.3296	-	0.646	113	95.7
Relative Return	QP	55.8662	0.4887	-0.00148	0.628	165	96.1
Relative Return	Quad	57.3841	0.4323	-0.00115	0.628	188	98.0

[†] QP = quadratic plateau model, LP = linear plateau model, and Quad = quadratic model

[‡] Without non-responsive sites (2002-3, 2002-5, and 2003-3).

[§] Relative return optimum N rate is equal to the economic optimum N rate.

Table 1.26. Models and economic optimum N rates for relative return for soil N (0 to 0.60 m) + fertilizer N.

Parameter	Model [†]	Model Parameters			R ²	EONR [§]	Plateau
		a	b	c			
<i>All Sites</i>						kg ha ⁻¹	%
Relative Return	LP	60.5490	0.2944	-	0.429	114	94.2
Relative Return	QP	53.9626	0.5401	-0.00181	0.422	149	94.2
Relative Return	Quad	59.257	0.3929	-0.00103	0.416	191	96.7
<i>Responsive Sites Only[‡]</i>							
Relative Return	LP	51.9010	0.3578	-	0.663	122	95.5
Relative Return	QP	47.0400	0.5614	-0.00161	0.647	174	96.0
Relative Return	Quad	50.4317	0.4695	-0.00116	0.643	202	97.9

[†] QP = quadratic plateau model, LP = linear plateau model, and Quad = quadratic model

[‡] Without non-responsive sites (2002-3, 2002-5, and 2003-3).

[§] Relative return optimum N rate is equal to the economic optimum N rate.

Table 1.27. Models and economic optimum N rates for relative return for soil N (0 to 0.90 m) + fertilizer N.

Parameter	Model [†]	Model Parameters			R ²	EONR [§]	Plateau
		a	b	c			
<i>All Sites</i>						kg ha ⁻¹	%
Relative Return	LP	55.174	0.3503	-	0.453	123	93.5
Relative Return	QP	44.5722	0.6272	-0.00198	0.448	158	94.2
Relative Return	Quad	52.9894	0.4335	-0.00107	0.439	203	96.9
<i>Responsive Sites Only[‡]</i>							
Relative Return	LP	48.3360	0.3482	-	0.655	135	95.5
Relative Return	QP	40.8432	0.5874	-0.00157	0.639	188	95.9
Relative Return	Quad	45.3413	0.4863	-0.00112	0.634	217	98.1

[†] QP = quadratic plateau model, LP = linear plateau model, and Quad = quadratic model

[‡] Without non-responsive sites (2002-3, 2002-5, and 2003-3).

[§] Relative return optimum N rate is equal to the economic optimum N rate.

Table 1.28. Relative return[†] compared to return at RONR at each location.

Location	Nitrogen application rates (kg N ha ⁻¹)						
	90	97	120 [‡]	135	151	160	172
	----- \$ gain or loss ha ⁻¹ -----						
2002 – 1	-83	-64	-19	-2	5	3	-3
2002 – 2	-47	-33	-2	5	0	-8	-24
2002 – 3	-59	-64	-79	-89	-100	-106	-114
2002 – 5	-59	-64	-79	-89	-100	-106	-114
2002 – 6	-10	-2	3	-7	-17	-23	-31
2003 – 1	-63	-28	-11	-21	-32	-38	-46
2003 – 2	-126	-95	-1	-11	-21	-27	-35
2003 – 3	-59	-64	-79	-89	-100	-106	-114
2003 – 4	-157	-133	-56	-6	-9	-15	-23
2003 – 5	-129	-109	-41	-1	-11	-17	-25
2004 – 1	-151	-113	-25	-1	-2	-8	-16
2004 – 2	-64	-47	-9	3	3	-2	-15
2004 – 5	-34	-3	-15	-24	-35	-41	-49
2004 – 6	-129	-98	-25	-2	1	-5	-13
Mean	-84	-66	-31	-24	-30	-36	-44
Std Dev.	46.1	40.5	30.4	36.3	39.8	40.1	39.4

[†] Based on using the most appropriate model for RWSA response (a 3:1 ratio with \$0.66 N kg⁻¹ and \$0.22 sugar kg⁻¹ prices) to N fertilizer at each site and inputting the relative return EONR.

[‡] The rate 15 kg ha⁻¹ below the best rate was added because a comparison of 15 kg ha⁻¹ above the best rate was already shown.

Table 1.29. Relative return[†] compared to return at RONR when soil sampling[§] at 0-0.30 m or 0-0.60 m.

Location	Nitrogen application rates (kg N ha ⁻¹) for 0-0.30 m							Nitrogen application rates (kg N ha ⁻¹) for 0-0.60 m						
	104	113	120 [‡]	140	165	175	188	114	120 [‡]	122	149	174	191	202
	----- \$ gain or loss ha ⁻¹ -----							----- \$ gain or loss ha ⁻¹ -----						
2002 - 1	-80	-57	-41	-10	5	3	-5	-80	-64	-59	-11	5	-1	-8
2002 - 2	-51	-32	-21	1	1	-7	-24	-61	-47	-42	-3	3	-9	-24
2002 - 3	-56	-62	-67	-80	-96	-103	-112	-55	-59	-60	-78	-94	-106	-113
2002 - 5	-56	-62	-67	-80	-96	-103	-112	-53	-57	-59	-77	-93	-104	-112
2002 - 6	-10	-1	3	-1	-17	-24	-32	-20	-11	-8	3	-12	-23	-30
2003 - 1	-58	-13	21	-16	-32	-39	-48	-58	-28	-18	-15	-32	-43	-50
2003 - 2	-152	-113	-82	-1	-17	-24	-32	-205	-179	-170	-51	-9	-20	-27
2003 - 3	-50	-56	-61	-74	-90	-97	-106	-44	-48	-50	-67	-84	-95	-102
2003 - 4	-180	-150	-127	-60	-5	-11	-20	-190	-170	-163	-73	-2	-13	-20
2003 - 5	-153	-126	-106	-47	-6	-13	-21	-185	-168	-162	-82	-9	-9	-17
2004 - 1	-157	-107	-75	-14	-1	-8	-17	-134	-103	-93	-9	-3	-15	-22
2004 - 2	-67	-45	-31	-4	3	-2	-17	-83	-67	-61	-11	4	-2	-14
2004 - 5	5	-1	-6	-19	-36	-42	-51	-25	0	-1	-19	-36	-47	-54
2004 - 6	-119	-82	-57	-10	0	-7	-15	-129	-102	-94	-15	2	-9	-17
Mean	-85	-65	-51	-30	-28	-34	-44	-94	-79	-74	-36	-26	-35	-44
Std Dev.	57.8	46.3	41.6	31.4	38.2	38.5	37.8	62.9	58.1	56.0	32.7	37.2	38.3	37.7

[†] Based on using the most appropriate model for RWSA response (a 3:1 ratio with \$0.66 N kg⁻¹ and \$0.22 sugar kg⁻¹ prices) to N fertilizer at each site and inputting the relative return EONR.

[‡] The rate 15 kg ha⁻¹ below the best rate was added because a comparison of 15 kg ha⁻¹ above the best rate was already shown.

[§] Comparison does not include the cost of sampling and analysis.

Table 1.30. Relative return[†] compared to return at RONR when soil sampling at 0-0.30 m or 0-0.60 m and including the cost of sampling[‡].

Location	Nitrogen application rates (kg N ha ⁻¹) for 0-0.30 m						Nitrogen application rates (kg N ha ⁻¹) for 0-0.60 m					
	104	113	140	165	175	188	114	122	149	174	191	202
	----- \$ gain or loss ha ⁻¹ -----						----- \$ gain or loss ha ⁻¹ -----					
2002 - 1	-93	-70	-23	-8	-10	-18	-98	-77	-29	-13	-19	-26
2002 - 2	-64	-45	-12	-12	-20	-37	-79	-60	-21	-15	-27	-42
2002 - 3	-69	-75	-93	-109	-116	-125	-73	-78	-96	-112	-124	-131
2002 - 5	-69	-75	-93	-109	-116	-125	-71	-77	-95	-111	-122	-130
2002 - 6	-23	-14	-14	-30	-37	-45	-38	-26	-15	-30	-41	-48
2003 - 1	-71	-26	-29	-45	-52	-61	-76	-36	-33	-50	-61	-68
2003 - 2	-165	-126	-14	-30	-37	-45	-223	-188	-69	-27	-38	-45
2003 - 3	-63	-69	-87	-103	-110	-119	-62	-68	-85	-102	-113	-120
2003 - 4	-193	-163	-73	-18	-24	-33	-208	-181	-91	-20	-31	-38
2003 - 5	-166	-139	-60	-19	-26	-34	-203	-180	-100	-27	-27	-35
2004 - 1	-170	-120	-27	-14	-21	-30	-152	-111	-27	-21	-33	-40
2004 - 2	-80	-58	-17	-10	-15	-30	-101	-79	-29	-14	-20	-32
2004 - 5	-8	-14	-32	-49	-55	-64	-43	-19	-37	-54	-65	-72
2004 - 6	-132	-95	-23	-13	-20	-28	-147	-112	-33	-16	-27	-35
Mean	-98	-78	-43	-41	-47	-57	-112	-92	-54	-44	-53	-62
Std Dev.	57.8	46.3	31.4	38.2	38.5	37.8	62.9	56.0	32.7	37.2	38.3	37.7

[†] Based on using the most appropriate model for RWSA response (a 3:1 ratio with \$0.66 N kg⁻¹ and \$0.22 sugar kg⁻¹ prices) to N fertilizer at each site and inputting the relative return EONR.

[‡] Cost of soil sampling to 0.30 m is \$13 ha⁻¹ and to 0.60 m is \$18 ha⁻¹.

Table 1.31. RWSA and payment economic optimum N rates plus preplant soil nitrate.

Location	Previous Crop	kg ha ⁻¹							
		REONR [†]	REONR [†] + NO ₃ -N (0-0.30 m)	REONR [†] + NO ₃ -N (0-0.60 m)	REONR [†] + NO ₃ -N (0-0.90 m)	PEONR [‡]	PEONR [‡] + NO ₃ -N (0-0.30 m)	PEONR [‡] + NO ₃ -N (0-0.60 m)	PEONR [‡] + NO ₃ -N (0-0.90 m)
2002 - 1	corn	152	165	175	183	158	171	181	189
2002 - 2	dry bean	137	153	167	176	143	159	173	182
2002 - 3	dry bean	0	19	31	47	0	19	31	47
2002 - 5	soybean	0	19	33	53	0	19	33	53
2002 - 6	corn	112	126	143	158	118	132	149	164
2003 - 1	corn	103	116	126	135	103	116	126	135
2003 - 2	dry bean	119	139	161	176	119	139	161	176
2003 - 3	soybean	0	28	47	59	0	28	47	59
2003 - 4	corn	137	158	171	179	139	160	173	181
2003 - 5	corn	134	156	177	189	121	143	164	176
2004 - 1	corn	142	157	163	170	141	156	162	169
2004 - 2	dry bean	143	158	174	189	126	141	157	172
2004 - 5	corn	98	111	120	129	108	121	130	139
2004 - 6	corn	145	157	169	184	159	171	183	198

[†] Economic N rates for RWSA are based on a price ratio of 3:1 (\$0.22 sugar:\$0.66 kg⁻¹ N cost).

[‡] Economic N rates for payment are based on a N cost of \$0.66 kg⁻¹.

Table 1.32. Correlation coefficient and P-value of soil parameters with economic optimum N rates with all locations.

r P-value	Yield at REONR	Yield at PEONR	Previous Crop	REONR	PEONR	INST	OM	Total N	TOC [†]	NO ₃ -N (0-0.30 m)	NO ₃ -N (0-0.60 m)	NO ₃ -N (0-0.90 m)
Yield at REONR	-	0.99 <0.0001	-0.13 0.6554	-0.14 0.6424	-0.13 0.6505	0.20 0.4937	0.16 0.5947	0.74 0.0023	0.04 0.8949	-0.27 0.3442	-0.32 0.2654	-0.21 0.4788
Yield at PEONR	-	-	-0.13 0.6469	-0.14 0.6323	-0.13 0.6465	0.21 0.4736	0.16 0.5829	0.83 0.0002	0.75 0.0019	-0.27 0.3442	-0.32 0.2456	-0.22 0.4544
Previous Crop	-	-	-	0.55 0.0417	0.59 0.0275	-0.52 0.0563	-0.58 0.0298	-0.12 0.6709	-0.32 0.2558	-0.47 0.0865	-0.50 0.0857	-0.60 0.0243
REONR	-	-	-	-	0.99 <0.0001	-0.63 0.0156	-0.59 0.0250	-0.12 0.8894	-0.32 0.2627	-0.53 0.0517	-0.38 0.1832	-0.48 0.0791
PEONR	-	-	-	-	-	-0.59 0.0268	-0.62 0.0186	-0.11 0.7119	-0.31 0.2824	-0.57 0.0314	-0.43 0.1206	-0.51 0.0481
INST	-	-	-	-	-	-	0.54 0.0483	-0.11 0.7017	0.48 0.0808	0.10 0.7333	0.03 0.9295	0.19 0.5072
OM	-	-	-	-	-	-	-	0.34 0.2355	0.69 0.0065	0.22 0.4516	0.02 0.9405	0.17 0.5571
Total N	-	-	-	-	-	-	-	-	0.24 0.4029	-0.21 0.4633	-0.36 0.2028	-0.30 0.3042
TOC	-	-	-	-	-	-	-	-	-	-0.22 0.4395	-0.32 0.2711	-0.16 0.5958
NO ₃ -N (0-0.30 m)	-	-	-	-	-	-	-	-	-	-	0.91 <0.0001	0.80 0.0006
NO ₃ -N (0-0.60 m)	-	-	-	-	-	-	-	-	-	-	-	0.94 <0.0001
NO ₃ -N (0-0.90 m)	-	-	-	-	-	-	-	-	-	-	-	-

[†] TOC = total organic carbon

Table 1.33. Correlation coefficient and P-value of soil parameters with economic optimum N rates for responsive sites.

r P-value	Yield at REONR	Yield at PEONR	Previous Crop	REONR	PEONR	INST	OM	Total N	TOC [†]	NO ₃ -N (0-0.30 m)	NO ₃ -N (0-0.60 m)	NO ₃ -N (0-0.90 m)
Yield at REONR	-	0.99 <0.0001	-0.13 0.7056	-0.30 0.3370	-0.28 0.4102	-0.14 0.6857	-0.09 0.7869	0.80 0.0031	-0.22 0.5207	-0.21 0.5330	-0.25 0.4612	-0.24 0.4858
Yield at PEONR	-	-	-0.13 0.7026	-0.30 0.3757	-0.27 0.4262	-0.12 0.7165	-0.09 0.7977	0.81 0.0026	-0.20 0.5619	-0.23 0.4943	-0.27 0.4243	-0.25 0.4517
Previous Crop	-	-	-	-0.13 0.7006	0.04 0.9114	-0.29 0.3820	-0.33 0.3154	-0.08 0.8177	-0.19 0.5732	-0.23 0.4936	-0.41 0.2109	-0.44 0.1754
REONR	-	-	-	-	0.88 0.0004	-0.08 0.8198	0.51 0.1084	-0.06 0.8558	0.40 0.2193	0.13 0.7131	-0.01 0.9823	-0.01 0.9927
PEONR	-	-	-	-	-	0.18 0.6024	0.35 0.2922	-0.03 0.9304	0.47 0.1487	-0.12 0.7298	-0.25 0.4535	-0.22 0.5035
INST	-	-	-	-	-	-	-0.35 0.2898	-0.42 0.1966	0.08 0.8083	-0.13 0.7067	-0.05 0.8811	-0.09 0.7950
OM	-	-	-	-	-	-	-	0.37 0.2692	0.53 0.0940	-0.02 0.9515	-0.18 0.5999	-0.20 0.5668
Total N	-	-	-	-	-	-	-	-	0.16 0.6429	-0.32 0.3370	-0.43 0.1879	-0.38 0.2460
TOC	-	-	-	-	-	-	-	-	-	-0.59 0.0539	-0.53 0.0963	-0.43 0.1868
NO ₃ -N (0-0.30 m)	-	-	-	-	-	-	-	-	-	-	0.88 0.0003	0.73 0.0104
NO ₃ -N (0-0.60 m)	-	-	-	-	-	-	-	-	-	-	-	0.96 <0.0001
NO ₃ -N (0-0.90 m)	-	-	-	-	-	-	-	-	-	-	-	-

[†]TOC = total organic carbon

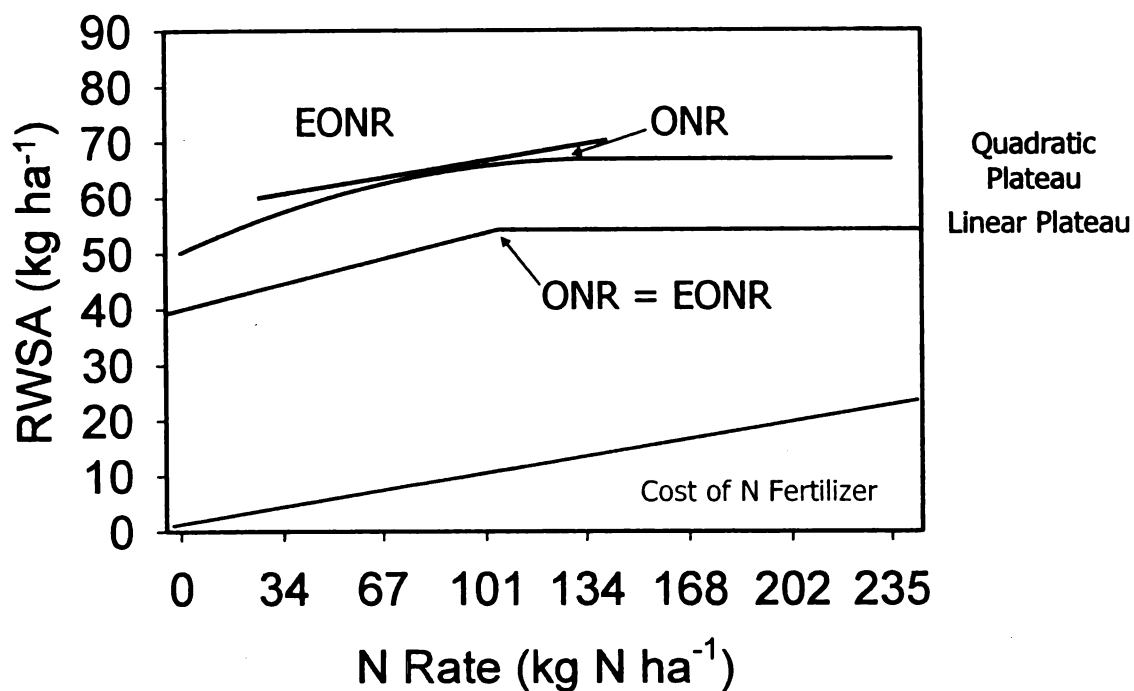


Figure 1.1. Illustration of the calculation of the economic optimum N rate (EONR). For the quadratic plateau model, the EONR is where the slope of the tangent to the curve is equal to the slope of the cost of N fertilizer. For the linear plateau model, the EONR is equal to the greatest distance between the model and the cost of N fertilizer.

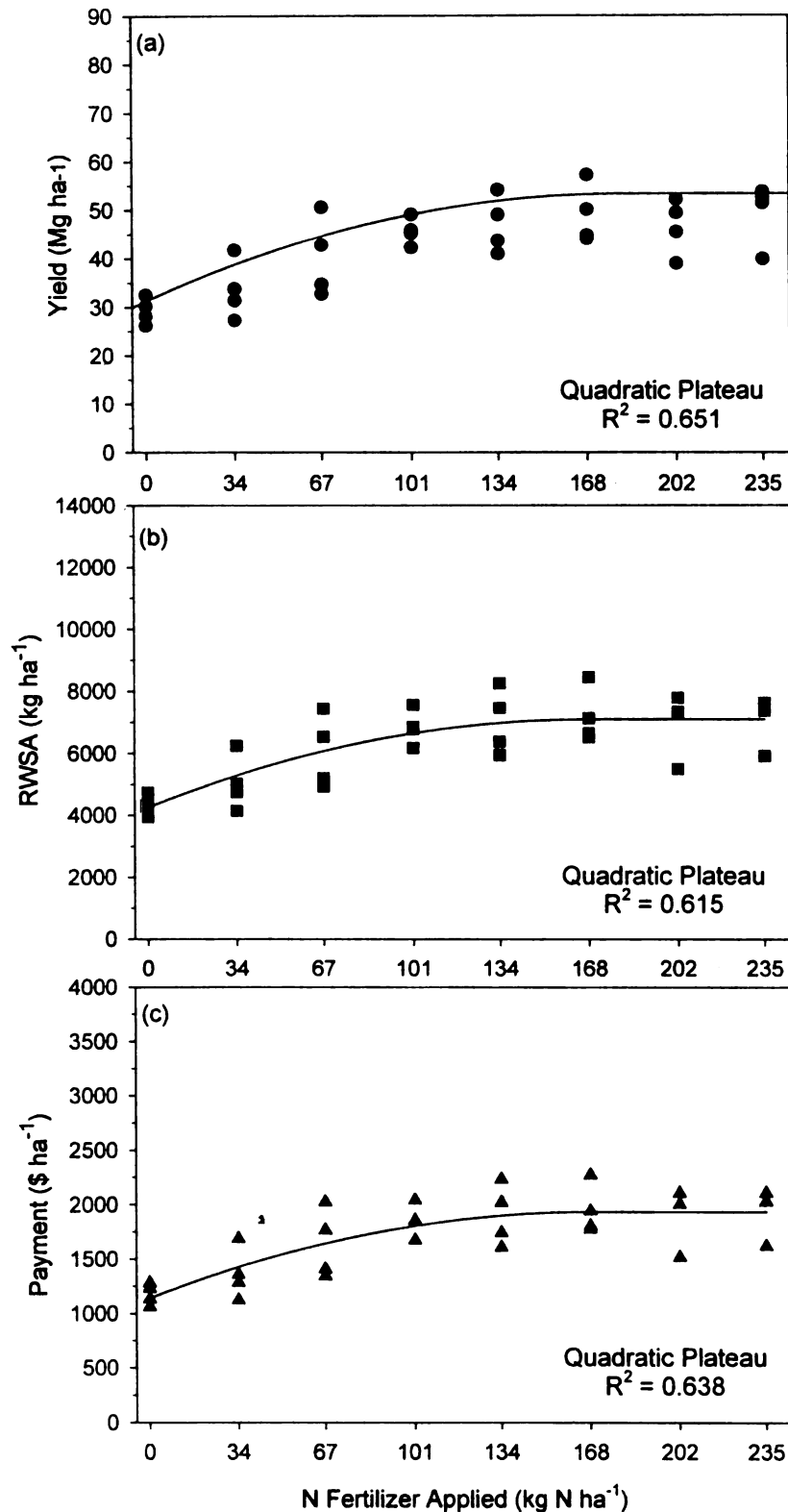


Figure 1.2. 2002-1 yield (a), RWSA (b), and payment (c) responses to N. The lines on each graph represent the chosen model for each parameter.

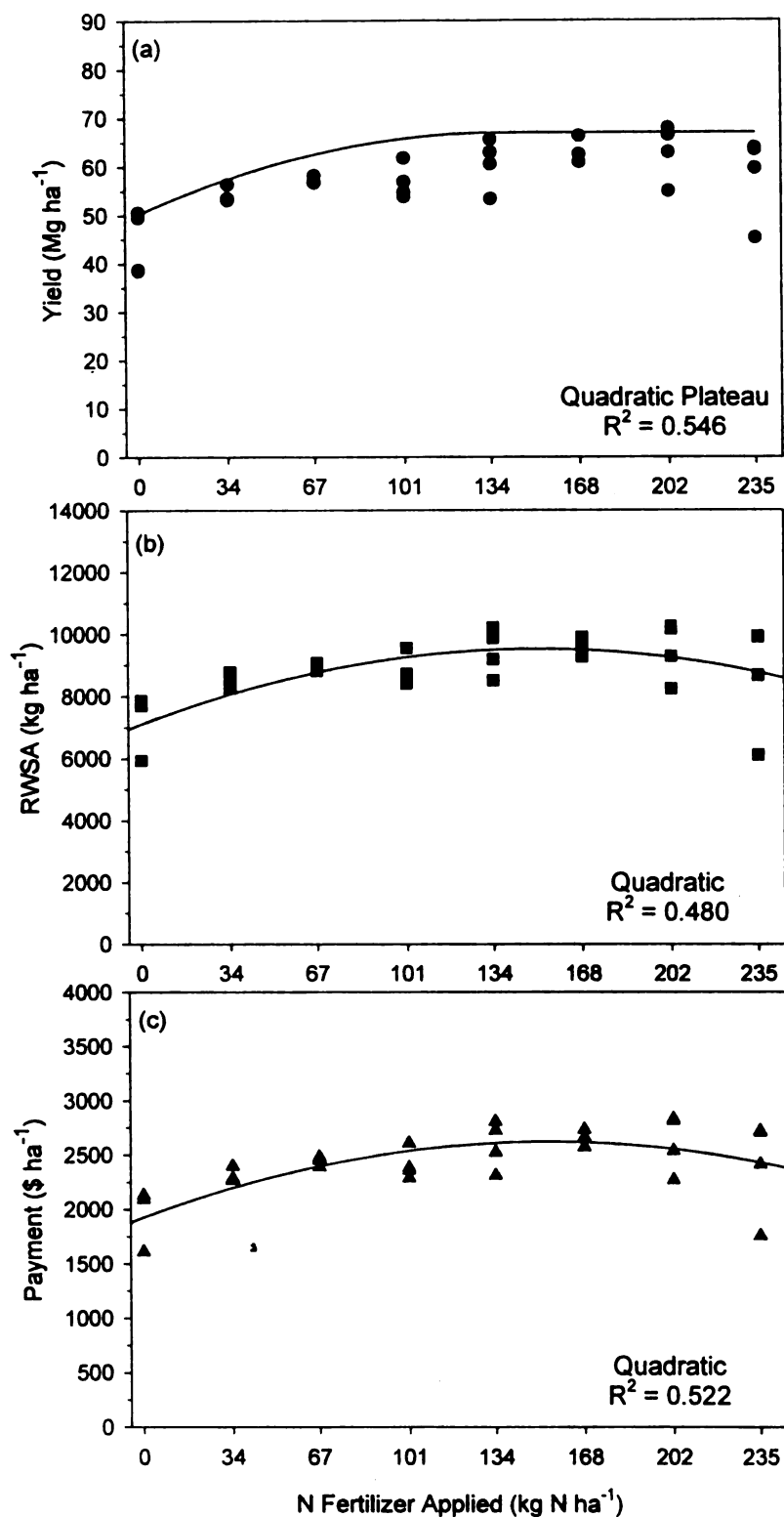


Figure 1.3. 2002-2 yield (a), RWSA (b), and payment (c) responses to N. The lines on each graph represent the chosen model for each parameter.

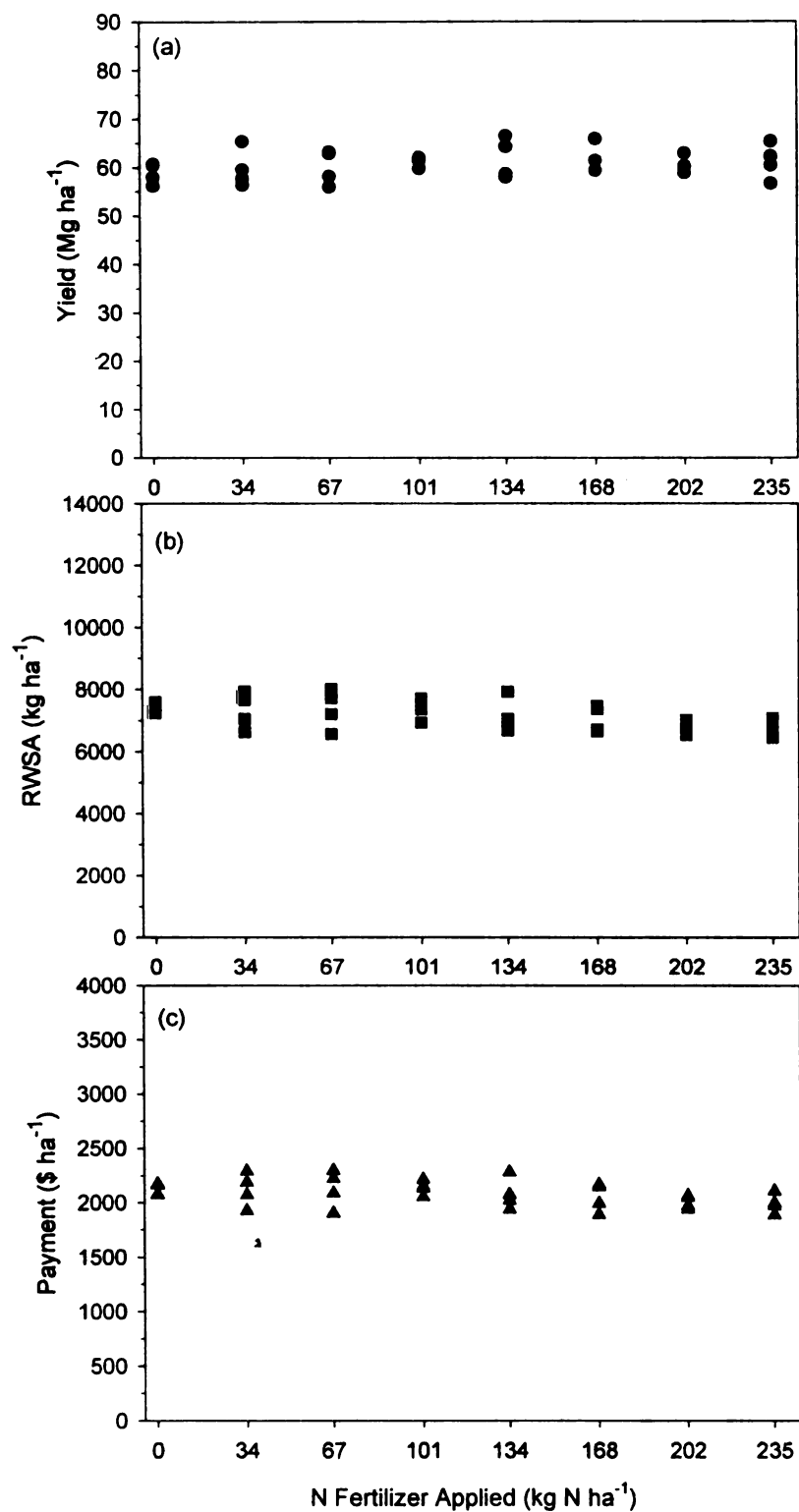


Figure 1.4. 2002-3 yield (a), RWSA (b), and payment (c) responses to N.

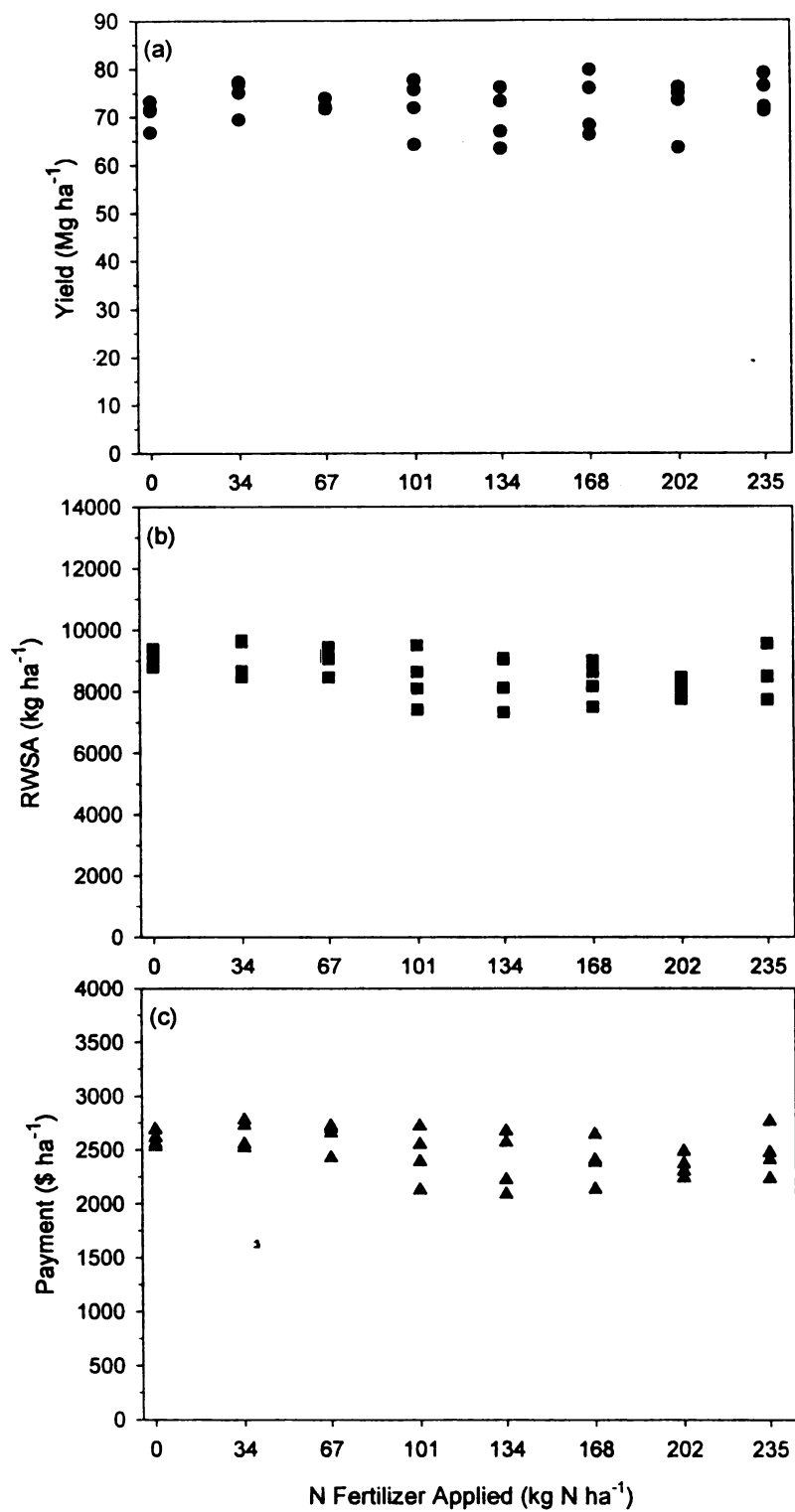


Figure 1.5. 2002-5 yield (a), RWSA, (b), and payment (c) responses to N.

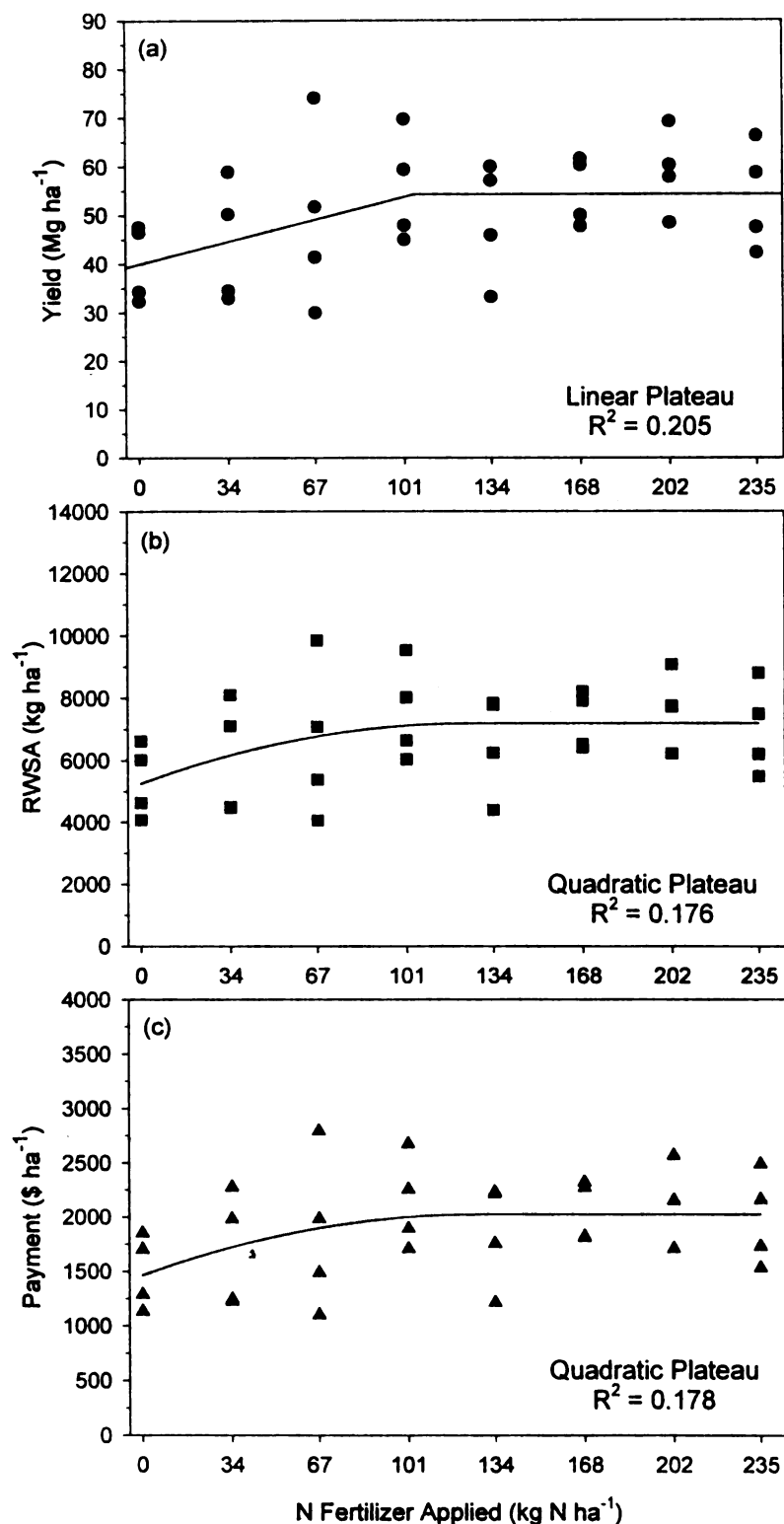


Figure 1.6. 2002-6 yield (a), RWSA (b), and payment (c) responses to N. The lines on each graph represent the chosen model for each parameter.

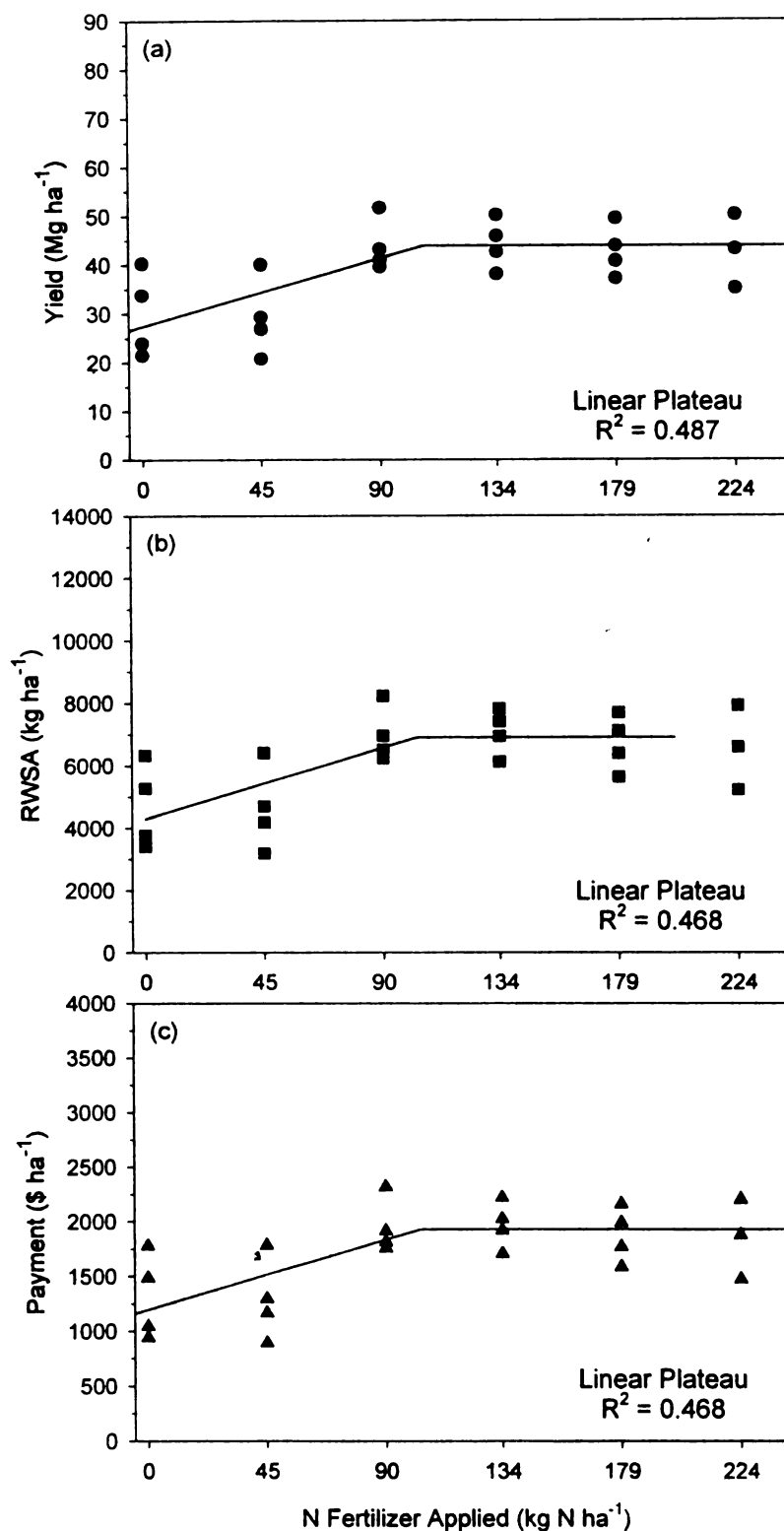


Figure 1.7. 2003-1 yield (a), RWSA (b), and payment (c) responses to N. The lines on each graph represent the chosen model for each parameter.

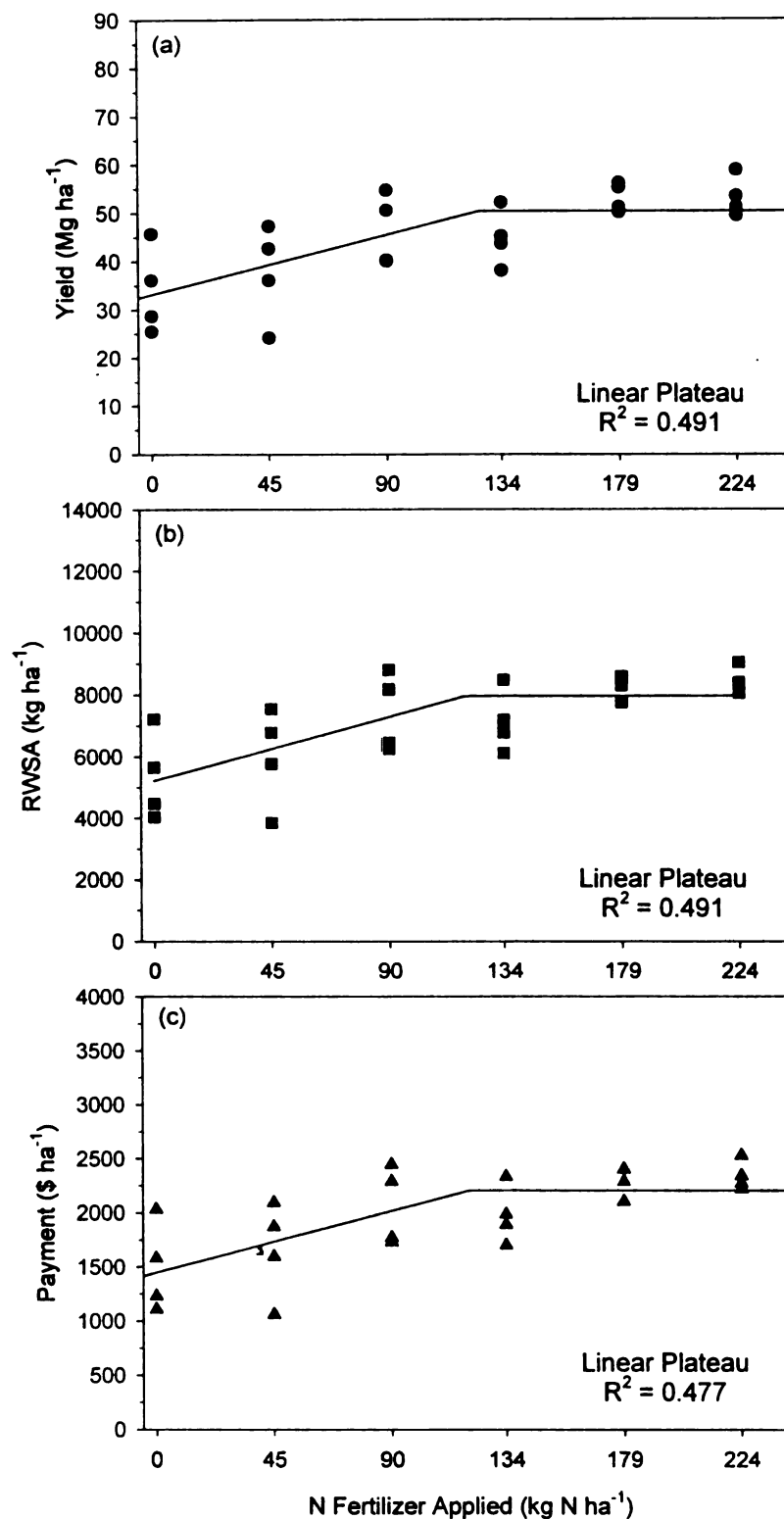


Figure 1.8. 2003-2 yield (a), RWSA (b), and payment (c) responses to N. The lines on each graph represent the chosen model for each parameter.

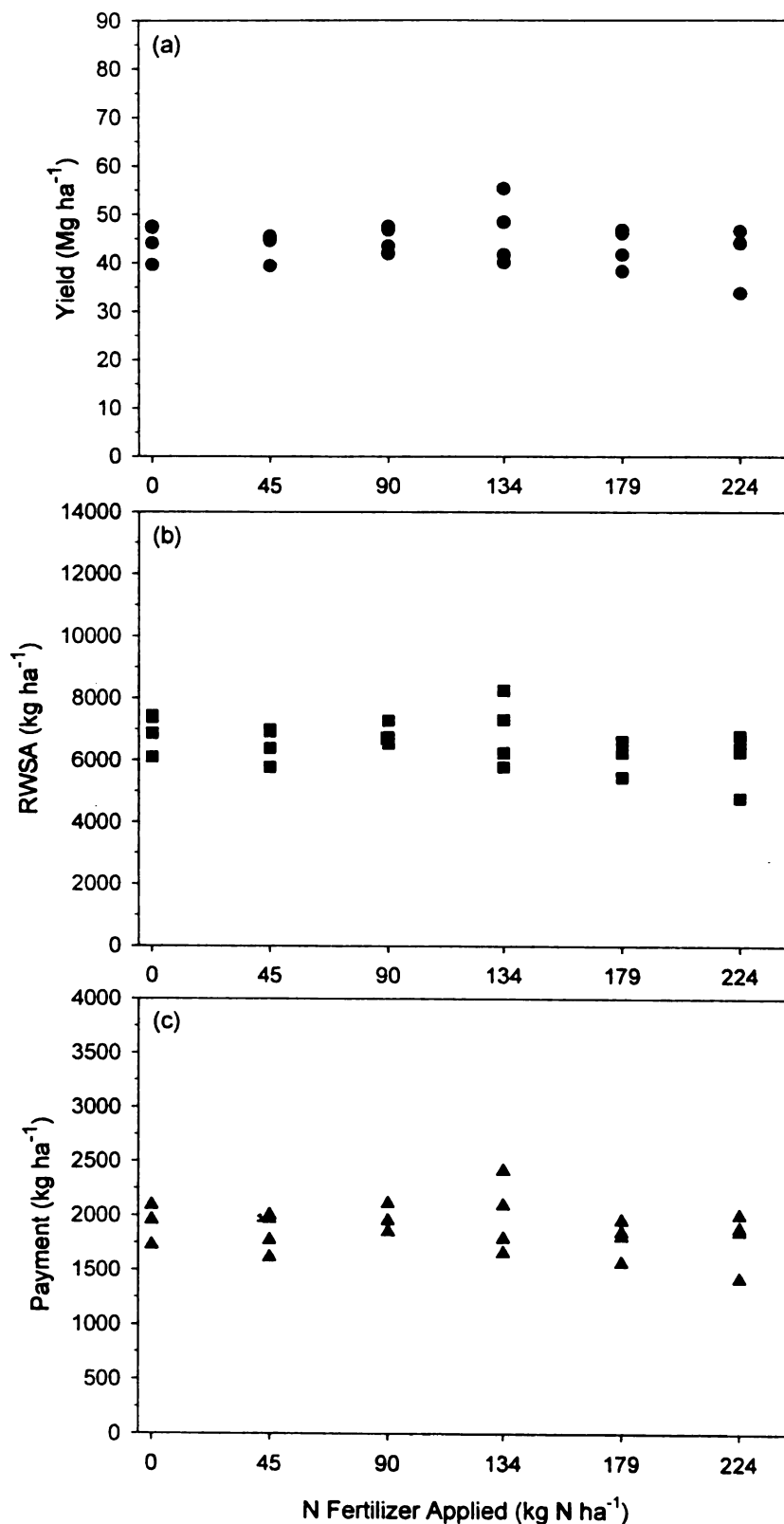


Figure 1.9. 2003-3 yield (a), RWSA (b), and payment (c) responses to N.

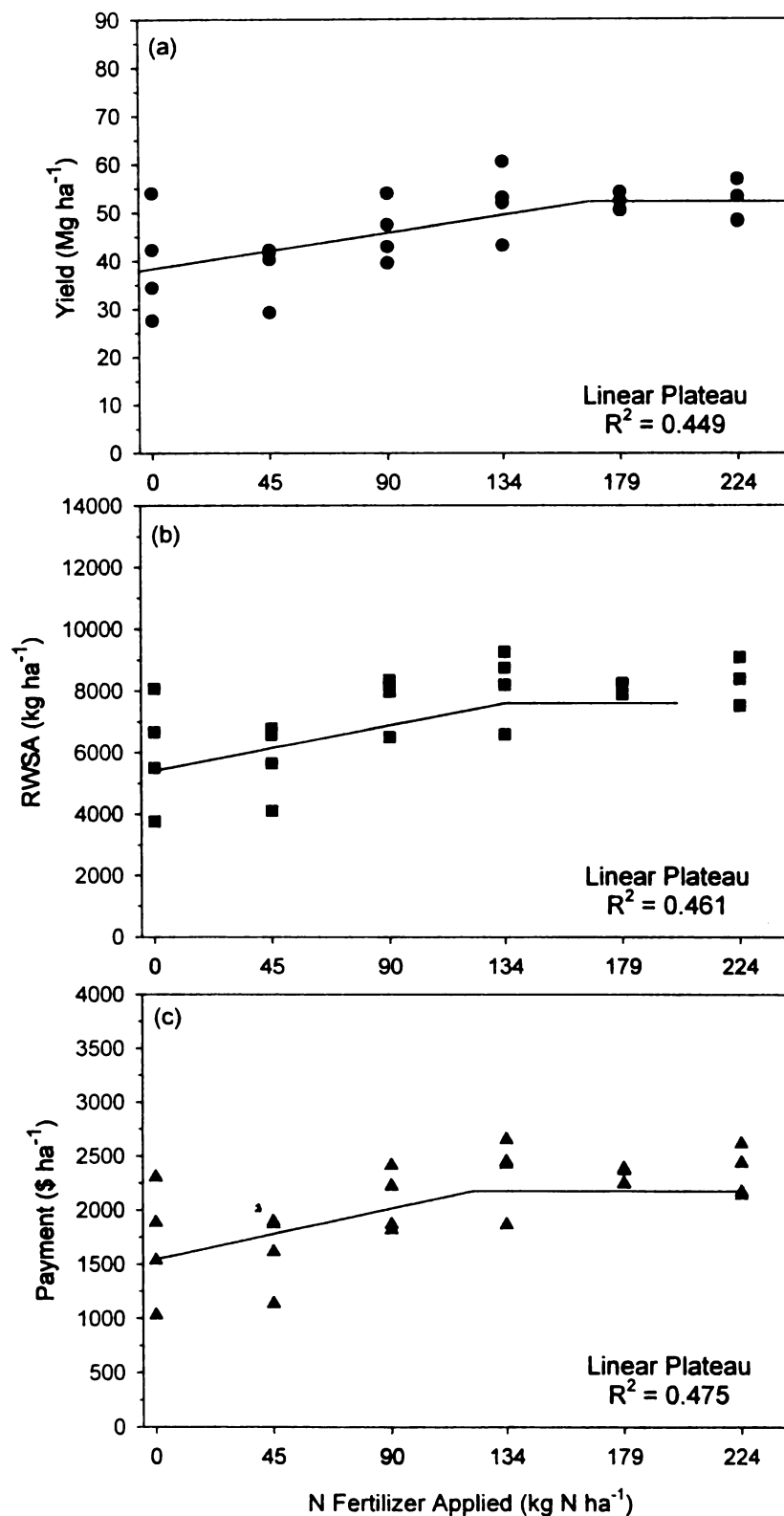


Figure 1.10. 2003-4 yield (a), RWSA (b), and payment (c) responses to N. The lines on each graph represent the chosen model for each parameter.

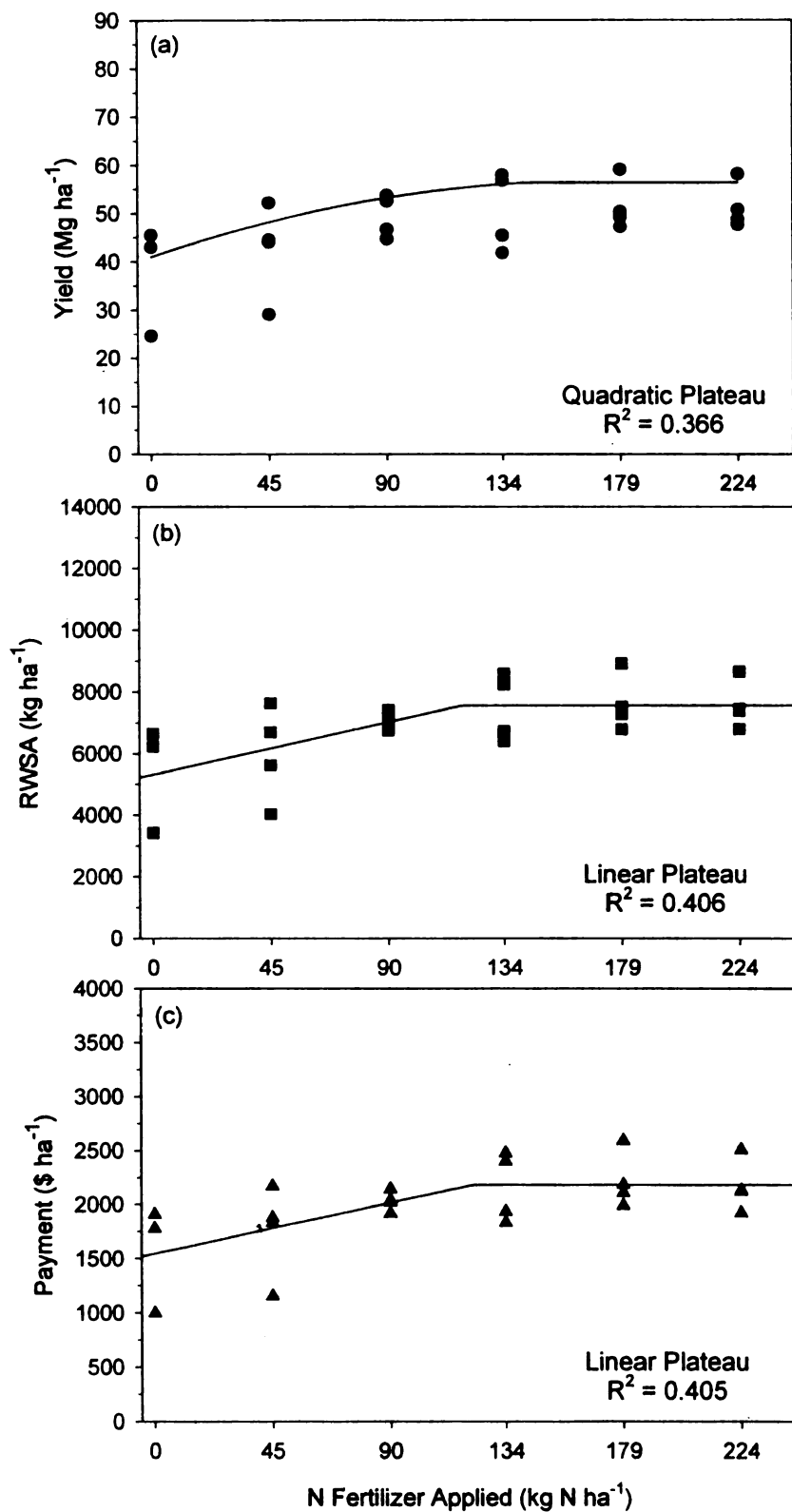


Figure 1.11. 2003-5 yield (a), RWSA (b), and payment (c) responses to N. The lines on each graph represent the chosen model for each parameter.

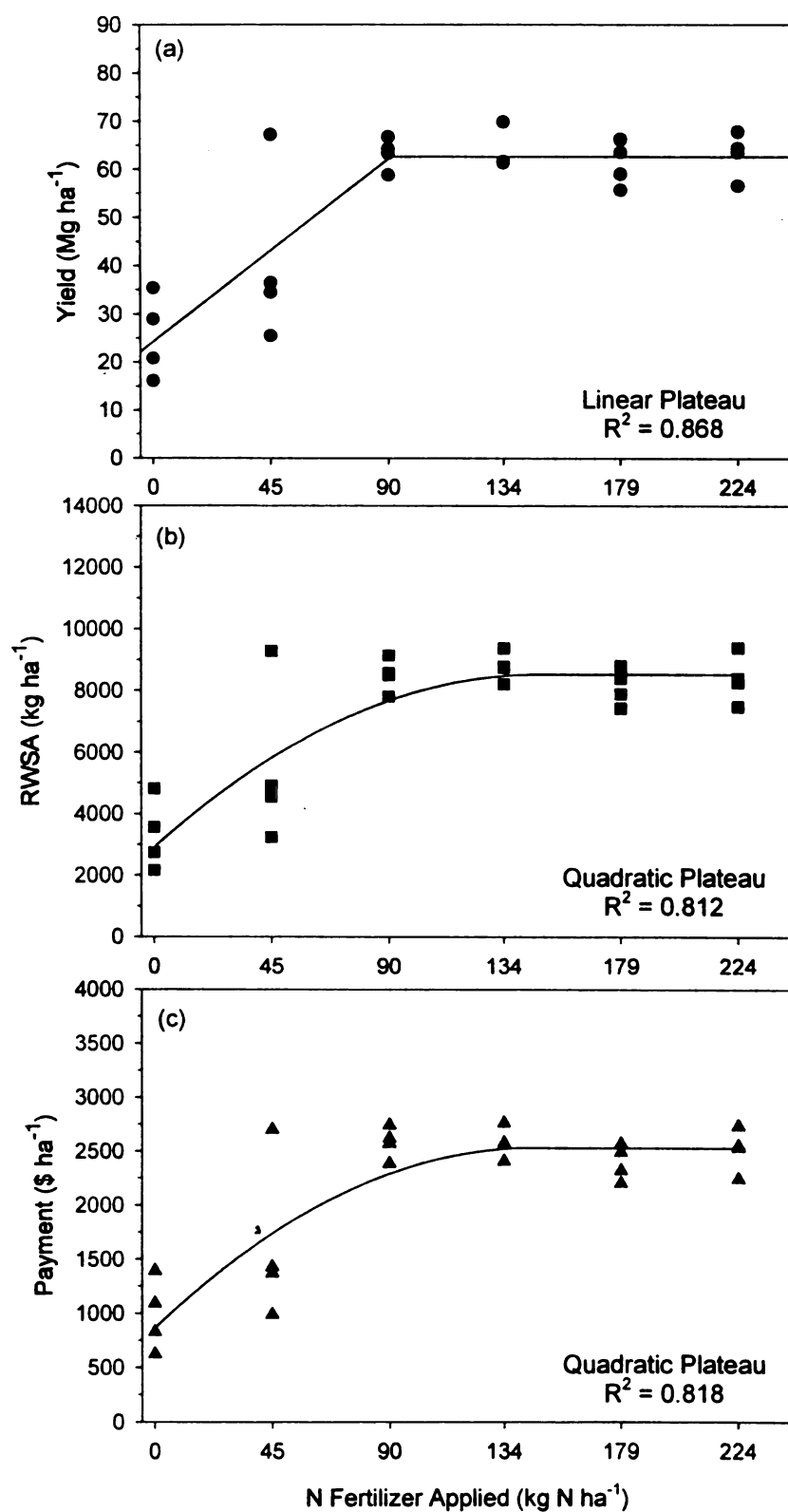


Figure 1.12. 2004-1 yield (a), RWSA (b), and payment (c) responses to N. The lines on each graph represent the chosen model for each parameter.

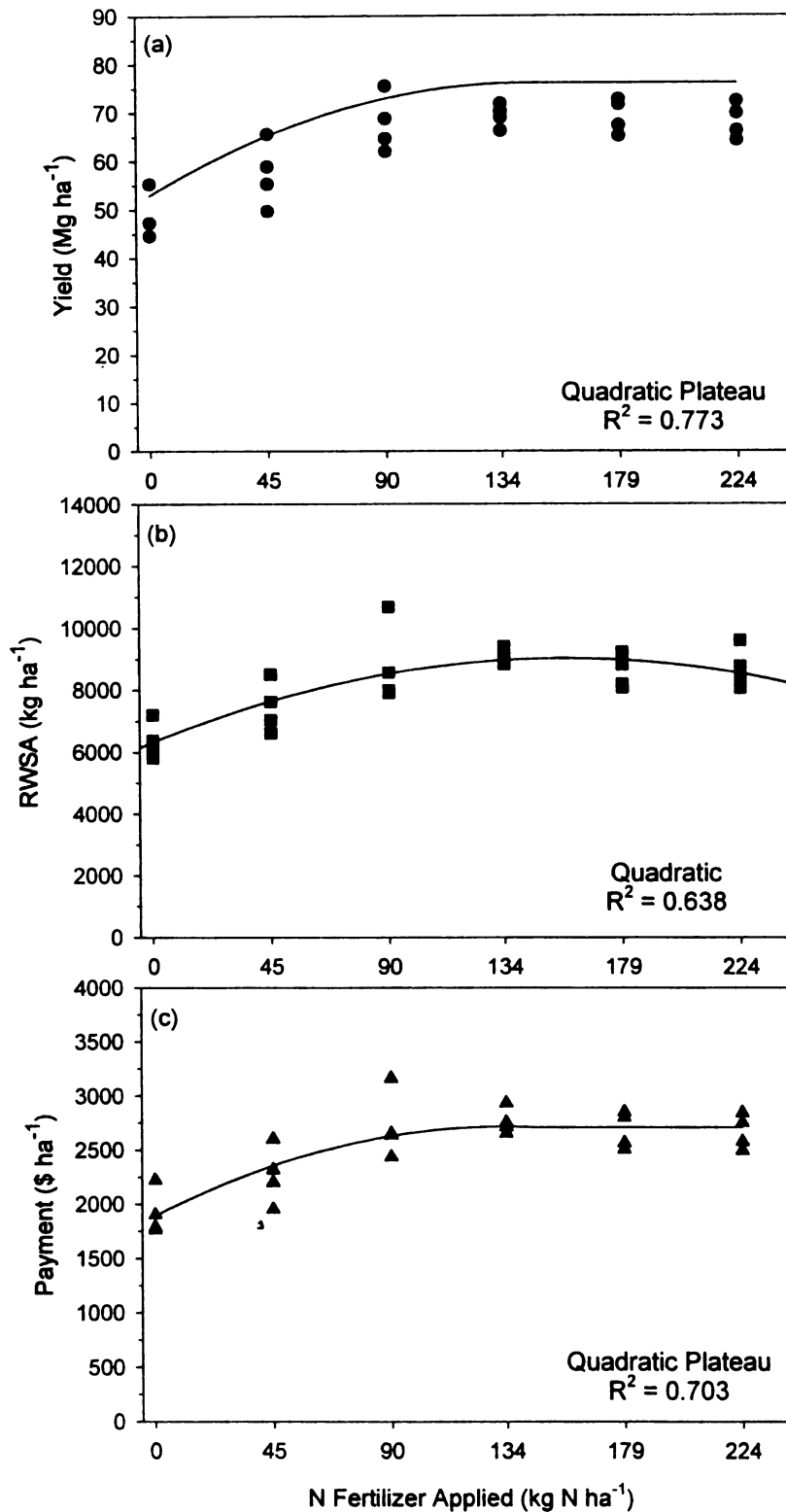


Figure 1.13. 2004-2 yield (a), RWSA (b), and payment (c) responses to N. The lines on each graph represent the chosen model for each parameter.

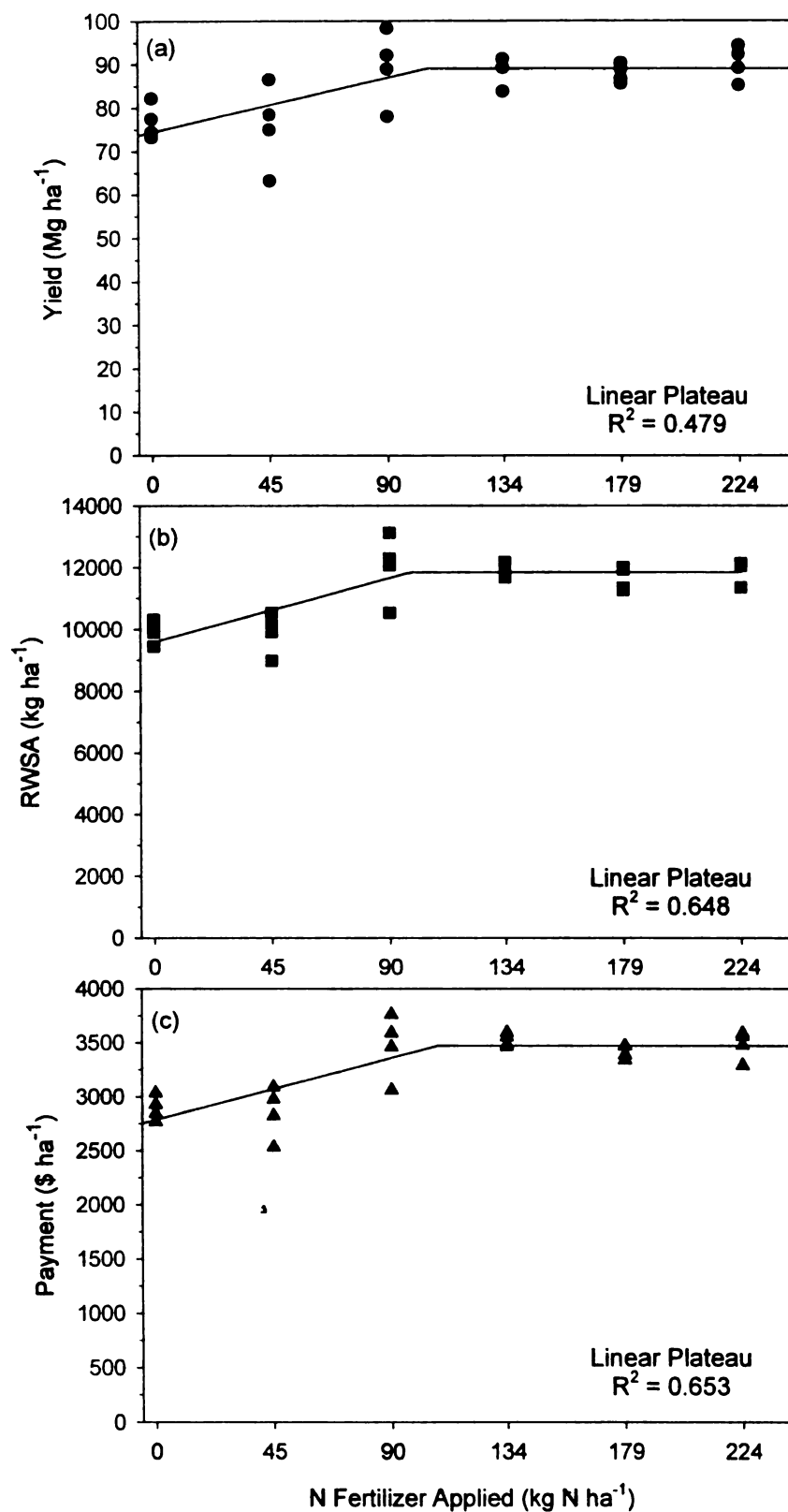


Figure 1.14. 2004-5 yield (a), RWSA (b), and payment (c) responses to N. The lines on each graph represent the chosen model for each parameter.

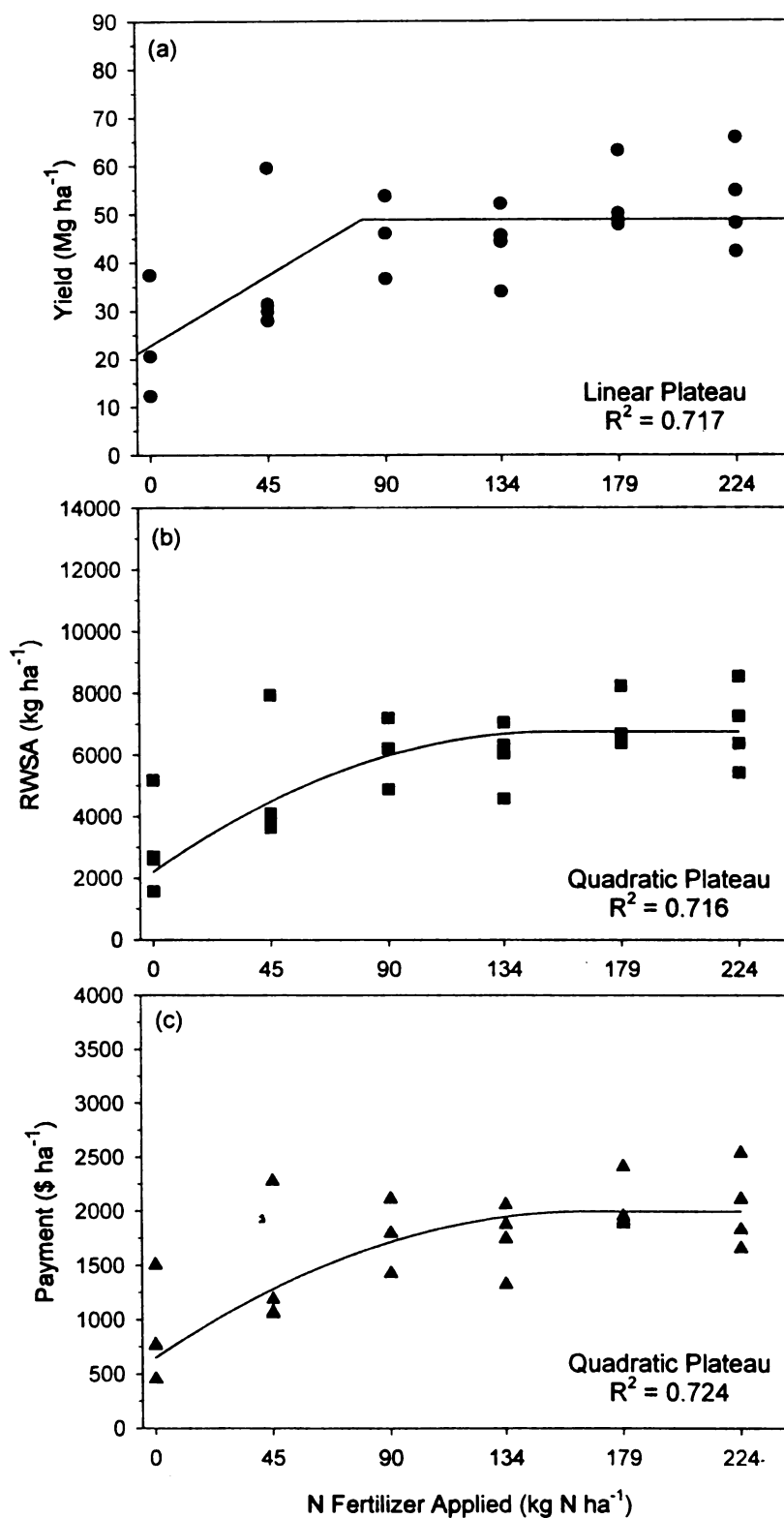


Figure 1.15. 2004-6 yield (a), RWSA (b), and payment (c) responses to N. The lines on each graph represent the chosen model for each parameter.

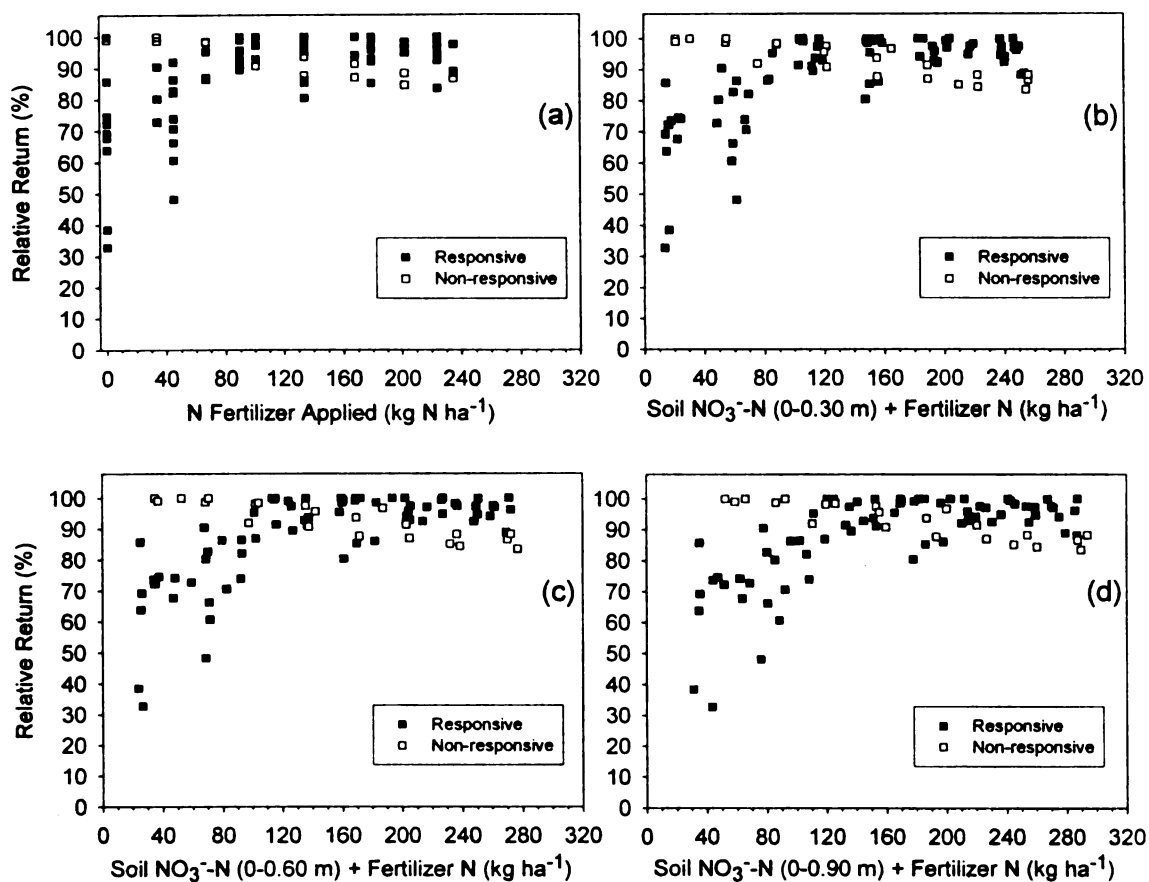


Figure 1.16. Relative return for applied fertilizer N (a) and soil NO₃⁻-N in 0 to 0.30 m (b), 0 to 0.60 m (c), and 0 to 0.90 m (d) soil samples plus fertilizer N.

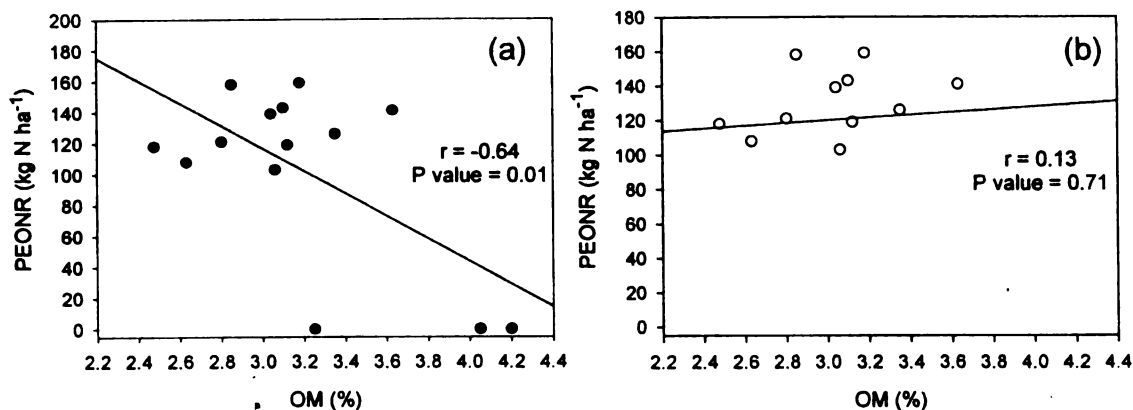


Figure 1.17. Relationships between organic matter and economic N rate for payment with all locations (a), and without non-responsive sites (b).

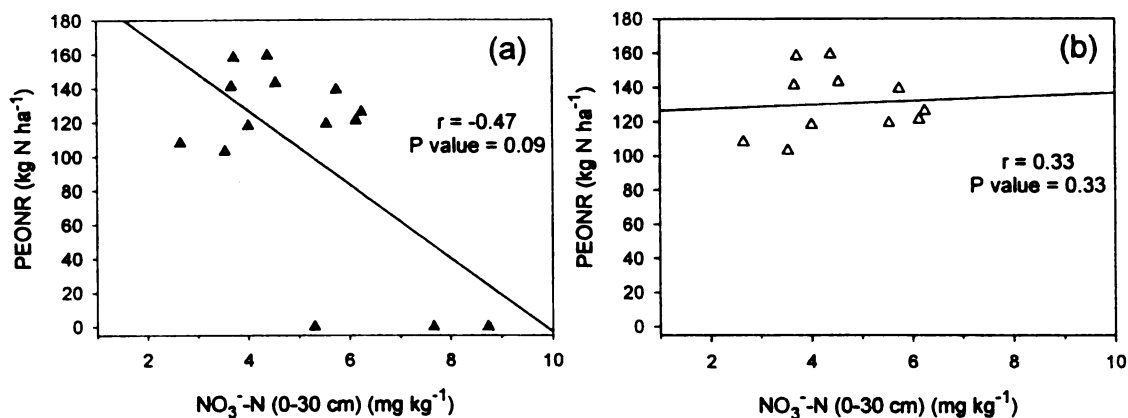


Figure 1.18. Relationships between NO₃⁻-N at a 0 to 0.30 m depth and economic N rate for payment with all locations (a), and without non-responsive sites (b).

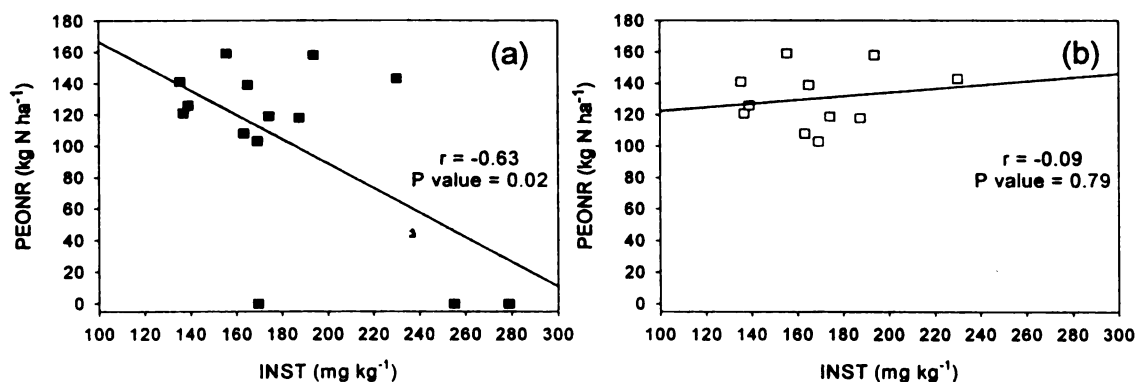


Figure 1.19. Relationships between INST at a 0 to 0.30 m depth and economic N rate for payment with all locations (a), and without non-responsive sites (b).

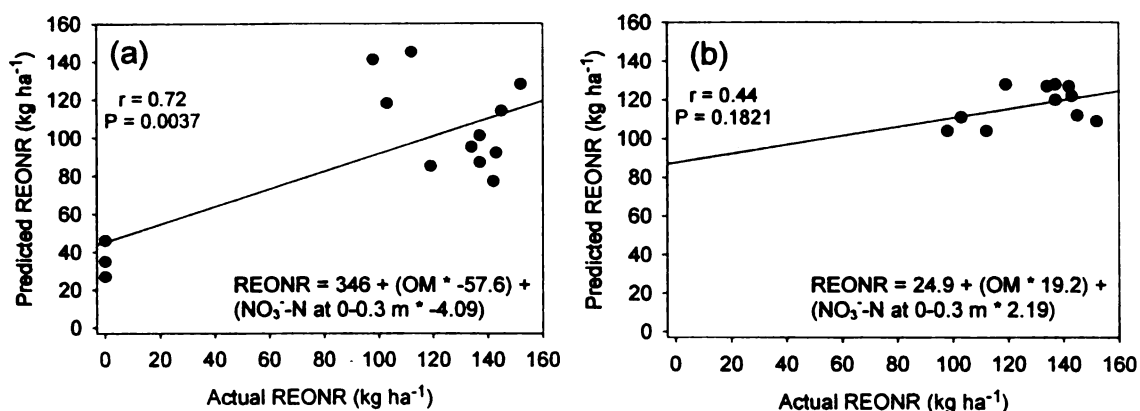


Figure 1.20. Actual REONR plotted with predicted REONR with all the data (a) and without non-responsive sites (b) using a model that includes OM and $\text{NO}_3\text{-N}$ at 0-0.30 m.

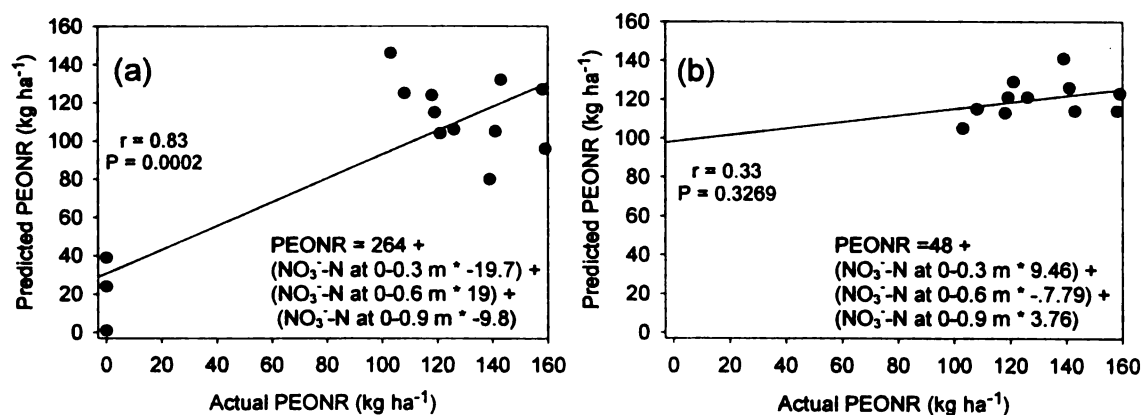


Figure 1.21. Actual PEONR plotted with predicted PEONR with all the data (a) and without non-responsive sites (b) using a model that includes $\text{NO}_3\text{-N}$ at 0-0.3 m, $\text{NO}_3\text{-N}$ at 0-0.6 m, and $\text{NO}_3\text{-N}$ at 0-0.9 m.

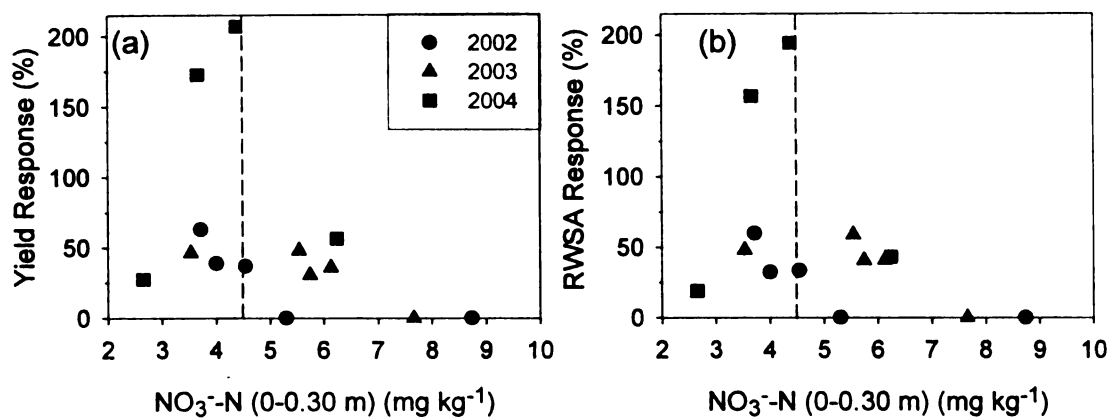


Figure 1.22. Yield (a) and RWSA (b) response to NO_3^- -N at a depth of 0 to 0.30 m.

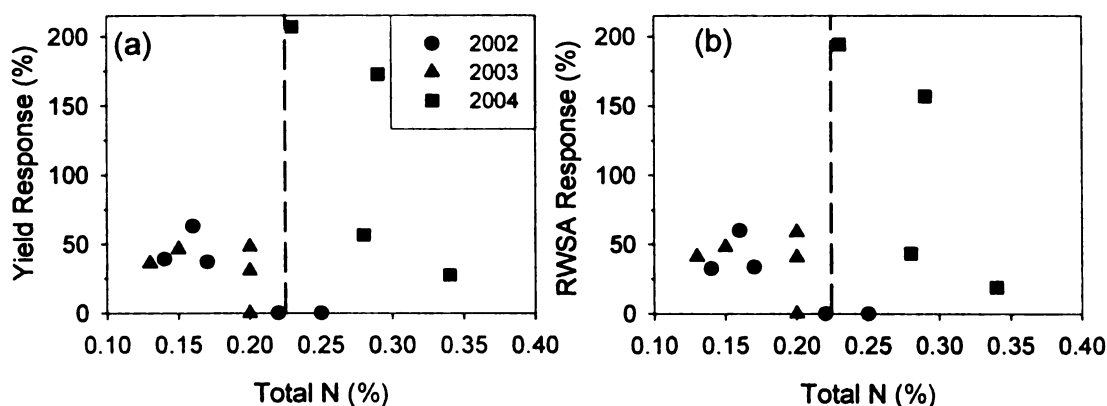


Figure 1.23. Yield (a) and RWSA (b) response to total N at a depth of 0 to 0.15 m.

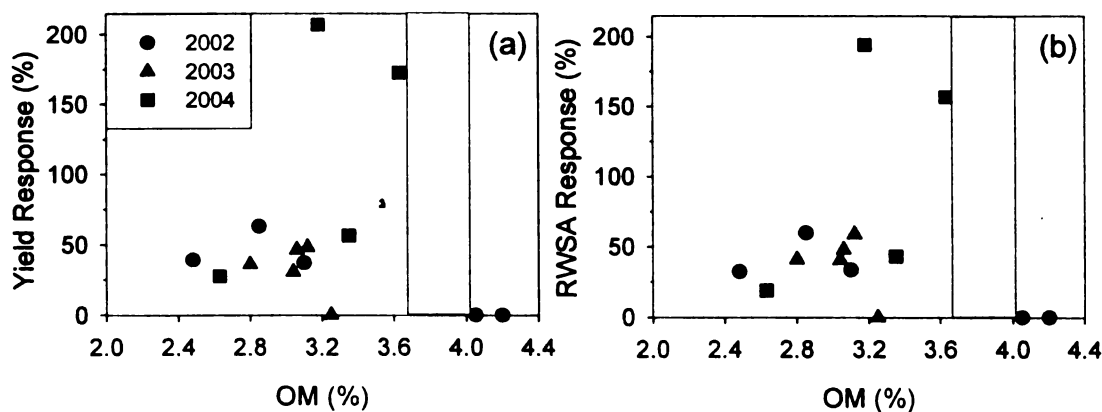


Figure 1.24. Yield (a) and RWSA (b) response to organic matter at a depth of 0 to 0.15 m.

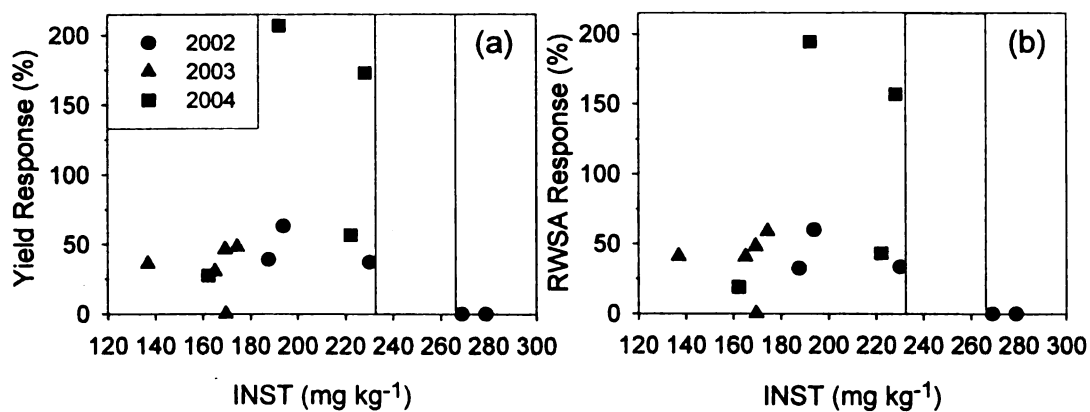


Figure 1.25. Yield (a) and RWSA (b) response to INST at a depth of 0 to 0.30 m.

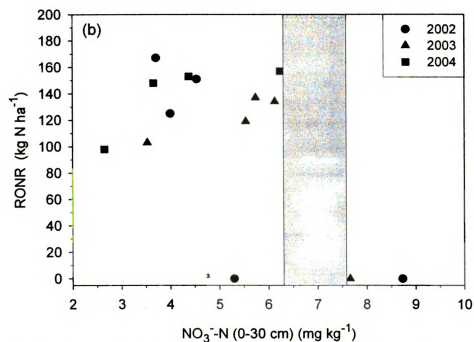
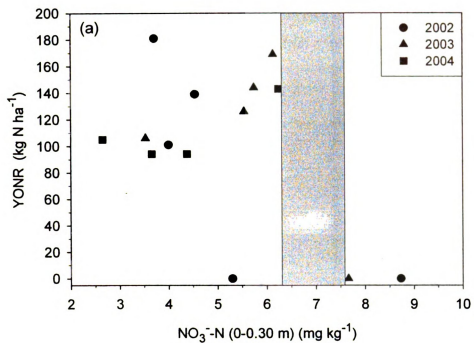


Figure 1.26. Yield (a) and RWSA (b) optimum N rates compared to $\text{NO}_3^- \text{-N}$ at a depth of 0 to 0.30 m at all locations.

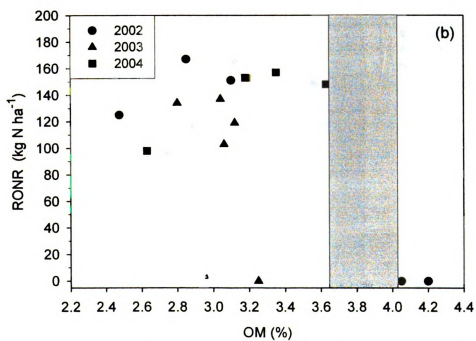
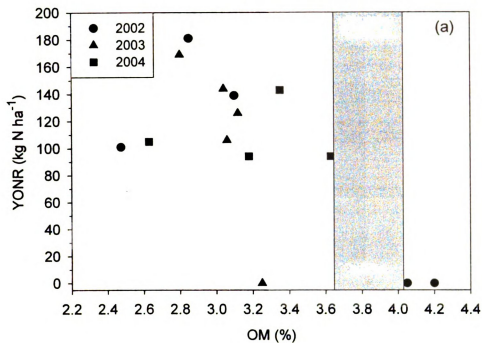


Figure 1.27. Yield (a) and RWSA (b) optimum N rates compared to organic matter at a depth of 0 to 0.15 m at all locations.

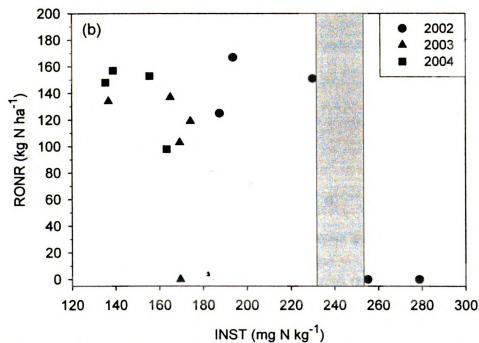
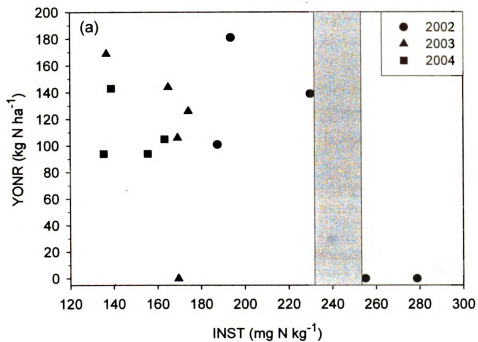


Figure 1.28. Yield (a) and RWSA (b) optimum N rates compared to INST at a depth of 0 to 0.30 m at all locations.

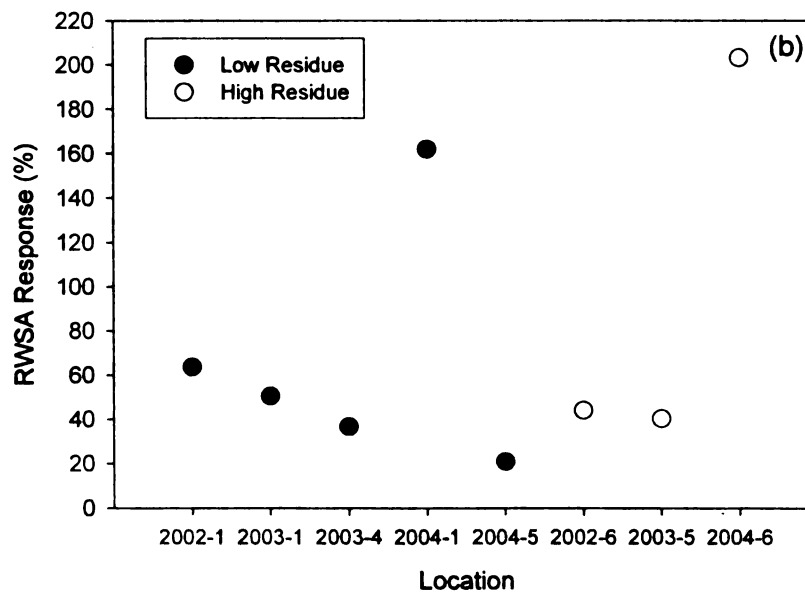
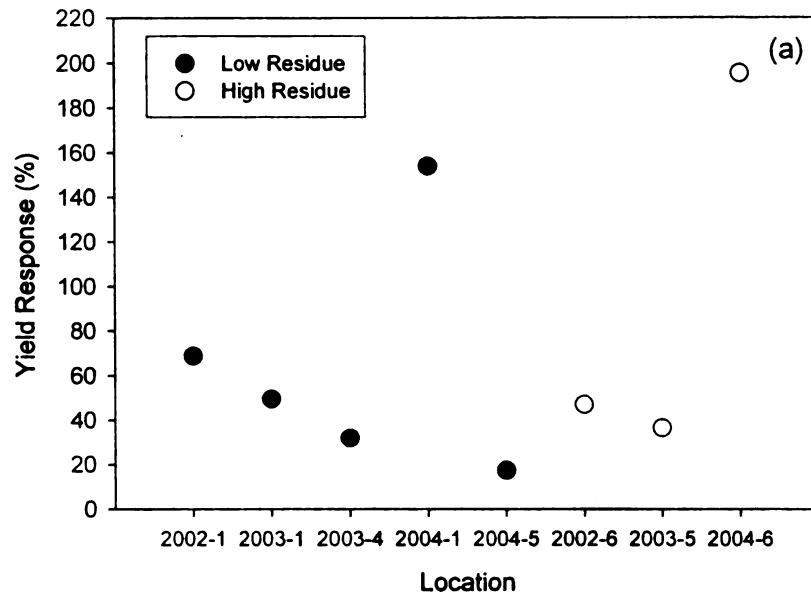


Figure 1.29. Sugarbeet ³ yield (a) and RWSA (b) response to N fertilizer at locations with low and high residue.

CHAPTER 2

NITROGEN FERTILIZER EFFECTS ON EARLY SEASON WEED EMERGENCE AND GROWTH

INTRODUCTION

Good crop production practices include control of pests, including weeds, and timely application of fertilizers (Scott and Jaggard, 1993). Weeds are difficult to control in sugarbeet (*Beta vulgaris* L.) production systems because of limited herbicide options that require weeds to be very small (less than 2 cm) at the time of application. Therefore, weeds are usually controlled by timely and repeated herbicide applications and cultivation. Weeds that emerge at the same time as the crop are very detrimental to sugarbeet yield and quality (Dotzenko et al., 1969). To avoid yield loss, weeds should be controlled by four weeks after sugarbeet emergence (Dexter, 2005). Therefore, limiting the number of weeds that emerge or reducing the growth of weeds would be very beneficial to sugarbeet growers.

Weed seed germination is triggered by various factors including soil temperature, soil moisture, light, and nitrates (Booth et al., 2003). Nitrates have triggered germination of some weed species, but not others (Fawcett and Slife, 1978; Sexsmith and Pittman, 1963; Steinbauer and Grigsby, 1957). Nitrogen timing and placement has influenced weed competition in crops such as corn and small grains (Alkämper, 1976; Anderson, 1991; Carlson and Hill, 1985; Hellwig et al., 2002; Pyšek and Lepš, 1991), as well as sugarbeets (Paolini et al., 1999).

Early N application caused *Sinapsis arvensis* to be more competitive with

sugarbeet; however, early application of N increased sugarbeet competitiveness with common lambsquarters (Paolini et al., 1999). Therefore, the timing of N fertilizer application in sugarbeet, as well as the placement of N fertilizer, may influence the germination, emergence, and subsequent management of weeds in sugarbeet. The objective of this research was to determine the influence of N on emergence and growth of weed species that are prevalent in the sugarbeet production region of Michigan. An extensive literature review is located in Appendix D.

MATERIALS AND METHODS

Field Experiment

This research was conducted at the Michigan State University Crop and Soil Sciences Agronomy Farm near East Lansing, Michigan in 2003 and 2004. The experimental design was a split plot with four replications. The main plot was the time of N application, and the subplot was the application rate of N. The entire field was tilled on April 15 and April 6 in 2003 and 2004, respectively, to a 10 cm depth with a Sunflower® field cultivator prior to the first N application. Nitrogen in the form of urea ammonium nitrate (UAN 28%) was preplant broadcast at rates of 0 (control), 56, 112, and 168 kg N ha⁻¹ and immediately incorporated with a Triple K® field cultivator (4 rows of 6.4 cm sweeps and rolling baskets) to a 5 cm depth. The field in 2003 was a sandy loam soil with a pH of 6 and 2.5% soil organic matter. The field in 2004 was a sandy clay loam soil with a pH of 7.3 and 2.1% soil organic matter. In 2003, N was applied on April 15, April

29, and May 21; 2004 application dates were April 6, April 20, and May 20. At each application date, HOBO[®] monitors were placed in each replication of the field at a depth of 2.5 cm to monitor soil temperature. Each weed species was seeded in a circular area 8 cm in diameter in the center 1 m² area of each plot. Weed species included redroot pigweed (*Amaranthus retroflexus* L.), velvetleaf (*Abutilon theophrasti* Medic.), common lambsquarters (*Chenopodium album* L.), ladysthumb smartweed (*Polygonum persicaria* L.), giant foxtail (*Setaria faberi* Herrm.), eastern black nightshade (*Solanum ptycanthum* Dun.), and common ragweed (*Ambrosia artemisiifolia* L.). Seed used in 2003 was collected in 2000 to 2001 and stored in a cooler at 4°C. Seed used in 2004 was collected from fields in 2003 and stored in a cooler at 4°C. Common ragweed and eastern black nightshade were not seeded in 2004 because of a lack of emergence in 2003. Seeding rates for each species varied (Table 2.1) and were based on preliminary germination tests where 100 seeds of each species were placed on moistened filter paper at a temperature of 22°C for a ten-day period. The seeding rates in the field were then based on the potential for 50 weed seedlings per species. Weed emergence and growth stage (leaf number) were documented every seven days until 42 days after planting. Seedlings in the circular areas were then harvested, dried, and weighed to determine total weed biomass. Two quadrats (0.25 m² each) were also evaluated in the non-seeded area to determine how N influenced the emergence and biomass of the natural field population of weeds.

In 2003, soil samples were collected from a depth of 0 to 8 cm before fertilizer application in the control plots and 7, 14, and 21 days after application in all plots. In 2004, samples were collected from 0 to 8 cm and 8 to 16 cm in the control plots prior to fertilizer application and 7, 21, and 35 days after application in all plots. An 8 to 16 cm depth was added in 2004 to determine if available N was increasing at this depth; a sign of potential leaching of applied N. All soil samples were air-dried, ground, sieved through a 2 mm sieve, mixed thoroughly to ensure homogeneity, and were analyzed to determine NO_3^- -N (Brown, 1998) and NH_4^+ -N (Keeney and Nelson, 1982).

Statistical Analysis

The PROC CORR procedure in SAS (SAS Institute, 1999) was used to determine if the N applied to the field was correlated to the total inorganic N (NO_3^- -N plus NH_4^+ -N) from soil analysis represented as N_i . Determinations of significant relationships between weed emergence or growth and the N treatment, time of N application, or the interaction between N and time of N application were made by using the PROC MIXED procedure (SAS Institute, 1999). Regression analyses were performed by fitting linear models with Sigma Plot (Sigma Plot, 2001).

Greenhouse Experiment

A greenhouse experiment was conducted to determine the effect of N on weed emergence. Soil was collected from the 2004 field. The soil was sieved through a 2 mm sieve and stored in a 4°C cooler. Common lambsquarters, giant

foxtail, ladysthumb smartweed, redroot pigweed, and velvetleaf seeds were buried in nylon sacks from May until August and then were stored in a 4°C cooler prior to use. Thirty seeds of each weed species were placed in a 150 mm diameter x 15 mm deep petri dish. Approximately 150 g of soil was placed on top of the seeds. Urea ammonium nitrate (UAN 28%) was sprayed over the petri dishes using a single tip track sprayer with a TeeJet® 8001E nozzle at rates of 0, 56, 112, and 168 kg N ha⁻¹. A similar volume of water was sprayed such that each petri dish received a total of 168 kg ha⁻¹ of liquid. Immediately after treatment, the petri dishes were transferred to the greenhouse where 20 mL of water was added to every petri dish. The petri dishes were then sealed with parafilm, and aluminum foil was used to cover the petri dishes to reduce bacterial or fungal growth inside the petri dishes. The petri dishes were placed on a greenhouse bench in a randomized complete block design, with three replications per treatment. Greenhouse temperature ranged from 25 to 33°C. After seven days, the petri dishes were evaluated for seedling emergence, and soil from each treatment was analyzed for NO₃⁻-N and NH₄⁺-N. This study was repeated three times.

Statistical Analysis

The PROC CORR procedure in SAS (SAS Institute, 1999) was used to determine if the N applied was correlated to the total inorganic N (NO₃⁻-N plus NH₄⁺-N) from the soil analysis represented as N_{it}. Weed emergence data was analyzed using the PROC GLM procedure with SAS (SAS Institute, 1999) to

determine significant differences between N treatments using Fisher's protected LSD at the 95% confidence level.

RESULTS AND DISCUSSION

Field Experiment

Soil Analysis

Soil samples were collected to determine the amount of available N (total inorganic N or N_{it}) in the soil prior to and following N application (Appendix E). Figures 2.1 and 2.2 depict the soil N levels at each seeding date in 2003 and 2004 at a depth of 0 to 8 cm. Total inorganic N in 2004 in the 8 to 16 cm depth, 21 days after N application was 15 kg N ha^{-1} (on average) in the plots that received N (Appendix F). Typically, N increased in plots with fertilizer N in the 8 to 16 cm depth by 5 kg N ha^{-1} compared to the control, indicating that some nitrate may have leached below the zone of incorporation (0 to 8 cm).

There was a significant correlation ($P = 0.0506$) between the amount of N available in the soil and the amount of N applied (SAS Institute, 1999) (Table 2.2). However, not the entire N that was applied was recovered by the soil test as available N. For example, at the April 15 application date in 2003, the N recovered one week after application was highly correlated with the N applied ($P = 0.0001$), and was at least 95% of what had been applied. However, by three weeks after application, the N in the 0 to 8 cm of soil was still correlated ($P = 0.0035$) to the N applied; but the N recovered was 40% of what had been applied. At no other sampling date in 2003 or 2004 did the N available in the soil

reach 95 to 100% of the N applied, although a correlation between what was applied and the amount of N available in the soil still existed. Differences in N availability may reflect natural N cycle losses including immobilization, volatilization, denitrification, and leaching.

The experiment was conducted in a field that had a previous soybean crop in 2003, and was fallow the year prior to seeding in 2004. The C:N ratio in soybean residue is 30:1, indicating that some N should have been available from the previous crop, and not all N would have been immobilized. In the fallow field, prior to 2004 research, weeds were allowed to grow, providing cover to the soil. The weeds C:N ratio may be comparable to alfalfa, approximately 13:1; therefore, more residual N should have been in this field compared to 2003 when the previous crop was soybean. Residues with larger C:N ratios immobilize more N than residues with lower C:N ratios. In 2003, more of the applied N may have been immobilized once soil temperatures reached 13°C. In 2004, N losses from denitrification or volatilization may have been more important, since N losses due to leaching into the 8 to 16 cm zone did not exceed 5 kg N ha⁻¹.

Nitrogen loss may also occur through denitrification, volatilization, and leaching. Denitrification of nitrate to N₂O gas increases in saturated soils and at temperatures ranging from 13 to 27°C. Volatilization of ammonia gas increases if urea is surface applied in warm, moist soils with large amounts of residue. If the field is irrigated or if it rains at least 1.3 cm after urea application, urea will be incorporated into the soil, and less total N loss may occur. Nitrate is the only

form of available N that is subject to leaching and is directly proportional to the amount of precipitation that occurs after N application.

Soil temperature and precipitation were not limiting for weed seed germination in 2003 and 2004; however, N loss could have occurred throughout the entire experiment. At the early N application dates (April 15 and April 6), the risk of loss to denitrification was minimal because the average daily soil temperature was below 13°C for 5 days in 2003 (Figure 2.3) and 10 days in 2004 (Figure 2.5). Precipitation was less than 1 cm through 7 days after N application in both years (Figures 2.4 and 2.6). However, this does not indicate that denitrification never occurred. The risk of N loss to volatilization was also low because the urea ammonium nitrate was incorporated with tillage immediately following application. Furthermore, during the early N application dates, the soil was cooler and drier than the later application dates, lowering the risk of immobilization and volatilization. Leaching during the early application dates should also have been minimal, as rainfall totals were less than 1 cm for 2003 and 2004 one week after application.

During the mid-application dates in 2003 and 2004 (April 29 and April 20), there were only 3 days in each year that were below 13°C; 7°C was the lowest temperature in 2003 and 11°C in 2004. Warmer temperatures were suitable for denitrification, and a 3.7 cm rainfall event on May 1 in 2003 may have increased denitrification. Precipitation in 2004 may not have caused saturated conditions as it totaled 3 cm over 7 days, but denitrification was still possible. The increased rainfall in 2003 and 2004 in late April could have contributed to

leaching of nitrate during this time. Volatilization losses would have been minimized because the N would have been incorporated by the rainfall event, which was greater than 1.3 cm.

During the application dates in May of 2003 and 2004, temperatures were within the range suitable for immobilization and denitrification (13 to 27°C). The May application date in 2004 was especially subject to denitrification as approximately 9 cm of precipitation occurred within seven days after N application. The warm, moist conditions in 2004 were also favorable for volatilization; temperatures in 2003 were suitable for volatilization, but there were only three days where approximately 1.5 cm of rainfall occurred. Because precipitation was sporadic in 2003, it is unlikely that nitrate leaching occurred. However, in 2004, the greater amounts of precipitation would cause nitrate to leach through the soil profile.

We can conclude that the N available in our research was in proportion to the N applied (Table 2.2), but the entire N applied was not available. Differences in previous researchers' results with the influence of applied N on weed emergence and growth (Fawcett and Slife, 1978; Freyman et al., 1989; Sexsmith and Pittman, 1963; Steinbauer and Grigsby, 1957) may be due to the previous crop and the temperature and moisture regime during the experiments, which may contribute to differences in available N. In all previous research, available soil N was not reported.

Weed Emergence

Because weeds vary in their time and duration of emergence, weeds were seeded at three dates, which correspond to the time period that sugarbeets could be planted in Michigan. Ideally, sugarbeets are planted in early April, but sugarbeets may not get planted due to wet conditions or are replanted in mid-May because of early season stand loss. Common lambsquarters and ladythumb smartweed are typically early emerging weeds, and lambsquarters has a much greater length of emergence than smartweed (Myers et al., 2004). Giant foxtail and velvetleaf emerge somewhat later in the growing season, followed by redroot pigweed (Myers et al., 2004). In 2003, greater numbers of ladythumb smartweed emerged following the earliest seeding date (April 15) (Figure 2.7), while common lambsquarters, giant foxtail, velvetleaf, and redroot pigweed emergence was greatest at the late seeding date (May 21) (Figures 2.7 and 2.9). In 2004, common lambsquarters and giant foxtail emergence was greatest during the earliest seeding date (April 6), and velvetleaf and redroot pigweed emergence was greatest at the late seeding date (May 20) (Figures 2.8 and 2.10). Ladythumb smartweed emergence was similar across all seeding dates in 2004 (Figure 2.8).

Differences in emergence may be affected by seed source and the relative degree of dormancy of the seed, as well as soil temperature. For example, common lambsquarters seed containing high amounts of nitrate emerged earlier because seed that contained nitrate was less dormant (Fawcett and Slife, 1978). Common lambsquarters seed containing low concentrations of nitrate may

emerge later because the seed may require other triggers, such as higher temperatures or additional nitrate, for germination (Baskin and Baskin, 1998; Fawcett and Slife, 1978). If seeds in our experiment were planted later in the season, (June and July), N may have had more of an effect on later emerging weed species like redroot pigweed.

Urea ammonium nitrate was applied at each of the three seeding dates to determine if N influenced the percent emergence of each weed species. Hypotheses were created based on previous reports in the literature, that N should increase emergence of common lambsquarters, ladythumb smartweed, velvetleaf, and have no effect on giant foxtail (Fawcett and Slife, 1978; Freyman et al., 1989; Hurtt and Taylorson, 1986). Figures 2.7 through 2.10 show the percent emergence of each weed species in the different N plots for each application date in 2003 and 2004. Common lambsquarters emergence increased with increasing N at all three application dates in 2003 (Figure 2.7). Common lambsquarters emergence increased by 10, 10, and 20% in the 168 kg N ha⁻¹ application rate compared to the control (0 kg N ha⁻¹) 42 days after application in 2003 at the April 6, April 29, and May 21 application dates, respectively.

Common lambsquarters emergence at all seeding dates was less than 10% in 2004 (Figure 2.8). Nitrogen application increased common lambsquarters emergence in the early (April 6) seeding date only. Overall, N may increase common lambsquarters emergence early in the growing season. It is possible that the source of seed in 2003 and 2004 may be a factor in the yearly

emergence differences. The seed in 2003 may have been less dormant because of longer storage conditions and/or greater nitrate concentrations in the seed because of maternal effects (Baskin and Baskin, 1998; Fawcett and Slife, 1978). Lower nitrate concentrations in the seed results in a greater effect of nitrate on emergence, because the seed may need additional exposure to nitrate for germination. Because the seed used in 2004 was collected the previous fall from fallow fields, common lambsquarters emergence should have responded to additional N, but the seed may have been in a deeper state of primary dormancy. Fawcett and Slife (1978) Freyman et al. (1989) also found no effect of N on common lambsquarters emergence, similar to results from 2004.

Ladysthumb smartweed emergence was less than 10% in 2003 and 2004 (Figures 2.7 and 2.8). Emergence of ladysthumb smartweed is thought to be triggered by low winter temperatures (Benech-Arnold et al., 2000). Lack of ladysthumb smartweed emergence may be due to storage conditions enforcing a greater degree of dormancy. Even though emergence of ladysthumb smartweed was low, N increased emergence in the early application dates (April 15, 2003 and April 6, 2004). In 2003, there was a significant increase in ladysthumb smartweed emergence as N rate increased in the late May application date (May 21), and in 2004, there was an increase as N rate increased in the mid application date (April 20). Nitrogen appeared to increase emergence of ladysthumb smartweed, supporting research by Freyman et al. (1989).

Giant foxtail emergence increased as N rates increased in both years only at the early seeding dates (Figures 2.9 and 2.10). Anderson et al. (1998) and

O'Donovan et al. (1997) found application of fertilizer N as ammonium nitrate or urea decreased the emergence of green foxtail. In this study giant foxtail emergence decreased in 2003 with the mid (April 29) and late (May 21) N application dates, supporting these researchers results with a different species of foxtail. However, in 2004, giant foxtail emergence was not affected with increasing available N in the mid (April 20) and late (May 20) N application dates. Fawcett and Slife (1978) found no effect of N on giant foxtail emergence. Nitrogen may not always influence the germination of giant foxtail seeds, but giant foxtail has dormancy cycling (Benech-Arnold et al., 2000), and as giant foxtail becomes unconditionally dormant, increased N may increase germination under cold soil temperatures only.

Velvetleaf emergence increased as available N increased at the early seeding date only in 2003 (Figure 2.9). In previous research, ammonium nitrate at 34 kg N ha⁻¹ stimulated velvetleaf emergence when applied in early May (Hurt and Taylorson, 1986), but had no effect on emergence when N was applied from 0 to 448 kg N ha⁻¹ (Fawcett and Slife, 1978). As with giant foxtail, it is possible that additional N increased emergence by decreasing seed dormancy only in early spring; and other dormancy factors were met as the season progressed, such that N had no effect on emergence at later dates.

Redroot pigweed emergence increased with N only at the mid-April seeding date in 2003 (Figure 2.9). Therefore, N had a limited effect on redroot pigweed emergence, similar to results of Schimpf and Palmblad (1980). Since redroot pigweed is a late emerging weed, applications of N beyond May 20 might

stimulate redroot pigweed germination and emergence later in the growing season.

Ideally, in this research it would have been desirable to precondition seeds to increase weed seed germination. It is difficult to make conclusions when emergence is less than 10% of the seed planted. However, seed was not subjected to cool and wet or warm and dry storage conditions or alternating temperatures in storage because this may confound the effect that nitrate or ammonium N has on germination and subsequent emergence of weeds.

Using two different seed lots from different years may have contributed to the variation in results, yet if the same seed was used each year (from 2000-2001), it would not have the same dormancy characteristics because it would be one year older in 2004. Understanding how dormancy is imposed in various weed species and what triggers release from dormancy, leading to subsequent germination and emergence is clearly of importance to weed scientists. It is difficult to design an experiment to look at the effect of available N on seed germination without understanding how seed age and maternal development influences dormancy and response to N. Perhaps this should be the focus of future research.

Weed Growth

Total weed biomass in the seeded area increased with increasing N application rates at all seeding dates in 2003 and in the early (April 6) and late (May 20) seeding dates in 2004 (Figures 2.11 and 2.12). These weeds would be

more difficult to control in sugarbeets where herbicides must be applied each time newly emerged weeds reach 1 cm in height.

The weeds at the late seeding dates (May 21 and May 20) in both years had greater biomass than the weeds at the earlier seeding dates because of warmer temperatures in the 42 days following seeding at the later dates. Weeds in late sugar beet plantings are more difficult to control with timely postemergence herbicide applications because growing degree days accumulate rapidly in later May and June (Dale, 2003).

In 2004, total weed biomass ranged from 0 to 10 g, which was less than 2003 (0 to 60 g). This was because of overall reduced populations of weeds in 2004. In 2004, weeds would be easier to control with timely herbicide applications because they did not grow as rapidly as in 2003. However, there was still a response to applied N in 2004, indicating that reducing N availability to emerging weed seedlings in the six weeks following sugarbeet planting would reduce weed growth and increase the grower's ability to make timely herbicide applications for better weed control.

Natural Weed Emergence and Growth

Natural weed populations in 2003 and 2004 included giant foxtail, redroot pigweed, and common lambsquarters. Weed densities in 2003 were 16, 3, and 40 m⁻², for giant foxtail, redroot pigweed, and common lambsquarters, respectively. Weed densities in 2004 were 72, 2, and 2 m⁻², for giant foxtail,

redroot pigweed, and common lambsquarters, respectively. Increasing available N did not increase the total number of weeds that emerged per square meter.

In 2003, giant foxtail emergence from natural populations was greater at the April 15 and April 29 seeding dates compared to the May 21 seeding date (Figure 2.13). In contrast, emergence was greatest in the May 20 seeding date in 2004 (Figure 2.14). Increasing amounts of available N in 2003 and 2004 did not increase emergence of giant foxtail in either year.

Natural populations of redroot pigweed were very low each year and increasing available N in 2003 or 2004 did not increase pigweed emergence (Figures 2.13 and 2.14). Common lambsquarters emergence also did not increase with available N in either year (Figures 2.13 and 2.14).

The field was tilled prior to experiment initiation in early April and then again prior to seeding each year. The field was tilled during the daytime which exposed some of the weed seeds in the natural seed bank to light. Small-seeded broadleaf weeds have a very low fluence response (VLFR), where the seeds have a high sensitivity to light (Benech-Arnold et al., 2000). VLFR's can be elicited with very short exposures to sunlight (milliseconds) (Benech-Arnold, 2000). Therefore tillage prior to experiment initiation and tillage prior to each seeding date and N application may have overridden any effect of applied N on germination of common lambsquarters and redroot pigweed. Furthermore, the spatial variability in the natural seed bank across the site made it difficult to determine the natural weed population response to N. Increased sampling

frequency or a uniform weed seed bank would improve the ability to detect differences in weed emergence of natural seed banks following application of N.

Greenhouse Experiment

Soil Analysis and Weed Germination

The relationship between N applied and N_R was highly correlated ($P < 0.0001$) in the petri dishes one week after application. More N was available than what was applied (Table 2.3). This could be due to enhanced microbial and enzymatic (urease) activity occurring in the petri dishes with the addition of N. Furthermore, under greenhouse environmental conditions, the amount of N applied as urea ammonium nitrate to the petri dishes may have limited environmental N losses.

For some weed species, applications of 56 kg N ha^{-1} resulted in emergence similar to the control (Table 2.4). However as N increased further, but may have resulted in volatilization and buildup of NH_3 gas within the sealed petri dishes. The urea portion (50%) of the urea ammonium nitrate would have broken down and released large amounts of NH_3 gas. NH_3 gas is toxic to seeds and may have caused a problem with fatal weed seed germination. Since the highest rates of N contained over 200 mg N kg^{-1} , the salt concentration in the petri dishes may have been another factor contributing to fatal germination since high salt concentrations are also toxic to small seedlings. Our results are similar to those of Sardi and Beres (1996) where different concentrations of ammonium nitrate were applied to redroot pigweed seed; 10 and 100 ppm of N stimulated

germination whereas 1,000 ppm of N as ammonium nitrate fertilizer significantly inhibited germination. If all N applied in the field was not subject to environmental losses, there could potentially be a loss of weed and crop emergence due to salt toxicities. This is one of the reasons why it is not advised to apply large amounts of N close to the crop seed at planting.

CONCLUSIONS

Applying urea ammonium nitrate preplant broadcast in the field increased plant available N; however, the actual amount of N available varied. The only date where available N equaled the N applied was on April 15, 2003. For the other N application dates, available N in the upper 8 cm of the soil profile one week after application was 40 to 70% less than what was applied. This loss may be attributed to leaching, volatilization, denitrification, or immobilization.

Applying urea ammonium nitrate increased available N and the emergence of some weed species, but not others. Broadcast applications of urea ammonium nitrate fertilizer in the early spring stimulated weed emergence; however the response varied by species, seed age, time of seeding, and year. Seed source may be an important component of the differences between years. Because the seed from 2003 was collected from two years prior, it may have been less dormant than seed used in 2004, which was collected from fields in 2003. Overall weed emergence was less in 2004. Emergence of weeds from the natural seed bank did not increase with available N, but it was difficult to measure because of the variability in the seed bank and emergence across the

field. Natural seed banks are comprised of seeds of various ages and dormancy requirements and may be harder to assess the influence of available N compared to a single seed source.

Total weed biomass increased as N availability increased at all seeding dates in 2003 and two of three seeding dates in 2004. Therefore, increased N availability can increase the growth of weeds and increase the competitiveness of the weed to the crop. Larger weeds may also be difficult to control, especially in sugarbeet production systems.

In sugarbeet, N is typically preplant broadcast at 50 kg N ha⁻¹. If N is sidedressed, 80 kg N ha⁻¹ are applied when sugarbeets reach the two to four true leaf stage, typically four to six weeks after planting. Weeds are controlled in sugarbeet with herbicide applications within 150 to 250 growing degree days (base 34°F) after planting, and repeated as weeds continue to emerge through May and June. If N increased germination and growth of weeds in early April and May, it would increase the number of post herbicide applications and make it more difficult to apply herbicides in a timely basis. However, this research does not support the hypothesis that applying N will increase emergence of these five weed species, regardless of the time of N application or sugarbeet planting date. Giant foxtail emergence in April may be stimulated by N application; and common lambsquarters and ladythumb smartweed emergence may also increase depending on the year and seed source. However, N stimulated weed growth, regardless of seeding and N application date. Therefore making N available to crop roots and not to weeds may improve weed control in

sugarbeets. The loss of available N in the 0 to 8 cm soil depth within one week after application may make N placement to benefit the crop and not the weeds difficult to accomplish. In 2004, 20% of the applied N was available in the 8 to 16 cm soil depth, implying some movement of N below the soil area where it was applied. If all N was applied below an 8 cm depth there could be a potential for loss in available N to the sugarbeet crop. A better strategy may be to not broadcast N because it is available to weeds across the entire field. If N is applied in the crop row only at planting and again at sidedress when the crop needs it 4-6 weeks after planting it would reduce the potential for N to stimulate weed growth in the first six weeks after crop emergence.

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Table 2.1. Weed seeding rates in 2003 and 2004. Rates were based on germination tests so that 50 plants per species would potentially emerge at 22°C.

Weed Species	Number of Seeds Planted	
	2003	2004
common lambsquarters	360	400
giant foxtail	120	800
ladysthumb smartweed	600	600
redroot pigweed	105	500
velvetleaf	65	300

Table 2.2. Correlation coefficients of applied N and available N.

Year	Sample Date	Depth (cm)	r	P value
2003	15 April			
	Week 1	0-8	0.813	0.0001
	Week 2	0-8	0.793	0.0002
	Week 3	0-8	0.684	0.0035
	29 April			
	Week 1	0-8	0.831	< 0.0001
	Week 2	0-8	0.776	0.0004
	Week 3	0-8	0.814	0.0001
	21 May			
	Week 1	0-8	0.759	0.0006
	Week 2	0-8	0.867	< 0.0001
	Week 3	0-8	0.889	< 0.0001
2004	6 April			
	Week 1	0-8	0.760	0.0006
		8-16	0.728	0.0014
	Week 3	0-8	0.743	0.0010
		8-16	0.626	0.0095
	Week 5	0-8	0.710	0.0020
		8-16	0.694	0.0029
	20 April			
	Week 1	0-8	0.899	< 0.0001
		8-16	0.699	0.0026
	Week 3	0-8	0.926	< 0.0001
		8-16	0.903	< 0.0001
	Week 5	0-8	0.740	0.0010
		8-16	0.747	0.0009
	20 May			
	Week 1	0-8	0.938	< 0.0001
		8-16	0.722	0.0016
	Week 3	0-8	0.890	< 0.0001
		8-16	0.713	0.0019
	Week 5	0-8	0.838	< 0.0001
		8-16	0.807	< 0.0001

Table 2.3. Soil analysis averaged over three replications from petri dishes 7 days after application.

	N Rate kg N ha ⁻¹	NO ₃ ⁻ -N mg N kg ⁻¹	NH ₄ ⁺ -N mg N kg ⁻¹	N _{it} mg N kg ⁻¹
Run 1	0	20	4	24
	56	72	54	125
	112	102	140	242
	168	130	246	376
Run 2	0	16	2	18
	56	53	29	82
	112	81	89	170
	168	89	141	230
Run 3	0	17	2	19
	56	52	33	85
	112	72	71	143
	168	109	155	264

Table 2.4. Emergence of velvetleaf (ABUTH), redroot pigweed (AMARE), common lambsquarters (CHEAL), ladythumb smartweed (POLPY), and giant foxtail (SETFA) with application of urea ammonium nitrate (28% N) at 0, 56, 112, and 168 kg N ha⁻¹ in petri dishes.

N Rate kg ha ⁻¹	ABUTH	AMARE	CHEAL	POLPY	SETFA
	% Emergence				
0	14	26	14	4.6	20
56	11	20	15	1.4	16
112	7	8	5	0.36	9
168	4	2	3	0.18	4
LSD (0.05)	2.4	3.3	2.7	1.2	2.5
CV (%)	31.4	26.5	34.3	82.4	23.0

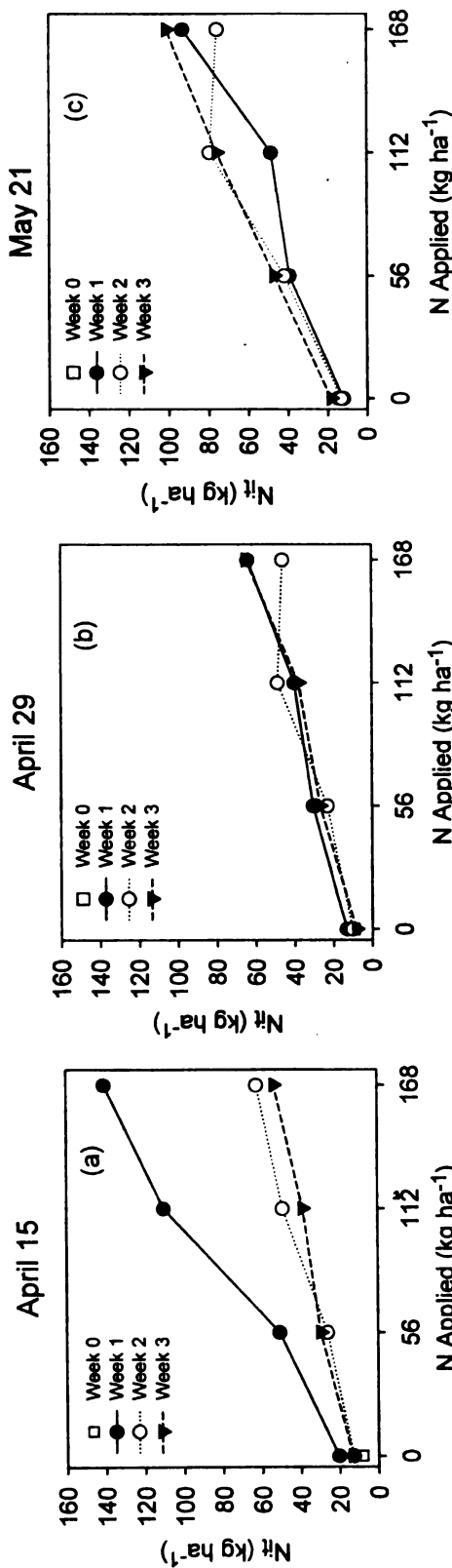


Figure 2.1. Total inorganic nitrogen (N_i) relative to nitrogen applied in 2003 at application dates April 15 (a), April 29 (b), and May 21 (c).

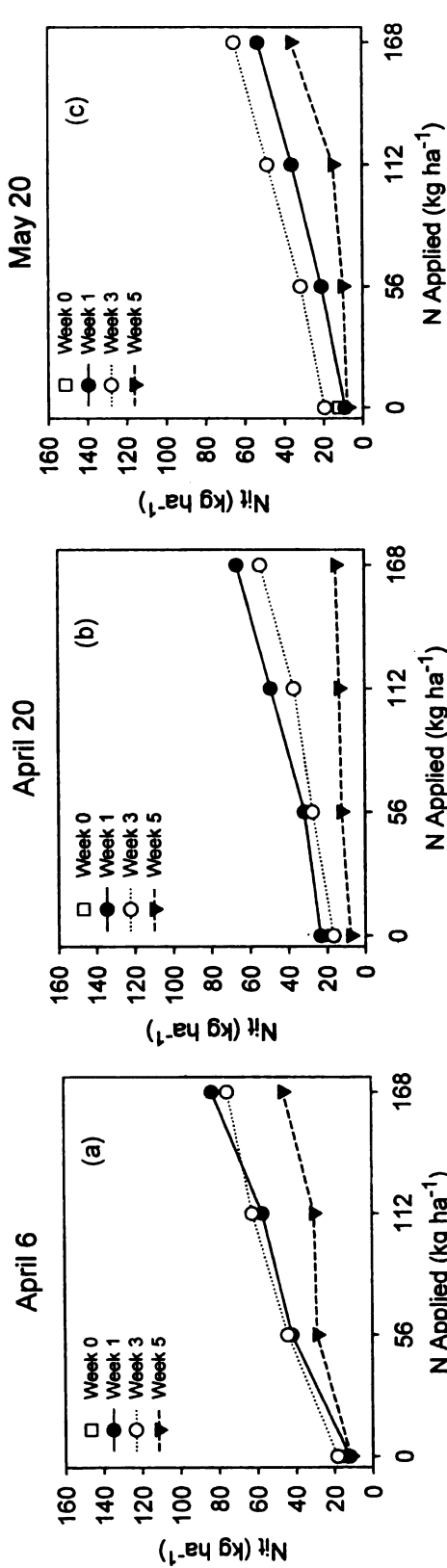


Figure 2.2. Total inorganic nitrogen (N_i) relative to nitrogen applied in 2004 at application dates April 6 (a), April 20 (b), and May 20 (c).

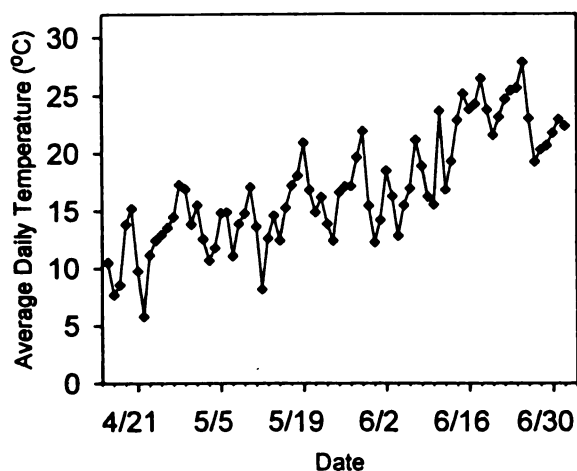


Figure 2.3. Average daily soil temperature in 2003.

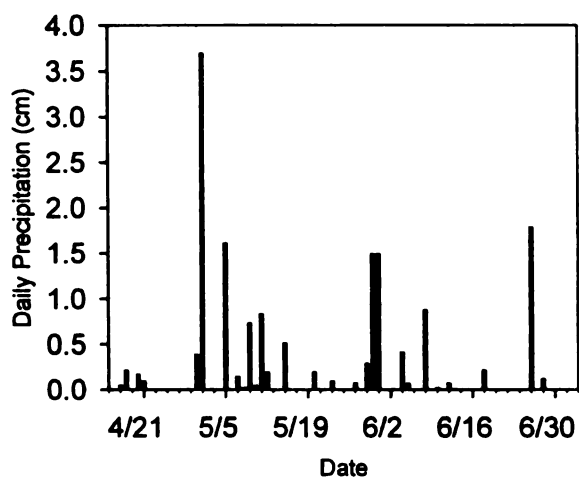


Figure 2.4. Average daily precipitation in 2003.

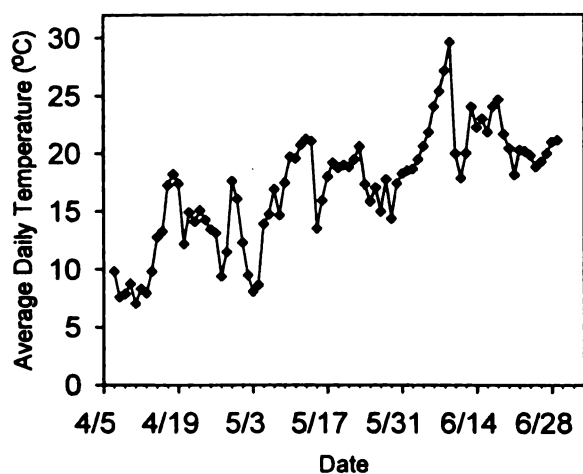


Figure 2.5. Average daily soil temperature in 2004.

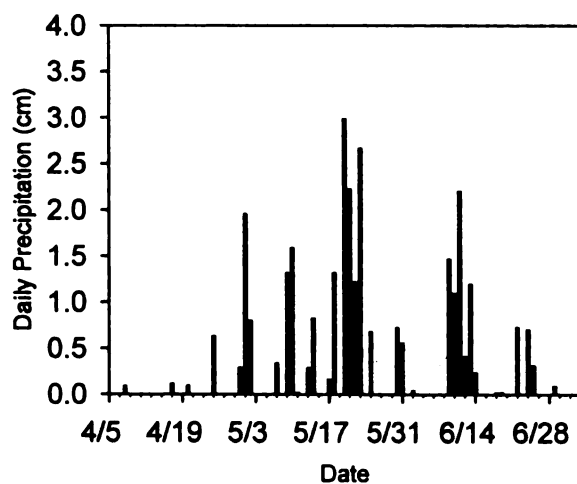
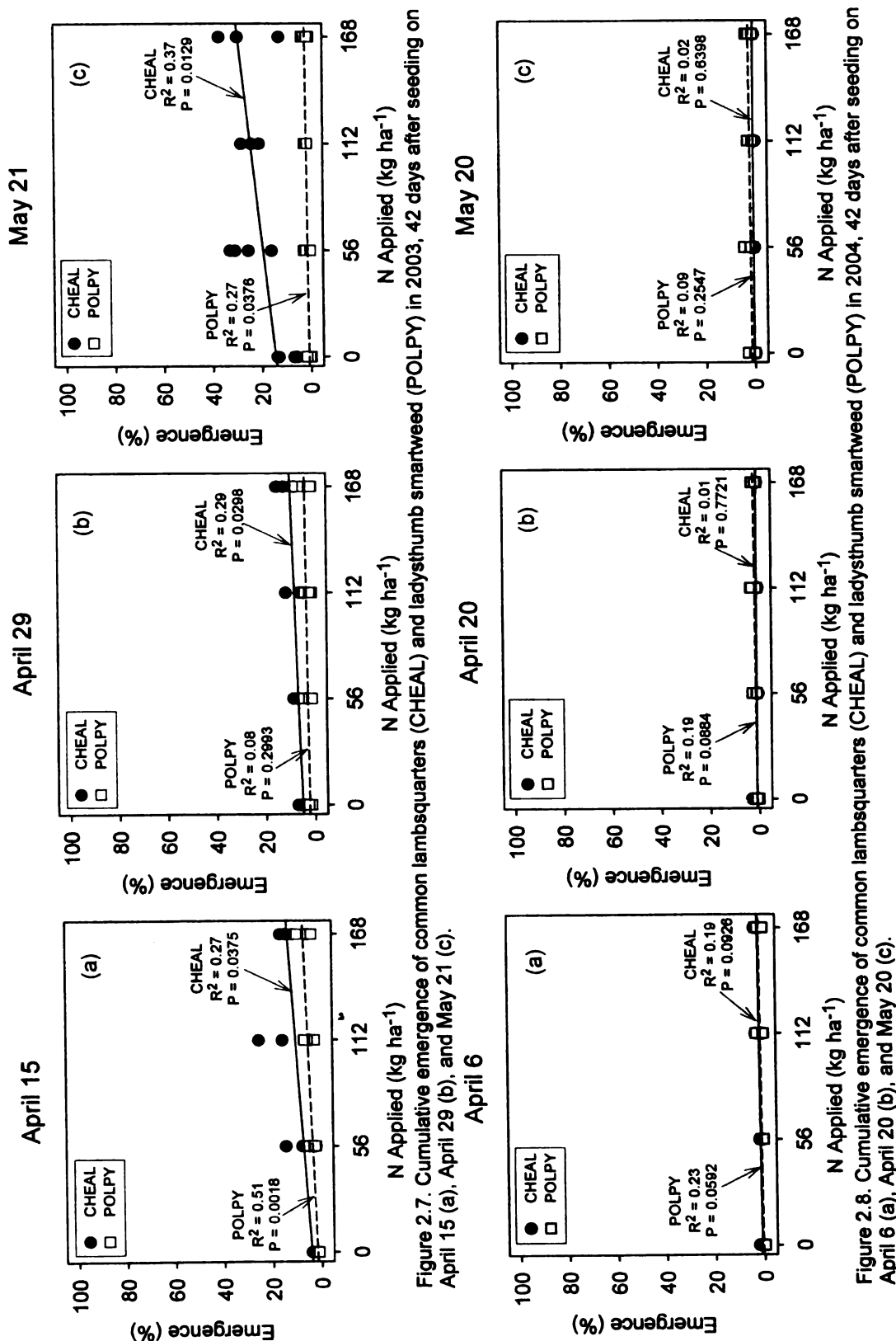
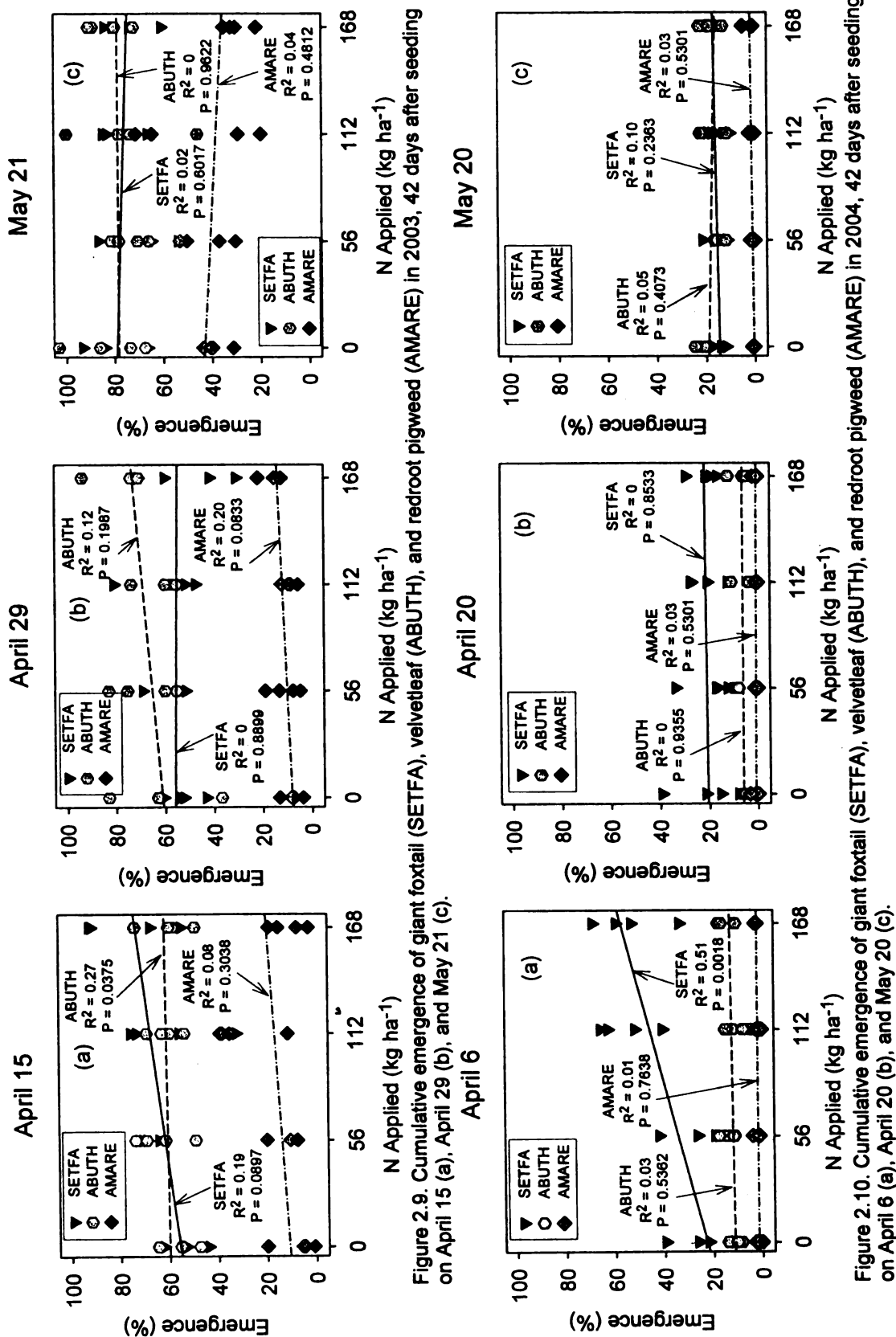


Figure 2.6. Average daily precipitation in 2004.





2003 Biomass

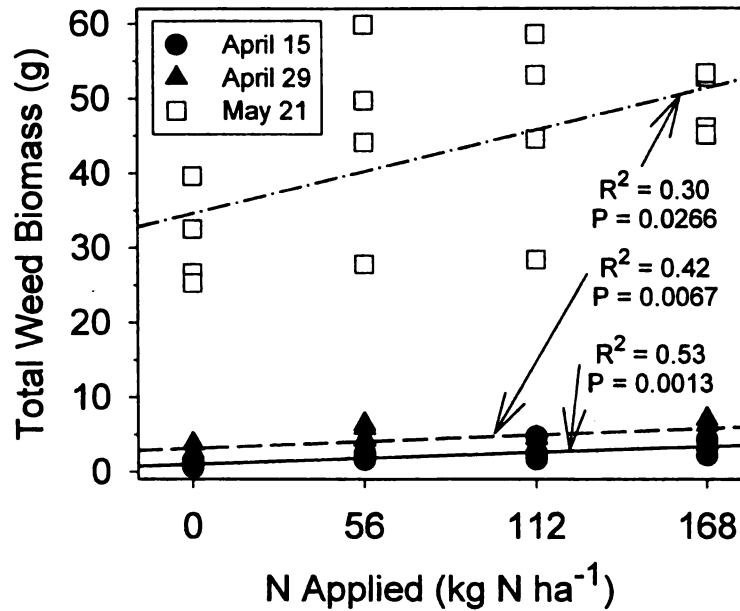


Figure 2.11. Total weed biomass in 2003, 42 days after seeding.

2004 Biomass

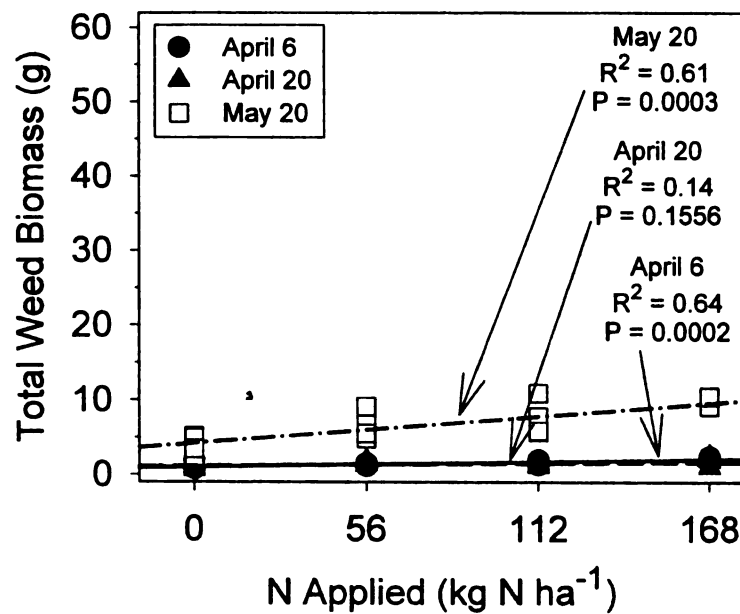


Figure 2.12. Total weed biomass in 2004, 42 days after seeding.

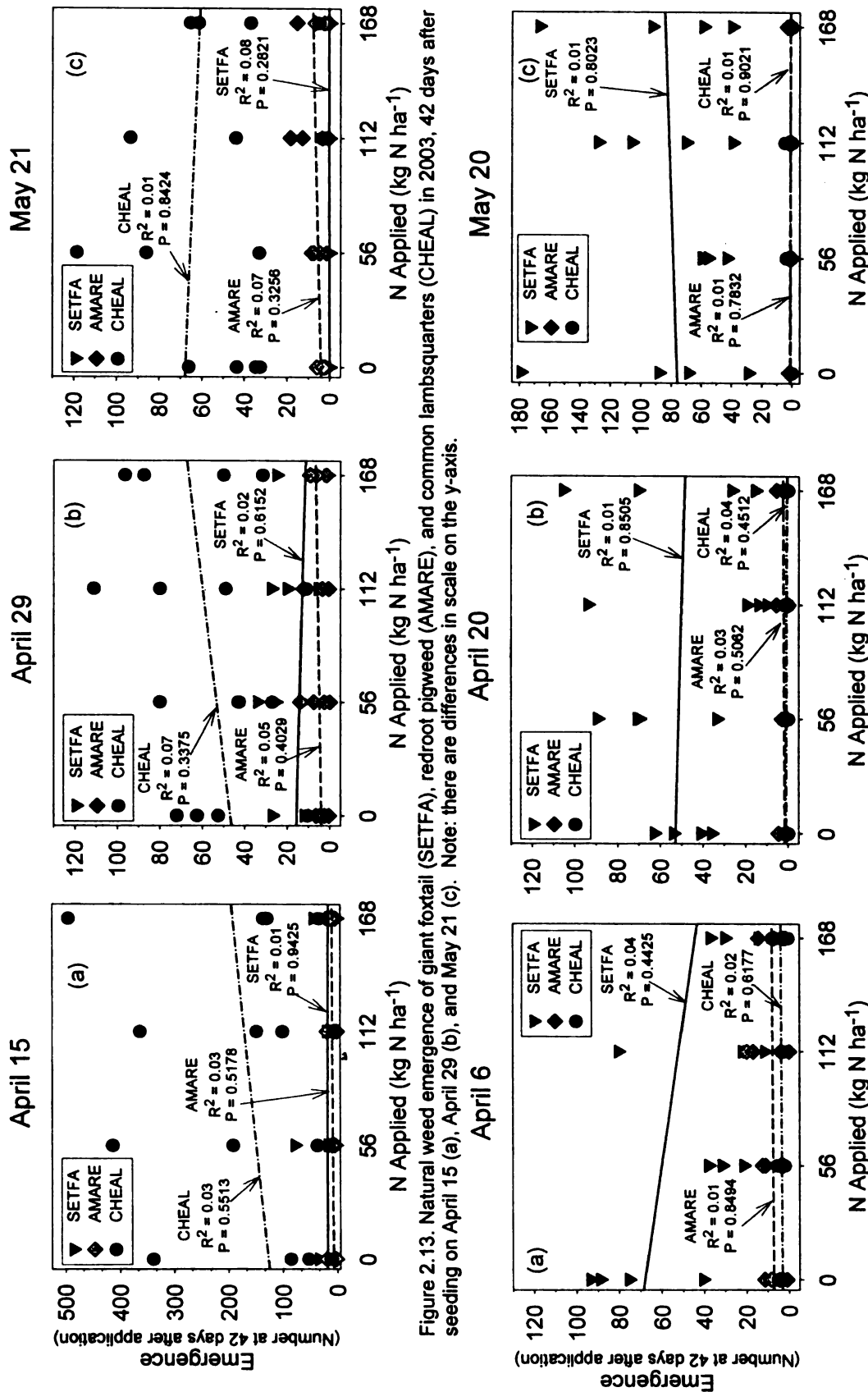


Figure 2.13. Natural weed emergence of giant foxtail (SETFA), redroot pigweed (AMARE), and common lambsquarters (CHEAL) in 2003, 42 days after seeding on April 15 (a), April 29 (b), and May 21 (c). Note: there are differences in scale on the y-axis.

Figure 2.14. Natural weed emergence of giant foxtail (SETFA), redroot pigweed (AMARE), and common lambsquarters (CHEAL) in 2004, 42 days after seeding on April 6 (a), April 20 (b), and May 20 (c). Note: there are differences in scale on the y-axis.

APPENDICIES

a

APPENDIX A

PROCEDURE FOR THE ILLINOIS NITROGEN SOIL TEST

The contents of this appendix is the Illinois Nitrogen Soil Test (INST) procedure contained in a technical note with the following citation:

Anonymous. 2002. The Illinois soil nitrogen test for amino sugar N: Estimation of potentially mineralizable soil N and ^{15}N . Technical Note 02-01. Rev. e. University of Illinois Department of Natural Resources and Environmental Sciences.

The format of the technical note was changed to meet the formatting requirements of the thesis.

Technical Note 02-01

The Illinois Soil Nitrogen Test for Amino Sugar-N: Estimation of Potentially Mineralizable Soil N and ^{15}N

Apparati

Diffusion unit (Fig. A.1). The unit illustrated consists of a 1-pint (473-mL) wide-mouth Mason jar¹ with an 86 mm dome lid (Ball® brand only) modified to support the bottom of a 60-mm (dia.) Pyrex® petri dish. The lid is modified by: (i) drilling a 9/64-inch (3.6-mm) hole approximately ½ inch (12-14 mm) from the edge; (ii) attaching a 6-32 × 1.5 to 2.5-inch stainless-steel machine screw with two O-rings (Viton®, 1/8 inch i.d., ¼ inch o.d.) and two stainless-steel nuts²; and (iii) fastening a screw-down mounting base for a nylon cable tie to the stainless-steel screw via a 1/8-inch cable clamp, a 6-32 × ½-inch nylon machine screw and nut, and four stainless-steel nuts³. To improve the fit of the lid, the cable clamp should be notched with a bench grinder so the nylon nut does not protrude beyond the clamp, and the nylon screw is ground flush with the nut. The cable tie for mounting the petri dish should be tightened sufficiently that the dish cannot slip from the mount, yet can be easily removed and replaced. A releasable cable tie is highly recommended⁴. After being tightened to support a petri dish, the cable

¹Suitable jars are available from Alltrista Corp., Muncie, IN, under either the Ball® (cat. no. 14400-66000) or Kerr® (cat. no. 70610-00518) brand name.

²The first nut should be tightened sufficiently that the O-rings are compressed moderately against the lid. The second nut is then firmly tightened against the first using two thin-head (ignition) wrenches.

³The cable clamp is secured on the stainless-steel screw between four nuts. One of these nuts is threaded approximately ½ inch onto the screw, and a second nut is tightened firmly against the first. The cable clamp is then placed on the screw. A third nut is added and tightened firmly against the clamp and the first two nuts. A fourth nut is tightened firmly against the nuts and clamp.

tie should be trimmed so the end extends approximately ¼ inch beyond the locking device, and should then be rotated to position the locking device approximately ½ inch from the mounting base⁵.

Electric hot plate. The West Bend Model 76220 griddle is useable as supplied if located so that drafts are minimized, but precision will be improved by (i) enclosing the griddle within a covered polyethylene box⁶, and/or (ii) replacing the stock controller with an electronic unit, such as the Johnson Controls A419⁷.

Proceed as follows to make the latter modification⁸:

1. Disassemble the stock controller and disable the thermocouple assembly by (i) clipping the input lead to the line cord, (ii) removing this assembly from the controller housing, and (iii) soldering the detached lead from the line cord directly to the output socket originally employed in conjunction with the thermocouple assembly. Reassemble the modified controller, which now lacks the central plug, and attach to the griddle. Retain the thermocouple assembly for use in step 3.

⁴Petri dishes vary in diameter. Also, cable ties tend to tighten during repeated handling. Releasable cable ties permit the readjustment of tension, whereas nonreleasable ties must be frequently replaced.

⁵A short length of cable tie must be left beyond the locking device to accommodate varying petri dish sizes. Positioning the locking device near the mounting base is essential for the apparatus to fit within the jar.

⁶The Rubbermaid Model 3A28 31-qt (29.3-L) Clear Lid Box is satisfactory if modified by cutting an electrical access port in one corner and a central hole in the top (for insertion of a thermometer). Modifications will also be required in the West Bend griddle specified, involving removal of the handles and grease drain assembly. The screws used to attach these components can subsequently be reinserted to serve as short legs, and should be supported on asbestos or other insulating pads placed in the bottom of the box.

⁷Available from Energy Equipment & Control at <<http://www.energyequipment.com>>.

⁸Modified griddles are available from Tim Smith, 2675 E 1500N Rd, Farmer City, IL 61842 (tsmith@agcentral.com).

2. Assemble an electronic control unit by (i) attaching the A419 controller to a 2-gang outlet box (e.g., Pass & Seymour WPB242) using a suitable box spacer, (ii) connecting the A419 with 14-3 AWG to a duplex receptacle, (iii) equipping the outlet box with a cable connector and a 14-3 line cord to power the A419 and a high-wattage dimmer (e.g., Pass & Seymour 91022-WV) that connects to the receptacle (see A419 and dimmer instructions for further wiring details), and (iv) installing a 2-gang wall plate after mounting the dimmer beside the receptacle in the outlet box. Set the internal jumper in the A419 to enable heating mode with cut-out at setpoint.
3. Using a hack saw or tubing cutter, remove both ends, and also the internal wiring, from the stock thermocouple assembly (as removed in step 1), so as to obtain a 1- to 1.5-inch long tube that will be used as a sleeve for the A419 thermocouple probe. Drill and tap the Al block on the lower surface of the griddle, such that a 6-32 × 3/8 inch stainless-steel machine screw can be installed to retain the thermocouple probe from the A419. Before installing this probe, drill the wall of the aforementioned sleeve to provide a through-hole for the retaining screw, and then insert the sleeved probe into the Al block, such that the connecting cable is positioned toward the center of the griddle. Avoid excessive force in tightening the retaining screw. Insert a piece of asbestos tape or other insulation to shield the cable from direct contact with the lower surface of the griddle.

Before using the modified griddle, plug the line cord into one of the two outlets on the electronic control unit, and then connect this unit to a source of power. After

accessing the menu of the A419, set the differential control value to 1 and the anti-short cycle delay to 0. Using a suitable voltmeter to measure voltage via the other outlet, adjust the dimmer switch to obtain 60-70 VAC while the A419 LED is illuminated. Adjust the setpoint temperature (in °F), such that a temperature of 49 to 50°C is obtained for 100 mL of deionized water in a Mason jar in the center of the griddle⁹.

Microburette (5-mL, graduated at 0.01-mL intervals) or automatic titrator equipped with an electrode designed for flat-surface measurements. A satisfactory electrode is available from Fisher Scientific (model no. 13-620-289). Microplate. If isotopic analyses are to be performed on NH_4^+ -N recovered by the Illinois soil N test, a Microtiter[®] plate is required for processing by the ¹⁵N Analysis Service. This plate is manufactured by Dynatech Laboratories, Chantilly, VA (cat. no. 001-010-2205), and is available from Fisher Scientific (cat. no. 14-245-71).

Reagents

Sodium hydroxide solution (2 M). Dissolve 80 g of reagent-grade NaOH pellets in approx. 800 mL of deionized water in a 1-L volumetric flask, and dilute to 1 L after the solution has cooled to room temperature, followed by thorough mixing. This reagent is conveniently dispensed from a 10- to 50-mL Dispensette[®] or Repipet[®], or may be stored in a tightly stoppered flask or bottle that prevents

⁹If the griddle is enclosed within a polyethylene box as specified, a temperature of 53 to 54°C is recommended.

absorption of atmospheric CO_2 . Alternatively, 2 *M* NaOH is available from Fisher Scientific (cat. no. LC24380).

Boric acid-indicator solution (4% H_3BO_3). While stirring vigorously with a motorized stirrer, dissolve 800 g of reagent-grade H_3BO_3 in approx. 18 L of deionized water in a 20-L Pyrex[®] solution bottle marked to indicate a volume of 20 L. Then add 0.099 g of bromocresol green and 0.066 g of methyl red (as water-soluble sodium salts), and bring the volume to 20 L with deionized water. With continuous stirring, adjust the pH of this solution to 4.2 to 4.3 by adding single NaOH pellets. When an aliquot of the H_3BO_3 indicator solution is diluted with an equal volume of deionized water, a pH of 4.8 to 5.0 should be obtained. A suitable reagent is obtainable from Fisher Scientific (cat. no. LC11750).

Sulfuric acid (0.01 *M* standard). Dilute 5.6 mL of concentrated H_2SO_4 to 10 L in a Pyrex[®] bottle marked to indicate a volume of 10 L, and mix thoroughly.

Standardize by titrating several 5-mL aliquots of a THAM solution that was prepared by dissolving 0.2430 g of dried, certified THAM (Sigma, St. Louis, MO) in 100 mL of deionized water in a volumetric flask. Determine the endpoint for these titrations as described in the procedure that follows. Calculate the exact molarity of the titrant as $0.05/V$, where V is the mean value for the milliliters of H_2SO_4 required to reach the endpoint. To determine the titer ($\mu\text{g N mL}^{-1}$), multiply the calculated molarity by 28000. Alternatively, 0.01 *M* (0.02 *N*) H_2SO_4 may be purchased from Fisher Scientific (cat. no. SA226).

Sulfuric acid (approximately 1 *M*). Add 27.8 mL of concentrated H₂SO₄ to 500 mL of deionized water in a volumetric flask. This reagent is required only if ¹⁵N analyses are to be performed.

Methanol. Anhydrous grade is satisfactory. This reagent is required only if ¹⁵N analyses are to be performed.

Procedures

Soil test method. Weigh 1.00 g of air-dried soil into a Mason jar. Attach a petri dish to the jar lid with a cable tie, and dispense 5 mL of H₃BO₃-indicator solution into the dish. Treat the soil sample with 10 mL of 2 *M* NaOH, and gently swirl the jar to mix the contents, while taking care to minimize soil adherence to the wall of the jar. Within 15 to 30 s, place the lid on the jar and seal it by firmly attaching a screw band, and then transfer the jar to the hot plate for heating at 48-50°C¹⁰. Up to 12 jars, arranged in a 3 × 4 array, may be heated on a single hot plate. After 1.5 and 3 h, exchange adjacent jars according to different patterns illustrated by Figure A.2. After 5 h, remove the jars from the hot plate and the petri dish from each jar, dilute the H₃BO₃ solution with 5 mL of deionized water, and titrate with 0.01 *M* H₂SO₄ to an endpoint established previously on the basis of the color (for manual titrations) or pH (for automatic titrations) obtained by mixing 5 mL of H₃BO₃ solution and 5 mL of deionized water in a petri dish.

Calculate the soil test level of mg N kg⁻¹ (ppm) as $S \times T$, where *S* is the milliliters

¹⁰Prior to placement of the sealed jar for heating, the heat control on the griddle must be adjusted as specified previously, with a sufficient period to ensure thermal equilibration.

of H_2SO_4 used in titrating the sample, and T is the titer of the titrant (for 0.0100 M H_2SO_4 , $T = 280 \mu\text{g N mL}^{-1}$).

Processing for ^{15}N analysis (optional). Following titration, acidify the sample with 1 M H_2SO_4 ($0.1 \mu\text{L} \mu\text{g N}^{-1}$), and evaporate the acidified solution to dryness on a hot plate ($50\text{--}90^\circ\text{C}$). Add 4 mL of methanol to remove H_3BO_3 , and eliminate the excess methanol by heating to dryness at $50\text{--}90^\circ\text{C}$. Then add 4 mL of deionized water, and again evaporate to dryness at $50\text{--}90^\circ\text{C}$. Dissolve the $(\text{NH}_4)_2\text{SO}_4$ in the dish in a sufficient volume of deionized water that a 0.05- to 0.3-mL aliquot containing 50 to 200 μg of N can be transferred to a plastic microplate. Carry out final drying of samples in the microplate in a low-temperature oven ($\leq 70^\circ\text{C}$).

Cleaning

For soil testing without ^{15}N analysis. Rinse the jars in warm tap water while scouring the inner surfaces of the jar with the fingers or a brush, followed by thorough rinsing with distilled or deionized water. Rinse the jar lids with distilled or deionized water, and then place them on edge to promote drying. Rinse petri dishes with distilled or deionized water, following (if necessary) immersion in warm tap water to remove solidified H_3BO_3 . Allow components to dry before reuse.

For soil testing with ^{15}N analysis. After rinsing jars with warm tap water, immerse them overnight in 0.2 M H_2SO_4 . Then scrub the inner surfaces

thoroughly under running tap water, rinse with deionized water, and dry.

Immerse petri dishes overnight in 0.2 M H₂SO₄, and after rinsing with tap water, immerse them overnight in distilled or deionized water to remove residual acidity.

Finally, rinse with deionized water and dry. Immerse jar lids overnight in freshly prepared 0.05 M KOH¹¹. Then immerse for at least 5 min in running tap water (≥20°C) to remove the KOH. Rinse with deionized water and dry.

Comments

The Illinois soil N test was developed to detect sites where corn is non-responsive to N fertilization, but may have application to other crops and to soils that are not under crop production. As developed, this test is performed on soil samples collected to a depth of 12 inches, prior to planting (i.e., mid-March to mid-April in the north-central USA). If samples cannot be dried soon after collection, they should be stored in a freezer. Drying can be done at room temperature, or more rapidly at 40°C in a forced-air oven. When drying is complete, samples should be crushed to < 2 mm, using a mechanical grinder. Dried samples can be stored

safely at room temperature. When the technique described is performed on soil samples collected to a depth of 1 foot in central or northern Illinois, a test value of 250 ppm or higher indicates that corn will be non-responsive to N fertilization, 300 ppm would be appropriate if this test is applied to soil samples taken to a

¹¹The lid must not be immersed in H₂SO₄ as is done in cleaning the jar and petri dish, because the silicone gasket will become acidified, and this will lead to underestimation of the diffused NH₃-N by creating a trap that competes with the H₃BO₃ solution.

assuming normal weather during the growing season. A critical value of approx. depth of 6 or 7 inches. Different critical values would likely be needed for other crops and/or climatic conditions. Work in progress has demonstrated that these values are affected by other soil and plant parameters.

The components required to modify the jar lid as illustrated by Fig. 1 can be obtained from the McMaster-Carr Supply Co. and Newark Electronics, hence the listing of part numbers in Table A.1. These components can, of course, be purchased from other sources, but care should be taken to obtain the same hardware specified, particularly in regard to the use of stainless-steel screws and nuts and Viton[®] O-rings. Corrosion will occur rapidly with ordinary steel, while Buna[®] O-rings are prone to premature failure because of cracking.

Table A.1. Part list for Mason-jar modifications.

The components needed to modify the Mason-jar lid can be obtained from the McMaster-Carr Supply Co. at < http://www.mcmaster.com > or Newark Electronics at < http://www.newark.com >.			
Source [†]	Catalog No.	Description	No. per lid
M-C	91783A161	Machine screw, 6-32 x 2 in. (s.s.)	1
M-C	91841A007	Hex nut, 6-32 (s.s.)	6
M-C	94609A150	Machine screw, 6-32 x 5/8 in. (nylon)	1
M-C	94812A113	Hex nut, 6-32 (nylon)	1
M-C	9464K11	O-ring, ¼ inc. o.d., 1/8 in. i.d. (Viton [®])	2
M-C	8876T14	Loop clamp (nylon)	1
NE	94F2858	Cable tie, 11 ½ in. (releasable)	1
NE	89F2507	Cable-tie mounting base (screw-down)	1

Temperature has a critical effect on test values obtained by the procedure described, so care must be taken to ensure proper adjustment of the heat control, with adequate time for thermal equilibration of the deionized water used for measuring temperature, prior to placement of jars on the griddle surface. An initial temperature of 49°C is always employed in our laboratory using an open griddle, whereas enclosed griddles are maintained at 54°C. This temperature must be measured exactly as described, using an open jar with 100 mL of deionized water, which is placed in the center of the griddle surface. A higher temperature will exist inside a sealed jar, particularly when surrounded by additional jars that reduce cooling by ambient air currents.

Due in part to air drafts, jars placed on the corners of the heating surface tend to be cooler than those in central positions, which can lead to lower soil test values when an open griddle is used. Experience has shown that this problem is largely eliminated by periodically exchanging jars on the heating surface, and that a two-step exchange is more effective than a single exchange.

To improve data quality, analyses should be performed in duplicate. Ideally, duplicate jars should be heated on separate griddles.

The 5-h period specified for heating must not be exceeded, as this may lead to recovery of other forms of soil organic N besides amino sugars. Moreover, prolonged heating may promote drying of the H_3BO_3 solution used to absorb

gaseous NH_3 and thereby vitiate the analysis. Neither problem has been observed if the jar is left unopened overnight at room temperature (approx. 25°C) after heating for 5 h, as is conveniently accomplished by equipping the griddle with an electrical timer. A timer is also useful for preheating the griddle to expedite temperature adjustments by the technique described.

The technique described recovers exchangeable NH_4^+ -N as well as amino sugar-N, and thus will not provide a reliable estimate of mineralizable soil N for sites that have received a recent input of NH_4^+ through application of ammoniacal fertilizer, manure, or sewage sludge. The need for this information will normally not exist in such cases, but if necessary, amino sugar-N can be estimated by correcting test values on the basis of NH_4^+ -N analyses by direct diffusion (see Technical Note 99-01).

The most common difficulty in performing the soil test described arises when jars crack upon heating, which vitiates the analysis. Experience has shown that this problem is more apt to occur with manured soils, owing to the higher pressures generated. To minimize the frequency of jar failure, only jars that are in perfect condition should be used.

When the technique described is performed using 5 mL of H_3BO_3 solution as specified, determinations are quantitative with up to 4 mg of N. Assuming the soil samples under analysis are weighed to within 0.01 g, the coefficient of variation (relative standard deviation) for replicate analyses should not exceed

2%. If desired, the technique described may be evaluated for accuracy in recovery of amino sugar-N by analyzing a standard solution of glucosamine. A suitable solution may be prepared by dissolving 1.5393 g of dried reagent-grade glucosamine-HCl¹² in 100 mL of distilled or deionized water, in which case the N content will be 1 mg mL⁻¹. When the technique described is performed on replicate 1-mL aliquots of this solution, recovery of glucosamine-N should exceed 97%, assuming (1) the use of clean (i.e., acid-free) petri dishes, jars, and jar lids; (2) adequate tightening of the jar lid to ensure a gas-tight seal; (3) proper adjustment of griddle temperature; and (4) accurate pipetting and standardization of titrant.

Reference

Khan, S. A., R. L. Mulvaney, and R. G. Hoeft. 2001. A simple soil test for detecting sites that are non-responsive to nitrogen fertilization. *Soil Sci. Soc. Am. J.* 65:1751-1760.

¹²A satisfactory reagent is available from Sigma, St. Louis, MO (cat. no. G4875). Before use, it should be dried for at least 2 d at room temperature in a desiccator containing Drierite[®] or silica gel.

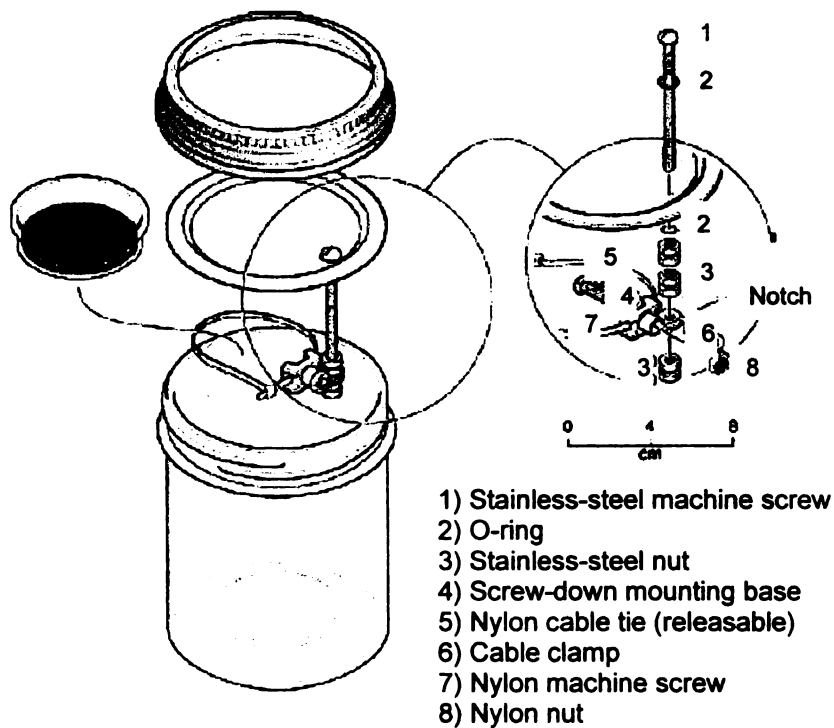


Figure A.1. Mason-jar diffusion unit.

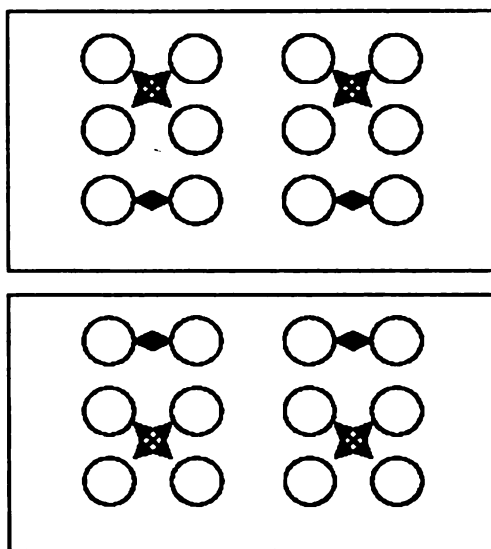


Figure A.2. Schematic diagram illustrating two-step rotation recommended after heating for 1.5 and 3 h.

APPENDIX B

ILLINOIS NITROGEN SOIL TEST (INST) AS USED FOR THESE STUDIES

Methods for determining values for the Illinois Nitrogen Soil Test (INST) are outlined in the University of Illinois Department of Natural Resources and Environmental Sciences Technical Note 02-01 (rev. f) (Anonymous, 2002 and Appendix A). With initial use of this procedure, it was difficult to obtain repeatable data. After training at the University of Illinois, minor modifications were made to the procedure to achieve reliable results. The following explains specific details from the Technical Note along with highlighting critical points in the procedure where attention must be focused to achieve reliable results. In addition, this appendix explains quality assurance/quality control measures necessary to monitor the accuracy or repeatability of this procedure.

MATERIALS AND METHODS

Laboratory Procedure

Apparati

Diffusion Unit. The diffusion unit was built as described in the University of Illinois Technical Note.

Electric Hot Plate. The West Bend Model 76220 was modified by placing four jar lids (2 lids per leg) to increase the incline along the shorter dimension of the

heating surface. The polyethylene box that enclosed the griddle was not used, and no modifications were made to the stock controller.

Microburette. A 5 mL, graduated at 0.01 mL was used.

Electrode. The pH electrode (Fisher Scientific model no. 13-620-289) used is designed for flat surface measurements.

Reagents

Sodium hydroxide solution (2 M). The sodium hydroxide solution was developed as stated in the Technical Note (Appendix A).

Boric acid-indicator solution (4% H_3BO_3). This reagent was purchased from Fisher Scientific (cat. No. LC11750).

Sulfuric acid (0.006 M). For ease of manual titrations, 0.006 M H_2SO_4 was used instead of the recommended 0.01 M sulfuric acid (H_2SO_4). Concentrated sulfuric acid (H_2SO_4) at an amount of 1.5 mL was diluted in a 2 L volumetric flask. The 2 L volumetric flask was filled to volume with deionized distilled water to make 0.006 M H_2SO_4 . The H_2SO_4 was stored in a Nalgene[®] bottle. The H_2SO_4 was standardized by titrating ten-5 mL aliquots of a Tris (Hydroxymethyl) Aminomethane (THAM) solution that was prepared by dissolving 0.243 g of dried, certified THAM in 100 mL deionized distilled water in a volumetric flask. The exact molarity of the titrant was calculated as $0.05/V$, where V is the mean value of H_2SO_4 in milliliters required to meet the endpoint. To determine the titer ($\mu\text{g mL}^{-1}$); the calculated molarity was multiplied by 28,000.

Procedure

Soil that was air-dried and ground through a 2 mm sieve was weighed to 1.000 ± 0.001 g and added to a Mason jar. Larger soil particles were manually removed, even though they passed through a 2 mm sieve. The electric griddle was plugged into a timing device which turned the plate on for 2.5 hours before the jars were placed on the hotplate. This was to ensure a constant temperature of 49°C. Temperature was measured by immersing a thermometer in 100 mL of water in a jar on the center of the hotplate. A petri dish was attached to the jar lid with a cable tie, and 5 mL of boric acid (H_3BO_3) indicator solution was dispensed into the dish. The soil sample was treated with 10 mL of 2 M NaOH, and the jar was gently swirled to mix the contents. Care was taken to minimize soil adherence to the wall of the jar by swirling the jar in contact with the laboratory surface for 5 seconds. Within 15 to 30 seconds, the lid was placed on the jar and sealed by firmly attaching a screw band, and then the jar was transferred to the griddle for heating at 49°C. A total of 12 jars were placed on the griddle, including the jar of water, a standard soil, and a duplicate soil sample. The screw on the jar pointed to the down slope position to aid in collecting and preventing condensation from entering the petri dish. After 1.5 and 3 hours the jars were rotated, and temperature was recorded in the jar with 100 mL of water. After 5 h, the jars were removed from the griddle. The H_3BO_3 solution was then diluted with 5 mL of filtered deionized water. Manual titrations were conducted with 0.006 M sulfuric acid (H_2SO_4) to an endpoint based on the pH of a mixture containing 5 mL of H_3BO_3 solution and 5 mL of deionized water in a petri dish.

Before titrating the samples, the pH of all reagents was recorded to monitor any chemical solution changes (e.g., absorption of CO₂). The soil test level of mg N kg⁻¹ (ppm) was calculated as S multiplied by T, where S was the mL of H₂SO₄ used in titrating the sample, and T was the titer of the titrant.

Cleaning

The jars were rinsed in warm tap water to remove most of the alkalized sample, followed by brief immersion in 0.2 M H₂SO₄. The jars were then rinsed three times in deionized water. The jar lids and petri dishes were rinsed in deionized distilled water.

Laboratory Quality Assurance and Quality Control

In order to maintain a temperature of 49°C throughout the 5 hour diffusion process, it was necessary to cover a HVAC vent in the in the laboratory to redirect airflow away from the area where the griddles were located. Each day the INST was measured, two griddles were used. The standard soil was crushed with a mortar and pestle after being ground to pass through a 2 mm sieve because accuracy may be improved if finely-ground soil was used. Both griddles contained the same samples and standards. Included in the 12 jars that were placed on each griddle were: a standard soil, a jar containing 100 mL of water (to measure temperature), nine samples, and a duplicate of one sample. Each griddle had a different soil sample designated as the duplicate. The samples were either soil or glucosamine.

Glucosamine was used to evaluate the recovery of amino sugar-N. A solution was prepared by dissolving 1.54 g of dessicator dried reagent-grade glucosamine HCl in 100 mL of filtered deionized water in a 100 mL volumetric flask. One milliliter of glucosamine was added to a jar, instead of soil, and the procedure above was followed. The N content of 1 mL of glucosamine is 1 mg mL⁻¹ when all N is recovered.

If the INST value of the same samples on different griddles differed by more than 10 mg N kg⁻¹, then the sample was reanalyzed.

Figure B.1 shows the standard soil over 158 data points with a mean of 147 mg N kg⁻¹ and a standard deviation of 5.0. For the standard samples, 97% were within two standard deviations of the mean. The Michigan State University procedure may not have the accuracy of the University of Illinois procedure, but it has good precision in conducting the INST.

The recovery of glucosamine over time is shown in Figure B.2. Mean recovery of glucosamine was 930 µg N mL⁻¹ or 93% with 99% of the data points within two standard deviations. This is 5% lower than the expected recovery described by the University of Illinois in the Technical Note.

To compare results from University of Illinois and Michigan State University, 2002 preplant soil samples collected to a depth of 0 to 0.15 m and 0.15 to 0.30 m were analyzed by both laboratories. Figure B.3 shows the relationship between Michigan State University and University of Illinois INST results. A regression line was fit to the data, and a significant correlation ($r = 0.93$) was found. The intercept of the regression was significant ($P = 0.0442$)

and positive, indicating Michigan State University analyses were biased and consistently less than the University of Illinois.

SUMMARY

The INST procedure is sensitive to many factors that could lead to erroneous results if not properly controlled. After modifying the procedure, repeatable data, albeit slightly biased, was obtained and monitored by using duplicate samples and a standard soil. If this procedure is performed accurately and carefully, it is possible to obtain usable, precise data from the INST.

LITERATURE CITED

Anonymous. 2002. The Illinois soil nitrogen test for amino sugar N: Estimation of potentially mineralizable soil N and ^{15}N . Technical Note 02-01. Rev. e. University of Illinois Department of Natural Resources and Environmental Sciences.

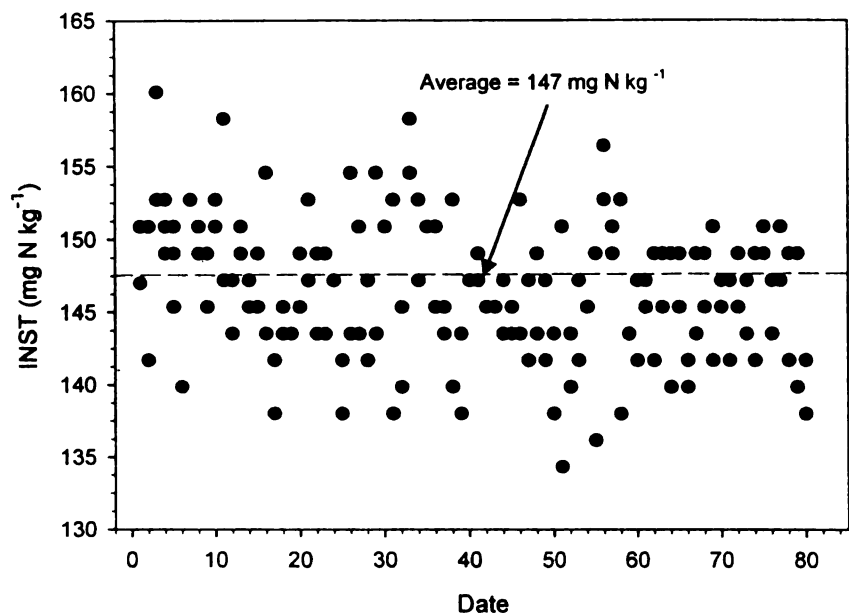


Figure B.1. Performance of the INST on a standard soil over time.

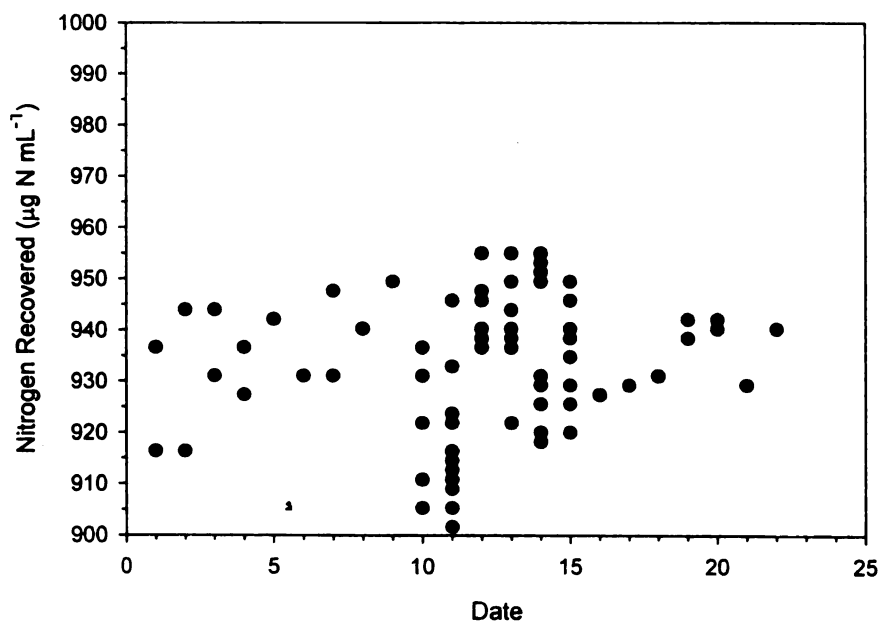


Figure B.2. Nitrogen recovered from a standard glucosamine solution.
100% recovery = 1000 µg N mL⁻¹.

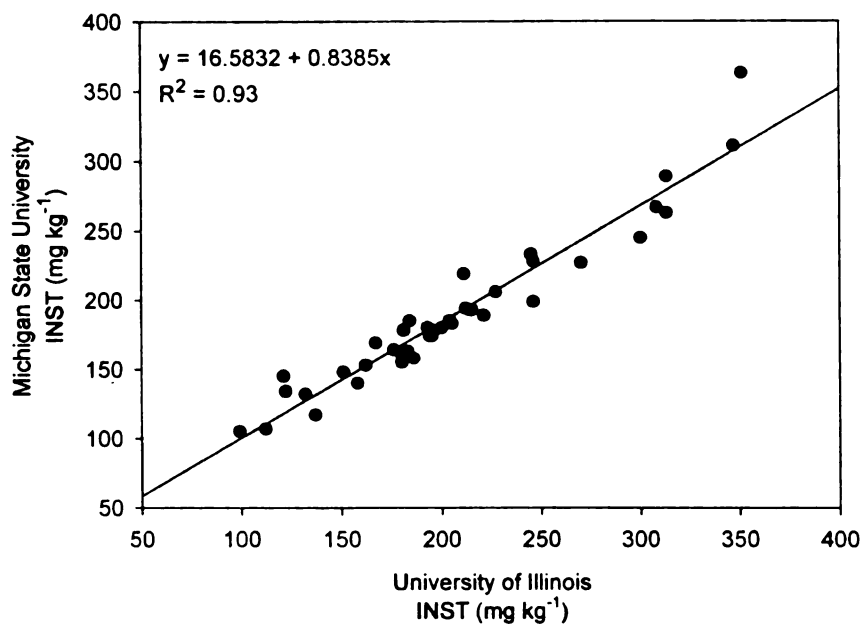


Figure B.3. Comparison of INST results at Michigan State University and the University of Illinois.

APPENDIX C: PROC REG Stepwise Model Interpretation

Introduction

PROC REG in SAS (SAS Institute, 1999) was used to try to determine a model that could predict optimum N rates using soil and field parameters. The overall goal is to obtain an equation that can be used to make N recommendations. This appendix describes the SAS code and output, along with an explanation of the criteria used to choose models.

Parameter Selection and SAS Coding

The parameters to be used in regression models were based on significant correlations in relation to RWSA economic optimum N rate (REONR) and payment economic optimum N rate (PEONR). The parameters included: previous crop, yield, INST in a 0 to 0.30 m sample, OM in a 0 to 0.15 m sample, and NO_3^- -N values in 0 to 0.30 m, 0 to 0.60 m, and 0 to 0.90 m samples. The SAS coding along with a portion of the data is provided in Figure C.1.

```
data bn;
input year loc previous yreonr reonr ypeonr peonr inst om nitrate30;
cards;
2002 1 2 21.5 136 21.6 141 193 2.85 13.37
2002 2 1 27.2 122 27.9 128 230 3.1 16.36
2003 1 2 19.3 91 19.4 92 169.25 3.06 12.69
2004 5 2 42.1 87 43 96 163.3 2.63 13.12
2004 6 2 29.9 127 32.2 140 155.63 3.18 12.02
;
proc reg data=bn;
model reonr=yreonr om nitrate30 nitrate60 nitrate90 INST previous
/selection=rsquare best=4 Cp;
model reonr=yreonr om nitrate30 nitrate60 nitrate90 INST previous
/selection=rsquare best=4 Cp;
run;
```

Figure C.1. An example of SAS code for a model used in PROC REG. Nitrate30 = NO_3^- -N at 0 to 0.30 m, nitrate60 = NO_3^- -N at 0 to 0.60 m, and nitrate90 = NO_3^- -N at 0 to 0.90 m.

Explanation of SAS Code Options

SELECTION = RSQUARE

“Guaranteed optimum subsets are obtained by using the MODEL statement option SELECTION = RSQUARE in PROC REG,” (Freund and Littell, 2000).

BEST = 4

“BEST = 4 specifies that only the best four (smallest error mean square) models for each subset are to be printed. This option prevents excessive output,” (Freund and Littell, 2000).

Cp

“Cp specifies the printing of Mallows C(P) statistic (denoted by C(P) in the output) for each subset. This is the most popular of several statistics used to aid selection of a final model,” (Freund and Littell, 2000).

This coding is a forward selection procedure in that it starts with one parameter and keeps adding one parameter at a time. Once a parameter is in the model, it does not necessarily remain in the model. Only the four best models for a given number of parameters are chosen. However, there is no guarantee that the perfect model is presented in this analysis.

Many parameters were analyzed, but some models were not used because they were not practical. For example, the INST was significantly correlated to OM ($r = 0.82$), and because the INST is not a regular soil test, models with INST were not considered. Typically, if a model included the INST value, it also included OM.

Explanation of SAS Output

An example of a portion of SAS output is included in Figure C.2. Not all values submitted in SAS code will be included in the model, only the best parameters are used. 'Number in models' is the number of variables/parameters in the model. The 'R-Square' column is the R^2 or goodness of fit of the model. The 'C(p)' column in the output gives computes Mallows' Cp statistic for each model.

The REG Procedure Model: MODEL1 Dependent Variable: peonr R-Square Selection Method			
Number in Model	R-Square	C(p)	Variables in Model
1	0.4139	6.7475	om
1	0.3744	7.8749	previous
1	0.2238	12.1788	nitrate30
1	0.1881	13.1998	nitrate90

2	0.5298	5.4367	om nitrate30
2	0.5215	5.6718	om nitrate90
2	0.5062	6.1108	om nitrate60
2	0.4999	6.2890	om previous

3	0.6523	3.9364	nitrate30 nitrate60 nitrate90
3	0.5556	6.6983	om nitrate30 previous
3	0.5480	6.9149	nitrate30 nitrate60 previous
3	0.5389	7.1752	om nitrate30 nitrate90

4	0.7175	4.0733	nitrate30 nitrate60 nitrate90 previous
4	0.6580	5.7723	ypeonr nitrate30 nitrate60 nitrate90
4	0.6553	5.8506	om nitrate30 nitrate60 nitrate90
4	0.5789	8.0322	om nitrate30 nitrate60 previous

5	0.7380	5.4873	om nitrate30 nitrate60 nitrate90 previous
5	0.7273	5.7912	ypeonr nitrate30 nitrate60 nitrate90 previous
5	0.6603	7.7068	ypeonr om nitrate30 nitrate60 nitrate90
5	0.5789	10.0319	ypeonr om nitrate30 nitrate60 previous

6	0.7550	7.0000	ypeonr om nitrate30 nitrate60 nitrate90 previous

Figure C.2. SAS output for model selection to determine a model for PEONR. Nitrate30 = NO_3^- -N at 0 to 0.30 m, nitrate60 = NO_3^- -N at 0 to 0.60 m, and nitrate90 = NO_3^- -N at 0 to 0.90 m.

The REG Procedure			
Model: MODEL1			
Dependent Variable: reonr			
R-Square Selection Method			
Number in Model	R-Square	C(p)	Variables in Model
1	0.3712	6.5893	om
1	0.3185	7.9787	previous
1	0.2117	10.7969	nitrate30
1	0.1733	11.8111	nitrate90

2	0.4833	5.6327	om nitrate30
2	0.4713	5.9493	om nitrate90
2	0.4538	6.4103	om nitrate60
2	0.4384	6.8161	om previous

3	0.6450	3.3658	nitrate30 nitrate60 nitrate90
3	0.4993	7.2111	nitrate30 nitrate60 previous
3	0.4991	7.2165	om nitrate30 previous
3	0.4903	7.4479	om nitrate30 nitrate90

4	0.6871	4.2562	nitrate30 nitrate60 nitrate90 previous
4	0.6493	5.2532	yeonrr nitrate30 nitrate60 nitrate90
4	0.6450	5.3647	om nitrate30 nitrate60 nitrate90
4	0.5258	8.5096	om nitrate30 nitrate60 previous

5	0.7198	5.3937	om nitrate30 nitrate60 nitrate90 previous
5	0.6949	6.0482	yeonrr nitrate30 nitrate60 nitrate90 previous
5	0.6494	7.2504	yeonrr om nitrate30 nitrate60 nitrate90
5	0.5260	10.5067	yeonrr om nitrate30 nitrate60 previous

6	0.7347	7.0000	yeonrr om nitrate30 nitrate60 nitrate90 previous

Figure C.3. SAS output for model selection to determine a model for REONR. Nitrate30 = NO₃⁻-N at 0 to 0.30 m, nitrate60 = NO₃⁻-N at 0 to 0.60 m, and nitrate90 = NO₃⁻-N at 0 to 0.90 m.

The REG Procedure			
Model: MODEL1			
Dependent Variable: reonr			
R-Square Selection Method			
Number in Model	R-Square	C(p)	Variables in Model
1	0.1062	-2.0238	nitrate30
1	0.0397	-1.6531	nitrate60
1	0.0260	-1.5772	nitrate90
1	0.0255	-1.5743	previous

2	0.1646	-0.3490	nitrate30 previous
2	0.1428	-0.2273	nitrate30 nitrate60
2	0.1246	-0.1261	om nitrate30
2	0.1191	-0.0957	nitrate30 nitrate90

3	0.2337	1.2667	nitrate30 nitrate60 nitrate90
3	0.2196	1.3451	om nitrate30 previous
3	0.2132	1.3808	om nitrate60 previous
3	0.1992	1.4584	om nitrate90 previous

4	0.2688	3.0709	yeonrp nitrate30 nitrate60 nitrate90
4	0.2514	3.1678	nitrate30 nitrate60 nitrate90 previous
4	0.2338	3.2661	om nitrate30 nitrate60 nitrate90
4	0.2318	3.2770	om nitrate30 nitrate90 previous

5	0.2768	5.0268	yeonrp nitrate30 nitrate60 nitrate90 previous
5	0.2690	5.0700	yeonrp om nitrate30 nitrate60 nitrate90
5	0.2630	5.1033	om nitrate30 nitrate60 nitrate90 previous
5	0.2328	5.2716	yeonrp om nitrate30 nitrate90 previous

6	0.2816	7.0000	yeonrp om nitrate30 nitrate60 nitrate90 previous

Figure C.4. SAS output for model selection to determine a model for REONR, without non-responsive sites. Nitrate30 = NO₃⁻-N at 0 to 0.30 m, nitrate60 = 0 to 0.60 m, and nitrate90 = 0 to 0.90 m.

Determination of the 'Best' Model

Using Mallows's Cp statistic, the best model is considered to be the one where the sum of the "number in the model" plus one equals the Cp statistic. For example, in Figure C.2, the best model for PEONR includes nitrate30, nitrate60, and nitrate90 because there are three variables in the model and the Cp statistic is approximately one plus three or 3.9364. The best model does not always have the best R² value. This model has the best R² in of the models that have three variables, but it is not the best R² in the output. Generally, the more variables that are included in a model, the greater the R² value.

Also, when considering a model, the P-value for each parameter in the model needs to be analyzed. If the model for nitrate30, nitrate60, and nitrate90 is analyzed, each parameter has a significant P-value. There are other models that may have at least one parameter that does not have a significant P-value. If there is a parameter that is not significant, then it should not be used and that model is invalid.

SUMMARY

For PEONR (also REONR), the model that includes all NO_3^- -N values at 0 to 0.30 m, 0 to 0.60 m, and 0 to 0.90 m would be a good model to evaluate because the Cp statistic equals the number of variables in the model plus 1, and all the terms in the model are significant. However, when plotting predicted PEONR with actual PEONR, the R^2 of the regression is 0.65, and the correlation coefficient (r) equals 0.81. Even though the correlation is strong, the error would not make this a good model for prediction purposes. Without non-responsive sites (Figure 4) none of the models has a Cp statistic that equals the number of variables in the model plus 1, therefore, regression models would not be applicable to predicting optimum N rates for sites that are responsive to N.

LITERATURE CITED

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SAS Institute. 1999. The SAS system for Windows. Release 8.1. SAS Inst., Cary, NC.

APPENDIX D

NITROGEN FERTILIZER EFFECTS ON EARLY SEASON WEED EMERGENCE AND GROWTH: A LITERATURE REVIEW

INTRODUCTION

Soil fertility is a key component of all farming systems. Fertilizer is applied in order to maintain or improve crop yield. The timing, application method, and application rate influence both crop and weed response to applied nutrients. The variation in crop and weed response to soil fertility programs indicates the importance of assessing fertilization strategies from a crop and a weed perspective to enhance crop competition with weeds.

Nitrogen (N), phosphorus (P), and potassium (K) are the three macronutrients applied in cropping systems. Crop and weed growth are dependent on the supply of these nutrients (Vengris et al., 1955). When other factors such as soil moisture and soil temperature are not limiting, optimum yields may be obtained when N, P, and K are available to meet crop demand.

Nutrient Influence on Weed Seed Germination or Emergence

Nutrients in the soil may enhance weed seed germination (Banks et al., 1976; Fawcett and Slife, 1978; Sardi and Beres, 1996). However, if nutrients are applied in excess, they can become toxic to the seedling and reduce emergence of both weeds and crops (Hume, 1982). Nutrients that influence weed seed germination and emergence include N, P, and K.

Nitrogen

Nitrogen is important for weed seed germination because N may replace or change other requirements for germination. The chilling or light requirement for seed germination can be replaced with N (Cohn et al., 1983; Egley and Duke, 1985; Steinbauer and Grigsby, 1957), particularly nitrate (Sexsmith and Pittman, 1963; Steinbauer and Grigsby, 1957; Toole et al., 1956). However, if seeds require light and nitrates for germination, the use of nitrate fertilizers alone does not increase the germination of these weed species (Fawcett and Slife, 1978; Hilton, 1984b; Schimpf and Palmblad, 1980; Hurtt and Taylorson, 1986).

Weed seeds that are exposed to greater N concentrations when developing on the parent plant may retain greater nitrate concentrations in the seed. Nitrate concentration in common lambsquarters seed from unfertilized plots contained $18.7 \mu\text{g g}^{-1}$ of NO_3^- , while seeds from plots fertilized with 280 kg N ha^{-1} contained $126.3 \mu\text{g g}^{-1}$ of NO_3^- (Fawcett and Slife, 1978). Seeds with greater nitrate concentrations are less dormant and are able to emerge without an application of nitrate fertilizer (Fawcett and Slife, 1978). If research is conducted in an area that has a high soil N content, seeds in the seed bank may have high nitrate concentrations, and additional N fertilizer may have little or no effect on germination of these seeds (Baskin and Baskin, 1998).

Different forms of N fertilizer contain varying amounts of ammonium or nitrate, the two forms of soil N available for plant uptake. When the granular formulation of urea is applied to the soil, it is converted to ammonia, which reacts with water to form ammonium (Vitosh, 1996). This ammonium is available for

plant uptake. Ammonium nitrate contains half of its' N as nitrate, which is also available for plant uptake. The response of weed seed germination to N may vary depending on the form of N. Fawcett and Slife (1978) found no effect of ammonium nitrate on emergence of common lambsquarters (*Chenopodium album* L.), velvetleaf (*Abutilon theophrasti* Medic.), redroot pigweed (*Amaranthus retroflexus* L.), jimsonweed (*Datura stramonium* L.) and giant foxtail (*Setaria faberi* Herm.). In contrast, ammonium nitrate increased corn spurry (*Spergula arvensis* L.) emergence (Freyman et al., 1989). Furthermore, Freyman et al. (1989) reported greater emergence of shepherdspurse (*Capsella bursa-pastoris* (L.) Medicus) in plots treated with urea, but not ammonium nitrate. The optimum rate of ammonium nitrate for emergence of corn spurry, common lambsquarters, and ladysthumb smartweed (*Polygonum persicaria* L.) was 100 kg N ha⁻¹ (Freyman et al., 1989). Other researchers have found that the addition of ammonium or urea restricted growth of ammonium or urea sensitive weeds such as common lambsquarters (Anderson et al., 1998). Out of the forms of fertilizer studied by Pyšek and Lepš (1991), liquid urea had the greatest influence on emergence of various weed species including wild buckwheat (*Fallopia convolvulus* L.), catchweed bedstraw (*Galium aparine* L.), and common chickweed (*Stellaria media* (L.) Vill.). Therefore, it appears that the N source, environmental conditions, and weeds species may influence how weeds respond to fertilizer N (DiTomaso, 1995).

Phosphorus

Phosphorus can enhance weed seed germination. Although it is not as well researched as N, germination of several broadleaf and grass weed species increased in response to P. For example, redroot pigweed, carpetweed (*Mollugo verticillata* L.), and henbit (*Laminum amplexicaule* L.) emergence increased with 22.4 kg P ha⁻¹ (Banks et al., 1976). Superphosphate and triplephosphate increased redroot pigweed germination at P rates of 10 to 1000 ppm (Sardi and Beres, 1996). Myers and Moore (1952) also detected an increase in grass emergence when 73 kg P ha⁻¹ was applied in the form of superphosphate each year for 24 years.

Some weed species, such as common lambsquarters may be indicators of phosphorus deficient soils (Schipstra, 1957). It may be possible in the future to use these and other weeds as indicators of nutrient deficient soils.

Potassium

Myers and Moore (1952) applied 733 kg K ha⁻¹ as potassium sulfate and Freyman et al. (1989) applied 65 and 125 kg K ha⁻¹ as muriate of potash and found no effect of potassium (K) on germination of many weed species including common lambsquarters, redroot pigweed, and wild oat (*Avena fatua* L.). However, Sardi and Beres (1996) found 10 to 100 ppm of potassium chloride and 10 to 1,000 ppm of potassium sulfate stimulated germination of redroot pigweed. In all of these studies, the K level in the soil was medium to high, indicating that the addition of K would not affect germination of weeds.

Nutrient Influence on Weed Growth

The addition of nutrients in fertilizer applications may increase the relative growth rate of weeds. Freyman et al. (1989) and Hoveland et al. (1976) reported that some weeds increased growth with increasing nutrients, while other species did not.

Nitrogen

Freyman et al. (1989) reported an increase in weed biomass with increasing N rate, whether the source was ammonium nitrate or urea. Blackshaw et al. (2002) discovered that the biomass of wild mustard increased with 50 kg N ha⁻¹, with the greatest growth occurring when N was surface broadcast compared to surface or point injected. Growth of ladythumb smartweed and common lambsquarters increased when 200 kg N ha⁻¹ was applied in either early April or late May in Canada (Freyman et al., 1989). Biomass of common lambsquarters increased five fold with increasing N rates of 0 kg N ha⁻¹ to 500 kg N ha⁻¹ (Freyman et al., 1989). In contrast, weed biomass was greater in soils treated with 0 and 40 kg N ha⁻¹ compared to 160 kg N ha⁻¹ (Grundy et al., 1993).

Phosphorus

Increasing rates of superphosphate up to 90 kg P ha⁻¹ increased the growth of several broadleaf and grass weeds including: redroot pigweed, jimsonweed, tall morningglory (*Ipomoea purpurea* L.), common dandelion (*Taraxacum officinale* Weber in Wiggers), common chickweed, wild mustard (*Brassica kaber* (DC.) L.C. Wheeler), annual bluegrass (*Poa annua* (L.), and

large crabgrass (*Digitaria sanguinalis* (L.) Scop.) (Hoveland et al., 1976).

Common lambsquarters biomass increased with the addition of 65 kg P ha⁻¹ (Freyman et al., 1989).

Potassium

Adding potassium to soil at 125 kg ha⁻¹ had no effect on the growth of common lambsquarters or ladythumb smartweed (Freyman et al., 1989). However, redroot pigweed, annual bluegrass, and large crabgrass growth increased in response to adding K up to 213 kg ha⁻¹ (Hoveland et al., 1976).

Influence of N on Weed Communities

Crop production practices such as tillage, row spacing, crop rotation, weed control practices, and fertilization influence the density and type of weeds present in a cropping system (Barbari et al., 1997; Derksen et al., 1995; Hartzler and Roth, 1993; Stevenson et al., 1997). Fluctuations in the weed community can be reversible and be either short term or long term; and directional, continuous, or nonseasonal (Miles, 1979).

Short Term

Short term effects on the weed community with addition of N are variable. Emergence of ladythumb smartweed and common lambsquarters increased with increasing N, corn spurry decreased, and there was no effect on emergence of shepherdspurse (Freyman et al., 1989). Decreases in weed density and species diversity can occur when available N is increased (Grundy et al., 1991; Grundy et al., 1992; Grundy et al., 1993; Mahn, 1988; Pyšek and Lepš, 1991). In

no-tillage systems, green foxtail (*Setaria viridis*) and field pennycress (*Thlaspi arvense*) populations decreased over time as N increased (O'Donovan et al., 1997).

In a six year crop rotation study, N rates ranging from 0 to 150 kg N ha⁻¹ had a slight impact on the weed community (Andersson and Milberg, 1998). Common chickweed was associated with N fertilized plots, and field horsetail (*Equisetum arvense* L.) was associated with plots not fertilized with N.

The form of N may influence how N affects the weed community. Plots treated with liquid urea had lower weed densities than plots treated with ammonium sulfate and calcium-ammonium nitrate (Pyšek and Lepš, 1991).

Long Term

Long term effects of applying N may influence the weed community by increasing the amount of nitrophilous weed species and decreasing the number of other weeds. With continuous applications of N over 22 years, Hume (1982) observed more nitrophilous weeds species such as common lambsquarters. When fertilizer is not applied, a change in the weed community may occur as well. For example, after 22 years of broadcast fertilizer applications in continuous wheat, Canada thistle (*Cirsium arvense* (L.) Scop.) populations increased in unfertilized plots (Hume, 1982).

Banks et al. (1976) studied the effects of various soil fertility treatments on weed types and populations. The lowest total plant numbers were found in soil with no fertilizer, whereas a complete fertility treatment increased the number of grass species and decreased the number of broadleaf weeds. However, others

have seen no effect of fertility treatments on weed communities in long term studies. Swanton et al. (1999) conducted a nine year study, and after repeated applications of ammonium nitrate ranging from 0 to 200 kg N ha⁻¹, weed density and species composition were not influenced. Application of herbicides may have had a stronger influence on the weed community and masked any effects of N (Swanton et al., 1999).

Influence of N on Velvetleaf, Ladysthumb Smartweed, Redroot Pigweed, and Common Lambsquarters

Information on velvetleaf and ladysthumb smartweed response to N is limited. Emergence and growth of ladysthumb smartweed increased with the addition of 200 kg ha⁻¹ of ammonium nitrate applied in early April or late May (Freyman et al., 1989). Ammonium nitrate at 34 kg N ha⁻¹ also stimulated velvetleaf emergence when applied in early or late May (Hurtt and Taylorson, 1986). In a contrasting study, 0 to 448 kg N ha⁻¹ of ammonium nitrate had no effect on velvetleaf emergence (Fawcett and Slife, 1978).

Redroot pigweed emergence was stimulated by 34 kg N ha⁻¹ (Hurtt and Taylorson, 1986), and by 112 kg N ha⁻¹ (Fawcett and Slife, 1978). Redroot pigweed growth increased with the addition of 220 kg N ha⁻¹ to the soil (Teyker et al., 1991). However, redroot pigweed emergence did not increase as N increased from 112 to 448 kg ha⁻¹ (Fawcett and Slife, 1978). Sardi and Beres (1996) compared concentrations of ammonium nitrate and urea; at 10 and 100 ppm redroot pigweed germination was stimulated, but the highest concentration

(1,000 ppm) of ammonium nitrate fertilizers and urea significantly inhibited germination. Schimpf and Palmblad (1980) found little evidence of nitrate stimulating germination of redroot pigweed. Redroot pigweed seeds may have been exposed to excessive N which could have been detrimental to seed germination.

Common lambsquarters is a nitrophilous weed species (Hume, 1982). Increasing rates of ammonium nitrate to 448 kg N ha⁻¹ applied in mid-May did not affect common lambsquarters density (Fawcett and Slife, 1978). In contrast, 100 to 300 kg N ha⁻¹ of ammonium nitrate applied in early April or late May increased common lambsquarters emergence (Freyman et al., 1989). Nitrate concentrations in common lambsquarters seed may influence seed dormancy and response to N. Seeds produced with 280 kg N ha⁻¹ of ammonium nitrate had greater germination compared to seeds produced on plants where no N was applied (Baskin and Baskin, 1998; Fawcett and Slife, 1978).

Influence of N on Foxtail Germination, Emergence, and Growth

Applying ammonium nitrate from 112 to 448 kg N ha⁻¹ had no effect on giant foxtail density (Fawcett and Slife, 1978). Anderson et al. (1998) and Schimpf and Palmblad (1980) found little evidence for nitrate stimulating germination of yellow foxtail (*Setaria glauca* (L.) Beauv.). Oxygen regulated in the hydrated seed over time may be a more important factor influencing giant and yellow foxtail emergence (Dekker and Hargrove, 2002).

Emergence of green foxtail (*Setaria viridis* (L.) Beauv.) is often associated with low residual N, and emergence of green foxtail decreased as N rates increased (Anderson et al., 1998; O'Donovan et al., 1997). Placement of N was not a factor in emergence of green foxtail. When N was either surface broadcast, or banded, emergence of green foxtail was not affected (Blackshaw, 2002; Kirkland and Beckie, 1998). In other research, N did not affect giant or yellow foxtail growth, but leaf area increased as the N rate increased (Blackshaw, 2002; Peterson and Nalewaja, 1992; Schreiber and Orwick, 1978).

Influence of N on Other Grassy Weeds Germination, Emergence, and Growth

The majority of N research with grassy weeds has focused on wild oat, downy brome (*Bromus tectorum* L.), witchgrass (*Panicum capillare* L.), and rigid ryegrass (*Lolium rigidum* Lam.). Applying N up to 90 kg N ha⁻¹ during the winter wheat growing season increased downy brome emergence and growth (Ball et al., 1996), especially when applied broadcast (Rasmussen, 1995). Rigid ryegrass used late season applications of N, and continued to produce tillers when N was available (Davidson, 1984).

Wild oat response to N¹ appears dependent on soil type. When high levels of granular limestone nitrate and liquid ammonium nitrate were applied on loamy soils, wild oat emergence was delayed 15 days; however, low levels of granular limestone nitrate and liquid ammonium nitrate applied on sandy soils stimulated germination and emergence of wild oat (Agenbag and De Villers, 1989). Wild oat

densities increased when rates of ammonium sulfate increased to 134 kg N ha⁻¹ (Carlson and Hill, 1985). Surface broadcast applications of N increased emergence of wild oat compared to banded N applications (Kirkland and Beckie, 1998; Reinertsen et al., 1984).

The dormancy of wild oat and several other grass species (*Bromus diandrus* Roth., *Hordeum murinum* L., *Lolium temulentum* L., and *Phalaris minor* Retz.) was irreversibly broken when treated with ammonia gas (Cairns and De Villers, 1986). Agabawi and Younis (1965) and Farina et al. (1985) demonstrated a dramatic reduction of the incidence of witchgrass in corn and sorghum with shifting the N source from ammonium nitrate to ammonium sulfate or urea. These forms of N would increase the concentration of ammonia gas in the soil thus increasing germination of witchgrass.

Fertilizer: Influence of Rate, Placement, and Timing in Crop Production

It is important to develop fertilization strategies for crop production that will enhance the competitive ability of crops and minimize weed competitiveness, yet reduce the potential environmental problems associated with water quality. Fertilizer banding in the crop row, substituting urea or ammonium for nitrate in fertilizer combinations, and changing the timing of nutrient application may influence weed response (DiTomaso, 1995). Fertilizer treatment could potentially be used to deplete seed reserves in fallow years by inducing weed seeds to germinate. This would reduce the amount of seed available to germinate the

next year, and weeds in the fallow year could be controlled with preplant cultivation (Sexsmith and Pittman, 1963).

N Placement in Small Grains

If weeds are capable of absorbing N earlier and more rapidly than the crop, a delayed N application may be a strategy to promote crop and not weed growth. Furthermore, fertilizer placement near crop roots versus shallow placement near weed roots may be another strategy to reduce N availability to weeds and reduce their competitiveness. Weed growth was reduced when fertilizer was deep banded compared to broadcast applications (Everaarts, 1992). Applying increased N may increase the ability of the cereals to suppress weeds (Grundy et al., 1993) but the timing and placement of N must favor the crop and not the weeds.

In winter wheat (*Triticum aestivum* L. emend. Thell.), the greatest demand for N is before tillering, but rigid ryegrass is stimulated by these late N applications (Davidson, 1984). Therefore, early N applications reduced the competitive effect of rigid ryegrass on winter wheat yield, and growers were encouraged to apply N fertilizers prior to the three- to four-leaf stage in winter wheat (Davidson, 1984). In contrast, Angonin et al. (1996) found that delaying the application of N until the end of *Veronica hederifolia* vegetative growth allowed the winter wheat to absorb N independently of weed density and reduced yield loss due to this weed.

However, in other research, winter wheat grain yield was optimized with a split application of 90 kg N ha⁻¹ applied preplant and during the growing season (Ball et al., 1996). In comparison, winter wheat did not respond to single application rates above 45 kg N ha⁻¹, but there was a significant increase of downy brome growth and uptake at the higher N rates (Cochran et al., 1990).

All N applications during the growing season of winter wheat increased downy brome biomass (Anderson, 1991; Ball et al., 1996). Nitrogen applied during the fallow season prior to planting (early spring) reduced downy brome competitiveness (Anderson, 1991; Ball et al., 1996). However, applying N at planting reduced winter wheat yield when infested with downy brome (Anderson, 1991) or Italian ryegrass (*Lolium multiflorum* Lam.) (Appleby et al., 1976).

Nitrogen should be placed in a manner which the crop has preferential access and the weeds have limited access can be challenging. Cochran et al. (1990) fall applied broadcast or banded ammonium nitrate in winter wheat using rates up to 190 kg N ha⁻¹. Winter wheat N uptake, growth, and yield increased with banded N application, but when weed infestations were severe, placement of N did not increase yield of winter wheat (Cochran et al., 1990; Rasmussen, 1995). If weeds are controlled properly, placement of N may not be of great concern.

Yield of spring wheat (*Triticum aestivum* L. emend. Thell.) and spring barley (*Hordeum vulgare* L.) increased with applications of N, especially when split between a preplant and postplant application. However, when wild oat densities exceeded 10 plants per m², spring wheat yields on fertilized plots were

generally lower than the yields attained in the unfertilized plots at the same wild oat density. Relative yield loss due to wild oat generally increased with the split N applications (Carlson and Hill, 1985).

Spring wheat biomass increased with application of 50 kg N ha⁻¹ whether it was applied by surface broadcast, surface or point injected (Blackshaw et al., 2002; Kirkland and Beckie, 1998). However, in the presence of weeds, surface broadcast N applications reduced spring wheat biomass because the weeds were more competitive. Banding fertilizer N to a 5 to 8 cm depth resulted in N being more available to spring wheat and spring barley compared to preplant broadcast N; banding at planting in spring barley decreased growth and competitiveness of green foxtail, but did not reduce availability of N to wild oat in spring wheat (Kirkland and Beckie, 1998; O'Donovan et al., 1997; Reinertsen et al., 1984). Banding N between the crop rows, together with herbicide use, considerably reduced weed infestations, compared with herbicide use alone (O'Donovan et al., 1997).

Spring wheat grain yield decreased with N fertilization up to 134 kg N ha⁻¹ in heavy infestations of wild oat, while the density of wild oat increased (Carlson and Hill, 1985). In competition with spring wheat, wild oat used N more effectively and gained a competitive advantage over spring wheat. Spring wheat grain yield in wild oat-infested plots generally declined with fertilization while the density of wild oat panicles increased (Carlson and Hill, 1985). The increased competitiveness of wild oat resulted in reduced crop yields. Pyšek and Lepš (1991) observed that increasing N to 140 kg N ha⁻¹ increased barley biomass

and competition with weeds. But if the cost of applying increased rates N beyond what the crop needs is more than the cost of controlling the weeds by alternative means, than increasing application rates of N may not be cost effective.

Nitrogen Placement and Timing in Corn

Nitrogen timing and placement in corn influence weed competition (Hellwig et al., 2002). The maximum growth rate and the N requirement in corn is later in the growing season than that of most weeds (Larson and Harway, 1977; Seibert and Pearce, 1993). Corn biomass increased by as much as 70% and reduced weed (*Sinapsis arvensis* and *Chenopodium album*) biomass by as much as 50% when fertilizer was delayed until sidedress (Alkämper, 1976). If fertilizer was banded instead of broadcast in late June, broadleaf weed densities, weed biomass, and N uptake by weeds in corn was reduced by 35, 50, and 42% (Swanton et al., 1999). Weedy corn yield was 50% lower when 80 kg N ha⁻¹ of urea (46% N) was applied compared to applications of 200 kg N ha⁻¹ (Tollenaar et al., 1994). When N is limiting in corn, corn yield is more affected by weed competition (Nieto and Staniforth, 1961; Tollenaar et al., 1994).

Nitrogen Placement and Timing in Sugarbeet

The time and rate of N application influences weed emergence in sugarbeet (*Beta vulgaris* L.). In a field study of common lambsquarters, redroot pigweed, kochia (*Kochia scoparia* L.), and foxtail (*Setaria* spp. L.), weed emergence increased as N application rate increased from 56 kg N ha⁻¹ to 224

kg N⁻¹ (Dotzenko et al., 1969). This study was on a clay loam soil with 1.9% organic matter (Dotzenko et al., 1969).

Time of N fertilization can be an important factor in enhancing the competitiveness of sugarbeet with weeds. When N was applied at a rate of 120 kg N ha⁻¹ 28, 42, or 56 days after sugarbeet emergence, time of N application did not affect biomass, yield, and yield quality of the weed-free sugarbeet crop (Paolini et al., 1999). However, timing of N application had an effect on crop yield in the presence of weeds. Early N application caused *Sinapsis arvensis* to be more competitive with sugarbeet. However early application of N increased sugarbeet competitiveness with common lambsquarters (Paolini et al., 1999).

SUMMARY

Plant response to N fertilizer is influenced by environmental factors such as soil moisture, soil temperature, the rate of N mineralization, and the type of N fertilizer. Soil moisture must be adequate for seed imbibition to trigger germination, and soil temperature must be above the minimum for weed species to germinate. Because time of weed emergence is specific to weed species, it is difficult to germinate many weed species in the field in early spring when N may be a limiting factor. The addition of fertilizer N may increase available N to the weeds. However, the effect of late spring N applications on weed seed germination may be masked and show no effect of fertilizer N on weed germination. Rapid mineralization and nitrification that occurs by mid-May under warm, moist conditions near the soil surface, may result in natural soil fertility

providing enough nitrate to saturate any mechanism affecting seed germination (Freyman et al., 1989).

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Appendix E. Total inorganic N (NO₃⁻-N and NH₄⁺-N) in 2003 and 2004.

	N Applied (kg ha ⁻¹)		0	56	112	168
Year	Sampling Date	Depth (cm)	Total Inorganic N			
			(kg ha ⁻¹)			
2003	15 April	0-8	8			
	Week 1	0-8	21	51	110	141
	Week 2	0-8	13	26	49	63
	Week 3	0-8	13	30	39	53
	29 April	0-8	10			
	Week 1	0-8	13	31	40	64
	Week 2	0-8	10	23	49	46
	Week 3	0-8	8	27	38	65
	21 May	0-8	14			
	Week 1	0-8	12	39	49	93
	Week 2	0-8	13	42	79	76
	Week 3	0-8	19	47	76	101
2004	6 April	0-8	15			
	Week 1	0-8	12	42	57	83
		8-16	6	9	10	13
	Week 3	0-8	18	44	62	75
		8-16	8	8	10	13
	Week 5	0-8	12	29	30	46
		8-16	9	20	20	23
	20 April	0-8	18			
		8-16	7			
	Week 1	0-8	23	32	49	67
		8-16	8	9	9	11
	Week 3	0-8	17	27	37	54
		8-16	10	17	20	27
	Week 5	0-8	8	12	13	15
		8-16	7	11	14	16
	20 May	0-8	12			
		8-16	10			
	Week 1	0-8	9	21	36	53
		8-16	8	10	11	16
	Week 3	0-8	20	32	48	65
		8-16	15	11	14	17
	Week 5	0-8	8	10	15	36
		8-16	8	11	14	28

Appendix F. Weed emergence from soil in petri dishes with sprayed with urea.

Species [†]	N Rate kg N ha ⁻¹	Run 1 -----	Run 2 Emergence (%)	Run 3 -----
ABUTH	0	53	33	50
	56	40	20	50
	112	17	23	30
	168	3	20	10
AMARE	0	80	90	100
	56	43	73	87
	112	3	30	53
	168	3	10	10
CHEAL	0	50	47	47
	56	23	60	77
	112	3	23	23
	168	3	17	10
POLPY	0	17	13	13
	56	7	3	3
	112	3	3	3
	168	3	0	3
SETFA	0	60	67	70
	56	57	57	53
	112	23	40	27
	168	3	30	10

[†] ABUTH = velvetleaf, AMARE = redroot pigweed, CHEAL = common lambsquarters, POLPY = ladythumb smartweed, and SETFA = giant foxtail.

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