Nitrogen Management in Romaine Lettuce Study

Introduction

Why Manage Nitrogen?

Romaine lettuce (*Lactuca sativa L. variety salvius*) like most crops, requires intensive nitrogen management for successful plant growth, optimization of health, prevention of economic losses, and avoidance of environmental contamination. While Romaine lettuce needs this essential element more than any other nutrient, it needs 80% of it during the last 3-4 weeks of its development for dry matter accumulation. Despite the atmosphere being 78% nitrogen, it is largely unavailable to non-leguminous crops like lettuce and is only introduced into the soil naturally in sparse amounts not substantial enough for agricultural purposes. Split applications are required as result of these circumstances which requires more labor costs to the grower. Moreover, not all sources of nitrogen applied are as plant available. Sources that are more bioavailable, have a higher potential for leaching into surface and ground water. This is rare in these vast amounts in almost all other crop nutrients. To make matters more difficult, leaching is exacerbated in more course soil textures and is compounded in more hot arid regions such as the San Joaquin Valley because lettuce requires longer irrigation sets that drive nitrates into rivers and streams poisoning both wildlife and livestock at a higher rate. These unique characteristics of nitrogen require crop advisors to manage nitrogen more closely than any other plant nutrient. Growers must therefore apply nitrogen to the soil at the right time, using the right source, at the right rate, and at the right place to maximize yields and profits while simultaneously doing so in an environmentally sustainable way.

Right Time and Place

Lettuce requires little nitrogen in the initial stages of growth and development and must be applied at the right time to ensure nitrogen remains in the right place for efficient root uptake. In the first month, only about 20% of the total nitrogen is required so farmers should avoid large applications pre-plant or at planting. Residual soil nitrogen concentrations should always be tested before or at planting to ensure they are at a minimum of 20 ppm. Applying nitrogen when concentrations exceed 20 ppm will only serve to waste money and contribute to the mounting problem of nitrate pollution because the nitrogen will not be utilized and be leached out of the root zone. In addition to the first potential broadcasted application, three more additional applications must be applied in what are called side-dress applications with 80% of the total 150-180 lbs/acre occurring in the last month. The most efficient way of delivering nitrogen at the right time and place is between the rows via drip line fertigation and injected via differential pressure injectors. Not only will this method prevent leaching it will also reduce the risk of the nitrogen turning into ammonia (NH_3) gas termed volatilization because excessive amounts won't be sitting idle in the soil. Denitrification occurs when nitrate-nitrogen ($N\text{-}NO_3$) is converted into nitrogen gas by bacteria and will also be prevented using this approach. Understanding the Romaine lettuce lifecycle will safeguard against pollution, poor crop yields and reduced profits because the grower will be able to better apply nitrogen at the most advantageous interval and location.

Right Rate and Source

Choosing the right rate at which to apply nitrogen fertilizer is directly influenced by the source and the source will also dictate at what rate to apply. Lettuce can only absorb inorganic nitrogen as ammonium (NH_4) or nitrate (NO_3) but prefers the nitrate form. Here in lies the fundamental complication of choosing the best quantity and type of nitrogen fertilizer; soil particles being an anion will more easily hold onto cationic ammonium thus preventing leaching. However, nitrates being anionic will repel the soil particles and be leached out of the root zone and into water supplies more easily if not used by the plant. For instance, if soil nitrogen analysis prescribes the need for 50 pounds/acre of nitrogen and the source is primarily ammonium, the crop may not be able to absorb enough nitrogen and show signs of chlorosis. An inexperienced farm manager may then apply too much the following application if not aware "Quick Nitrate Soil Tests" are not testing for ammonium and not cognizant a crop can still show signs of deficiency regardless of ample nitrogen being in the soil profile. This ammonium may then convert over to nitrates too quickly, leach, volatilize, nitrify, and/or cause toxicity symptoms. If timed correctly though, could result in less split applications reducing labor costs because the ammonium could convert over to nitrate when its most needed if precise planning is conducted. Choosing an ammonium source may also cause the pH of the soil to become too acidic causing toxicity and deficiency symptoms in other nutrients. Water nitrate levels also should be checked as they will serve as a credit to the nitrogen budget and influence the rate of fertilization. Choosing the right rate and source are very complex decisions that can have antagonist effects but if done correctly can have additive or even synergistic effects if managed properly.

Management Tools

Managing nitrogen in cool season crops such as Romaine lettuce can clearly be a daunting task as discussed. Fortunately, several tools exist today that can help growers, researchers, crop advisors, and applicators manage nitrogen delivery. An online tool called CropManage, is a databased driven software, that can aid growers in numerous plantings, irrigate and fertilize in a more efficient manner. Utilizing CIMIS ET data, crop coefficients by stage of growth, soil texture, "Quick Nitrate Tests", irrigation equipment, laboratory soil tests, weather station data, and GPS locations of plantings, it can automate irrigation and fertilization events. It provides in laymen's terms how long to run irrigation sets reducing the risk of over irrigation and fertilization. CIMIS and "Quick Nitrate" data can be used without the program but for those that are technologically savvy, CropManage is a more intuitive tool. In addition, many nitrogen calculators and guides exist through UC Extensions and local farmer coalitions. The Certified Crop Advisor website can also provide fertilizer management tools but assume the user has a technical agricultural vernacular to navigate its methodology. Mid-rib lettuce nitrate sap analysis while can't provide nitrogen application requirements, can be used to assist in confirmation of plant health issues and evaluate efficiency of long term fertilization programs. The Cardy Meter and LAQUA Twin Nitrate Meter both can both conduct these tests with the latter being able to test water and soilless media nitrate levels as well. Although tissue sampling done conventionally in a laboratory is the most accurate, it is far too time consuming and costly for growers who often need nitrate levels yesterday. These resources are great but they all still do not negate the requirement for having an extensive knowledge of agronomy.

Romaine Lettuce Production in California

Romaine lettuce can be grown nearly year around with two major seasons per year throughout California. It is a typically considered a cool-season crop tolerant of heat unlike most varieties of lettuce making it ideal for California production. Night time temperatures of 45°F and daytime temperatures of 73°F are ideal. The Central Coast, Southern Coast, and the Central Valley are the major production locations for Romaine lettuce with the most being in Monterey Country because temperatures are closest to these climate ranges. Romaine lettuce can be planted in early August until early September and harvested in October to mid-November. In early November to late December plantings can be made for a harvest in April. Although lettuce can be planted in the fall, it is not recommended to apply nitrogen fertilizers at planting because the winter rains will leach nitrates below the root zone. Cool soils can persist into the early spring causing ammonium toxicity because ammonium is slow to convert into nitrate. Noteworthy, is that is not advised to use manures in production of lettuce due to health concerns.

Objectives of the Experiment

- Determine the influence of three side-dressed nitrogen fertilizer split-treatment rates on:
  - Romaine lettuce yield
  - Soil nitrate (ppm NO3-N)
  - Tissue nitrate (ppm NO3-N)
- Is there a connection between soil nitrate concentrations and tissue nitrate concentrations?
- Do tissue nitrate concentrations affect yields?

Materials & Methods

Experimental Design

This field experiment was carried out at California State University, Fresno, CA Horticulture Unit (36.8173816,-119.7349161) during January 2018 to April 2018. The soil was determined to be a loam by conducting a texture by feel using the flow diagram provided by the United States Department of Agriculture (USDA): Natural Resource Conservations Service (NRCS) and confirmed with a saturation percentage of 50% provided by Dallavalle Labatory. The plot was cultivated using a tractor drawn rotary tiller with light bed-shaping prior to installation of irrigation system. The plots previously had pumpkins grown on them in the fall of 2017 and were not planted or harvested uniformly throughout the field. Just adjacent to this experiment was a critical weed free period experiment that was being conducted using the same crop, planting, and harvest dates as our own and may have introduced some effect on this experiment. Remarkable notes, were heavy grazing by rabbits and squirrels, heavy spring rains, no herbicide applications, and some disease that required a fungicidal treatment of Quadris (Azoxystrobin) as per label rates. Hand weeding and hand hoeing were the primary tools used to exterminate weeds although it was not done uniformly.

This Randomized Complete Block Design (RCBD) nitrogen management experiment was carried out on two beds that were each 408 linear feet long and five feet wide. Each bed had two rows of romaine lettuce spaced one foot apart. Each bed was further divided into 8 plots for a total of 16 plot on both beds. Only 15 plots were used however. Three foot borders to the north and south were used for entering and exiting the entire field. The plots were 50 feet by five feet. Blocks of four plots were separated by one foot borders to the north and south for irrigation pipes. Each of the three treatments was replicated five times on five plots chosen at random. Each treatment represents a block so three blocks were used and the five plots within each of the three blocks were randomized. The blocks were randomized as well.

Growing of Plants and Fertilizer Applications

Romaine lettuce (*Lactuca sativa L. variety salvius*) grown in Salinas, CA were transplanted in two rows three part apart on one bed with two non-pressure compensated lines with 12-inch spacing on January 30, 2018 and harvested on April 24, 2018. There were three different nitrogen treatment rates that all utilized the same fertilizer source and delivery system. The treatments were a "Grower's Practice" Treatment A which received adequate amounts of nitrogen, "Slightly Reduced N" Treatment B, and "More Reduced N" Treatment C which relied solely on residual soil nitrogen. There was no fertilizer added at pre-plant or transplant because a soil composite at 0-8 inches from Dallavalle Laboratory was 102 ppm NO3-N and the averaged composite soil samples per plot using NO_3 Quick Nitrate test were 132 ppm. Treatments are expressed in pounds per acre (lbs./A). All liquid fertilizer treatments were delivered via Mazzei® differential pressure injectors. No amendments such as gypsum were required. Noteworthy were that soil Zn was high at 6 ppm, soil B was low at 0.2 ppm, soil EC (dS/m) was high at 6.75, soil Ca was high at 37.2 (meq/l), and soil Na high at 9.1 (meq/l).

Figure 1. *Treatment values in lbs./acre*

Location of Treatment	Sidedress 1	Sidedress 2	Pre-Harvest	**Total Nitrogen Fertilizer Applied**
Date of Treatment	03/06/18	03/19/18	03/30/18	
Material Applied	UAN-32 (UreaNH4NO$_3$, 32%)	CAN-17 (CaNH4NO$_3$), 17%	CN-9 (Ca(NO$_3$)$_2$, 9%)	
Method of Application	(Fertigated)	(Fertigated)	(Fertigated)	
Treatment A (Grower's Practice)	35	50	80	**165**
Treatment B (Slightly Reduced N)	5	20	55	**80**
Treatment C (More Reduced N)	0	0	0	**0**

Measurements

Soil nitrate concentrations were gathered on a per plot basis. Each plot comprised of a composite soil sample at 0-8 inches. Standard "Quick Nitrate Test" protocol was followed using nitrate-specific test strips and dilute $CaCl_2$ extract. Although some side-dresses received a portion of the nitrogen in ammonium form, only nitrate was tested for in the soil. Six quick nitrate soil tests were done throughout the experiment.

Tissue sap nitrate was conducted with the LAQUA portable nitrate meter. 20 mid-ribs from lettuce leaves is ideal for collection however due to heavy grazing and poor weeding only 5-10 mid-ribs were collected per plot. Each sample per plot was pulverized into a liquid using a garlic press and the liquid collected. Tissue sap nitrate readings were expressed in NO_{3}-N ppm from the extracted liquid. Two tissue sap nitrate tests were conducted throughout the experiment.

Harvest was conducted on April 24, 2018 by hand. Only marketable heads of lettuce were collected. Total number of heads of lettuce and total weight of freshly cut heads of lettuce per plot was collected. Each individual head of lettuce was not weighed but instead an average per head was deduced from heads of lettuce and total weight per plot.

Standard Error

Uncertainty and the degree of error in a reported measurement can be represented using error bars which are graphical representations of the variability of data. They provide a general indication of the accuracy of the reported values and give a quantitative value to the level of accuracy. Human error was held to a minimum and statistical noise was mitigated by replication and the use of averages. Outliers were also thrown out if human error was blatant. Within this context, error bars are still provided to ensure trends observed are within the normal limits of previously replicated experiments

Results and Discussion

Yields and Soil Nitrate Relationship

In 2007-2009, state-wide Romaine lettuce yields were 14.5-16.3 tons/acre. *Figure 2.1* and *figure 2.3* used the yields/plot data to extrapolate yield/acre for comparison purposes. All three treatments were at least 3 tons/acre lower than state averages. The excessive rain and unusually cold winter and spring temperature may have contributed to the overall low yields. In addition, excessive grazing and poor weed suppression likely are key causes of the nearly uniform reduced yields/acre. Despite all blocks getting different rates of nitrogen fertilizers the yields/plot and yields/head were not significantly different which can be explained because all the blocks had ample nitrogen for the entire season assuming all is taken up by the plants. The "Slightly Reduce N" had the highest yields but only marginally which was unexpected since it got about half the rate as the "Grower's Practice." However, residual soil nitrate levels were quite high and perhaps the "Grower's Practice" received excessive nitrogen. With nitrate levels of 141 ppm (*Figure 3.1 & 3.2*) in the Treatment A block, it already had the equivalent of 282 lbs./A in the top six inches of soil which is an ample supply for the season. Before the first side-dress it was still very high at 141 ppm. A grower should not apply 35 lbs./A of nitrogen when soil nitrate levels are this high or even 5 lbs./A as with Treatment B. As expected Treatment C had the lowest yields since it got no additional fertilizer.

Yields and Tissue Nitrate Relationship

The tissue sap nitrate tests (F*igure 4.1 & 4.2*) positively correlate with the amount of nitrogen added but do not correlate to the yields. While Treatment A had the highest tissue nitrate, it did not have the highest yield. Treatment C had the lowest tissue nitrate levels which correlates with its 0 lbs./acre N fertilization rate and its low yields. Treatment B as predicted had the second highest levels of nitrates in its tissue but had the highest yields.

Soil Nitrate, Tissue Nitrate, Yields, and Rate Relationship

When *Figure 1, Figure 3.2,* and *Figure 4.2* are compared, they further explain the results. In the first three weeks, the soil nitrate test remained almost constant with some slight changes because the plant is not taking up much nitrogen in during this stage of grwoth. Some error was likely due to error in the "Quick Nitrate Test" reporting methods and conversions of residual ammonium into nitrate and leaching because of heavy rains. However, after the first side-dress all soil nitrate levels were nearly identical after drastically declining. The N was not likely taken up by the lettuce during this stage of growth when reasoned based upon later yields and tissue nitrate analysis. Leaching again is likely the culprit due to unusually heavy rains and loamy soils. After side-dress two, Treatment B had an unexpected increase in soil nitrate while Treatment A remained almost constant. Treatment A soil nitrates levels continued to decline until harvest and was likely due to rapid uptake by the lettuce at this stage of growth. This can be further strengthened with the fact that Treatment A had the highest tissue nitrate concentrations. Treatment C showed a steady decline in both soil nitrate and tissue nitrate which correlated to its low yields.

Conclusion

The influence of three side-dressed nitrogen fertilizer split-treatment rates on Romaine lettuce yield, soil nitrate (ppm NO3-N), and tissue nitrate (ppm NO3-N) was determined. The data was by no means definitive due to significant error but adding additional nitrogen treatments when soil nitrate levels (ppm NO3-N) are above 130 ppm, does not seem to have any significant effect on yields. Soil nitrate levels did correlate to tissue nitrate levels. Soil nitrate levels seems to be a better predictor of yields than tissue nitrate analysis.

Figure 2.1

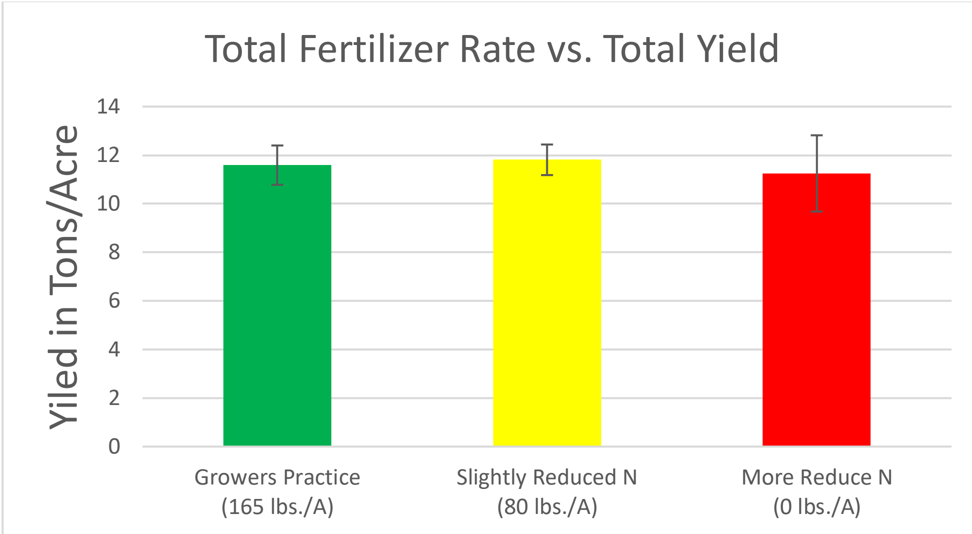

Figure 2.2

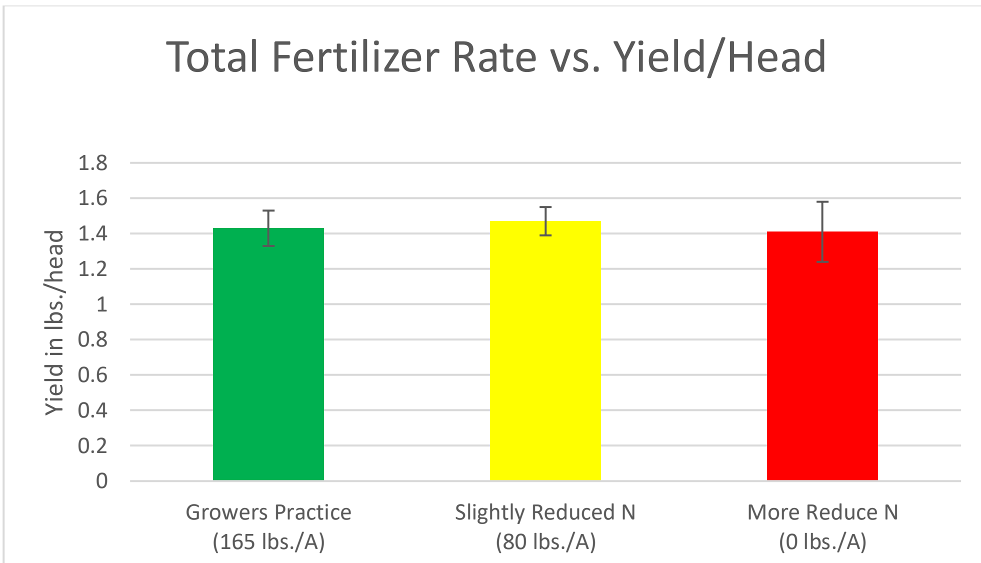

Figure 2.3

One Cut Yield			
Plot Number	**Yield (lbs./plot**	**Head weight (lbs./head**	**Yield (tons/A)**
A1	142.32	1.52	12.40
A3	123.72	1.33	10.78
Average	**133.02**	**1.43**	**11.59**
Standard Error	9.30	0.10	0.81
B1	128.34	1.39	11.18
B3	142.81	1.55	12.44
Average	**135.58**	**1.47**	**11.81**
Standard Error	7.23	0.08	0.63
C1	111.14	1.24	9.68
C3	147.17	1.58	12.82
Average	**129.15**	**1.41**	**11.25**
Standard Error	18.01	0.17	1.57

Figure 3.1 *Six soil nitrate tests taken.*

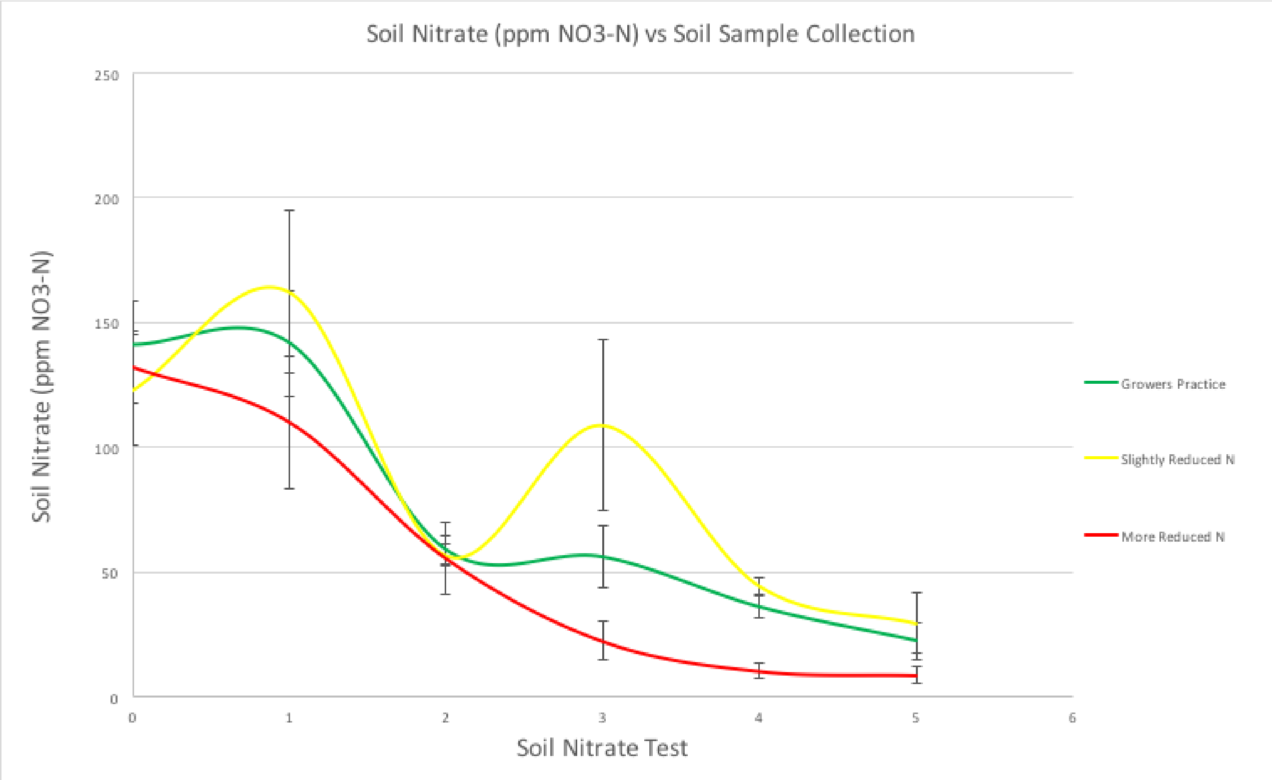

Figure 3.2

SOIL NITRATE (ppm NO_3-N)						
Treatment	First 1/30/2018 At-Transplant (Residual)	Second 2/20/2018 Before Sidedress 1	Third 3/13/2018 After Sidedress 1 (3/5)	Fourth 4/3/2018 After Sidedress 2 (3/19)	Fourth 4/17/2018 After Pre-Harvest (3/30)	Residual 4/24/2018 Post Harvest (Residual)
Grower Practice						
A1	150	175	75	75	50	25
A2	150	157.5	67.5	70	35	12.54
A3	150	61.3	50	10	40	50
A4	75	175	57	50	25	12.5
A5	180	140	45	75	30	12.5
Average	**141**	**141.76**	**58.9**	**56**	**36**	**22.51**
Standard Error	17.49	21.14	5.52	12.39	4.30	7.29
Slightly Reduced N						
B1	180	270		75	37.5	52.5
B2	120	175	52.5	175	50	25
B3	135	87	67.5	200	35	11
B4	45	105	45	15	50	
B5	135	175	62	80	50	
Average	**123**	**162.4**	**56.75**	**109**	**44.5**	**29.5**
Standard Error	21.94	32.31	4.47	34.26	3.39	12.19
Moderately Reduced N						
C1	150	175	67.5	45	10	22.5
C2	135	175	100	20	5	5
C3	150	70	60	12.5	22.5	8
C4	75	75	38	12.5	5	5
C5	150	55	12.5		10	4
Average	**132**	**110**	**55.6**	**22.5**	**10.5**	**8.9**
Standard Error	14.54	26.74	14.66	7.71	3.20	3.47

Figure 4.1 *Two tissue sap nitrate tests were taken*

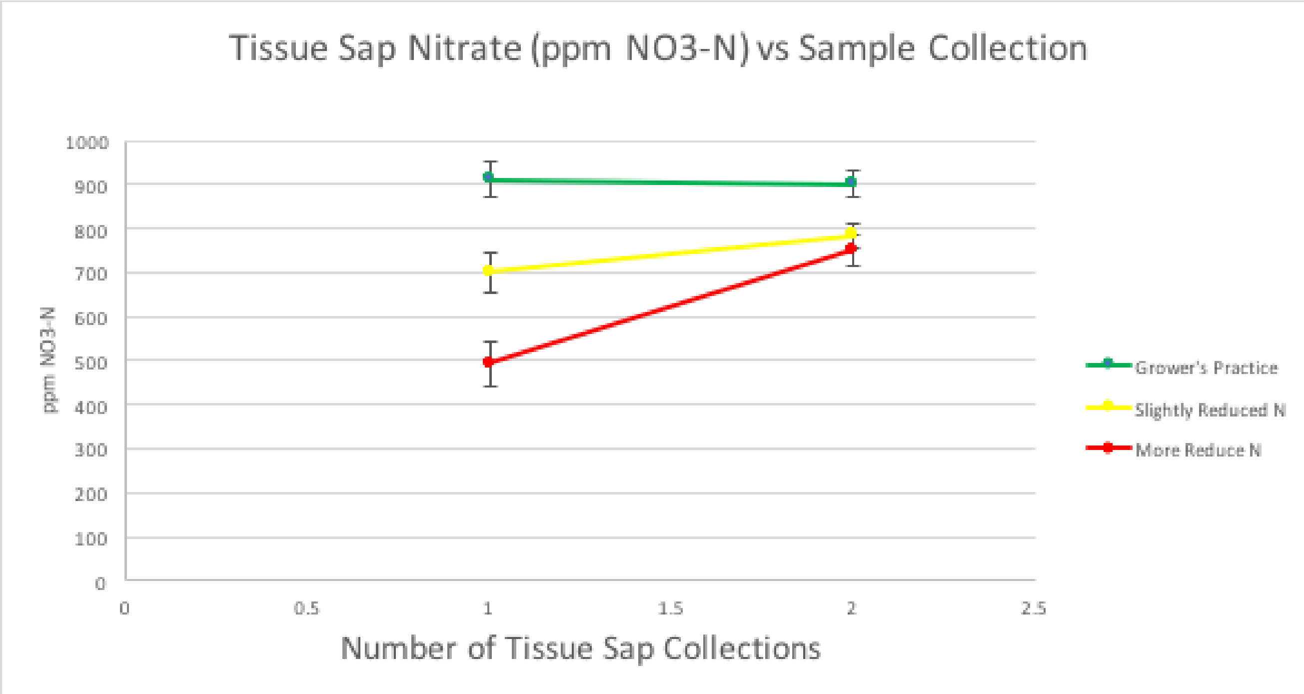

Figure 4.2.

Tissue Sap Nitrate (ppm NO3-N)		
Treatment	4/3/2018 4 Days after Pre-Harvest Application	4/17/2018 18 Days after Pre-Harvest Application
Grower Practice		
A1	905	882
A2	1063	973
A3	837	792
A4	860	928
A5	883	928
Average	909.60	900.60
Standard Error	39.99	30.73
Slightly Reduced N		
B1	679	747
B2	747	701
B3	543	792
B4	814	815
B5	724	860
Average	701.40	783.00
Standard Error	45.20	27.44
Moderately Reduced N		
C1	611	792
C2	452	860
C3	543	656
C4	543	724
C5	317	724
Average	493.20	751.20
Standard Error	50.78	34.67

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