AN ABSTRACT OF THE DISSERTATION OF

Shannon B. Cappellazzi for the degree of Doctor of Philosophy in Soil Science presented on December 7, 2018.

Title: Using Algal Biomass as a Fertilizer

Abstract approved: ____

David D. Myrold

Algae can be used in a variety of wastewater systems to capture nutrients while fixing carbon dioxide from the atmosphere. I conducted field trials at three locations in Oregon with both corn and potato crops to assess the agronomic value and environmental impact of using the resulting algal biomass as a fertilizer. I compared the performance of algal biomass to a high-nitrogen (N) organic fertilizer, feather meal, and a conventional standard, urea. Soil nitrate, and petiole N, were measured throughout the season, and overall yield, produce N, and quality were measured at harvest. These data were used to calculate relative efficacy and resulting agronomic value. The emissions of carbon dioxide and nitrous oxide were measured through the course of the same field trial at two of the locations. These data were used to determine the amount of C added to the soil system from each fertilizer and the comparative gaseous losses

from these sources of fertilizers. Several laboratory incubations were performed to help explain some of the variation and interactions found in the field trials. These data were used to calculate the N and carbon (C) mineralization rates of several subsamples of algal biomass in each of the three soils from the field trial. Although algal processing methods and nutrient media used can impact the overall mineralization rates of algal biomass added to the soil, algal biomass can be as effective at delivering N to the plant as both feather meal and urea per unit of N. In addition, roughly 50% of the C that was added to the soil as algal biomass was not respired as carbon dioxide by the end of the field trial. Therefore, it is likely to increase soil C, which is crucial in efforts to reinvigorate the biological community that support a functioning, healthy soil and could help to mitigate climate change. Considering the high degree of variability possible from algal biomass, it is recommended that material be characterized prior to application as a fertilizer and that site-specific edaphic and climactic characteristics be used in estimations of fertilizer application rates. I recommend the value of algal biomass be priced at a slight discount relative to feather meal on a price per unit of N basis.

Using Algal Biomass as a Fertilizer

by

Shannon B. Cappellazzi

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APPROVED:

Major Professor, representing Soil Science

Head of the Department of Crop and Soil Science

Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Shannon B. Cappellazzi, Author

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It has been a long, winding journey filled with love, support, challenges, humbling experiences, and the occasional triumph. I had the opportunity to work with nearly all of the professors in the soil science department through my time and strive to retain wisdom from each along the way. I will forever be grateful to Dr. Maria Dragila for showing me a path to to pursue my own ideas which allowed me to feel a strong sense of purpose in the work and enabled me to push through the challenges. Dr. David Myrold provided dependable advice with a steady hand to guide me without dictating my direction. Dr. Markus Kleber opened new opportunities, set high hurdles to overcome, and in so many ways trained me to be a rigorous scientist.

My family instilled in me a desire to find my greatest use. Long lines of hard working producers and engineers inspired and drove me to work on creative solutions for land management. While taking a non-conventional path to get here, I believe my family is largely responsible for pushing me toward improving agricultural management practices through the study and application of soil science.

Many friends have influenced my path along the way. They wind in and out of daily life as we change location or have families, but each conversation, each adventure, and each new perspective have formed the way I think about the world. Whether it was camping, swimming, throwing a disc, hitting balls, or talking at Bombs, the comradery found among friends from all different walks of life has enriched my mind and soul.

Finally, to my new husband Jed, thank you. Thank you for the love, support, enriching conversations, calming presence, instigation of fun, and help. You helped me navigate and pursue my path from the first moment we were friends. The look in your eyes when you see me brings comfort and a sense of knowing that together we can make it through any challenge. Finishing this dissertation you proved that time and again as you stepped up to help me in every way possible. I will remember this time in the next hard time and know that our team has what it takes to persevere.

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Chapter 1 Dissertation Introduction

For generations, agricultural producers knew that in order to maintain fertility and tilth in their soils, they needed to add manures and/or other organic matter to their land. This wisdom was not based on the understanding of the heterotrophic microbial community that mineralizes nutrients to make them available to plants. This cultural wisdom was passed through generations and allowed 40 centuries of farmers to thrive on the same land (King, 2004). Longstanding agricultural practices are often held paramount because the wisdom of generations is likely to be passed down, when it is successful. As agricultural researchers move forward with recommendations related to best agricultural management practices, we must respect this wisdom while providing producers with data pertinent to making economically and environmentally responsible decisions.

The last century brought a new level of scientific understanding of our natural world. Controlled experiments within the scientific method allowed us to isolate specific causal mechanisms and elucidate new understanding of how energy is transferred and transformed and how unseeable entities move through our universe. However, a myopic focus on specific issues facing soil scientists can lead to inaccurate conclusions. The soil is a complex, interdependent body that brings together chemistry, biology, physics, geology, climatology, and time. If one studies the nature of soil organic matter using harsh chemical extracting solutions, they may characterize constituents that are not found in situ, and minimize the utilization of organic matter in soil functions. If one calculates the nutrients required for plant growth without an understanding of the microbes responsible for regulating their availability, they may conclude that all that is needed to grow plants are applications of mineral nutrients. No doubt, results of applying this acquired knowledge were outstanding. Application of mineral nutrients brought obvious yield and productivity increases leading to rapid adoption and the capacity to feed more people with less work. Unfortunately, with the passage of time, it has been found that mechanical aeration and fertility management based solely on readily-available mineral fertilizers have led to the loss of soil carbon which has impacted the capability of soils to function as vital, living ecosystems which support life as we know it.

In the decades since the industrial revolution, a confluence of economic factors have driven producers, particularly dairy producers, to manage more animals on less land. First, in the physical economy, the greater the quantity of a good (animals) produced the lower the per-unit cost because the fixed costs are spread over a larger number of goods. Second, dairy production requires animals to stay in close connection with facilities in order to collect milk on regular, often 12-hour, time intervals. Third, mineral nutrients have replaced manure as the primary source of soil fertility inputs. As a result, there is an increased number of dairy cows managed entirely in large-scale, concentrated animal feeding operations. This concentration decreases the distribution of manure spread on farm land because the cost of transportation is greater than the value of the mineral nutrients therein. It also increases challenges related to the buildup of phosphorus and potassium on lands adjacent to facilities where high volumes of manure are added. While it can be argued from an ecological viewpoint that research should focus on encouraging smaller, grass-fed production models, the trend toward larger farms is not likely to change until there is the social and political will to account for the positive and negative environmental externalities of various production methods. With this goal in mind for the future, here I focus on improving production practices within the current economic system to make dairy production more profitable by being more efficient with natural resources.

One area with great room for efficiency improvement in dairy production is manure management. It has been estimated that at least half of the nitrogen excreted from a cow is lost during storage, transport, handling, and application. In 2012, the National Academy of Sciences committee on Development of Algal Biofuels stated:

> "R&D is needed to incorporate nutrient recycling into algal biofuel production systems. The potential for combining the use of wastewater in algae cultivation and the production of a fertilizer co-product is worth further investigation."

Integrated algae-dairy production systems have demonstrated the ability to capture nutrients excreted by cows and carbon dioxide from the atmosphere and store them as stable biomass. There is potential for using this material to extract biodiesel, with economic benefits relative to the price of oil. Further incorporation of an anaerobic digester produces heat and captures biogas which can be used in part, to dry the algal biomass grown on the liquid effluent from the anaerobic digester. The resulting biomass is a concentrated, dry material thereby allowing the material to be transported to cropland not immediately adjacent to the production facility. There exist many life-cycle assessments of the environmental benefits that this type of facility could bring about. In time, economists can use these to quantify the externalities and provide a true cost of production, but for now, I focus on the current market benefits of this biomass when used as a fertilizer.

To quantify the impact of using algal biomass as a fertilizer, I measured various parameters in the soil, plant, and atmosphere in concurrent trials in an effort to understand the agronomic value and environmental impacts of using this material under various climatic and edaphic conditions. I compared performance to a mineral fertilizer, urea, and feather meal, a high-nitrogen organic fertilizer with widespread acceptance in the certified organic market. I had an express goal of providing producers with tangible information regarding how this product would work on their farms. How much nitrogen is delivered to the crop? How much nitrogen is lost? How much carbon is added to the soil system? In doing so, I found interactions and variability that are inherent in nature. This encouraged laboratory incubations and literature searches to understand why organic materials, particularly algal biomass, might decompose at different rates under different conditions. The idea that there are multiple variables to consider, is not unexpected. The dynamics depend on the nutrients contained in the product, the availability of those nutrients to the microorganisms present, the physical nature of the soil, and the moisture and temperature of the environment. While I was unable to use these data alone to model N mineralization predictions for organic matter in a variety of environments, I list conditions that I expect have an impact and that should be considered for site-specific producer decision-making models. Providing producers with timing and quantity of nitrogen available from algal biomass will help them decide the most efficient nutrient management strategy using this product. Estimations of the total amount of carbon added to the system will encourage adoption among producers who understand the benefits of feeding the myriad microbial communities responsible for moderating soil functions and ecosystem services. Listing considerations of variables that impact the utilization and storage of organic matter will help producers make decisions in real-time as researchers work to better describe the relationships of multiple interacting variables.

Chapter 2 Agronomic Value of Using Algal Biomass as a Fertilizer

Abstract

Algal biomass grown on wastewater effluent can be an effective nitrogen (N) fertilizer. A high N organic fertilizer, feather meal, and a conventional standard, urea, were used to compare production efficacy against algal biomass at six field trials. Each fertilizer source was applied at three rates of N and used to grow corn and potatoes at three different sites across Oregon. Soil nitrate and potato petiole N were measured throughout the season, and overall yield, produce N, and crop quality were measured at harvest. These data were used to calculate relative efficacy and resulting agronomic value. A laboratory incubation was performed to calculate the N mineralization rate of each fertilizer in three soils from the field trial. Although algal processing methods and the nutrient media used can impact the overall N mineralization rate of algal biomass added to the soil, algal biomass can be as effective at delivering N to the plant as both feather meal and urea per unit of N. I recommend that the value of this algal biomass be priced at a slight discount relative to feather meal on a price per unit of N basis.

Introduction

Nitrogen (N) is often the most rate-limiting nutrient in agricultural systems. This is particularly challenging in organic agriculture where most available nutritive amendments, predominantly manures and composts, provide a relatively balanced percentage of N, phosphorus (P) and potassium (K). In most soils, it takes years of organic matter (OM) additions for the pool of soil organic N (SON) to be large enough to mineralize enough N for most crops during their period of rapid N uptake (Havlin et al., 2010; Jenkinson and Rayner, 2006; Magdoff and Van Es, 2009). In order for a producer to apply sufficient N from manure to meet the needs of optimal crop production, they regularly apply P and K far in excess of crop requirements (Hart et al., 1997; Zheng et al., 2004). Buildup of P can increase the likelihood of non-point source nutrient pollution, which can lead to large-scale eutrophication events (Heisler et al., 2008; Sharpley et al., 2001). Buildup of K can lead to an imbalance in uptake of other cations (Kayser and Isselstein, 2005; Moore, 2015b) and hypocalcemia, or milk fever, in ruminants that are fed crops with an average total-ration K content over 3% (Hart et al., 1997; Kelling et al., 2002). As the demand for organic food products continues to increase (ERS, 2018), organic producers search for fertilizers that deliver specific nutrients, predominantly, those high in N (Cayuela et al., 2009; Hadas, 1994). Organic by-products of agriculture such as feather meal (FM) and blood meal, with NPK analyses at 13-0-0 and 14-0-0, respectively, were traditionally used in small quantities as concentrated protein sources in animal feed rations (Cotanch et al., 2002). However, over the last ten years, they have become popular organic fertilizers and the commodity prices for these ingredients has increased from \$200 ton^{-1} to over \$1200 ton^{-1} because of their efficacy in delivering N to plants without overloading the soil with other nutrients (Skinner, 2016).

Applying manures and composts at rates high enough for non-limited yield also increases the likelihood of N pollution (Kessel and Reeves, 2002; Singh et al., 2014). In order to accumulate enough N to meet the needs during the period of high N uptake, it is often recommended that these materials are applied well in advance of crop demand so that plant available nitrogen (PAN) as ammonium (NH_4^+-N) or nitrate (NO_3^-) can build up in the soil (Chang and Janzen, 1996b; Sullivan, 2008a). This has been known to cause NO_3^- leaching which has downstream impacts on human drinking water (Knobeloch et al., 2000) and the health of aquatic ecosystems (Heisler et al., 2008). Schreiber et al. (2012) showed that when there is an N imbalance between what is mineralized and what the plant needs, there is an increased rate of nitrous oxide (N_2O) emissions, a greenhouse gas (GHG) with 295-310 times the global warming potential of carbon dioxide (CO_2) (De Klein et al., 2006; FAO et al., 2010). It is estimated that 9-59% of N applied as manure is lost to the atmosphere as ammonia (NH_3), unless the manure is immediately incorporated (Magdoff and Van Es, 2009; Pfluke et al., 2011). This rate depends on soil pH, moisture content, wind, and how quickly it is incorporated (Bouwmeester et al., 1985; Holcomb et al., 2010; Ndegwa et al., 2008). Although not a GHG, NH_3 particulates react with oxides of nitrogen (NOx) to negatively impact air quality with linkages to respiratory problems (Asman et al., 1998; Hristov et al., 2009). A controlled study, using isotopically labeled ^{15}N to track the fate of N excreted from cows, reported approximately half of the excreted N could not be accounted for 24 hours after application (Hristov et al., 2009). Losses of N are strongly dependent on management; Herrero et al. (2013) estimated 40-80% of N excreted by cattle was lost to the environment based on a variety of modeled management practices.

Manure management has always been a challenging component of an animal production operation. Producers have increasing pressure, and in some cases regulations from governments and society to emit less, pollute less, and reduce costs while simultaneously increasing food production. Recent efforts to reduce nutrient loss, GHG emissions, nuisance odors, and problematic soil nutrient buildup have centered on the idea of integrating anaerobic digesters (AD) and algae production into dairy operations (Chowdhury and Freire, 2015; Fenton and Ó hUallacháin, 2012; Mulbry et al., 2008b; Mulbry et al., 2005; Pittman et al., 2011; Rawat et al., 2011; Sturm and Lamer, 2011). Anaerobic digesters can chemically reduce and capture manure nutrients into biogas useful for electrical production (Alcántara et al., 2013; Saunders et al., 2012). Further, incorporation of algae ponds allows nutrient capture from liquid effluent into stable biomass, capture of CO_2-C from the atmosphere, and biodiesel production when oil prices are high (Benemann and Oswald, 1996a; Sheehan et al., 1998; Zhang et al., 2013). Extensive work has been done on the engineering challenges associated with these projects (Amer et al., 2011; Benemann and Oswald, 1996a). Less effort has been made to quantify the C and N dynamics of the resulting algal biomass (AB) as a fertilizer, though greenhouse and incubation trials have measured production similar to other commercial sources of organic fertilizer (Mulbry et al., 2007; Mulbry et al., 2005). Algal cultivation using the liquid effluent of an anaerobic digester operating on dairy manure can capture 70-97% of the N and 50-99% of the P in the effluent (Chen et al., 2012; Jiménez-Pérez et al., 2004; Kebede-Westhead et al., 2006; Mulbry et al., 2008b). The AB can be dried with heat and energy produced by the anaerobic digester (Ledda et al.,

2016) making a potentially valuable fertilizer product that is concentrated enough for efficient transport and long-distance crop fertilization (Pizzaro et al., 2006).

Increasing nitrogen use efficiency (NUE) has been a central goal of fertility extension programs for decades. The 4R approach promotes the use of the right source, right rate, right placement, and right timing of fertilizers (Roberts, 2016). The source, rate, placement, and timing, are considered “right” when the specific fertilizer has bioavailable nutrients, at the right quantities, synchronized with plant demand (Roberts, 2016). Organic producers also aspire to these goals but have been frustrated by limited product availability with mineralization dynamics capable of delivering N synchronized with plant N demands (Cayuela et al., 2009; Pang and Letey, 2000).

Products with a carbon to nitrogen (C:N) ratio less than the C:N ratio typical of soil bacteria, 6:1, mineralize rapidly (Gale et al., 2006; Magdoff and Van Es, 2009; Manzoni and Porporato, 2009). Current production of these forms of OM is limited. There are only so many chickens, hogs, and cattle processed for food each year, so the price of the respective by-products useful as fertilizer continues to rise. Meanwhile, each dairy cow excretes roughly 120-160 kg of N per year (Petersen et al., 2007; Van Horn et al., 1994). There are about 9 million dairy cows in the US alone (ERS, 2018), and conservatively 50% of excreted N is lost to the environment (Hristov et al., 2009). This leaves an annual 500 million kg of N opportunity for US dairy producers to capitalize on. They could supply a growing market, diversify revenue streams, reduce emissions, and spread the benefits of excreted nutrients outside of the land directly adjacent to their dairy. However, this kind of system would require significant capital expenditure and government incentives to build renewable energy facilities are fleeting. In order to adopt any new agricultural management practice a producer must recognize the economic benefits and risks involved. If AB provides a source of N that can be predictably timed to crop N demands, then producers may find it economically advantageous to develop this environmentally beneficial management system.

The general goal of this research is to assess whether AB is as effective at delivering N to crops as either FM or urea (UR) when fertilized at the same rate of total N. In order to assess this, I tested several hypotheses. (1) Soils fertilized with AB will mineralize organically bound N to PAN at the same rate as FM because they both have C:N ratios less than 6:1. (2) Potatoes planted into soil fertilized with AB will take N into their biomass at the same level and time as potatoes planted into soils fertilized with FM or UR because there will be as much N made plant available, timed in accordance with plant uptake needs. (3) Total N taken into plant produce fertilized with AB will be the same as those fertilized with FM or UR because the nutrient availability will be similar from each fertilizer. (4) Soils fertilized with AB will yield crops equal to those fertilized with either FM or UR because these fertilizers are equally effective. (5) Organic fertilizer products (AB and FM) will continue to mineralize after crop removal, creating increased risk for NO_3^--N leaching because the microbially-mediated slow-release of organically bound N will continue after crop harvest. I used results of field trials and laboratory incubations to address these hypotheses and assess the economic value of this product as a fertilizer.

Methods

Field Trial Overview

Field trials were established at three geographically distinct Oregon State University research stations in; Corvallis (CL) in the Willamette Valley, Madras (MD) on the terrace of the Deschutes River Valley, and Klamath Falls (KF) in the Klamath Lake Basin. The three sites were chosen to ensure that observed differences were not unique to one set of edaphic characteristics or a specific microbial community, and to minimize potential total crop loss due to unpredictable weather. The CL soil is mapped by USDA Soil Survey Staff as Chehalis, a fine-silty, mixed, mesic cumulic Ultic Haploxeroll. The MD soil is mapped as Madras, a fine-loamy, mixed, mesic Aridic Agrixeroll. The soil at KF for the potato trial is mapped as Fordney, a mixed, mesic Torripsammentic Haploxeroll, while the soil at the corn trial is mapped as Poe, a sandy, mixed, mesic Typic Durochrept. Site characteristics are available in Table 2-1. Although all three sites are xeric in their moisture regime and mesic in temperature these classifications belie the agriculturally-relevant differences for crop production. The average annual rainfall in Corvallis is 109 cm, with 12 cm of snow, whereas the average rainfall in Madras 28 cm with 38 cm of snow, and Klamath Falls averages 35 cm of rain and 89 cm of snow. They also range in elevation with Corvallis near sea level at 72 m, Madras at 683 m, and Klamath Falls at 1249 m. Corvallis annual temperature is 11.7^{o}C, Madras is 9.6^{o}C, and

Klamath is 9.2°C (usclimatedata.com). These differences impact timing, intensity, and availability of irrigation, length of the growing season, and the impact of climate on the soil development. While, accumulation of growing degree days (Figure 2-1) using the minimum 50 system, shows similar patterns among sites, the soil temperature at 10 cm (Figure 2-2) is considerably different and important for differences related to microbial activity and mineralization rates.

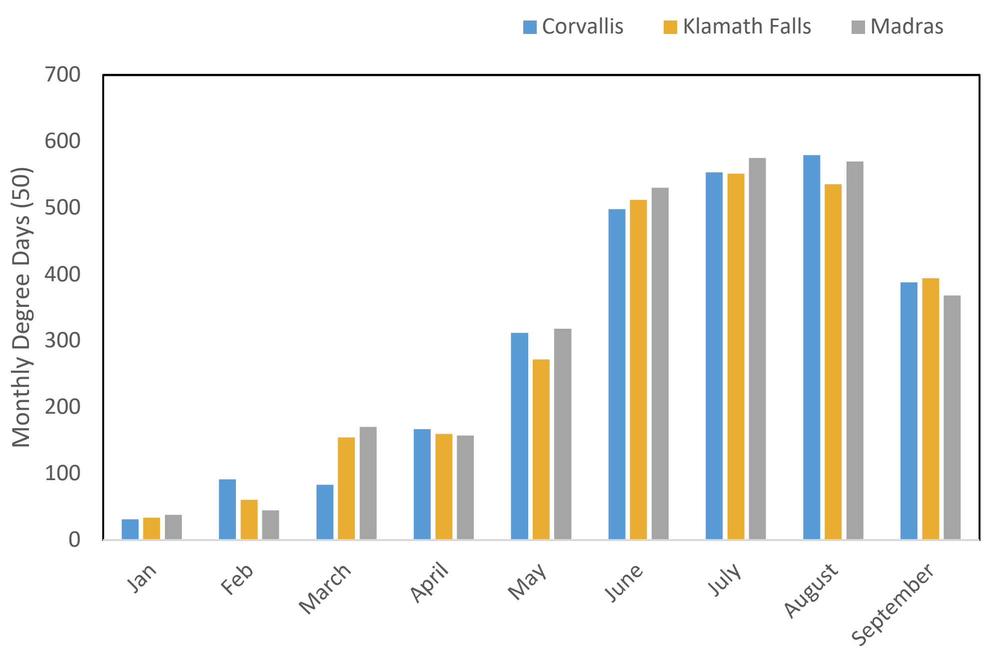


Figure 2-1 Monthly Degree Day by Month

Accumulation of Degree Days each month. Total GDD accumulation for Corvallis was 2702, Klamath Falls was 2672, and Madras was 2770 during the course of this trial in 2015.

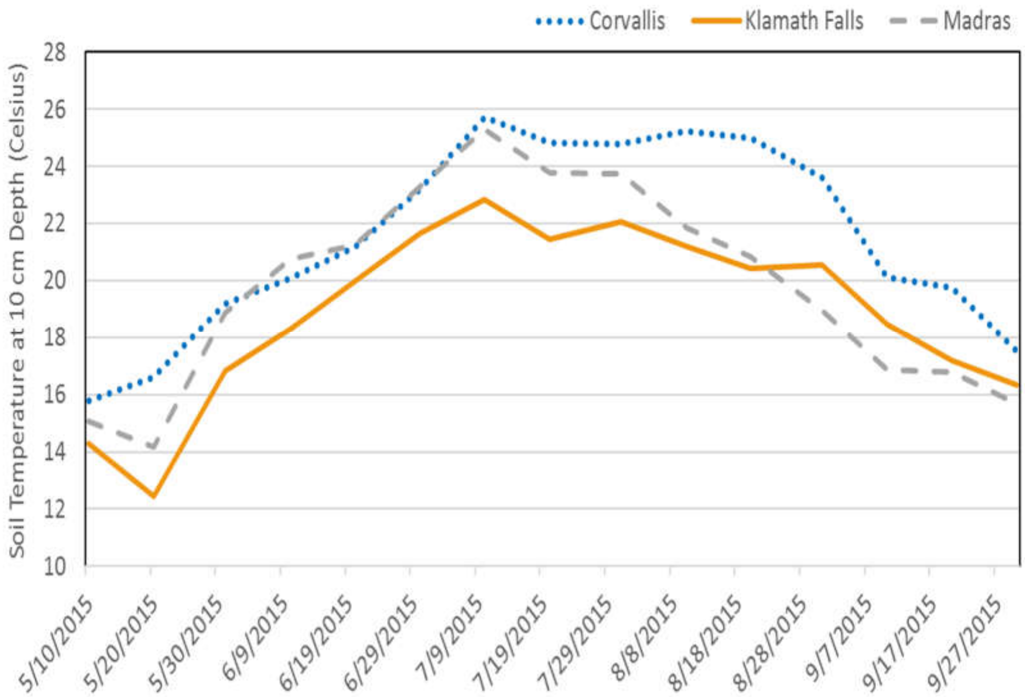


Figure 2-2 Soil Temperature at 10 cm by Site
Soil temperature was higher in Corvallis than Klamath Falls by roughly two to four degrees throughout the season, while Madras soils varied from the highest to the lowest temperatures.

Two crops were grown at each site, Anthem sweet corn (*Zea mays* L.) and Yukon Gold potatoes (*Solanum tubersoum*). Each have well-documented plant N uptake dynamics and are important organic commodity crops. In order to assess the agronomic value of using algal biomass (AB) as an organic fertilizer, I chose to compare AB to a widely used high-N organic fertilizer, feather meal (FM), and a conventional standard, Urea 46-0-0 (UR). A control (0N) with no N fertilizer addition was also used in each block. The AB was produced by a startup company as a by-product of a facility capturing nutrients from a food industry wastewater system. There was a difference in the drying process and moisture content of AB delivered, the impact will be discussed in further detail in Chapter 4. The FM was a commercially available product from Pro-Pell-It!® (Advanced Marketing, St. Paul, OR). Nutrients available in each of these organic fertilizers are available in Table 2-2.

Prior to trial establishment, soils were sampled for heterogeneity and nutrients and were blocked accordingly. In KF an aerial application of micronutrients was applied to the potato crop. In MD and KF super triple phosphate was applied at 125 kg ha^{-1} where soil test results indicated the potential for confounding nutrient limitations. To reduce other confounding factors, herbicides, insecticides, and fungicides were also applied at each site in accordance with locally appropriate management practices directed by each farm manager.

Table 2-2 Soil Nutrients and Texture by Site and Crop

Location	Crop	pH	Sand	Silt	Clay	Total C	Total N	P*	K**	S**	Ca**	Mg**	B**	Fe**	Mn**	Cu**
			%					mg kg^{-1}								
Corvallis	Corn	6.3	52	22	26	1.25	0.13	254	191	5	2532	739	0.5	300	28	3.5
Corvallis	Potato	6.3	53	30	18	0.71	0.08	245	268	4	1845	513	0.3	289	39	5.0
Klamath Falls	Corn	6.6	81	11	8	0.50	0.05	97	372	10	1364	247	0.4	62	65	1.2
Klamath Falls	Potato	5.8	79	14	7	0.60	0.07	113	442	12	1274	175	0.7	72	88	2.6
Madras	Corn	6.6	43	37	20	1.16	0.13	98	436	7	1941	614	0.4	59	73	2.8
Madras	Potato	6.1	43	36	21	1.02	0.12	94	461	9	1985	713	0.4	65	67	2.9

* Available orthophosphate as quantified by Bray II extraction procedure using a colorimetric spectrophotometer

** Available nutrients extracted by the Mehlich III procedure quantified on ICP-OES

Analysis performed by Brookside Laboratory, New Bremen, OH

Table 2-1 Nutrients in Organic Fertilizers Used

Material	C	Total N	NH_4^+-N	P	K	S	Ca	Mg	B	Fe	Mn	Cu	pH	C:N
	%								mg kg^{-1}					
Feather Meal	50.5	13.7	0.04	0.23	0.16	2.6	1.3	0.11	5.1	293	54	4.9	5.1	3.7
Algal Biomass	44.8	7.7	0.13	1.16	0.38	0.7	0.69	0.21	9.2	3387	212	48	5.7	5.8

Total C and N performed at OSU Central Analytical Laboratory, Corvallis, OR

Remainder of analyses performed at Brookside Analytical, New Bremnen, OH

Later testing at OSU Central Analytical Laboratory, indicate the Fe in this report was off by an order of magnitude and should have been 33870

The optimal rate of N fertilizer for each trial was determined using the soil test results in Table 2-1, which differed by site and by crop, ranging from 133 to 160 kg N ha^{-1}. Each fertilizer was banded at three different rates. Rates were normalized at 100% (R), 75% (M), and 50% (L) of each site-specific recommendation. Corn trial UR treatments received 26 kg N ha^{-1} (30 lbs N $acre^{-1}$) at planting and the remainder of the total N rate 30 days later, while the full seasonal total of the organic fertilizers were applied at planting. The placement and timing of nutrient applications were performed in accordance with best management recommendations (Bender et al., 2013; Roberts, 2016; Zotarelli et al., 2008) in order to assess the source and rate of fertilization. All plots in the potato trials received split applications, with 50% banded at planting and the remaining 50% side-dressed and incorporated through re-hilling at 30 days (Goffart et al., 2008; He et al., 2012; Lang et al., EB1871).

Plant Sampling

To assess potato N uptake dynamics, the fourth fully-expanded petiole was sampled on at least 15 plants per plot starting around day 45, and every two weeks thereafter. At the remote sites, Madras and Klamath Falls, sampling was not performed during one of the planned days. Petioles were stripped of their leaves in the field, and brought to the laboratory to be dried and analyzed for total N on an Elementar Vario MACRO cube® (Langenselbold, Germany). At harvest, potatoes were dug and laid on the soil surface to collect all potatoes in one row of each plot for yield measurements. Potatoes were cleaned, counted, and assessed for quality prior to sorting by mass in a potato processing machine. In every corn plot, the ears of every third plant in each of the three middle rows were collected for yield. The total aboveground biomass was collected from every sixth plant. Corn ears were weighed fresh in the field and brought to Corvallis for yield and quality measurements.

Soil Sampling

Soils at each site and for each crop were sampled on the planting date, roughly 30 days and 60 days after planting, at harvest, and three weeks after harvest. Care was taken to sample within the crop row, in-between two plants, because fertilizers were banded and the goals was to capture the nutrient status near the concentrated root zone. For each sample during the growing season, five subsamples per plot were taken to a depth of 15 to cm. These subsamples were combined in a bag and placed into a cooler, each within 15 minutes of collection. Three subsamples were used for post-harvest samples taken using a soil auger at each of four depths, 0-15 cm, 15-30 cm, 30-45 cm, and 45-60 cm.

Fertilizer-by-Soil Incubation

Soil samples from the control plots of each of the three potato trials were used for the incubation. Algal biomass, FM, and UR were applied to each of the three soils used in the field trial in a factorial design. A control treatment (0N) with no fertilizer added was also used with each soil type. After sieving to 2 mm, and letting sit at room temperature for 3 days, samples from each soil were placed in a jar to measure baseline CO_2-C respiration and NO_3^--N. The incubation set-up followed procedures described in detail in Cappellazzi (2018, Chapter 3). Briefly, four tubes, one for each destructive sampling date, were put into one quart-sized canning jar with three jars of each treatment used as replicates. Water was added to all tubes to reach 50% water-filled pore space, and were incubated at 23°C. Lids were placed on the jars for two hours in order to measure CO_2 respiration on days 0, 1, 2, 3, 4, 7, 15, and 22 using a Picarro Isotopic CO_2 Analyzer (Picarro Inc. Santa Clara, CA). Nitrate measurements were made using a Lachat FIA (Hach Company, Loveland, CO) by destructively sampling the tubes on day 0, 3, 7, 15, and 22, extracting the soil with 2M KCl solution in a 4:1 solution to soil ratio.

Statistics

The experimental design for the field trial was an augmented factorial block, with three fertilizers, three rates, and a control in each block. This design is unbalanced so a mixed model was used to account for both fixed (fertilizer and rate) and random (block and site) effects (Marini, 2003). The mixed model does not assume normality in the variance distribution. On average 4% of data points were calculated to be outliers using the modified Thompson Tau Test and were removed prior to data analysis. Each crop was analyzed separately with the exception of post-harvest soil NO_3^--N. For analysis of the fertilizer, rate, block, and interactions, an analysis of covariance (ANCOVA) was performed with the Proc Mixed model in SAS (v.9.4, SAS Institute, Cary, NC) using generalized least square means for fixed effects and restricted maximum likelihood estimation (RMLE) to estimate variance components. Laboratory data were analyzed with a two-way ANOVA using PROC GLM. All treatment differences were compared with Tukey's honestly significant differences (HSD) post-hoc test and were considered significant when $p<0.05$.

Results

Soil Nitrate Field Trial

There were no differences in NO_3^--N at planting between treatments within each site, but there were significant differences between sites, with MD highest, then CL, then KF averaging 24.2, 21.7, and 7.8 mg kg^{-1} NO_3^--N in corn crops, respectively. At each site there was also a significant difference between initial NO_3^--N values for corn and potatoes; this was expected because corn was planted one month after potatoes and the additional degree-day accumulation would have allowed for more microbial N mineralization.

A comparison of N dynamics between organic and conventional fertilizers in the corn trials was not tested because of differences in the timing of application. In comparing the AB treatments with the FM treatments at day 0, 30, 60, and at harvest, there was not significant covariance by site or block. On day 30, at the beginning of V10 growth phase, the recommended rate of fertilization increased soil NO_3^--N from the FM treatment above the low rate of FM and AB but not the recommended rate of AB (Figure 2-3). There were not differences in soil NO_3^--N between AB and FM at respective rates.

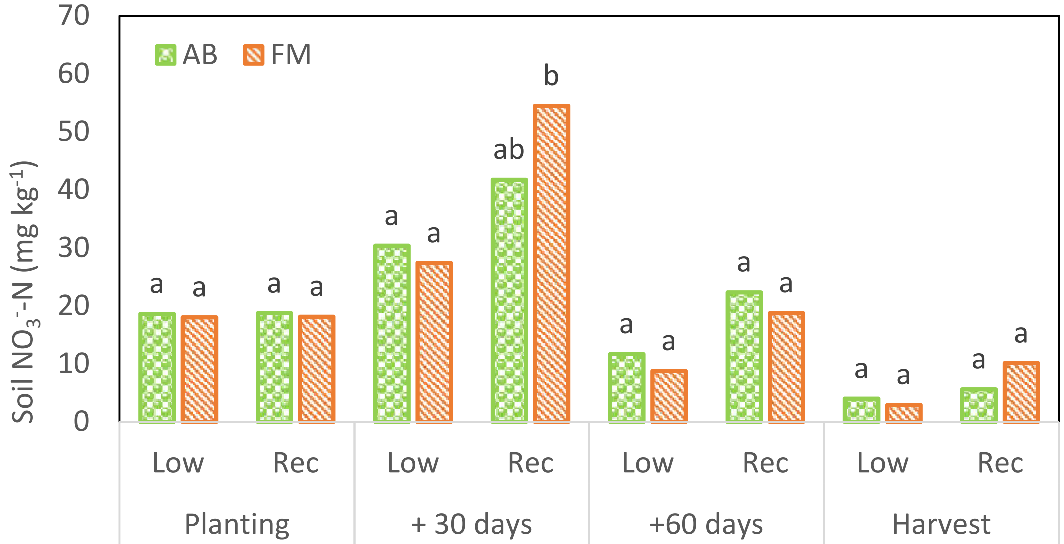


Figure 2-3 Soil Nitrate-N in Corn Trials
AB=algal biomass, FM=feather meal, Low=50% of recommended rate of fertilization, Rec=100% of recommended rate of fertilization. Bottom row indicates the relative time that samples were taken from each site. N≥9, all sites are averaged for each treatment. Grouping by letter compares fertilizer and rate for each date, means with the same letter are not significantly different at $p<0.05$.

All potato fertilizer treatments were applied at the same time, therefore soil NO_3^--N dynamics for all treatments can be compared. The mixed model explained no covariance by site nor block but at all time-points after planting there were differences by fertilizer and rate. The plots that received UR trend highest after application (Figure 2-4). However, the only significant difference between AB and other fertilizers was at the highest application rate at harvest. Controls were significantly lower in all cases (0N data not shown).

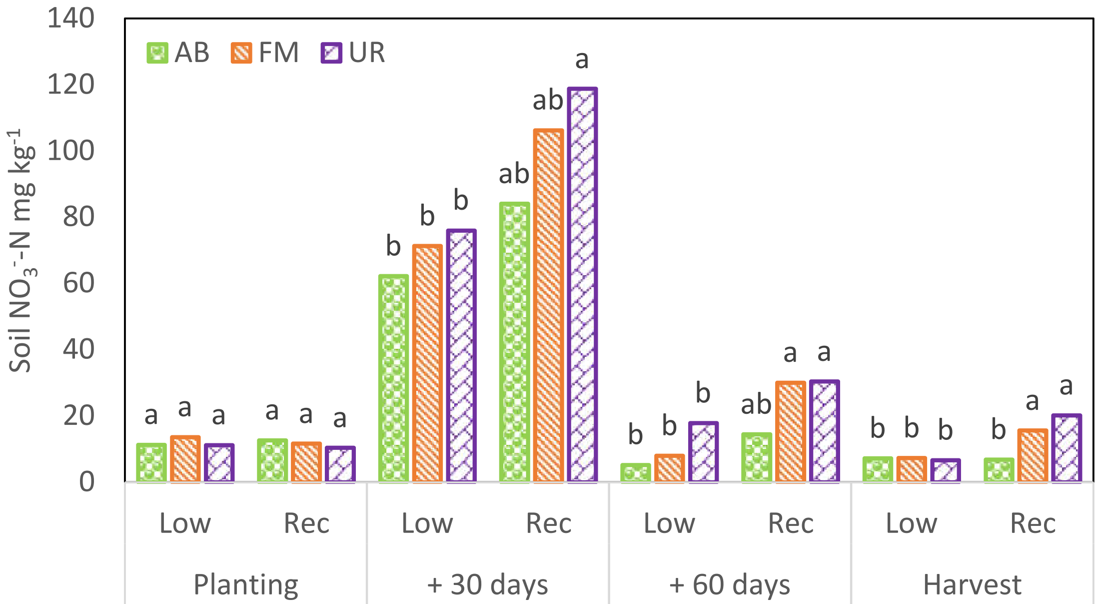


Figure 2-4 Soil Nitrate-N in Potato Trials
AB=algal biomass, FM=feather meal, UR=urea, Low=50% of recommended rate of fertilization, Rec=100% of recommended rate of fertilization. Bottom row indicates the relative time that samples were taken from each site. N=12, all sites are averaged for each treatment. Grouping by letter compares fertilizer and rate for each date, means with the same letter are not significantly different at $p<0.05$ with Tukey's HSD.

In this study petiole N was used as a way to assess N uptake timing. Sufficiency levels have been reported for both NO_3^--N and total N so producers can determine real time additional fertilizer N needs. There were significant differences in petiole N uptake by site, fertilizer, and rate, but not by block. Data in Figure 2-5 are total petiole N from plots that received the recommended rate of N application for each fertilizer with sites in separate panels. Total N uptake trends are similar for the plots that received lower application rates and the full dataset is available in Appendix Figure 9. Petiole N data displays an interaction, between sites and fertilizer type. In CL, plots that received AB are not different from plots without N fertilizer, but they are significantly lower than the plots that were fertilized with FM and UR at each time point. The FM fertilized plots are the same as UR fertilized plots with the exception of the first sampling time. In KF, FM is the same as both AB and UR in the first two measurements, but AB is significantly lower than UR at each time points. Whereas in MD, plots receiving the FM and AB fertilizer demonstrate similar N uptake dynamics and are not lower than UR until the last sampling date. The current understanding suggests that for optimal yield at 49 days-after-planting, potato (Sebago variety) petioles with at least 3.7% N are considered adequate. At 57, 69, and 89 days, those values are reported as 3.4, 3.1, and 2.5% N, respectively (Reuter and Robinson, 1997).

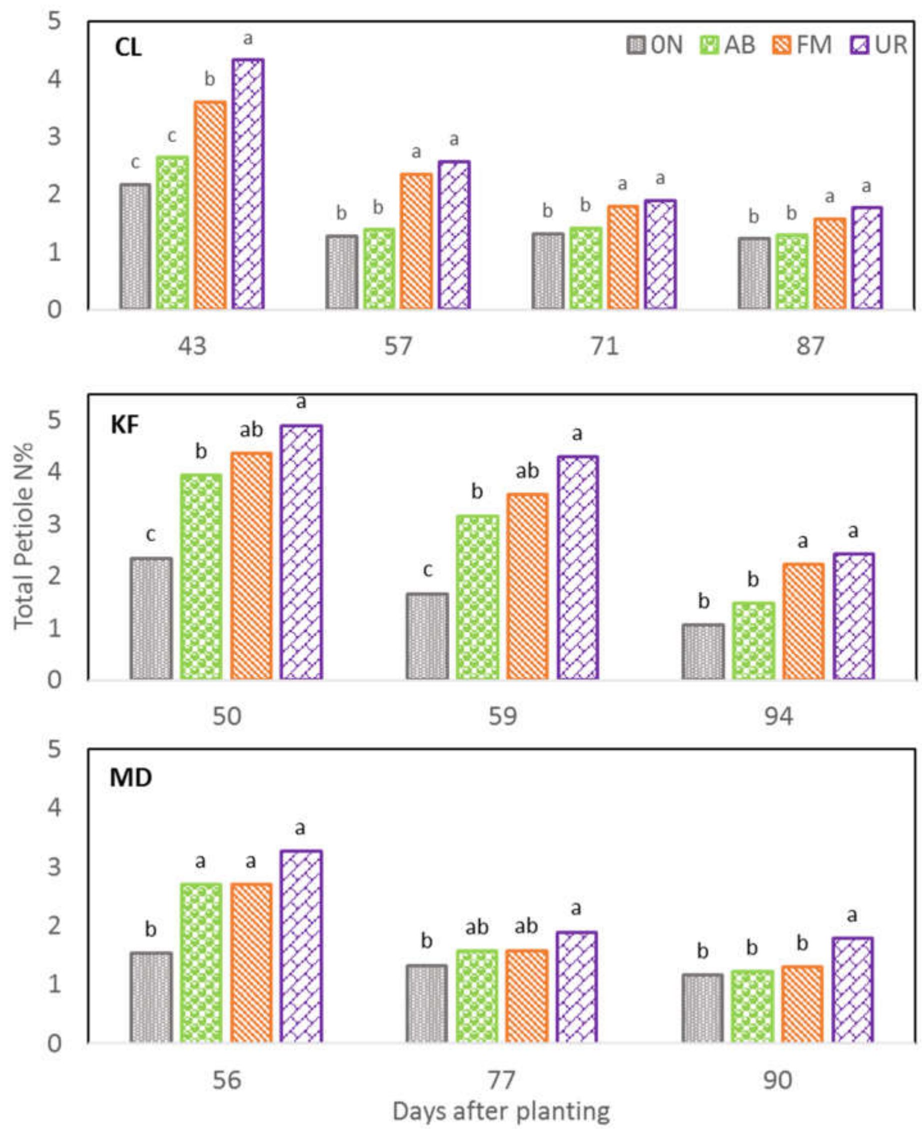


Figure 2-4 Total Petiole N by Site and Days After Planting
Displaying results from recommended fertilizer rate. 0N=control, AB=algal biomass, FM=feather meal, UR=urea. N=4, Grouping by letter compares fertilizer for each date, means with the same letter are not significantly different with Tukey's HSD p<0.05.

Yield and Quality

In the potato trial there was no covariance in yield by site or block, therefore all sites were analyzed together. There was no significant difference by application rate. Total yield for the 0N was lower than each fertilizer treatment and there were no differences between fertilizer treatments. The total potato yield were; 49 Mg ha^{-1} for 0N, 60 Mg ha^{-1} for AB, 62 Mg ha^{-1} for FM, and 64 Mg ha^{-1} for UR (265, 325, 340, 348 cwt $acre^{-1}$ respectively). The same pattern was found for the marketable size, 113-397g (4-14oz), with yields at 38, 46, 48, 48 Mg ha^{-1} (207, 252, 263, 263 cwt $acre^{-1}$) for 0N, AB, FM, and UR respectively. There were inconsistent trends among individual size classes.

All potato quality metrics were different by site, but not by fertilizer rate or fertilizer material. Data are summarized in Table 2-3. In general, MD sites had the highest quality potatoes, with the least hollow heart, presence of *Rhizoctonia sp.*, and greening.

Table 2-3 Potato Quality by Site

	Specific Gravity	Hollow Heart	Greening	Growth Cracks	Rhizoctonia
	------------mean----------------		-------------------rating 1-5-----------------------		
Corvallis	1.091 a	3.8 c	3.6 c	4.7 ab	4.0 c
Klamath Falls	1.085 b	1.6 b	4.0 b	4.6 b	4.4 b
Madras	1.091 a	0.7 a	4.5 a	4.9 a	5.0 a

Means with the same letter are not significantly different at p<0.05. The letter a is always indicative of the most favorable value for market purposes. Specific gravity is a measured value. Hollow heart is the occurance count out of 10 potatoes that are >283g. Greening, growth cracks and rhizoctonia are ratings 0-5 based on visual observation with 5 being no damage.

Corn trial ear yield was significantly different by site, with CL demonstrating the highest average yields, followed by KF, and MD corn trial resulting in very low yields (Table 2-4). In the CL corn trial there were differences by fertilizer but no difference by rate and no interaction. Analyzing by fertilizer alone, AB fertilized plots yielded statistically lower than FM and UR fertilized plots, but not the 0N. The FM and UR fertilized plots were not different from the 0N plots. In KF, the plots differed by fertilizer but not by rate, and there was no interaction. Ear yield was the same for AB, FM, and UR-fertilized plots and all were significantly higher than 0N plots. Madras FM treatments were lower than UR but not different from 0N or AB. The AB was the same as UR and higher than 0N. Quality parameters assessed for corn did not vary by fertilizer treatment and followed similar patterns as the yield regarding site differences.

Table 2-4 Corn Yield by Site and Fertilizer

	Corvallis	Klamath Falls	Madras
	-------------------	kg ha^{-1}	-------------------
Control	3990 ab	1238 b	1262 c
Algal biomass	3616 b	2925 a	1992 ab
Feather meal	4145 ab	3067 a	1758 bc
Urea	4435 a	3294 a	2265 a

Means with the same letter are not significantly different at $p<0.05$
Yield has been extrapolated from three rows of harvested corn in experimental plots

Total Ear Nitrogen Uptake

Total ear N uptake, Table 2-5, was calculated by multiplying the total yield of marketable ears by the percent of N in the ear. By site, total ear N followed the same pattern as total yield with 105 kg N ha^{-1}, 66kg N ha^{-1}, and 27kg N ha^{-1} in the corn ears on average for CL, KF, and MD, respectively. In order to assess whether AB was as effective at delivering crop N, I wanted to assess the average for all sites. To do this I normalized the data by dividing each value by the mean of the highest treatment at each site. With this approach there were no difference among fertilizers at each respective application rate. However, there was a trend where AB treatments were lower than FM and UR overall and at individual sites.

Table 2-5 Total N in Corn Ears

Fert	Rate	All Sites Relative %	Klamath Falls	Corvallis	Madras
			---------------kg N ha^{-1}---------------		
0N	N	52 b	25 c	106 abc	18 a
AB	L	63 b	62 ab	62 c	25 a
FM	L	79 ab	52 b	131 a	28 a
UR	L	89 ab	73 ab	121 a	32 a
AB	M	67 ab	61 ab	66 bc	29 a
FM	M	78 ab	77 a	108 ab	23 a
UR	M	90 a	81 a	122 a	30 a
AB	R	79 ab	71 ab	107 ab	26 a
FM	R	93 a	84 a	139 a	28 a
UR	R	92 a	72 ab	124 a	36 a

For relative % of total N uptake data were normalized by dividing by the average of the highest treatment at each respective site to compare fertilizers performance relative to each other. N=12 for all sites, n=4 for each site. Means with the same letter are not significantly different at $p<0.05$. 0N=control, AB=algal biomass, FM=feather meal, UR=urea, N=none, L=50% of recommended N, M=75% of recommended N, R=100% of recommended N.

Post-Harvest Soil Nitrate

After harvest, soil NO_3^--N resulting from N fertilizer applied in excess of crop demands can become a source of non-point pollution. To estimate whether NO_3^--N might enter groundwater, post-harvest soil samples were taken. There was no covariance between sites nor between crops. There were differences by both fertilizer and rate as well as an interaction at the two intermediate depths. The accumulation of NO_3^--N at the 15-30cm depth was highest in KF sandy soil whereas the other two sites were highest at the surface. Plots that received UR had significantly more NO_3^--N than all other treatments at all depths, roughly double the NO_3^--N from the AB fertilized plots (Figure 2-5). The NO_3^--N in FM and AB treatments were the same at each depth and NO_3^--N levels from the AB plots were the same as 0N at each depth. There were no differences in NO_3^--N levels among the low-rate treatments. Medium-rate treatments resulted in significantly higher NO_3^--N levels than 0N, but there were no differences among treatments that received fertilizer (Appendix Figures 10, 11, and 12). For reference the US EPA's drinking water maximum contamination level of 10 mg kg^{-1} NO_3^--N (Derby et al., 2009). It has been reported that if a soil sample in Oregon has more than 20 mg kg^{-1} NO_3^--N in a 0-30 cm depth sample three weeks after harvest, absent other management issues, excess N has been applied (Sullivan and Cogger, 2003). When excess N is used there is an increased likelihood of NO_3^--N leaching to groundwater with severity largely dependent on texture and depth of the vadose zone. While none of the average values were above this threshold, in the KF potato trial, the plots that received the medium and recommended UR rate averaged 16 and 20 mg kg^{-1} NO_3^--N, respectively, and were significantly higher than the other treatments.

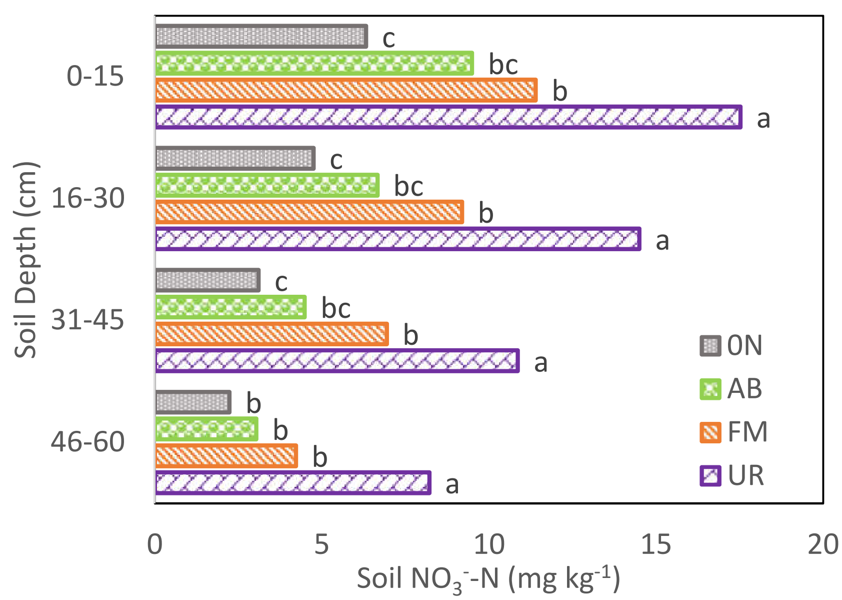


Figure 2-5 Post-Harvest Soil Nitrate-N by Depth and Treatment
Displays only recommended rate of fertilization. 0N=control, AB=algal biomass, FM=feather meal, UR=urea. N=12, all sites are averaged for each fertilizer. Grouping by letter compare fertilizer within specified depth, means with the same letter are not significantly different at $p<0.05$.

Fertilizer-by-Soil Incubation

Soil NO_3^--N measurements at the end of a 22-day incubation, using each fertilizer in each soil, are presented in Figure 2-6. Using the equivalent of 150 kg N ha^{-1} application rate (188 µg N g^{-1} dry soil), the NO_3^--N measured from FM treatments was 188, 172, and 199 µg N g^{-1} dry soil for soils from CL, KF, and MD, respectively. The 0N soil mineralized 47, 46, and 42 µg N g^{-1} dry soil making the net N mineralization from FM, 77%, 66%, and 85% of the total N applied to each soil, respectively. Similarly, for AB, 57%, 55%, and 52% of the total N applied had mineralized over the 22-day incubation for each soil, respectively. The average daily mineralization rate of N applied as fertilizer in the AB treatment averaged 9.1, 8.7, and 8.2 kg N ha^{-1} day^{-1} for CL, KF, and MD soils, respectively. These rates were statistically lower than FM derived NO_3^--N at 12.2, 10.5, and 13.4 kg N ha^{-1} day^{-1} or NO_3^--N from UR, 12.5, 18.5, 12.1 kg N ha^{-1} day^{-1} for CL, KF, and MD, respectively. The mineralization rate of AB was not different by soil but FM was significantly higher in MD than other soils, and UR was significantly higher in KF than other soils.

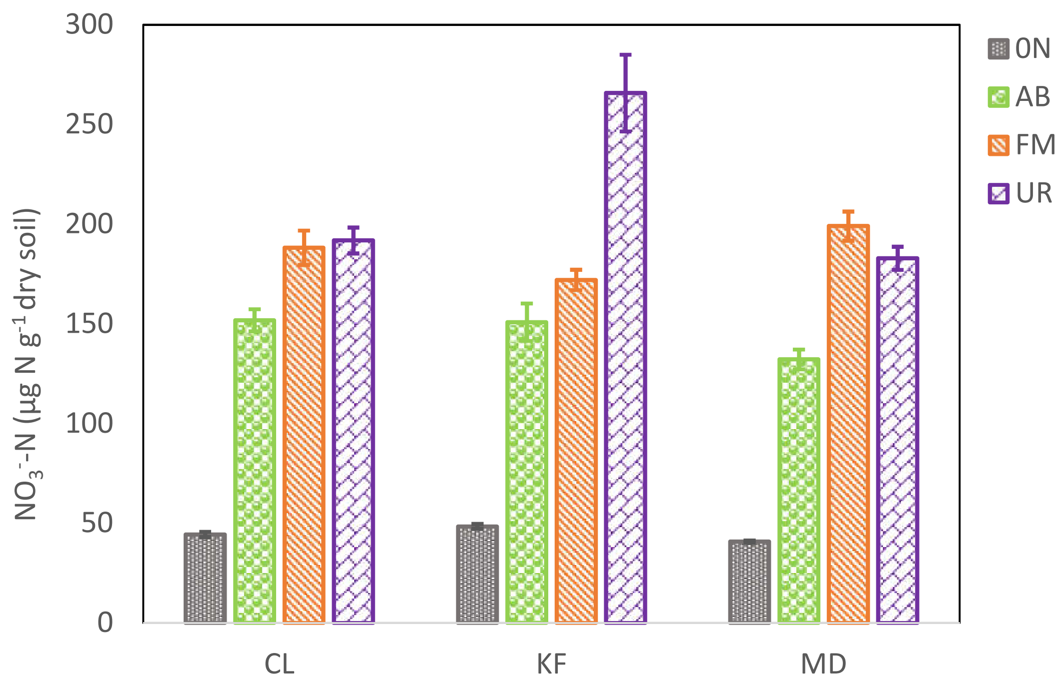


Figure 2-6 Soil Nitrate-N Laboratory Incubation
Soils incubated for 22 days with fertilizers at 23°C and 50% water-filled pore space. CL= Corvallis, KF= Klamath Falls, MD=Madras. 0N=control, AB=algal biomass, FM=feather meal, UR=urea. Error bars represent the standard deviation of three replicates.

Discussion

Corn crop

It was hypothesized that AB would mineralize organic N to PAN at the same rate as FM. This hypothesis was supported by data from both the corn and potato trials with no difference in soil NO_3^--N at day 30 and 60 days. The mineralization rate in the laboratory incubation was lower for AB than for FM. The disparity in results could be due to interactions with the plant roots and environment in the field or higher variation from field samples decreasing power to identify true differences.

The most critical period for N availability starts around 30 days after planting, when corn is at the V10-V14 growth stage. It is estimated that new corn varieties take up roughly 7 kg N ha^{-1} day^{-1} (7.8 lbs N $acre^{-1}$) for optimal yield (Bender et al., 2013). In the field, total NO_3^--N that can be measured in a soil sample is the excess NO_3^--N not taken up by the plant, microbes, or lost to the environment. The laboratory incubation with no crop present, allowed us to eliminate plant uptake and NO_3^--N leaching losses to better assess the NO_3^--N mineralized over a specific time frame. Averaged by site, the mineralization rate of N applied as fertilizer in the AB treatments was roughly 8.7 kg N ha^{-1} day^{-1}, which was lower than either FM or UR. However, the N mineralization rate from AB fertilization is closer to the uptake rate for corn. This close match in N mineralization rate and N uptake optimizes NUE and minimizes the potential for environmental loss. The reduced potential for N pollution from AB is evident in post-harvest NO_3^--N testing, where AB treatments were not different from 0N treatments. The ability of AB to deliver enough N is evident given that, total yield and ear N uptake was not different between the AB treatments and FM or UR.

The corn field trial in MD had very low yield, with 14 out of 40 plots not producing any ears of marketable size. This was likely the result of weed and water management issues (Figure 2-7). There was no covariance by site but there was substantially more NO_3^--N in the MD soil from both AB and FM at day 30 than in either

CL or KF. If corn was not taking up N from the soil at this point in the season, it could have also led to the low-yield issues. In the soil-by-fertilizer incubation, MD soil mineralized AB at the same rate as the other soils. FM was higher than the other fertilizers, but not to the same degree as the field trial. While I did find yield differences, they could be the result of numerous factors related to poor management and it would be inappropriate to ascribe fertilizer efficacy from a crop with overall poor performance.

The soil in the KF corn trial was roughly 70% sand, lending to low inherent nutrient content and ideal conditions for a fertilizer trial. Differences between fertilized and non-fertilized plots were visibly apparent throughout the season (Figure 2-7). This site provided non-confounding evidence to support the hypothesis that crops fertilized with AB had yields similar to plots fertilized with either FM or UR at the same N fertilization rate.

Soil at the CL site was not N-limited, as evidenced by the 0N plots yielding as much corn, with the same quality, as other treatments. In CL, yield was lower from plots treated with AB than from either FM or the UR. It is unclear why a material with a C:N ratio of 5:1 would decrease yield, as immobilization was unlikely. This field had the highest soil organic carbon (SOC) level of any site. The CO_2-C respired, indicative of microbial activity, at this site was higher than any other site, with the CO_2-C respiration rate in 0N soils averaging higher than the respiration of many other plots treated with fertilizers (Cappellazzi, Chapter 3). These measurements provide what seems like an inconsistent story related to N and C limitations. Schimel et al., (2006) described that even when soil actively immobilizes N, adding C almost always enhances respiration. There are numerous interactions influencing the utilization of organic materials and a more thorough exploration of the enzyme kinetics and microbial biomass might help elucidate the interacting forces at this site.

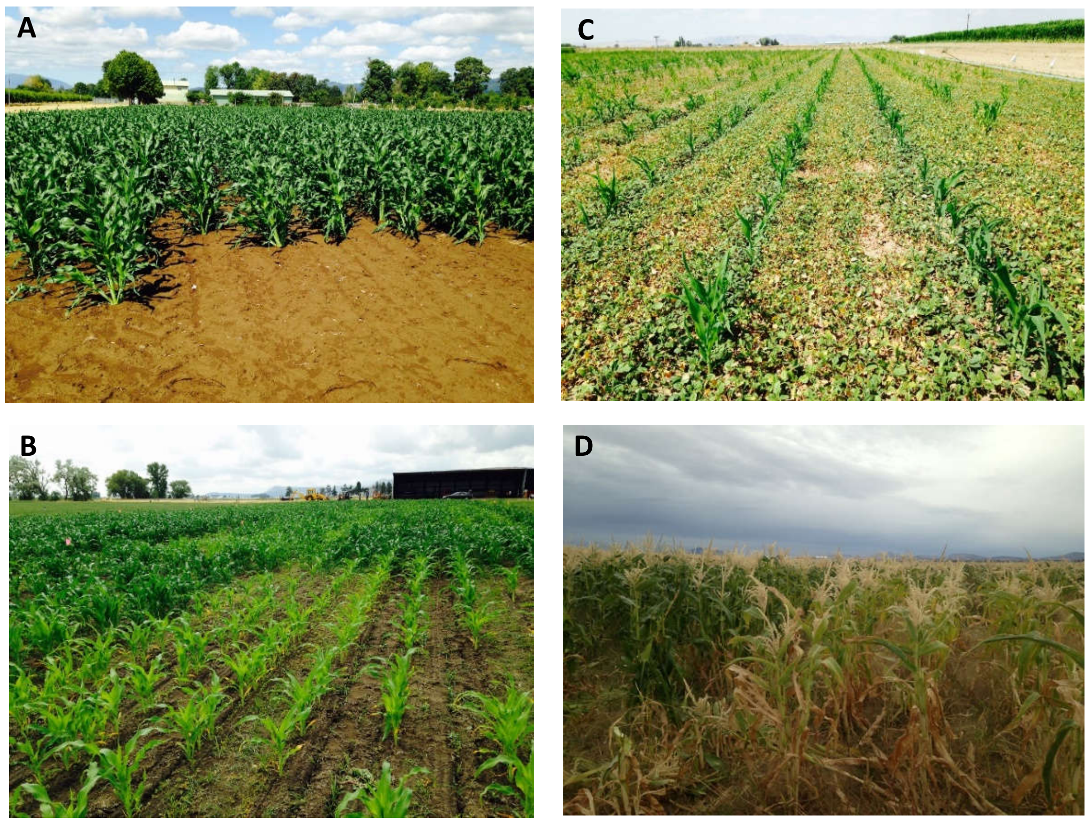


Figure 2-7 Corn Trial Images
Throughout the trial there were no visual differences in Corvallis (panel A) and the control plots were not lower than the treatments. The corn trial in Klamath Falls had visible and yield treatment differences, control plots in the forefront of the picture appear chloritic (panel B). In Madras there were significant challenges with weeds and corn emergence from the beginning of the trial (panel C) and potential moisture limitations near harvest (panel D).

Potato Crop

Given that petiole-N was considerably lower than the recommended sufficiency level for all fertilizers in MD, for all except the recommended rate of UR in CL, and for anything below the recommended rate in KF, it was interesting that I did not measure a statistical difference in total yield among sites or treatments. It has long been known that potato petiole-N recommendations need to be specific to days-after-planting and variety (Collins et al., 2016; Nasholm et al., 2009; Sisson, 1991). Additionally, potato yield expectations are partially a function of growing season duration (Ziadi et al., 2012). Potatoes produced in the Columbia Basin are often grown for up to 150 days and can yield two times the potatoes produced in this trial (Sullivan et al., 1999). This trial was limited to a 100-day growing season due to cold fall weather in KF and MD. With this reduced season length, sufficiency levels for petiole-N could be reduced. In an Idaho trial, Yukon Gold potatoes delivered an acceptable yield even when petiole NO_3^--N was considerably lower than conventional N recommendations (Moore et al., 2013). Regardless of the recommended sufficiency level, petiole-N in AB fertilized plots at CL sites were the same as 0N plots, yet yield from AB fertilized plots was significantly higher. If it were only soil NO_3^--N that was low, I might consider whether potatoes were taking up organic forms of N. However, I have found no literature regarding organic N uptake in potatoes and I used total-N in the petiole, which should be reflective of total new-tissue plant N. It is unclear why there is an incongruous result between petiole-N, soil-N, and total yield response to AB in CL potato trial.

The plots fertilized with AB had statistically similar amounts of soil NO_3^--N as FM and UR, but there was a trend in the data. It appeared UR was highest, then FM, then AB, until the end of the season when the organic fertilizers were statistically lower than UR. It is often thought that organic fertilizers parse their N slowly throughout a season. In both soil NO_3^--N and petiole-N data, it is only at end-of-season time points where UR is significantly higher than the organic fertilizers. This could be the result of a slightly higher rate of N availability through the season resulting in an accumulation of UR derived NO_3^--N when crop demand for N decreased. The harvest date soil NO_3^--N levels were very similar to post-harvest NO_3^--N results, with no significant difference between dates for each fertilizer. This indicates little additional mineralization after harvest. During post-harvest measurements, plots that received UR had more NO_3^--N remaining in the soil than the organic fertilizers at every depth. There was no rain or irrigation during this period, thus I can infer N movement occurred sometime during plant growth. Russet Burbank potatoes need roughly 4-5 kg N ha^{-1} d^{-1} during their rapid N uptake period (Sullivan et al., 1999). Yukon Golds, often have a lower yield than Russets and have a lower N uptake requirement. From laboratory incubation mineralization rates, I expect all tested fertilizers provided sufficient or excessive PAN during this rapid uptake period. However, the UR treatment resulted in the greatest downward movement of NO_3^--N during the growing season.

Produce Quality Related to Nitrogen Availability

The general observation arising from Chapman et al., (1992) was that sufficient fertilizer application usually yielded good tuber quality. Potato quality determines the market for the produce. For a crop such as Yukon Gold potatoes, this is particularly important because the target market is the fresh grocery store potato. The quality metrics help evaluate crop value, thus impacting organic fertilizer value, they also provides clues into conditions potatoes experienced in regard to N and water during the season. In-season stressors influence the prevalence of hollow heart (Hiller et al., 1985; Ziadi et al., 2012) which can be caused by early-season rapid-growth associated with excess N availability (Navarre and Pavek, 2014). It can also be the result of uneven, excessive, or poorly-timed N applications (Hiller et al., 1985), but responses are inconsistent (Ziadi et al., 2012). Growth-cracks, resulting from differences in the development rate between inner and outer tuber tissue, can be associated with excess irrigation followed by dry conditions (Navarre and Pavek, 2014). The poor greening score from the CL potato trial was likely the result of an irrigation blowout where several plots were saturated, the above ground biomass became lodged, and many potatoes were exposed at the surface. The lower *Rhizoctonia* sp. prevalence in MD is likely due to a long duration without potatoes at this experiment station.

Comparisons to Manure

Manure and composts have been used for millennia to provide crop nutrients and improve soil tilth. The overarching goal of this project is to use AB as a means of capturing nutrients from manure, thereby replacing it as a nutrient source. It is worthwhile then, to compare AB benefits with those of manure. Measuring net N mineralization of manured soils, Sullivan et al., (1999) found a net rate of 0.6-1.0 mg N kg^{-1} day^{-1}. Zaman et al. (1999) measured 0.5-3.2 mg N kg^{-1} day^{-1}, each far below the rapid N uptake rates of most crops. N mineralization rates from these organic fertilizers was considerably higher and expected to meet the needs of most crops during rapid N uptake, eliminating the need of early application, which is often recommended when using manure to provide nutrients.

Although there are plenty of challenges involved with manure application, researchers must also acknowledge the benefits. An important benefit of using manure is that it adds C to the system. Moore et al. (2015a) found that manure applications significantly increased soil organic matter from 1.4%, to 1.7% and 2.0% for biennial and annual applications, respectively. This trend has been repeatedly shown from manure applications (Angers et al., 2009; Chang and Janzen, 1996b). Increasing SOM has been found to increase water holding capacity, decrease bulk density, increase resilience under harsh weather conditions, and increase the rate of nutrient cycling (Khaleel et al., 1981; Magdoff and Van Es, 2009). Further work to estimate C additions to soil from AB will be discussed in Chapter 3.

Carbon to Nitrogen Ratios use in Fertilizer Valuation

The N fertilizer value of an organic material has regularly been estimated by using the C:N ratio of the material (Gale et al., 2006; Magdoff and Van Es, 2009). In a study on potential methods for estimating the N fertilizer value of organic residues, Delin et al., (2012) used 15 common agricultural by-products and a mineral-N source (ammonium nitrate) in a ryegrass greenhouse trial. Considering several possible predictors, they concluded that the C:N ratio was the best predictor of a product's mineral fertilizer equivalency (MFE) with a coefficient of determination of 0.83. Applying their formula to the organic fertilizers used in this trial, AB and FM would have MFEs of 58% and 69%, respectively. Considering only plant-available N above that provided by soil organic N in each respective situation, the MFE predictions fit well with some of our N mineralization data. Using KF soil, which was most similar to the sandy loam used in the Delin et al. trial, in the potato petiole, AB and FM took up 65% and 74% as much N as UR on the first sampling and 58% and 68% as much N as UR on the second sampling respectively. However, in KF, potato yield was nominally higher for AB and statistically higher for FM treatments than UR, at 343, 354, and 332 cwt, respectively. Corn N uptake was higher than would be predicted with MFE AB and FM averaging 80% and 92% as much N as UR respectively.

A single linear formula using C:N ratio as a predictor of fertilizer equivalency is very useful for general ideas; however it may underestimate the N delivery capacity of materials with a low C:N ratio. In the referenced work, Delin et al. (2012) suggest their results agree with those of Gale et al., (2006), who found composted materials mineralized slower than fresh materials even at a similar C:N. The slope of this line is influenced by materials that are known to have slower mineralization rates. The N mineralization rate of soils fertilized with FM and blood meal, the two amendments with the lowest C:N, were both under-predicted using the MFE equation. Additionally, it was found that incubations underestimated N delivered in the pot experiment, indicating N dynamics were different when plant roots were present. Soil type should also be taken into consideration. From the laboratory incubation, mineralization efficiency relative to UR in CL was 61% and 97%, in MD it was 66% and 110%, and in KF it was 47% and 57% for AB and FM in each soil, respectively. Collectively, these observations indicate interactions occur between soil characteristics, plant roots, organic matter condition, and climactic factors, which should be considered when estimating the mineralization of organic matter as a fertilizer.

General Patterns and Statistical Significance

Considering the statistical significance with $p<0.05$ of each individual parameter, one would conclude there is no difference among the three fertilizers when applied at the same N application rate. When the individual parameters are considered together, however, there is a trend toward lower N availability, uptake, and delivery to the crop with AB, as opposed to either FM or UR. As a means of assessing overall trends, Figure 2-8 shows the primary parameters used to assess fertilizer efficacy, where site, rate, crop, and block are combined and only fertilizers are compared. Although there is too much variation to pick up statistical differences, there is a pattern. This may indicate that I did not have the statistical strength to demonstrate differences. Though we used Smith's index of soil variability to calculate the optimal plot size and number of replicates, revisions of our harvest plan to account for variable emergence could have impacted our power calculations. More replications of each treatment, more intensive sampling, or multiple trial-years would have provided more statistical power. Instead the patterns demonstrate the possibility of a type II error, i.e. there is no difference when in fact there is a difference in the ability to deliver N to the crop.

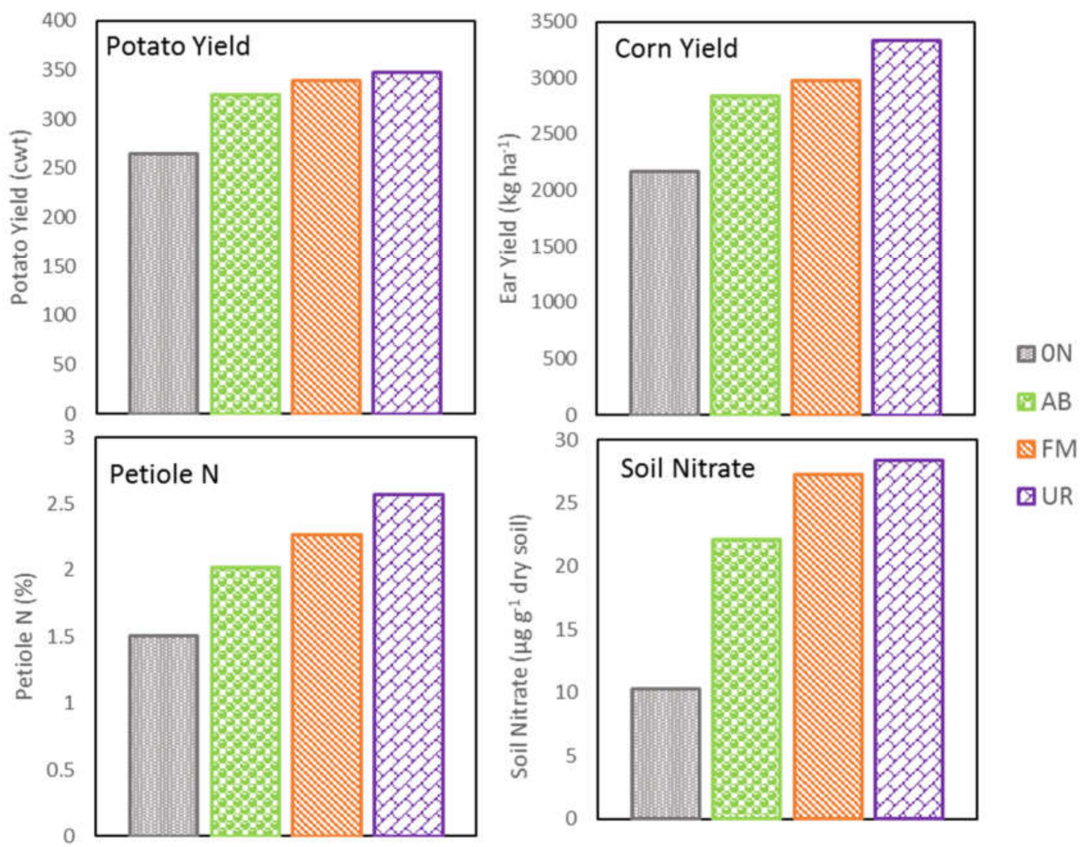


Figure 2-8 General Trends in Fertilizer Efficacy
Main N efficacy metrics averaged over all sites and rates. Used to demonstrate the potential that there was insufficient statistical power to detect real treatment differences.

Applications to Management

The data from two different lab incubations (Cappellazzi, 2018 Chapter 3) indicate that a majority of N mineralization from AB and FM had taken place within the first 22 days. Thus, it would be reasonable to advise that each of these fertilizers be applied using similar timing as mineral fertilizers, with application just prior to the period of rapid N uptake. The understanding of mineralization dynamics from this study will allow a producer to maximize product efficiency and minimize potential environmental loss. Nitrous oxide production has been related to systemic N imbalance with higher production related to soil NO_3^--N measurements in excess of plant needs (Schreiber et al., 2012). Results from my parallel trial measuring the greenhouse gas emissions of this field trial found an increased N_2O production rate from plots fertilized with FM starting about 22 days after planting, which continued to roughly day 33 (Cappellazzi, 2018 Chapter 3). This aligns with a period of soil warming, rapid N mineralization of FM, and the period of time just before the corn entered the V10 growth stage, requiring high N uptake rates. It follows then, that this increased rate of N_2O production might be indicative of N mineralization in excess of crop needs and that it was unnecessary to apply organic fertilizers at planting.

These laboratory incubations also demonstrated that not all of the applied-N was mineralized over 22 days. On average the AB, FM, and UR-treated soils mineralized 55%, 76%, and 90% of the applied N to NO_3^--N, respectively. These calculations are considered the net mineralization, above what was mineralized from SOM. Although the

N mineralization rate seems to permit similar application timing with mineral fertilizer, a lower percent of the total N applied becomes plant-available over that time. If the N application rate is precisely calculated, taking into account N mineralization from SOM, it would be advisable to use a slightly higher rate of N from these organic fertilizers, in accordance with MFE calculations by Delin et al., (2012).

Another management concern would be differences in characteristics among batches of AB (Cappellazzi, 2018 Chapter 4). The facility we were working with was new and still working to refine their process. As a result, there was variably moldy or pyrolyzed algal biomass delivered. For a product to be trusted and adopted by producers, consistency is needed. It has been recommended to the company that consistency will be required to decrease performance variation and increase producer confidence and adoption.

Site specific soil and climactic differences may be particularly important for organic fertilizer application rate recommendations due to the reliance on the microbial community for cycling nutrients. The AB and FM both performed particularly well in KF potatoes. This soil is sandy and has a low SOC content. Other studies have found that OM additions are disproportionately beneficial in sandy soils (Lichner et al., 2013; Thomas et al., 2015). The organic fertilizers could have performed particularly well at KF because they provided C to a soil that was C-limited, providing the microbial community energy (Schneider et al., 2012) to perform nutrient cycling functions. Alternatively, there could have been less NO_3^--N leached through this sandy soil profile from organic fertilizers. If the majority of the product was organically bound and mineralized at a rate that closely matched the needs of the crop, less N would have moved down the soil profile resulting in higher NUE. Managers on this site are particularly judicious with irrigation, and only apply enough water to percolate through the root zone. Even so, there was more NO_3^--N lower in the profile from UR than from AB or FM in KF.

Another option is that many studies have measured, higher mineralization rates or N availability in a sandy soil compared to those with more clay when controlling for OM content (Oades, 1988; P. Nannipieri, 1999; Thomas et al., 2015). Clay may act to trap N or make OM inaccessible to the microbial community (Cao et al., 2011; Chen et al., 2018; Johnston, 1996; Kleber and Johnson, 2010). There is typically more C in a high-clay soil, because the organic matter is physically protected from degradation, therefore organic fertilizers may become trapped in a higher clay soil and not be accessible for microbial mineralization. From this, it might be particularly advantageous to use organic fertilizers in sandy soils for more complete nutrient utilization (Cayuela et al., 2009), and decreased risk of nutrient pollution that is often found in sandy soils (Derby et al., 2009). Sandy soils without the ability to trap mineralized N, and that have a higher leaching potential and regular C-limitations, may particularly benefit from fertilization with AB or FM.

Potential Implications

In the first field trial to use algal biomass (AB) as a N fertilizer, the AB used was as effective at delivering N to crops as either feather meal (FM) or urea (UR) when fertilized at the same rate of total N. With this in mind, I could recommend this AB be priced equivalent to FM on a price-per-unit of N basis for an organic crop, or equivalent to the price of UR per unit of N if used on a conventional crop. However, the mineralization rate of AB was lower than FM in the laboratory incubation, there is considerably less history with this product, there is a chance of a type II error, and many producers are likely to give more weight to an overall trend than a statistical calculation. For these reasons it would make sense to start this market with a discount until more research with farm-scale trials have been conducted. Using the grand averages provided in Figure 2-8, potatoes fertilized with AB yielded 96% as much produce as those fertilized with FM and 93% as much as those fertilized with UR. Corn fertilized with AB yielded 94% and 86% as much as those fertilized with FM and UR, respectively. In the laboratory, AB mineralized 63%, 71%, and 59% as much as the FM in Corvallis, Klamath Falls, and Madras respectively. The C:N ratio of AB would suggest a mineral fertilizer equivalence of 10% less than FM. With this in mind, and the understanding that more trials are needed before the market will settle on a price, it is recommended that AB be priced at a 10% discount per unit of N to FM. If FM has a guaranteed analysis of 13% N and is conservatively selling for \$1000 Mg^{-1} in bulk totes to producers, then the price per unit N is \$7.70. With a guaranteed analysis of this AB at 7% N with a 10% discount, the bulk price could fairly be set to \$485 Mg^{-1} or \$6.90 per unit of N. The manure from each cow can produce roughly 1.5 Mg of dry algal biomass (Andrews, 2013), so for a 1000 cow dairy, the potential gross income from algal biomass fertilizer sales could be \$720,000 annually. This pricing does not take into account the impact of using a material that has the potential to add C back to the soil, thereby increasing the soils functional capacity. Pricing of ecosystem services related to the C-content of a soil will need to be solidified before this can be included in the valuation of a fertilizer.

Chapter 3 Carbon and Nitrogen Emissions using Algal Biomass as Fertilizer

Abstract

Soil carbon (C) restoration is crucial in efforts to reinvigorate the biological community that support a functioning, healthy soil and to mitigate climate change. Increasing the amount of C in the soil is, in essence, a balance of adding more C each year than is lost through respiration. I used four agronomic field trials comparing algal biomass to feather meal and urea to quantify greenhouse gas emissions (carbon dioxide and nitrous oxide) resulting from each fertilizer source. Controlled laboratory incubations were also performed to measure carbon dioxide. All fertilizers caused a significant increase in carbon dioxide respiration above the control treatment that received no fertilizer. Roughly 50% of the C added as algal biomass fertilizer was respired, while nearly all of the C added as feather meal was respired, and more C was respired than was added in the treatments receiving urea. From this, I expect algal biomass has the potential to increase soil carbon when added annually at an agronomically relevant rate, while urea may exacerbate the depletion of soil C. Nitrous oxide emissions were highest from the feather meal treatments, followed by similar emissions from algal biomass and urea. Coupling emissions data with fertility results indicated that synchronization of plant nitrogen uptake and nitrogen mineralization is an effective strategy for reducing nitrogen lost as nitrous oxide.

Introduction

Soil carbon (C) restoration is pivotal to reinvigorating the health of soil and agricultural systems (Singh et al., 2011). Soil health relates to the capacity of the soil to function as a vital living ecosystem (Doran, 2002). This living ecosystem contains myriad microbial populations interdependent on each other, dominated by heterotrophic organisms who require organic C for nutrients and energy to carry out the ecosystem services that humans rely on (FAO et al., 2017; Sylvia et al., 2005). Soil organic matter (SOM) is roughly 50% organic C (Pribyl, 2010). It has long been recognized that SOM: increases water holding capacity, buffers changes in pH, provides a substrate for, and modulates nutrient cycling rates, decreases erosion, strengthens aggregate stability, purifies surface and ground water, and builds the resilience of the system (Antle et al., 2006; Ellert, 1997; Lal, 2009; Yuste et al., 2011). The scientific community now understands that each of these functions is carried out or supported by the microbial community that relies on that soil C, which is why adding organic matter can improve so many soil conditions (Verstraete and Mertens, 2004). Although not the only indicator of soil health, a soil with low C is less capable of sustaining plant and animal productivity, air and water quality, and the myriad ecosystem services provided by a healthy soil (Singh, 2018b).

Soil C restoration has also been identified as one of the most cost-effective management strategies (FAO and ITPS, 2015; Naucler and Enkvist, 2009) for reducing carbon dioxide (CO_2) emissions to the atmosphere and critical in efforts to combat climate change (IPCC, 2014; Minasny et al., 2017). Soil is home to the largest pool of carbon cycling in the terrestrial biosphere, with roughly 1500 Gt C in the top meter and an estimated 2300-3300 Pg estimated in the top three meters of soil (Amundson, 2001; Guo and Gifford, 2002; Schlesinger, 1995; Tarnocai et al., 2009), 800 Pg in the atmosphere, and 550 Pg in plant matter (Singh, 2018b). Human land-use, including deforestation, burning of biomass, and agricultural activities have caused an estimated net 133 Pg C contribution to global emissions of C (Lal, 2004; Sanderman et al., 2018). When virgin soil is first tilled to be put into agricultural production, there is a precipitous drop in soil organic C (SOC) (Mann, 1986). Some soils have lost one half to two thirds of their original organic C, with estimated cumulative losses ranging from 30-90 Mg C ha^{-1} (Guo and Gifford, 2002; Lal, 2004). In the last 80 years, long-term research trials in Pendleton, OR have lost an average 50% SOC under all but the manured treatments, compared to the grassland control (Ghimire et al., 2015).

Agricultural management practices largely determine whether soil is a C source or sink (Singh, 2018b). The addition of OM to the soil can rebuild soil C over time, if more C is added each year than is respired. Through extremely active regenerative practices, it may be possible to reach pre-cultivation SOC ranges within 100 years (Amundson, 2001). The amount of C that any organic material adds to a soil depends on a confluence of factors: (1) rate; how much is applied and how often; (2) concentration of each element; including C, H, O, and the plant essential nutrients; (3) climate; moisture and temperature dynamics of the environment; (4) soil; parent material, texture, aggregate structure, organic matter, pH, living biota (above and below ground), and all their interactions (LaRowe and Van Cappellen, 2011; Singh, 2018b). Models to predict rates of C utilization and storage will be continually improved until all of these inter-related factors are described (Singh, 2018b).

Soils near dairies that receive repeated applications of manure, tend to have high SOC. In a recent survey of soils in Oregon, I found SOC averaged 6% on dairies with intensive grazing rotations, 4% on crop lands with repeated manure nutrient additions, and 2% on neighboring soils without manure applications (Andrews, report for NRCS 2018). Ding et al. (2007) found that SOC in an intensively-cultivated silt loam increased from 0.45 to 0.86% C after 13 years of organic manure applications. Jenkinson and Rayner (2006), working with the Rothamsted classical experiments have shown that annual manure applications averaging 3 tons of C yr^{-1} over 125 years, has increased SOC from 25 ton C ha^{-1} to nearly 100 tons C ha^{-1} without a significant decline in the rate of C increase. Though increasing soil carbon can be beneficial for many environmental parameters, repeated manure applications also has negative environmental consequences.

Loss of N to the environment from dairy manure starts from the moment it is excreted, through treatment, storage, and during and after land application. High rates of manure application have been shown to contribute to NO_3^--N leaching (Ball-Coelho et al., 2003; Chang and Janzen, 1996a), which have downstream impacts on human drinking water (Knobeloch et al., 2000) and the health of aquatic ecosystems (Heisler et al., 2008). It has also been shown that an imbalance between mineralized N and plant requirements for N, causes an increased rate of nitrous oxide (N_2O) emissions (Schreiber et al., 2012), a greenhouse gas (GHG), with 295-310 times the global warming potential of CO_2 (FAO and ITPS, 2015; FAO et al., 2017; IPCC, 2014). It is estimated 9-59% of N applied as manure is lost to the atmosphere as ammonia (NH_3) unless it is immediately incorporated into the soil (Hargrove, 1988; Pfluke et al., 2011). While not a GHG, NH_3 particulates react with oxides of nitrogen and impact air quality and have been linked to respiratory problems (Asman et al., 1998). A controlled study tracking the fate of N excreted from cows reported approximately half of the excreted N could not be accounted for 24 hours after application (Hristov et al., 2009).

Recent efforts to reduce nutrient loss, GHG emissions, nuisance odors, and problematic soil nutrient buildup have centered on the idea of integrating anaerobic digesters (AD) and algae production into a dairy operation (Chowdhury and Freire, 2015; Fenton and Ó hUallacháin, 2012; Kebede-Westhead et al., 2004; Kothari et al., 2013; Mulbry et al., 2008a; Rawat et al., 2011; Wilkie and Mulbry, 2002). Anaerobic digesters can chemically reduce and capture manure C into methane-rich (CH_4) biogas used for electrical production (Goodrich, 2005; Saunders et al., 2012). Further incorporation of algal ponds allows for the opportunity to capture nutrients from liquid effluent into stable biomass, capture CO_2-C from the atmosphere, and make biodiesel when oil prices are high (Benemann and Oswald, 1996b). Algae grown on the liquid effluent of an anaerobic digester using dairy manure can capture 70-97% of the N and 50-99% of the P in high-nutrient-load effluent and store it in their cells (Mulbry et al., 2008b; Olguin, 2003; Wilkie and Mulbry, 2002). The algal biomass can be dried with the heat produced by the anaerobic digester(Ledda et al., 2016) to make a concentrated and valuable fertilizer that can leave the dairy in a truck and fertilize distant cropland (Pizarro et al., 2006). Extensive work has been done on the engineering challenges associated with algal production (Benemann and Oswald, 1996b; Sheehan et al., 1998). Less effort has been made to quantify the C and N dynamics of the resulting algal biomass (AB) as a fertilizer (Mulbry et al., 2005; Rothlisberger-Lewis et al., 2016). If a conscientious farm advisor wants to encourage a producer to adopt this kind of a system, it will be important for them to be able to describe the associated environmental benefits from an agriculturally relevant perspective as well as benefits related to climate change.

The goal of this research is to assess the environmental impacts of using algal biomass (AB) as a fertilizer. There are many environmental impacts of integrating algae production into a dairy operation. Here I focus on the fate of N and C released as GHG emissions associated with fertilizer application and the potential to build soil C. Specifically, I tested the following hypotheses. (1) AB application will result in more CO_2-C production than fertilization with feather meal (FM) or urea (UR) because more C is added to achieve the same N rate. (2) Application of AB or FM will result in a net increase of C to the soil because there will be less CO_2-C production than total C added, while UR applications will result in higher CO_2-C loss from the system than is added with fertilizer. (3) Soils fertilized with AB or FM will continue to have a higher rate of CO_2-C respiration throughout the growing season than soils fertilized with UR or 0N because the microbial community will mineralize the organic fertilizers slowly throughout the growing season. (4) AB or FM application will result in less N_2O loss than fertilization with UR due to reduced N imbalance. (5) Under similar application rates and climactic conditions, N_2O production is a function of microbial activity because there are a several microbially mediated pathways for N_2O production. (6) N_2O production will remain elevated throughout the N mineralization period because a portion of the N_2O will be lost during mineralization.

Methods

Field Trial Overview

Fertilizer efficacy trials were established at three OSU research field stations. Two of these sites were used for chamber-based gas measurements, Corvallis (CL) and Madras (MD), OR. The CL soil is mapped as Chehalis, a fine-silty, mixed, mesic, cumulic Ultic Haploxeroll. The MD soil is mapped as Madras, a fine-loamy, mixed, mesic Aridic Argixeroll. These soils are both in a xeric moisture regime, rarely experiencing rain during the growing season but were irrigated. At each location, Anthem sweet corn (*Zea mays* L.) and Yukon Gold potatoes (*Solanum tuberosum*) were grown as separate trials at recommended fertilizer rates based on soil test results for the target crop. Fifty percent of the full fertilizer rate was banded immediately prior to planting potatoes with AB, feather meal (FM), or urea (UR). After 30 days, the second half of the fertilizer was side-dressed and the potatoes were re-hilled to incorporate the material. In the corn trials, organic fertilizers were banded at planting, but only 26 kg ha^{-1} of UR was banded, following best management practices. The remainder of the UR fertilizer was applied 30 days later and incorporated by hand with a hoe.

Gas Chamber Design

Recommendations set forth by the GraceNET protocol for gas sampling (Parkin and Venterea, 2010) were followed with minor modifications as described below. Gas sampling chambers were modified #10 food service cans with an interior diameter of 15.88 cm and total height of 17.8 cm. In order to reduce temperature perturbations, the aluminum chambers were coated white. Removable plastic lids were fitted with butyl rubber sampling septa as well as a vent tube 5 cm long with 5 mm diameter, to equalize pressure inside the chamber during sampling (Hutchinson and Livingston, 2001). Chamber lids were only secured during sampling, never exceeding 60 minutes. Chambers were inserted into the soil immediately following fertilization such that half of their height was above ground. The headspace varied slightly based on insertion depth, ranging from 8-10 cm. This allowed for adequate headspace while limiting diffusive gas transport beneath the chamber. Potato-field chambers were removed and replaced before and after the second round of fertilization and re-hilling. Otherwise they were not moved throughout the trial. Chambers were placed directly in-line with the fertilizer band to capture treatment differences. When plants grew into the chambers, they were eliminated so the scope of trial could be isolated to gas efflux from the soil.

Gas Sampling

Gas was sampled daily following fertilization for four to seven days and weekly thereafter. Samples were normally taken from 10:00-11:00 am to capture the estimated average daily temperature. At each sampling date for each chamber, four samples were taken, each twenty minutes apart. For each chamber, four glass 20 mL sampling tubes were fitted with a septa, sealed with a crimp-top clamp, labelled, and placed in a small plastic bag. Immediately prior to sampling, lids were attached to the chambers, the time zero sample tube was evacuated in the field using a syringe, and 12 mL of gas was pulled from the chamber and inserted into the sample tube. In MD, a Hydroprobe was used to take measurements of soil temperature and moisture in real time. In CL, soil samples were taken on each sampling date for a gravimetric moisture measurements. Time was recorded and the AgriMet weather and soil temperature data were used to estimate air and soil temperature at time of sampling. Monthly, gas samples were shipped to Oklahoma State University for analysis on their Varian 450-GC gas chromatography mass spectrophotometer (GCMS) (Varian BV, Middleburg, The Netherlands). Each vial was analyzed for carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4).

Flux Calculations

The first way I approached the flux calculations for chamber-based gas measurements from the field trial was the Hutchinson Mosier 4-point flux model. This model was developed (Hutchinson and Mosier, 1981) to eliminate bias imposed by linear regression models that significantly underestimate the true flux due to chamber space limitations, which cause decreased diffusion rates over time (Livingston et al., 2006). Without a closed chamber, gas diffusion is assumed to be linear at a stable temperature and pressure; however it has often been observed that the slope (flux rate) between time-points decreases over time in a closed system (Livingston et al., 2006; Matthias et al., 1978; Parkin et al., 2012b). To account for this phenomenon, the following formula has been developed and used as a standard for many gas chamber-based studies:

$$F_0=(C_{A1,2}-C_0)^2/[t_{A1,2}*(C_{A1,2}-C_3-C_0)]*\ln[(C_{A1,2}-C_0)/(C_3-C_{A1,2})] \qquad \text{Eq. 1}$$

where F_0 is the flux, C is concentration, t is the time in hours, the subscripts describe time points 0, 1, 2, or 3, and $_{A1,2}$ is the average of the concentration or time at points 1 and 2.

This formula only works if:

$$[(C_{a1,2}-C_0)/(C_3-C_{a1,2})] > 0 \text{ and } 1< [(C_{a1,2}-C_0)/(C_3-C_{a1,2})] >0 \qquad \text{Eq. 2}$$

In the initial analysis only 48% of the N_2O and 57% of the CO_2 data fit the requirements (Appendix Table 1). Other researchers have had similar experiences (Livingston and Hutchinson, 1995), reporting roughly 40% of controlled laboratory experiment data did not match the required Hutchinson Mosier equation conditions (Parkin et al., 2012b). Using only data that fit their model caused significant data bias to be reported.

With the Hutchinson Mosier formula unsuitable for representation of the breadth of this trial, I used a second order polynomial to fit the four time points of each sample using the Excel LINEST array. This has been analyzed by Parkin et al. (2012a) as an acceptable alternative. Flux values calculated from the second order polynomial (LQuad) were compared to values available from the Hutchinson Mosier flux calculations and linear flux calculations. The LQuad flux values were found to be intermediate in magnitude, had a lower CV within treatments on each date than either of the other two methods, and provided season-long gas production values in accordance with literature reported gas flux. Appendix Table 1 provides a comparison of the flux calculations from each method.

Analysis

The IPCC emission factor (EF) from fertilizer is calculated by measuring the gas flux above that of an unamended soil, then dividing by the total applied N or C (Shcherbak et al., 2014). For this trial, emission factors (EFs) were calculated using both a median value extrapolation and the cumulative production of N_2O-N or CO_2-C above the cumulative production from the 0N plots, divided by the amount of N or C applied with each fertilizer, respectively. To calculate cumulative production, daily flux values were integrated with the time between measurements for each block. In each calculation the control treatment average at the respective site was subtracted from each replication.

In order to assess the total amount of C added or lost from the system, the total C added to the soil in each fertilizer treatment for each site-specific recommendation was calculated. In the field trial, there were differences by site and crop, but not fertilizer treatment, so the CO_2-C evolved from the three fertilizers were averaged for each site-by-crop trial to estimate the relative percent of C added or lost from the system from fertilizer application. In the laboratory incubation, the individual cumulative treatment losses were used to estimate C addition because they were each statistically different from each other.

Fertilizer-by-Soil Incubation

There were three different batches of AB received in one ton totes from the company who produced the material. AB samples from batch two and three, respectively (AB2 and AB3), feather meal (FM), urea (UR), and a control with no fertilizer (0N), were applied to each of the three soils used in the field trial in a factorial design. Soil samples from the control plots of each of the potato trials were used for the incubation, CL, MD, and Klamath Falls (KF). After sieving to 2 mm, and letting sit at room temperature for 3 days, samples from each soil were placed in jars to measure baseline CO_2 respiration and NO_3^--N. The incubation set up followed procedures described in Cappellazzi, 2018 (Chapter 4). Briefly, four tubes each with 45 g soil and 8.5 mg N, one for each destructive sampling date, were put into one quart-sized canning jar with three jars of each treatment used as replicates. Lids were placed on the jars for two hours in order to measure CO_2 respiration on days 0, 1, 2, 3, 4, 7, 15, and 22 using a Picarro Isotopic CO_2 Analyzer (Picarro Inc. Santa Clara, CA). Nitrate measurements were made using a Lachat FIA (Hach Company, Loveland, CO) by destructively sampling the tubes on day 0, 3, 7, 15, and 22, extracting the soil with 2M KCl solution in a 4:1 solution to soil ratio.

Statistics

A random complete block design was used for the field trial with each fertilizer and a control appearing once in each of four blocks. SAS 9.4 (v.9.4, SAS Institute, Cary, NC) was used for all statistical analysis. The proc mixed model with restricted maximum likelihood approach (Milliken and Johnson, 2009) showed that for both CO_2 and N_2O production there was covariance by site and crop when data from the MD corn trial were included. The MD corn trial had fewer measurements, and crop management challenges served as a reason to exclude these data from general analyses, though individual site data are provided. After transformations of raw data into flux values, the four replicate treatments from each sampling date were assessed for outliers and removed according to a Thompsons Modified Tau Test. The minimum detection limit (MDL) was calculated for each sampling date based on the ambient gas concentration, the coefficient of variation CV of the GCMS standards, deployment time, and a scaled slope factor developed by Parkin et al., (Parkin et al., 2012b) for each different type of flux calculation. Because LQuad values passed the calculated MDL over 90% of the time, it was determined that all data would be provided in figures with MDLs provided. The MDL along with flux rates for each date, site, and crop are available in Appendix Table 2.

The variance of the gas flux data was not normally distributed. General patterns were assessed with a non-parametric Kruskal-Wallis test, which assesses rank-scores of median values to provide the probability of differences caused by treatments. Because this test only tells us whether there is a within-set difference, two treatments at a time were compared to provide groupings. These tests work well with a large number of observations but are likely to yield errors with only four replications. For this reason, gas measurements on each individual date were analyzed using a mixed model and Tukey's HSD test to assess treatment differences. Mixed models do not assume normal distribution and are recommended when there is uneven sample size caused by missing data (Kravchenko and Robertson, 2015). Parameters in the factorial laboratory incubations were analyzed with a two-way ANOVA using Proc GLM. For all tests, differences are reported when the probability that the differences were due to chance was $p < 0.05$.

Results

Carbon Dioxide Respiration – Field Trials

Examining the data en masse, provides us with a general overview of the behavior of the CO_2-C emissions from each fertilizer. These data are displayed as median values in Figure 3-1. The skewness for each fertilizer is 1.11, 1.57, 6.05, and 2.24 for 0N, AB, FM, and UR, respectively. A histogram of the distribution of all CO_2 measurements gathered during this trial is skewed with results from most data points demonstrating a very low flux value in each of the treatments causing a high peak on the left, and a long right tail. When analyzing the data from sites and crops together, respiration caused by

AB, FM, and UR were higher than respiration without any N fertilization. The CO_2-C evolved from AB is not different from UR, and FM is higher than either of the other two.

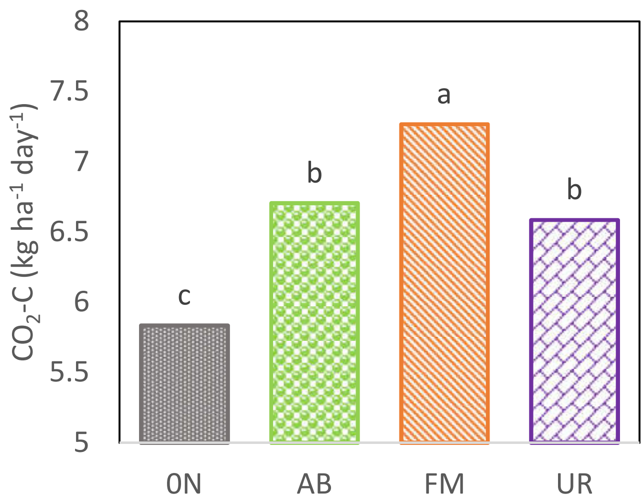


Figure 3-1 Daily Median CO_2-C for All Field Sites
Includes multiple time points for two different locations and two different crops. N≥180. 0N represents control plots with no nitrogen added. AB, FM, and UR are plots that received algal biomass, feather meal, or urea, respectively. Letters indicate differences at $p<0.05$ determined by a Kruskal-Wallis test of individual treatment comparisons.

Figure 3-2 displays each site-by-crop trial independently. There is a similar pattern of significance where FM is the highest, and 0N is lowest. In the corn trials, which each had potentially confounding errors (described in Appendix 2), there was no difference between AB and the other treatments. In the CL potato trial, there was no statistical difference between FM and UR was demonstrated, but AB was higher than both 0N and UR. In the MD potato trial, the pattern was the same as the overall pattern of compiled data.

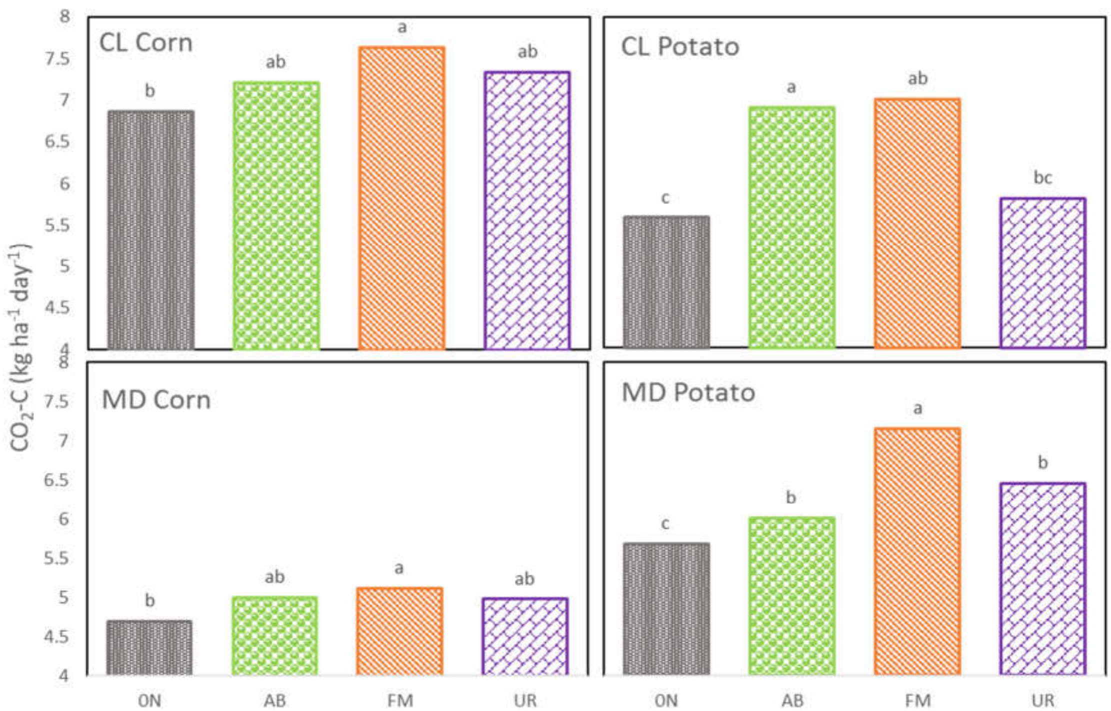


Figure 3-2 Daily Median CO_2-C by Site and Crop
This includes multiple time-points. N≥44. 0N represents control plots with no nitrogen added. AB, FM, and UR are plots that received algal biomass, feather meal, or urea, respectively. Letters indicate differences at $p<0.05$ determined by a Kruskal-Wallis test of individual treatment comparisons.

Cumulative production of CO_2-C for each crop at each site are displayed in Figure 3-3. These data were normally distributed so average values were reported. Corvallis potatoes were the only site where significant fertilizer differences were observed. The CL potato plots fertilized with AB were highest, but not significantly different from those fertilized with FM, and FM fertilized plots were not significantly different than UR fertilized plots. In the MD potato trial, plots fertilized with FM nominally had the highest cumulative CO_2-C production through the season, but there were no differences among FM, AB, and UR, though FM was higher than 0N. In both corn trials, treatments were not different from each other, nor different from the control.

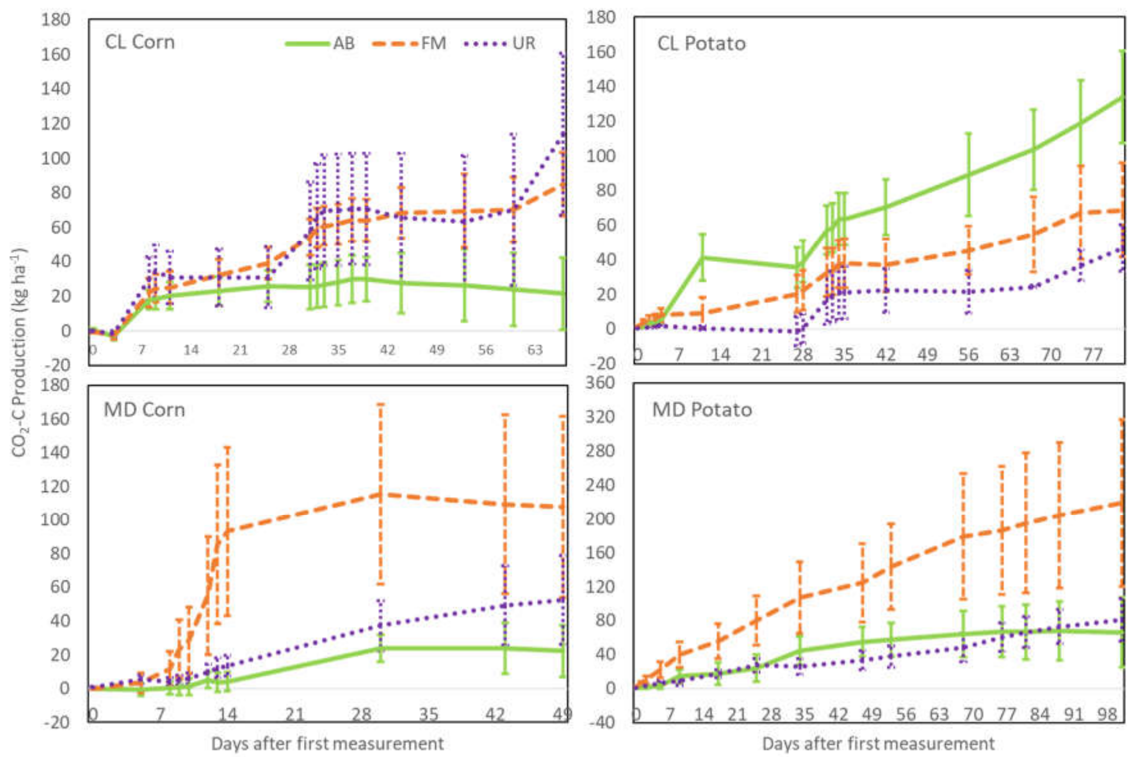


Figure 3-3 Cumulative CO_2-C Production from Fertilizer in Field Trial
AB, FM, and UR represent plots that received algal biomass, feather meal, or urea, respectively. Flux calculations for each date are integrated with the time between measurements to estimate total CO_2-C emissions through the growing season. Emissions from the control treatment are subtracted from each replicate to yield CO_2-C produced as a result of the fertilizer application. Error bars represent the standard deviation of the integrated value of four replications at each time point.

Table 3-1 provides calculated values for each site and fertilizer relative to C additions or losses. The AB treatment adds roughly two times as much C to the system to deliver the same amount of N as FM. With similar respiration rates this makes the emission factor (EF) half that of FM, with roughly two times more C added to the soil from AB. UR adds a negligible amount of C to the system and on average between sites results in an EF of 128%, or a net C loss from the system. Considering just the total CO_2-C lost, FM fertilization appeared near neutral, while AB respired roughly 50% of what was applied.

Table 3-1 Carbon Source or Sink Calculations for Field Trials

Site by Crop	Total SOC		CO_2-C lost		C added from fertilizer			Gross CO_2-C C^{-1} added			Emission Factor		
			Fert Ave	0N	AB	FM	UR	AB	FM	UR	AB	FM	UR
	%	---------------------------	---kg ha^{-1}---				---------------------------	------------------	---% ---				------------------
CL Corn	1.3	10400	544	470	1175	631	65	46	86	837	6	12	114
CL Potato	0.7	5907	658	585	1332	715	74	49	92	889	5	10	99
MD Potato	1.0	8486	647	526	1253	673	70	52	96	924	10	18	173
Average	1.0	8264	616	527	1253	673	70	49	91	883	7	13	128

CL=Corvallis, MD=Madras, 0N=control, AB=algal biomass, FM=feather meal, and UR=urea.
Fert Ave is the average cumulative respiration of AB, FM, and UR at each respective site.

Table 3-2 Carbon Source or Sink Calculations for Laboratory Incubation

	Total SOC	Total SOC	CO_2-C lost				C added			Gross CO_2-C lost C^{-1} added			Emission Factor		
			AB	FM	UR	0N	AB	FM	UR	AB	FM	UR	AB	FM	UR
Soil Source	%	---------------------------	---μg C g^{-1} dry soil---						---------------------------	------------------	---%---				------------------
CL	0.7	6830	462	568	317	258	1263	728	82	37	78	387	16	43	72
KF	0.6	5900	344	415	261	187	1263	728	82	27	57	318	12	31	90
MD	0.9	9260	352	385	270	196	1263	728	82	28	53	329	12	26	90
Average	0.7	7330	386	456	283	214	1263	728	82	31	63	345	14	33	84

CL=Corvallis, MD=Madras. Fert Ave is the average cumulative respiration of AB, FM, and UR at each respective site. 0N=control, AB=algal biomass, FM=feather meal, and UR=urea.

Carbon Dioxide Respiration – Laboratory Results

The field data provided general patterns and trends that suggest higher CO_2-C production from FM, followed by AB and UR, with 0N causing the lowest emissions. The laboratory incubation provided the opportunity to do a similar analysis in a controlled environment, with all three soils, and two different batches of AB. The 0N treatment resulted in respiration that was significantly lower than all fertilizers at each site and was subtracted from each treatment to report respiration as a result of fertilizer addition (Figure 3-4). Feather meal treatments resulted in the highest CO_2-C respiration rate in each soil with cumulative C loss above 0N of 310, 228, and 189 µg C g^{-1} dry soil for CL, KF, and MD, respectively. The only instance where CO_2-C respiration rate was not significantly higher was CL soil on the last measurement date where it was the same as AB3. There was no difference between CO_2-C production between AB2 and AB3 when incubated with the MD soil, but in soil from CL and KF respiration from AB2 was only 72% of respiration caused by the incubation with AB3.

The right side panels of Figure 3-4 display the total CO_2-C µg g^{-1} dry soil day^{-1} of each organic fertilizer, there was a significant spike in CO_2-C production that increased for each of the first three days after fertilization. Soils treated with UR also resulted in more CO_2-C production than 0N for the first three days, but it did not increase each day. Seven days after the start of the incubation, UR was not different from 0N, and at two weeks, no fertilizer treatments were different from the 0N, except with soils from KF. In KF, both AB and FM treatments caused higher CO_2-C production than the 0N at the two-week measurement. Only the two AB treatments caused higher CO_2-C production than 0N on day 22.

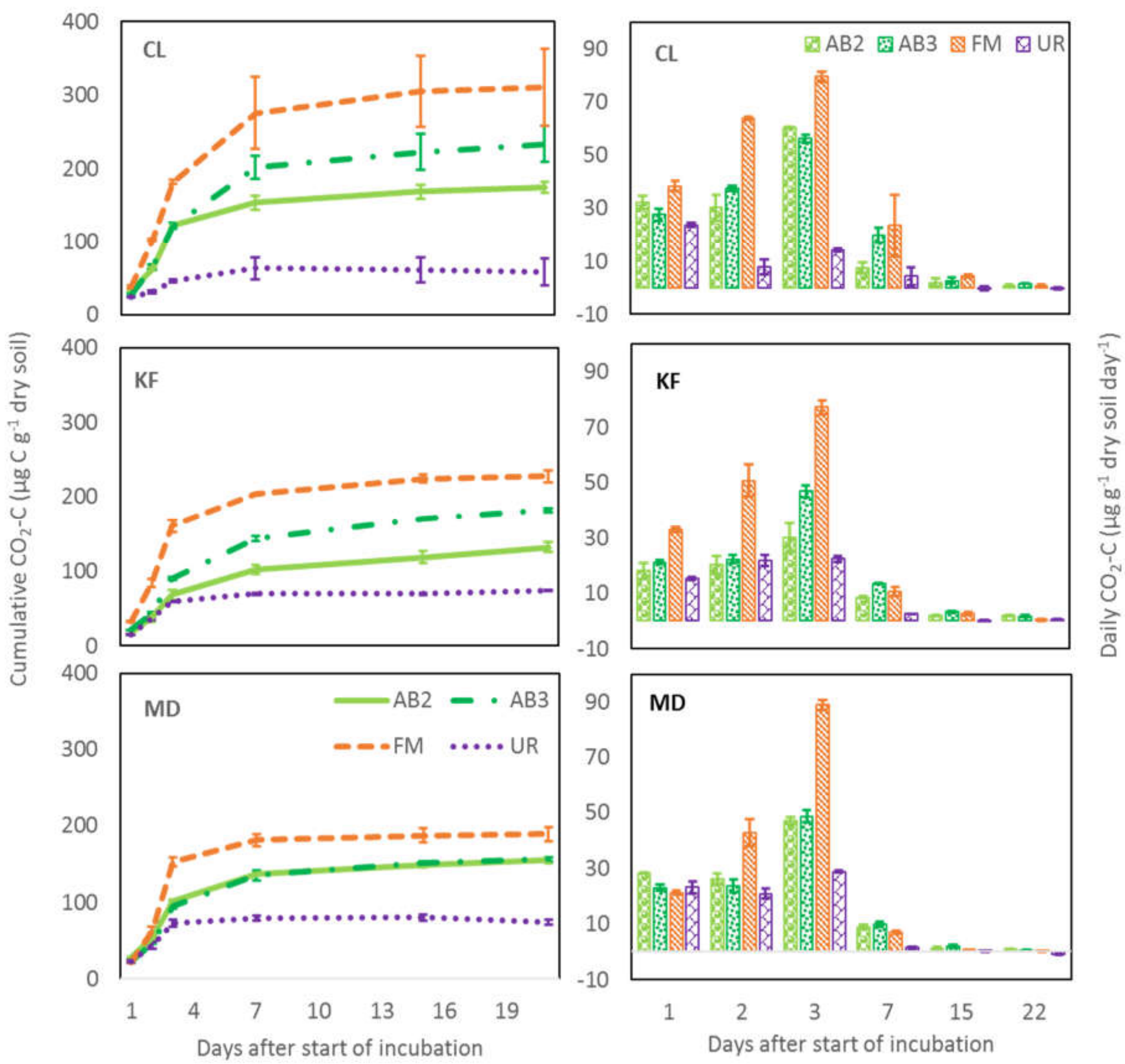


Figure 3-4 CO2-C Production from Fertilizers in Laboratory Incubations
AB2, AB32, FM, and UR represent incubations that received algal biomass from batch 2, algal biomass from batch 3, feather meal, or urea, respectively. CL, MD, and KF represent soils from Corvallis, Madras, and Klamath Falls respectively. Panel on left displays cumulative production through 22-day incubation, error bars represent the standard deviation of the integrated value of three replicates at each time point. Panel on right displays daily measurements of CO_2-C, error bars are daily standard deviation. Emissions from the control treatment are subtracted from each replicate to yield CO_2-C produced as a result of the fertilizer application.

Using these data to assess the total C source or sink allows us to use cumulative CO_2-C production from each fertilizer independently. Differences between the AB products will be discussed in in Chapter 4. Here, they have been averaged for comparison with field measurements. The total C added from AB treatments was roughly twice as much as FM and CO_2-C production was lower, resulting in considerably less CO_2-C evolved during the incubation. Table 3-2 displays calculations of total C additions and losses due to fertilization and the resulting respiratory burst. On average the C EFs are 14%, 33%, and 84% from AB, FM, UR fertilization in 22 days of the experiment, respectively.

Nitrous Oxide Flux

Urea and FM fertilization resulted in higher N_2O-N emissions than AB and all fertilizer treatments were higher than 0N (Figure 3-5). Figure 3-6 displays the median of each site-by-crop trial. In the CL potato trial, all fertilizers caused similar N_2O-N production, and were higher than 0N. Both the CL corn trial and MD potato trial trend toward higher N_2O-N from the UR and FM plots, and in the MD corn trial there was too much variability to state that treatments caused the difference in N_2O-N production. Nitrous oxide-N produced in this field trial ranged from 0.6-0.9% of total N applied as fertilizer using daily median values or season-long cumulative production. The EF, the percent of N fertilizer emitted as N_2O-N above what was emitted by the control, calculated using the extrapolated median, ranged from 0.01-0.22% and was slightly higher using cumulative means, 0.07-0.43%.

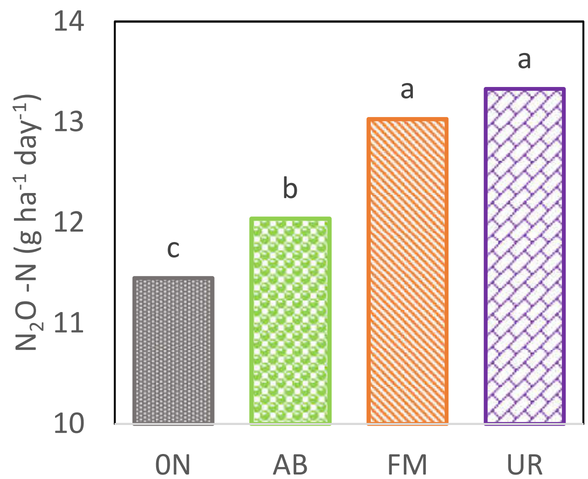


Figure 3-5 Daily Median N_2O-N for All Sites
Includes multiple time points for two different locations and two different crops. N=180, Madras corn is excluded. 0N represents control plots with no nitrogen added. AB, FM, and UR are plots that received algal biomass, feather meal, or urea, respectively. Letters indicate differences at p<0.05 determined by a Kruskal-Wallis test of individual treatment comparisons.

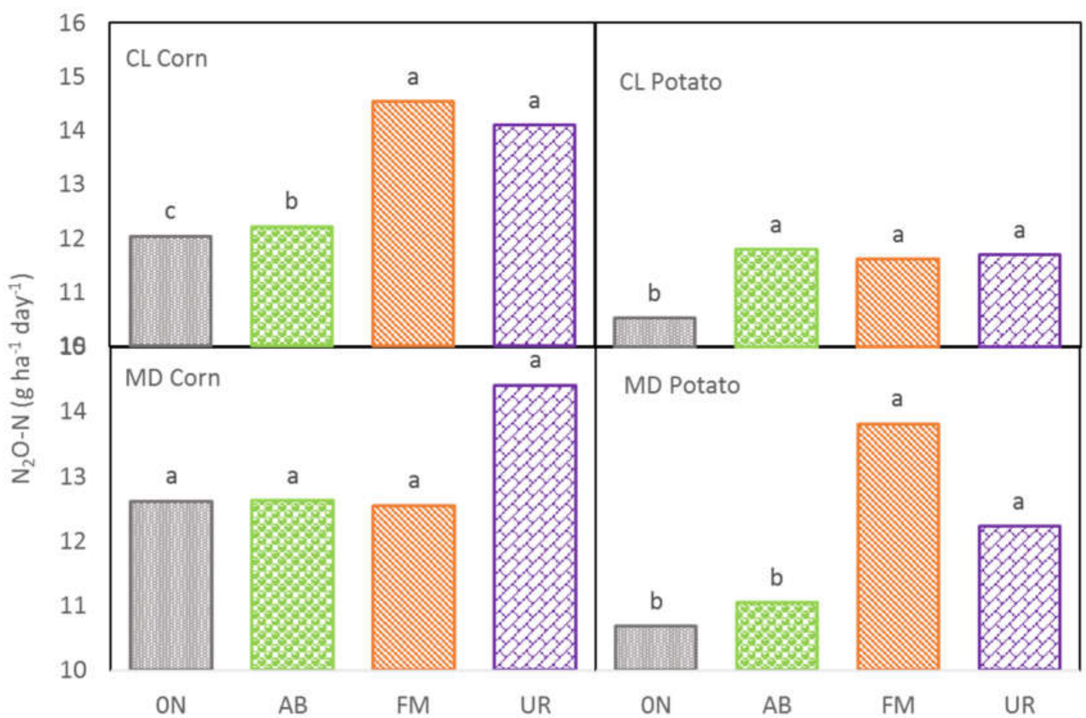


Figure 3-6 Daily Median N_2O-N for Each Site
Data include multiple time points. N≥44. 0N represents control plots with no nitrogen added. AB, FM, and UR represent plots that received algal biomass, feather meal, or urea, respectively. Letters indicate differences at p<0.05 determined by a Kruskal-Wallis test of individual treatment comparisons

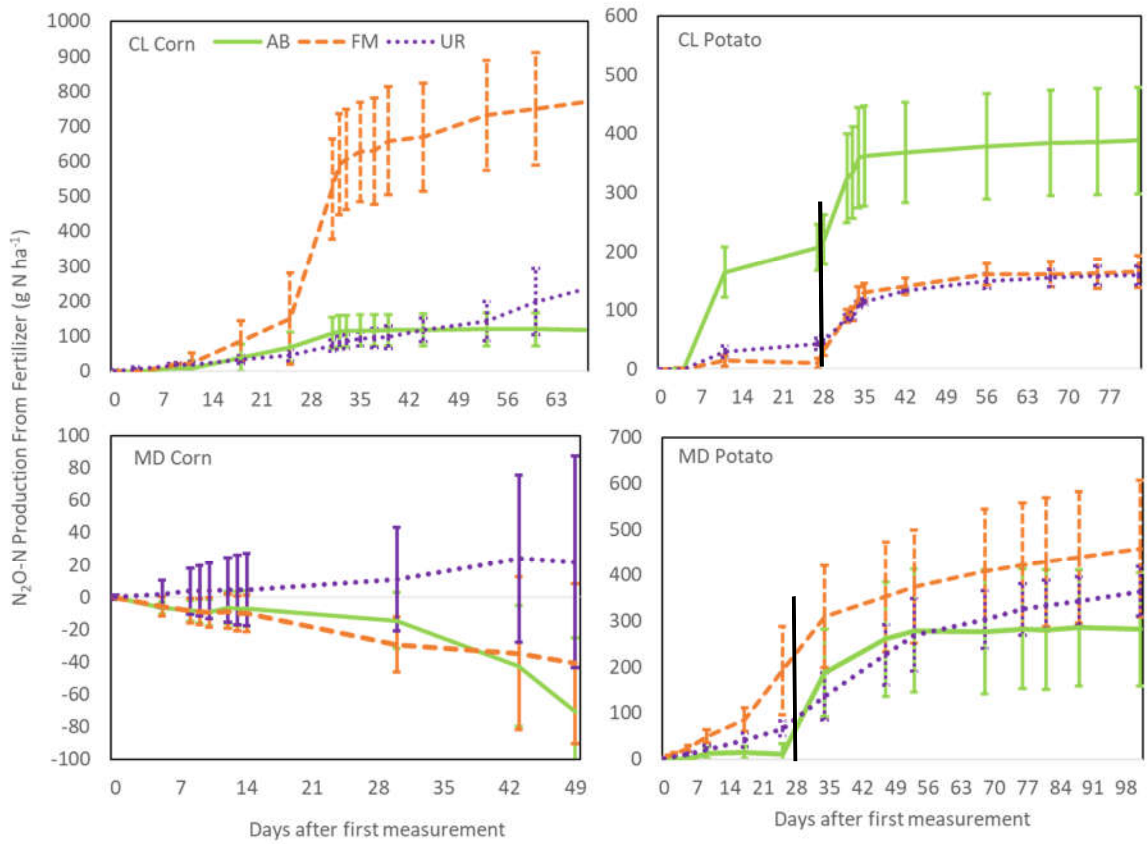


Figure 3-7 Cumulative N_2O-N Production from Field Sites

AB, FM, and UR represent plots that received algal biomass, feather meal, and urea, respectively. Flux calculations for each date are integrated with the time between measurements to estimate total N_2O-N emissions through the growing season. Emissions from the control treatment are subtracted from each replicate to provide N_2O-N produced as a result of fertilizer application. Error bars represent the standard deviation of a four integrated values at each time point. Black line indicates the second fertilization event.

In the CL corn trial, plots fertilized with FM produced significantly more N_2O-N than the other fertilizer treatments (Figure 3-7). Corvallis potato plots fertilized with AB produced significantly more N_2O-N than the other fertilizers. The negative cumulative production from the MD corn plots that received organic fertilizers suggests that organic fertilizers produced less N_2O-N than 0N, but differences were not significant because of high variance. Within MD potato trial there were a few dates with significantly higher flux-rates from FM treated plots, but by the end of the trial there were no differences in N_2O-N production between fertilizer treatments. Emission factors ranged from 0.07-0.22%, 0.08-0.43%, and 0.09-0.21% for AB, FM, and UR treatments using cumulative production values, respectively.

Setting MD corn results aside for a moment, there is a short term increased N_2O-N production following fertilization. This is most evident in potato trials where there were two different fertilizer applications, near day 0 and 30. For the CL potato trial this was on day 28, June 18th. N_2O-N production rate was higher for each fertilizer treatment for the next seven days, with rate decreases after the initial flush. Table 3-3 provides data on the limited dates where there were significant differences by fertilizer. In the CL potato trial the increase in emission rate was higher for AB than other treatments, both after the initial fertilization and the second fertilization. In the MD potato trial the N_2O-N production in AB fertilized plots remained low after the first fertilization event, and increased rapidly in the days following the second fertilization event which took place on day 30, June 15th. Unfortunately, there was a miscommunication regarding pesticide application and gas samples were not taken immediately following fertilization. On day 35, the N_2O-N flux rate was significantly higher than before this fertilization event, with AB treatments having the greatest flux rate. In the CL corn trial there was not significant N_2O-N production immediately following planting and fertilization. Feather meal N_2O-N production increased gradually for the first 30 days and then increased rapidly on July 16th and 17th. Weekly gas sample measurements were typically taken the day before irrigation events. However, as the season progressed the irrigation schedule was adjusted and on July 16th when I arrived for sampling, irrigation was running. I waited until later in the afternoon to take samples from very wet soil. Conditions were constant across the site, but plots that received FM had a larger reaction to the change in condition. At this point in the season, gas samples from the corn trial were sampled every 7 days, so a very high measurement for one day led to a marked impact on the N_2O-N accumulation value.

Table 3-1 Daily N_2O-N Flux Means with Statistical Differences for Potato Plots

Corvallis								
Fertilizer	2-Jun	18-Jun	19-Jun	23-Jun	24-Jun	25-Jun	26-Jun	Season
0N	12 b	12 b	12 b	12 b	12 b	12 b	10 b	886 c
AB	36 a	15 a	26 ab	38 a	22 a	37 ab	13 ab	1274 a
FM	14 b	12 b	35 a	27 ab	15 ab	42 a	17 a	1051 b
UR	16 b	13 ab	16 b	22 ab	14 b	32 ab	15 ab	1045 b

Madras						
Fertilizer	16-May	17-May	18-May	21-May	2-Jun	Season
0N	11 b	11 b	11 b	11 b	12 b	1171 b
AB	11 b	11 b	11 b	11 b	12 b	1454 ab
FM	14 a	16 a	15 a	15 a	16 a	1628 a
UR	13 ab	13 ab	13 ab	13 ab	14 ab	1535 ab

0N=control, AB=algal biomass, FM=feather meal, UR=urea.
Values with the same letter are not significantly different at $p<0.05$

Nitrous Oxide Production as a Function of Carbon Dioxide Respiration

N_2O-N production can be better explained (higher R^2) by CO_2-C respiration in CL than in MD (Figure 3-8). At each site, the relationship was strongest from AB fertilized plots. The slope of the relationship between N_2O and CO_2 measurements indicates less N_2O-N was produced for every unit of CO_2-C respired from AB or UR than from FM.

There was a very low rate of N_2O-N production per unit of CO_2–C respired in the 0N treated plots. The MD data were less normally distributed than CL and the formula for the linear regression relies predominately on a few exceptional samples in each treatment. In MD, N_2O production was not a function of microbial activity, assuming CO_2-C as a proxy for activity.

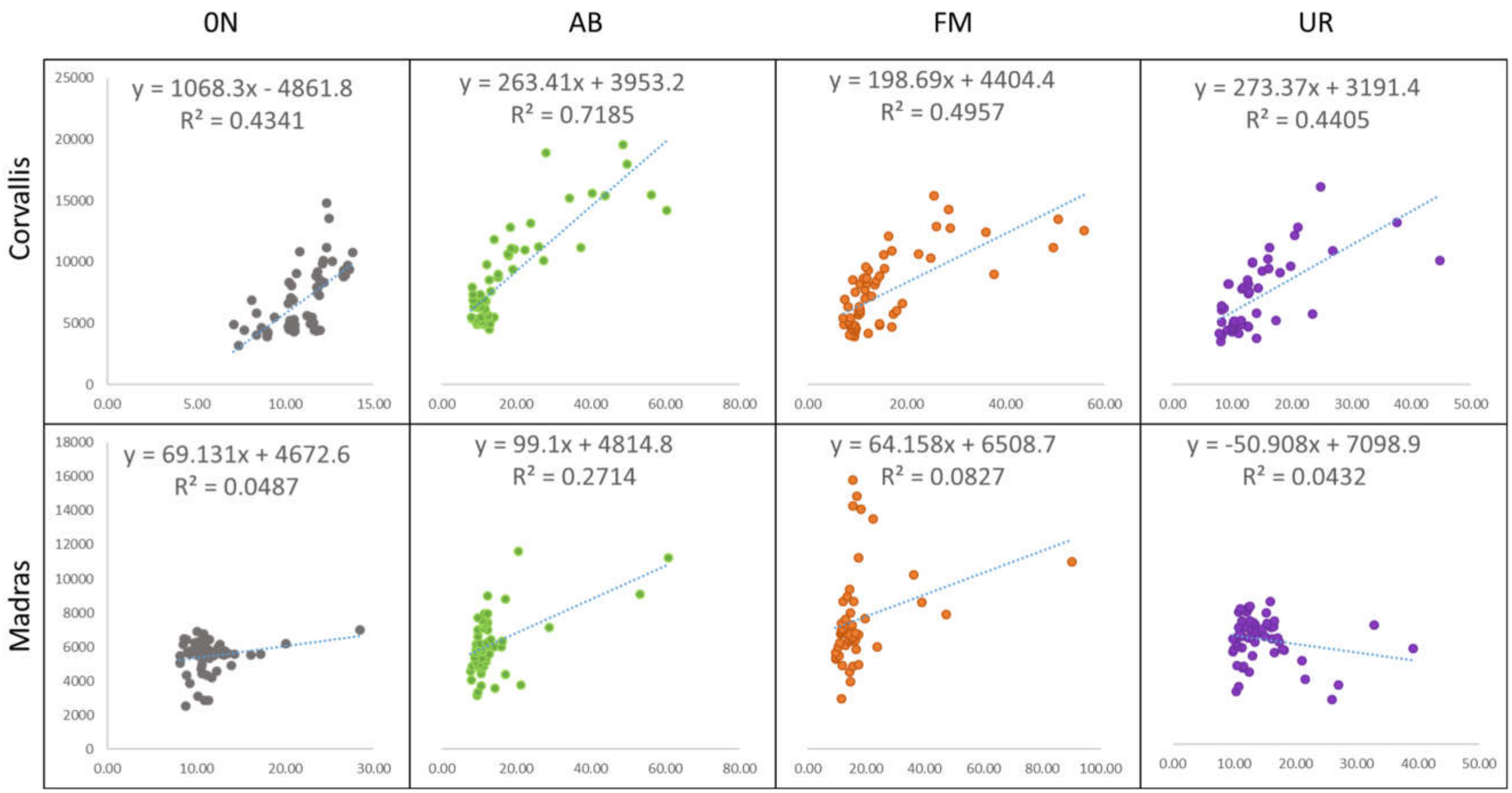


Figure 3-8 Correlation between daily N_2O-N and CO_2-C emissions in Potato Plots

ON, AB, FM, and UR are the control, algal biomass, feather meal, and urea, respectively. All daily values from potato plots with a quantifiable flux measurements for both CO_2-C and N_2O-N are represented by individual dot. Results have been separated by site, with treatment correlations for each fertilizer in Corvallis on the top row, and individual treatments from Madras on the bottom. The Y axis is CO_2-C in g ha^{-1}. All Corvallis treatments are on the same scale, all Madras treatments are on the same scale. The X axis is N_2O in mg ha^{-1}.

Discussion

Carbon Dioxide Lessons from the Field

Models describing the loss of SOC assume the predominate form of soil C loss is through respiration of CO_2-C (Amundson, 2001). The CO_2-C field-trial measurements provide evidence that soil fertilized with FM may cause higher emissions of CO_2-C than soil fertilized with AB or UR and that each of these fertilizers cause higher CO_2-C production than 0N. There was a high degree of variability and the data were not normally distributed, resulting in limited power to distinguish differences at the individual treatment level. However, because twice as much AB is needed to apply the same amount of N as in FM, AB results in less CO_2-C production per applied unit of C.

This research demonstrates that when fertilizing with UR, more CO_2-C was lost from the system than total C added from fertilizer. Considering the contribution of CO_2-C loss due to fertilizer addition, the UR soils respired 17% more C than that respired by 0N soil. Although these differences will only marginally impact the total percent of SOC in one year, the overall C balance of annual applications will change SOC over time. In field trials Adedeji (1986) and Ding et al., (2007) measured an increased rate of SOC mineralization as a result of mineral N fertilization. These data do not support their assertion, rather UR fertilization is likely to add to the year-over-year C losses associated with cultivation (Mann, 1986) and largely attributed to tillage practices (Dolan et al., 2006). This is in agreement with results interpreted by Khan et al. (2007) in long-term experiments in the Morrow plots, that synthetic N fertilization exacerbates soil C loss.

However, other studies have found no change in SOC (Singh, 2018a) and there are those that have found N fertilization to increase the SOC pool (Christopher and Lal, 2007; Jung, 2010); though these increases are attributed to increased biomass production that was left in the field.

Carbon Dioxide Lessons from the Laboratory Incubation

Laboratory CO_2-C respiration data provided clear treatment differences that generally matched field-trial respiration trends, (FM>AB>UR>0N). Given that AB adds the most C to the soil to achieve an equivalent N application rate, laboratory data supports the supposition from the field trial that of the fertilizers used, AB is likely to return the most C to the soil. Over this short-term incubation the total amount of C respired was 31% of that added, however, 0N soils respired between 40-60% of what the AB treatments respired. When respiration from 0N is subtracted, 12-16% of the total C added in the form of AB fertilization was respired, depending on the soil used. Similarly, 34% and 84% of the C from fertilizer was respired from FM and UR, respectively. In a year-long incubation, Rothlisberger-Lewis et al. (2016) used an algal material that had been extracted for lipids and found roughly 45% of the C added was mineralized and it increased SOC by 0.2% and 0.3% when applied at 1.5% and 3% of soil on a dry weight basis, respectively.

A difference was found between the two AB products used. These subsamples came from two different batches of AB shipped from the same company with the same manufacturing process, but each batch and each subsample per batch varied in particle size, total C and N, and moisture (Cappellazzi, 2018 Chapter 4). Individual samples used for this incubation were analyzed for total C and N, and moisture prior to incubation and the application rate was calculated to deliver the same amount of N in each treatment. This caused a slight difference in the total C added from these two batches, 1.13 and 1.2 mg C g^{-1} dry soil for AB2 and AB3, respectively, so a small difference in respired C would be expected. However, there was no difference in utilization of the two AB subsamples in the MD soil. AB2 had lower CO_2-C respiration than AB3 in CL and KF, but the mineralization rate was the same at every time point in MD. Incubation soil samples from CL and KF had lower soil C than soil samples from MD. They also had a higher relative portion of sand-sized particles, and lower aggregate stability. These factors could have contributed to variable rates of C utilization between soils from these AB batches.

The majority of the respired C, from fertilizer C added, occurred during the first week of the trial. After one week, organic fertilizers had mineralized 79-96% of the total CO_2-C mineralized over the course of the experiment. After the first week, UR treatments in CL and MD soils mineralized less C per day than the 0N, thus when subtracting CO_2-C respired from the 0N, UR treatments had mineralized 94-108% of the total C mineralized by day 7. Because the major efflux comes from the first several days after fertilization I did not extrapolate results from a 22-day trial to a full year. The fertilized plots demonstrated a steep increase in CO_2-C production in the days immediately following fertilization and then a rate more similar to the 0N plots thereafter. Relating the laboratory data to the CL potato field trial the data demonstrates similar patterns with a spike in CO_2-C directly following fertilization followed by an emission rate similar to the control. In contrast, the MD potato trial seemed to have a relatively steady rate of CO_2-C production throughout the season for FM fertilized plots, which demonstrated an immediate increase in CO_2-C after the first fertilization event. In the MD potato plots fertilized with AB there was a small change in slope immediately following the second fertilization event, but then leveled off again.

Nitrous Oxide as a Means of Assessing N Balance

The terrestrial N cycle is microbially mediated with many alternative routes, end-products, and dependent clauses based on edaphic, organic, and climactic conditions (Dalal et al., 2003). In the 2012 review of NO and N_2O turnover, Schreiber states that "biological N_2O formation is highly dynamic in response to N imbalances imposed on a system." Similarly, (Firestone and Davidson, 1989) explain that the highest rates of N_2O emissions are likely to occur where N availability to microorganisms exceeds carbon availability. The result of lower N_2O production in AB than FM and UR might be evidence that AB fertilizers cause less of a C and N imbalance on the system. This could be a result of the C:N ratio of this fertilizer being nearly the same as the generalized C:N of the bacterial community, 6:1, and N mineralization timing more closely matching the N demands of the crop (Cappellazzi, 2018 Chapter 1).

The cumulative production estimations from each site-by-crop plot may not have had enough temporal repetitions to depict the N dynamics throughout the growing season. Integration through time without equal time between measurements means that an individual date with a high measurement is multiplied by more days than others with a shorter interval between measurements, which can dramatically increase the overall production curve. In addition, in each of these systems, measurement dates were missed directly after fertilization. The high yield of corn from the 0N plots in CL (Cappellazzi, 2018 Chapter 2) indicates all fertilizers were applied at rates exceeding crop nutrient requirements. Considering evidence for increased N_2O under N imbalance, it would appear that only FM mineralized more N than was needed. However, in the laboratory incubation, three days after adding the fertilizers, 80% of N applied as urea was in plant available form (NO_3^--N + NH_4^+-N) indicating, I may have missed the initial peak in N_2O production from UR-fertilized plots (Dalal et al., 2003). This was also the only field site where AB fertilizer application did not result in similar yields as FM and UR in the agronomic trial (Cappellazzi, 2018 Chapter 2). Carbon and N mineralization was not assessed in the laboratory incubation using soil where corn was grown in CL. It is unclear why mineralization was suppressed in this soil, but that would be reflective of low yield, CO_2-C, and N_2O-N production.

The general, N_2O EF measured in this study, 0.01-0.43%, were on the low end of the range typical of a fertilizer application, which fall between 0.01-9.9% of N applied in cereal crops (Dalal et al., 2003), and well below the likely EF of fertilizer applications calculated from the top down model used by Davidson (2009) of 1.6-2.7%. This is likely due to conservative application rates, banding, and immediate incorporation. Many emission factors have been used to scale up global N_2O emissions, ranging from a 1% global estimate by the IPCC to a 1.8% estimate for the US north-central region (Shcherbak et al., 2014). These estimates have used the N fertilization rate in a linear relationship to estimate N_2O production, but Shcherbak et al. (2014) argue this relationship is non-linear, with emission rates increasing faster as fertilizer application rate increased. Broucek (2017) also reported that N_2O increased faster than increased rates of NO_3^--N measurements in soil samples. These results lend credence to the importance of optimizing the rate and timing of N application for decreased environmental loss from the system.

Microbial respiration can be used to predict total N mineralization, with organically fertilized soils R^2=0.78 (Delin et al., 2012) and reasonably well in native soils R^2=0.41 (Franzluebbers et al., 2000), but the same was not found for N_2O-N production. Because of the multiple microbially mediated steps in the N cycle (mineralization, nitrification, and denitrification) that can results in N_2O production during the breakdown of OM to plant available nitrogen that total microbial activity would be well correlated with N_2O production from the organic fertilizers. While CO_2-C and N_2O-N were well correlated in CL AB treatments, this was more of the exception than the rule. In MD, the two measurements seemed uncoupled. This could be due to the highly skewed nature of the data in which most N_2O flux rates hovered around a small range with a few high flux rates dictating the regression. The difference in the emission behavior between the sites could be reflective of sampling date distribution or that aggregate structure, N balance, and climate are more critical to the production of N_2O than total microbial activity (Firestone and Davidson, 1989).

Comparison to Manures

The amount of CO_2-C lost per unit of C added from AB in this trial is similar to estimates of C lost from either liquid slurry applications or solid manures, where roughly 50% C applied is respired as CO_2-C in the first year (Ding et al., 2007; FAO et al., 2010). Literature reports for manure C-losses are highly variable and depend on application method, pretreatment, edaphic, and climactic conditions. Even if the rate of C storage per unit of C added is the same, it doesn't mean the total C addition is the same. Manures have 1-4% N and are often applied at rates near 10 Mg of dry matter per hectare to meet crop N needs. Even if 75% of applied C is lost, that would result in 1250 kg C added ha^{-1}. I estimate that applying the agronomic rate of AB, near 2 Mg ha^{-1}, would result in C additions of about 400 kg C ha^{-1}. It would take many more years to build the same SOM content. However, in contrast to manure, AB is valuable enough to leave the farm (Pizarro et al., 2006) so soils that are below a critical SOC content might start to receive this biomass and restore vital function. It should be noted that the C in the AB is largely the result of CO_2 fixation during the effluent nutrient-capture process, thereby directly drawing down CO_2-C in the atmosphere.

The EF for N_2O-N in this study was lower than the EF used in IPCC estimates of 1-1.25% of N applied. The IPCC values take into account the global range of fertilizer types, practices, and application rates. The range of values in this study are considerably lower than measurements of manured systems, where EF values lie within 2-16% of N applied (Cambareri et al., 2017; Myrold, 1992; Mogge et al., 1999). Major emission differences are based on application rate, C substrate availability, pH, and moisture (Mosier et al., 1998; Shcherbak et al., 2014). When fertilizer is added in excess of plant uptake demands, the system gets 'leakier' and there is an increased risk for the loss of NO_3^--N and N_2O. While extension publications are careful to discuss potential environmental losses, (Downing et al., 2007; Sullivan, 2008b) manure is often applied when plants don't need it so that it can build up PAN (Petersen et al., 2007; Yang et al., 2011). Fields manured in the spring have demonstrated N_2O production spikes April-June, before corn starts its period of rapid N uptake (Cambareri et al., 2017; Mogge et al., 1999). In the agronomic trial associated with this project (Cappellazzi, 2018 Chapter 2) AB resulted in N mineralization timing closely aligned with corn N requirements, post-harvest NO_3^--N levels that were not different than 0N soils, and yield that was equivalent to the other fertilizers. This, in conjunction with lower N_2O production rates, indicate AB would result in less loss of N to the environment after land application than manure.

Although outside the scope of this trial, the major difference between a dairy under business-as-usual conditions and one that has integrated algae and an anaerobic digester, is related to management prior to land application of the fertilizer. It has been shown that lagoon storage of dairy slurry results in emissions of an average of 103 g CH_4-C m^{-1} d^{-1}, 637 g CO_2-C m^{-1} d^{-1} (Leytem et al., 2011). Composting of the solids typically results in roughly 50% of total biomass to be lost, primarily as CO_2, but also 5% as CH_4 from anaerobic pockets invariably created during active composting (Hao et al., 2004). Conversely, an integrated algae-dairy system with an anaerobic digester removes the lagoon storage and composting processes. Instead this system provides the opportunity to recover CH_4 and CO_2 gasses during anaerobic digestion (Wang et al., 2010) and capture atmospheric CO_2 during algae production (Benemann and Oswald, 1996b). The energy produced by the anaerobic digester is estimated to be more than enough to operate the equipment required for the algae capture system (Sturm and Lamer, 2011; Zhang et al., 2013). These benefits tip the balance of C capture strongly in favor of using algal biomass. Similar to the C story, N is also lost prior to manure application. Storage of liquid manure in lagoons is estimated to result in 12% of N to be lost through NO_3^--N leaching (FAO et al., 2010), and the IPCC estimates that 40% of N is lost as NH_3. (IPCC, 2006). Producing a compost from the separated solids has also been demonstrated to lose anywhere from 20-40% of the total N through volatilization (Eghball et al., 2002).

Generally, there is a lot of room for improvement in dairy manure management. The typical Holstein dairy cow excretes roughly 62 kg a day of feces, of which 88% is water. Of the 12% that is dry matter 4.6% (on dry matter basis) is in some form of N at the time of excretion (Van Horn et al., 1994). On a typical 1000 cow dairy, that creates roughly 340 kg of N day^{-1} or roughly 120,000 kg N yr^{-1}. Even estimating that 50% of excreted N is captured for reuse, that leaves roughly 60,000 kg N yr^{-1} lost. To put it in economic terms, I calculated the value of lost N based off the cost of urea fertilizer, around \$500 Mg^{-1}, and calculated that a well-managed, 1000 cow dairy, will lose roughly \$75,000 worth of N per year using conventional fertilizer pricing, or \$530,000 worth of organic N fertilizer.

This says nothing of the environmental costs and benefits of each production practice. Unfortunately, our current economic system does not include positive or negative environmental externalities in the cost of food production. In 1936, in a work on humus, the contemporary term for SOM, Waksman wrote:

> *"The importance of humus in human economy seldom receives sufficient emphasis. Suffice to say that it probably represents the most important source of human wealth on this planet. Nature has stored in and upon the earth, in the form of humus, the source of a vast amount of readily available energy, a large part of the carbon needed for life processes, and most of the combined nitrogen, so much needed for plant growth."*

As scientist's understanding of this vast source of natural capital has evolved, numerous economists have created frameworks and models for the quantification of soil ecosystem services. There are numerous groups who are now trying to work with producers to provide some kind of a carbon farming system, including the Regen Network, Cool Farm Alliance, and the Carbon Cycle Institute, and some progressive governments. I hope this work will help inform economists on direct and indirect costs of adopting an integrated dairy-anaerobic digester-algae manure management system.

Conclusions

The application of algal biomass (AB) caused an increased CO_2-C production above the control and urea treatments, but less than feather meal (FM) in a laboratory incubation in each of three different soils. The field trial data provided variably-significant results but respiration from AB was generally similar to urea (UR) and lower than FM plots. The cumulative CO_2-C loss from AB treated plots was near 50% of C added to the soil. This makes it likely that fertilization with AB would add to SOC stocks through repeated applications at agronomically recommended levels.

The production of N_2O was higher from FM and UR fertilized plots than from AB. Comparisons with the parallel agronomic trial indicate this is the result of better timing between plant uptake and N mineralization when fertilizing with AB than with FM or UR. The N_2O burst measured in various plots from each fertilizer was recorded for several days after fertilization, but did not last through the entire period of expected N mineralization. AB fertilization resulted in a lower emission factor than the current estimates used by IPCC.

Management practices that reduce nutrient loss and return C to the soil provide great promise in relation to global warming abatement, but also to enhance a wide range of soil functions and ecosystem services. Considering the shift in C balance related to using AB as a fertilizer source, these data demonstrate a great opportunity to capture, use, and store C. The “4 per 1000” call on nations to increase the C content in the top 40 cm of their soils by 0.4% per year, is a lofty goal. The use of AB as a fertilizer moves us closer to this target while simultaneously tightening the N cycle in dairy manure management and increasing soil carbon vital to a soil health.

Chapter 4 Characterization of Algal Biomass used as Fertilizer

Abstract

Algae cultivation is an effective means of capturing wastewater nutrients from a variety of sources. In particular, nitrogen and phosphorus losses from the dairy industry could be largely mitigated with better manure management strategies, including anaerobic digesters with algal integration. The resulting algal biomass has great potential for use as a fertilizer. The specific growing conditions and downstream processing impact the total nutrient and lipid content of the material. These variations affect the rate of carbon and nitrogen mineralization by the soil microbial community. Even with algal biomass products containing the same carbon to nitrogen ratio, differences in mineralization rate were measured leading to an investigation of how edaphic and climatic conditions interact with the characteristics of the algal biomass to influence the functional value. Here, I discuss the factors that influence variation in algal biomass and how they impact the utilization of this product as a fertilizer.

Introduction

Many high nitrogen (N) organic fertilizers are by-products of other agricultural processes and are sold as bulk commodities based on their total N content. In 2012, the National Academy of Sciences Committee on Development of Algal Biofuels stated:

> "R&D is needed to incorporate nutrient recycling into algal biofuel production systems. The potential for combining the use of wastewater in algae cultivation and the production of a fertilizer co-product is worth further investigation."

Wastewater-produced algal biofuel provides an opportunity for a new fertilizer co-product to be developed for use on the ever-increasing land needed for organic agriculture. The high degree of variability of wastewater feedstocks used as the growing media, the number of different production practices being implemented, and environmental factors that influence the final algal biomass (AB) necessitates the characterization of the resulting biomass prior to use as a fertilizer.

Algae have successfully demonstrated nutrient removal from dairy and piggery waste (Kebede-Westhead et al., 2006; Zhu et al., 2013), and food and aquaculture processing facilities (Gupta et al., 2016; Rodrigues and Oliveira, 1987; Wuang et al., 2016). In addition, many types of wastewater treatment facilities have already integrated algae into their production systems to capture nutrients (Benemann et al., 2016; Woertz et al., 2009). Integrated algae-dairy models have been designed in order to overcome nutrient and greenhouse gas (GHG) management issues faced by industrial animal agriculture and in so doing, overcome a primary production barrier for algal biodiesel production, nutrient costs (Craggs et al., 2004; Lincoln et al., 1996; Wilkie and Mulbry, 2002; Woertz et al., 2009; Zhang et al., 2013). Extensive work at the USDA labs in Beltsville, MD has shown that algae grown on dairy effluent can recover 70-97% of nitrogen (N) and 50-99% of phosphorus (P) nutrient inputs (Kebede-Westhead et al., 2004; Mulbry et al., 2008b). More industrial and agricultural operations seem poised to take on the integration of algae into wastewater nutrient capture and many startups are still trying to produce a viable biodiesel.

The high concentration of protein, 18-45%, in AB has led to the interest in this product as an organic N fertilizer. Nitrogen mineralization in soil, the process by which organically bound N becomes plant available, is largely driven by the enzymatic depolymerization of organic matter with enzymes excreted by microorganisms (Schimel and Bennett, 2004). Trials by Sullivan et al. (2008a), Gale et al. (2006), and Delin et al, (2012) all show that in general, the amount of N mineralized can be well predicted by the C:N ratio of the organic material. Those authors do not claim that C:N is the only factor or that exceptions do not exist under certain conditions, but C:N is regularly used in agronomic applications to estimate the potential for N mineralization of organic amendments and fertilizers. Testing several AB products with similar C:N ratios, I found considerably different mineralization rates leading us to further question the mechanisms of control.

The stoichiometry of marine phytoplankton is generally around $C_{106}H_{175}O_{42}N_{16}P$ (Anderson, 1995), but in controlled environments the nutrient concentration varies as a function of the type and concentration of growing media used, phylogenetic groups, pH, temperature, and light conditions (Garcia et al., 2018; Geider and La Roche, 2002). Other agricultural by-products, such as feather meal (FM) and blood meal have far less variability and so have a simple market valuation based on their price per unit of N. Although one could estimate fertilizer value by quantifying the total macronutrients in AB, several unique characteristics of algae production may influence the timing and quantity of nutrient availability. Algae are often grown to produce biofuels, imparting a high lipid content (Li et al., 2014; Ramasamy Sakthivel, 2011). Algal biomass can also be pyrolyzed to capture biogas (Biddy et al., 2013; Vargas e Silva and Monteggia, 2015) or grown to remove hazardous contaminants (Munoz et al., 2006; Munoz and Guieysse, 2006). Rothlisberger-Lewis et al., (2016) found that algal biomass with a high portion of algaenan was more resistant to decomposition supposing that the high concentration of O-alkyl functional groups decreased the rate of decomposition. Each of these conditions could have an influence on the rate by which this biomass is utilized by the soil microbial community. The variability of AB may allow for specialized fertilizer development but also highlights the need for individual product testing until a model is created that successfully predicts the nutrient utilization and storage through laboratory characterization.

Waksman, (1936) in his treatise on humus (what we would call organic matter (OM) today), related the understanding of Pasteur, that decomposition of OM by microorganisms was a function of the organisms involved and the environmental conditions, noting that decomposition is incomplete in the absence of oxygen. He went on to describe the chemical nature of humus and called for a more detailed chemical analysis to understand its formation and utilization. In the decades since, soil scientists have focused on the chemical nature and moved toward the view that C storage is a function of the “recalcitrance” of the organic matter. This term has been variously-defined and overused to describe the “quality” of C and propensity toward stability of C in the soil (Kleber, 2010). Definitions range from the amount of lignin (Aber et al., 1989), to the time it has remained in the soil (Stott and Martin, 1990), to the number of enzymatic steps required for degradation (Bosatta and Agren, 1999). This view of C quality has led to anomalies of “high quality” materials being found in very old SOM (Kleber et al., 2011) and “recalcitrant” materials readily decomposing under specific conditions (Marschner et al., 2008).

The paradigm now emerging is that the nominal oxidation state of carbon (NOSC) is related to the Gibbs free energies of half-reactions describing complete mineralization (LaRowe and Van Cappellen, 2011). The bioenergetic potential can then be estimated by macronutrient ratios including C, H, N, O, P, and S (LaRowe and Van Cappellen, 2011) of a specific compound depending on the terminal electron acceptors available (Keiluweit et al., 2017). This framing allows for variations in both the molecular structure of the organic matter, and multiple edaphic characteristics to be taken into account when estimating C and N mineralization dynamics. I will explore the implications of this new conceptual approach in relation to interactions found between the organic fertilizers and soil types in various field and laboratory trials I conducted while working to quantify the agronomic and environmental impact of using algal biomass as a fertilizer. Application of this new paradigm may help crop advisers and producers make decisions related to how organic amendments and fertilizers might behave under their site-specific conditions.

In my field trials and laboratory incubations to assess the fertilizer value of AB, the agronomic and GHG measurements varied by site, with some metrics higher, others lower, and some similar to FM or urea (UR). This variation led to the following hypotheses: (1) AB of larger particle size will mineralize at a slower rate because there is not as much surface area for microbial access. (2) AB that is dried under high-heat conditions will mineralize at a slower rate, even if the C:N ratio of the AB. (3) Edaphic characteristics of texture and aggregate stability influence the mineralization rate of the different batches of AB.

Materials and Methods

General Field Trial Description

A field trial to assess the agronomic value of using AB as a fertilizer was established at three geographically dispersed Oregon State University (OSU) research stations. The experiment was described in detail in Chapter 2 (Cappellazzi, 2018). Briefly, at each location there were two crops, corn and potatoes. Urea (UR), feather meal (FM), and a control with no N fertilizer (0N) were used to compare the performance of AB. In each plot there were four blocks and in each block there were three rates of each fertilizer plus one control. Petiole samples were taken to assess in-season N uptake dynamics from the potato plants. In each plot, soil NO_3^--N was measured at five times through the season to monitor soil N mineralization dynamics. In each of the plots with the highest rate of fertilizer, static chambers were kept in place through the season to take repetitive measurements of CO_2-C and N_2O-N in the field. Details are reported in Chapter 3 (Cappellazzi, 2018). Yield and quality were assessed for each crop at the end of the growing season.

Field Trial Site Differences

The three field sites were selected with the understanding that OM decomposition dynamics are dependent on soil and climactic conditions. Each of these soils has been managed for agricultural research for several decades. For this reason, they all have a history of various additions of fertilizers and pesticides throughout the years. Preliminary sampling was performed using grid sampling of each plot, with five subsamples per cell, and 16 cells per plot. Variations in pH and moisture were measured and used to determine appropriate blocking patterns in MD. Grid samples were mixed and submitted to Brookside Laboratory (New Bremen, OH) for complete analysis. Water stable aggregates were measured at OSU Central Analytical Laboratory using the Cornell Sprinkle Infiltrometer method (Moebius-Clune et al., 2016). Briefly, air dried soil was placed on a sieve and a hanging rain-simulator dispersed 1.25 cm of water over 5 minutes. Mass difference was used to calculate the aggregates remaining on the sieve.

The soil type in Corvallis (CL), OR at the OSU Vegetable Research farm is mapped as a Chehalis soil series, a fine-silty, mixed, mesic cumulic Ultic Haploxeroll. This deep soil has formed in a flood plain with repeated deposits of sand and silt (Image 1) during the end of the last glaciation as a result of the Missoula Floods. Although both sites are mapped as Chehalis, there was a substantial difference in the soil between the sites for the corn and potato plots. The corn plot was also closer to the Willamette River and at a slightly lower elevation. Generations of deposits in this depression resulted in higher clay content. The site for the corn plots had a history of cover crops between each summer growing season. The higher clay and history of cover crops likely both contribute to total soil organic carbon (SOC) that is almost two times higher in the top 15 cm than in same depth increment of the potato plots, Table 4-1.

Image 1. Willamette Soil Series at OSU Vegetable Farm. Soil pit dug at OSU Organic Growers Club at the Vegetable Research Farm in Corvallis. Drying patterns make some rhythmites of sand and silt easy to distinguish in this deep, well-drained Haploxeroll.

Image 2. Madras Soil Series at the Central Oregon Agricultural Research Center. Two pits in what was the corn plot from this trial. Image on the left was a pit, 70 cm deep with evidence of a buried A horizon. The pit on the right was dug roughly 30 meters away and was 35 cm deep with considerably more rock in the last 5 cm.

The soil type in Madras (MD), OR at the Central Oregon Agricultural Research Center is mapped as a Madras soil series, a fine-loamy, mixed, mesic Aridic Agrixeroll. Here, a shallow soil formed on upland terraces from windblown deposits above volcanoclastic sediments from the Deschutes Formation. Many mound and depression formations are seen in the natural landscape of this area. According to local producers, when the irrigation district was established, this area became useful for cropping systems and the land was leveled. This caused the natural A horizons to be removed from some areas and deposited into the depressions causing the Bt horizon to be exposed, becoming an A horizon. I expect this is responsible for the high degree of variation in the clay content of the surface soil as well as variation in depth to bedrock. When working these fields after a heavy rain or irrigation event the differences in clay behavior were visible. Areas with highly smectitic clay spots appeared to have rapid infiltration, and were very sticky. When taking the post-harvest subsamples, it became clear that there was a hummocky pattern to the depth to bedrock which varied from 30 cm to 70 cm depth within each of the MD plots. The blocking was effective to capture some, but not all, of the variation.

The soil type in Klamath Falls (KF) at the Klamath Basin Research and Extension Center for the potato plots is mapped as a Fordney soil series, a mixed, mesic Torripsammentic Haploxeroll, whereas the soil at the corn plots is mapped as Poe soil series, a sandy, mixed, mesic Typic Durochrept. Soils at this station are deep, alluvial-lacustrine sediments weathered from tuff, basalt, diatomite, and ash. Though these two sites are in different map units, the diagnostic characteristics were largely in the subsoil. The Poe series has two horizons designated as Cqm below 76 cm, indicating cemented silica layers, whereas the Fordney series does not have such horizons. These differences would impact the water and nutrient movement and root space available to a crop. However, when the potato field was trenched for new irrigation pipe, there was also an apparent cemented silica layer in the soil mapped as Fordney. In the surface layer, these soils were very similar and marked differences in properties were not observed in the field or in the field trial results.

Image 3. Potato site at Klamath Basin Research and Extension Center. This trench, dug across the potato site, is in map unit 19A with 72% Fordney Series. Soil demonstrated a strongly-cemented silica layer not described in the Fordney series description. Potatoes are shallow rooted and likely would not have been influenced by this horizon.

Table 4-1 Soil Characteristics by Site and Crop

Location	Crop	C	N	Sand	Silt	Clay	Aggregate Stability	P*	K**	Ca**	pH
		%						$mg\ kg^{-1}$			
Corvallis	Corn	1.25	0.13	52	22	26	30	254	191	2532	6.3
Corvallis	Potato	0.71	0.08	53	30	18	20	245	268	1845	6.3
Klamath Falls	Corn	0.50	0.05	81	11	8	16	97	372	1364	6.6
Klamath Falls	Potato	0.60	0.07	79	14	7	18	113	442	1274	5.8
Madras	Corn	1.16	0.13	43	37	20	37	98	436	1941	6.6
Madras	Potato	1.02	0.12	43	36	21	40	94	461	1985	6.1

* Available orthophosphate as quantified by Bray II extraction procedure using a colorimetric spectrophotometer

** Available nutrients extracted by the Mehlich III procedure quantified on ICP-OES

Analysis performed by Brookside Laboratory, New Bremen, OH

Aggregate Stability performed using Cornell Sprinkle Infiltrometer with simulated hard rain for 5 minutes at Oregon State University Central Analytical Laboratory

Algal Biomass in this Trial

The AB used for this trial is composed of a consortium of algal species grown as part of a process designed to capture nutrients from a wastewater system using anaerobic digestion as a pre-treatment. Algae were grown on liquid effluent from this process and dried prior to shipment. Though it has not been registered organic, the steps described in the manufacturing process would not preclude the AB from organic registration, were the company to pursue this market.

Three separate shipments of algal biomass were received during the course of the field trial. Most of the first shipment looked nearly black and had many large pieces of algal biomass (AB1). There was a delay in subsequent shipments as the company worked to install a new drying machine, which dried the algae at a substantially lower temperature to reduce what they described as “burning of the material”. The next two deliveries (AB2 and AB3, respectively) arrived with condensation apparent on the top of the plastic tote and a substantial amount of fungal growth throughout the top 20 cm of material. Care was taken to remove as much of the fungal infested algal biomass as possible prior to bagging treatments used in the field trial. Samples of each delivery were saved, and analyzed for moisture, nutrients, and particle size distribution.

Algal biomass characterization was performed at OSU Central Analytical Laboratory. Moisture of the AB was calculated gravimetrically after drying at 80^{o}C for 24 hours. Total C, N, and S were determined through dry combustion using an Elementar Vario MACRO cube ® (Elementar Langenselbold, Germany). Extractable ammonium

(NH_4^+-N) was quantified using a Lachat FIA (Hach, Loveland, CO) after standard extraction with 2M KCl. All other extractable nutrients were estimated using the Mehlich 3 soil extraction procedure, followed by elemental quantification with an Agilent 5100 inductively coupled plasma optimal emission spectrometer (Agilent 5100 ICP-OES, Santa Clara, CA) (Mehlich, 1983). Total nutrients were determined by microwave digestion with nitric acid in a Multiwave Go (Anton Paar GmbH, Graz, Austria) followed by nutrient concentration determination with the same Agilent ICP-OES. Total ash content was calculated from the mass loss difference after OM combustion with a muffle furnace (Gavlak et al., 2005). Particle size distribution was calculated using a 100 g subsample placed on top of a sieve stack shaker. After 2 minutes of shaking, the sieves were removed and the mass of each size fraction was measured.

Particle Size-by-Batch Laboratory Incubation

I set up a laboratory incubation to test the C and N mineralization dynamics of the first two batches of AB products, because of the striking visual differences. Two size fractions were used for each product, 0-0.5 mm was considered the fine fraction, and 2-5 mm was considered the coarse fraction. The AB products had a similar total N content, but differed in manufacturing process. The AB from batch 1 (AB1) looked charred and was dried in the high-heat drum drier oven; batch 2 (AB2) had been dried in the low-heat tumble drier. There was also a control with no fertilizer product added (0N).

Sandy soil from the KF potato field trial was used for this laboratory incubation because it was comparable to soil used in a similar trial by Delin (2012) and the low clay content would minimize sorption to and physical protection of the AB products. Prior to trial set-up, soil was removed from the refrigerator, sieved to 2 mm, and allowed to adjust to temperature for 3 days. The bulk density and current moisture status were used to calculate the additional water needed to reach an optimal microbial cycling rate at 60% water-filled pore space. Each amendment was applied at the same rate, 111 µg N g^{-1} dry soil, the equivalent of 100 kg N ha^{-1}. For the fine fraction, each AB was mixed thoroughly with the soil sample, the mixture was added incrementally to the 50 mL centrifuge tube (tube), using a tamping device to achieve a uniform bulk density (D_b) of 1.4 g cm^{-3}, which is the D_b measured in the field where this soil was sampled. For the coarse fraction, three pieces of each AB were selected to equal the total mass of AB needed per tube. While packing each tube, the three pieces were evenly spaced at three depths in the tube. After all of the tubes had been packed with soil and fertilizer, water was added to the top of each tube (Franzluebbers and Haney, 2018). A polyethylene film was secured over the jar with a canning-jar ring to minimize water loss while allowing for gas exchange. Jar incubations were measured for CO_2-C respiration with a Picarro G2102 Isotopic CO_2 Analyzer (Picarro Inc., Santa Clara, CA) and NH_4^+-N and NO_3^--N using a Lachat Flow Injection Analyzer (Hach Company, Loveland, CO) on 0, 3, 7, 14, 28, 49, and 77 days after extraction with 2M KCl solution in a 4:1 solution to soil ratio.

Fertilizer-by-Soil Laboratory Incubation

Two AB subsamples, AB2 and AB3 as well as FM, UR, and 0N, were applied to each of the three soils used in the field trial in a factorial design. Soil samples from each potato field control plot were used for the incubation, CL, MD, and KF. After sieving to 2 mm, and letting sit at room temperature for 3 days, samples from each soil were placed in a jar to measure baseline CO_2-C respiration and NO_3^--N. The incubation set-up followed the same procedure described above, though only one size fraction of each AB, 0.5-2.0 mm was used. Tubes for four destructive sampling dates were put into one, quart-sized canning jar with three jars of each treatment used as replicates. Lids were placed on the jars for two hours in order to measure CO_2-C respiration on days 0, 1, 2, 3, 4, 7, 15, and 22 using a Picarro Isotopic CO_2 Analyzer (Picarro Inc., Santa Clara, CA). Nitrate measurements were made using a Lachat FIA (Hach Company, Loveland, CO) by destructively sampling the tubes on day 0, 3, 7, 15, and 22, extracting the soil with 2M KCl solution in a 4:1 solution to soil ratio.

Statistics

The field trial experimental design was an augmented factorial block, with three fertilizers, three rates, and a control with no N fertilizer in each block. This design is unbalanced so a mixed model was used to account for both fixed (fertilizer and rate) and random (site and block) effects. Prior to analysis, outliers were removed using the results of a modified Thompson Tau Test. For analysis of the fertilizer, rate, block, and interactions, an analysis of covariance (ANCOVA) was performed with the Proc Mixed model in SAS v9.4 (SAS Institute, Cary, NC) with generalized least square means for fixed effects and restricted maximum likelihood estimation (RMLE) to estimate variance components. Laboratory incubations were a factorial design and analyzed by two-way ANOVA at each date. Tukey's honestly significant difference (HSD) post hoc tests were used to compare mean differences at $p<0.05$ level for all analyses.

Results

Characterization of Batches of Algal Biomass

Observations of the visual differences in AB products received, coupled with early measures of variation in performance from the field trial led to this analysis. Table 4-2 provides the visual appearance and total C, N, and S for both fine and coarse sized fractions of six subsamples of AB and FM. Subsamples five and seven were from AB2 and AB3 respectively. Each had a portion that was colonized by mold. The heavily-colonized material was discarded and not used in the field trial. However, there was still some mold on a portion of the remaining product. Samples four and six are representative of product that had some mold and were used in the field trial. Samples two and three are images of AB1 and look the most like char, with large, brittle, low D_b pieces. This material was applied to all potato trials at planting.

Table 4-2 Visual Appearance and Carbon, Nitrogen, and Sulfur Concentrations from Two Size Fractions

Subsample Number	Visual Appearance	Batch ID	Description	Size	C	N	S
					--------------	%	--------------
1		FM	Uniform	Uniform	52.6	14.3	1.9
2		AB 1	char chunks	fine	48.1	8.64	2.0
		AB 1	char chunks	coarse	48.8	8.82	1.9
3		AB 1	char chunks	fine	44.2	7.98	1.8
		AB 1	char chunks	coarse	49.0	8.97	1.5
4		AB 2	some mold	fine	46.2	7.88	1.9
		AB 2	some mold	coarse	44.2	7.58	1.9
5		AB 2	very moldy	fine	47.0	8.36	1.8
		AB 2	very moldy	coarse	47.7	8.29	2.0
6		AB 3	some mold	fine	43.1	7.55	1.4
		AB 3	some mold	coarse	46.4	7.45	1.4
7		AB 3	very moldy	fine	43.0	7.60	1.9
		AB 3	very moldy	coarse	43.5	7.84	1.9

Table 4-3 Algal Biomass Nutrient Content by Batch

		Total Nutrients									Extractable Nutrients					
ID	Description	θ	C	N	P	K	S	Ca	Mg	Fe	NH_4-N	P	K	Ca	Mg	Fe
		%									mg kg^{-1}					
AB 1	char chunks	5.9	48.1	8.6	1.5	0.3	1.7	0.5	0.20	3.67	4.60	81	414	349	143	266
AB 1	char chunks	5.5	46.2	8.0	1.5	0.3	1.6	0.56	0.18	3.84	229	74	457	563	164	295
AB 2	some mold	9.0	46.2	7.9	1.4	0.4	1.6	0.48	0.20	3.26	1170	99	952	845	398	389
AB 2	very moldy	10.6	47.0	8.4	1.4	0.4	1.7	0.47	0.21	3.45	1410	88	833	879	235	321
AB 3	some mold	8.8	44.2	7.5	1.3	0.4	1.4	0.44	0.15	3.53	2810	167	816	664	235	664
AB 3	very moldy	25.6	43.0	7.6	1.5	0.5	2.0	0.55	0.25	3.82	6150	277	2550	2397	757	673
AB Average		10.9	45.8	8.0	1.4	0.4	1.7	0.5	0.2	3.6	1962	131	1004	950	322	435
AB StD		7.5	1.9	0.4	0.1	0.1	0.2	0.0	0.0	0.2	2282	79	788	735	231	186
AB CV		68.5	4.1	5.4	5.7	19.6	11.8	9.4	16.7	6.3	116	60	79	77	72	43

Batch-specific moisture, total nutrients, and extractable nutrients are provided in Table 4-3. The C:N ratio averaged 5.7 with a coefficient of variance (CV) of 2.3 and the N:P averaged 5.6 with a CV of 6.0. Total nutrient variability was relatively low; N ranged from 7.5-8.6%, P from 1.3-1.5%, K from 0.3-0.5%, S from 1.2-1.7%, Ca from 0.44-0.56%, Mg from 0.15-0.25%, Fe from 0.33-0.38%, and total ash from 11.2-12.8%. There was higher variation as a result of the extractable nutrient tests, Mehlich 3 and 2M KCl, with a trend toward lower availability for products with a charred appearance. Table 4-4 provides the particle size distribution measured for each batch, with considerably more large AB pieces in the first shipment.

Table 4-4 Particle Size Distribution of Three Batches of Algal Biomass

Batch	>8	2-8mm	0.5-2mm	<.05mm
	------------------------------	---------%---------	-----------	------------
AB1	22%	26%	35%	17%
AB2	11%	28%	40%	21%
AB3	7%	35%	41%	16%

Separated using sieves and a sieve shaker

Particle Size-by-Batch Incubation

In the particle size-by-batch incubation fine particles of each AB batch initiated a higher rate of C mineralization earlier than the coarse size fraction. By day seven of the incubation the CO_2-C production in treatments that received the coarse materials was greater than that of the fine particles on average for all AB products, by the end of the trial, on average the coarse size fraction had resulted in a higher cumulative CO_2-C production. There were significant differences in the both the C and N mineralization rate between the different AB batches. AB1 treated soils caused lower soil respiration rates than AB2 treated soils.

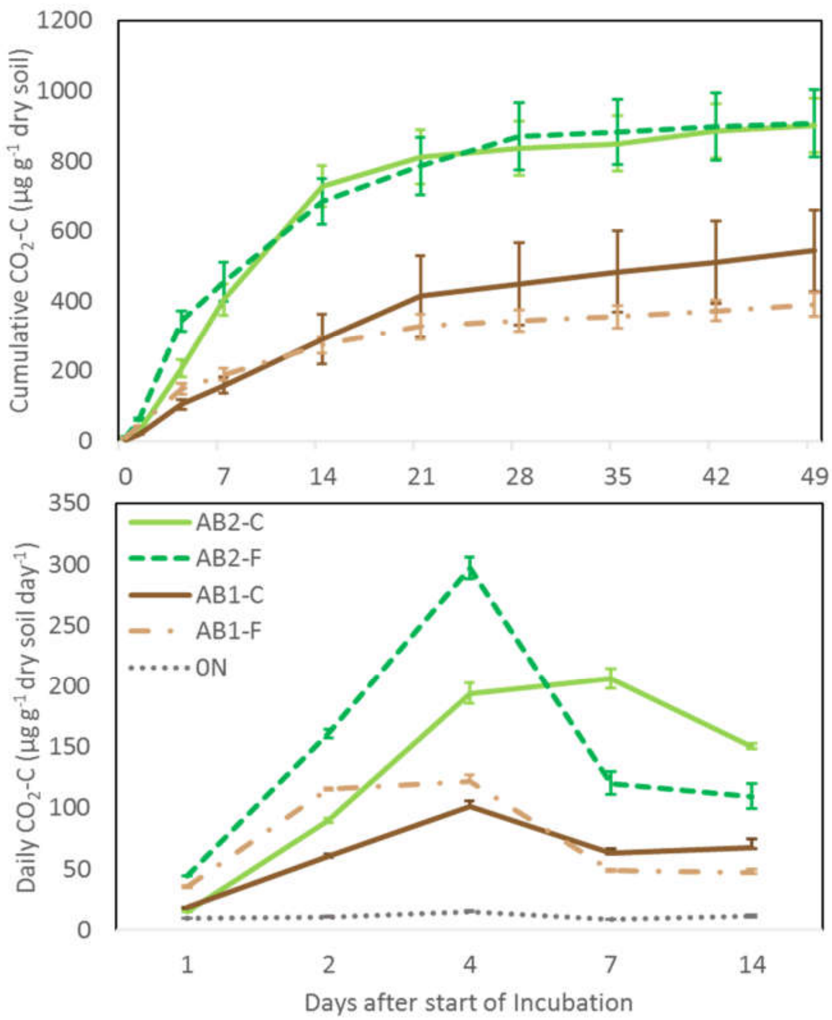


Figure 4-1 CO_2-C Respiration Particle Size-by-Batch Laboratory Incubation
N=3, AB1=first batch of algal biomass, AB2=second batch of algal biomass, C= coarse 2-5 mm particle size, F=fine 0-0.5 mm particle size, 0N=control with no fertilizer. Top panel shows the cumulative respiration over 7 weeks, panel B shows the daily flux for first two weeks of incubation.

The accumulation of NO_3^--N in the incubation tubes followed a pattern similar to treatment trends to the CO_2-C respiration but with more pronounced differences. The AB2 treated soils mineralized roughly three times more N than the soils treated with AB1. The fine textured AB2 material mineralized more N in the first week of the incubation than either size fraction of AB1 through the duration of the 6-week incubation. By the end of the second week and throughout the remainder of the incubation, there was no difference N mineralization between the fine and coarse size fractions in either AB treated soil.

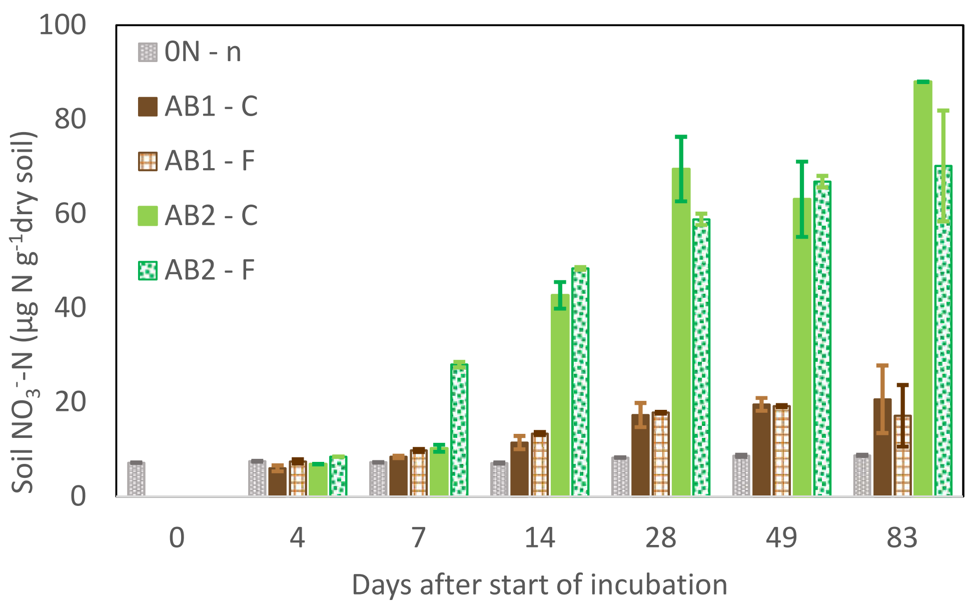


Figure 4-2 Soil Nitrate Size-by-Batch Laboratory Incubation
N=3, AB1 is first batch of algal biomass delivered, AB2 is second batch of algal biomass, C only in these figures represents coarse particle size, 2-5mm particle size, F represents fine particle size, 0-0.5mm particle size, 0N is the control with no fertilizer.

Petiole N Fertilizer-by-Site

I used the total N content in potato petioles in the field trial to compare N uptake dynamics among the fertilizers. Potatoes had a split application of fertilizer with the first half of the AB dose from AB1. The second half of the potato fertilizer was applied roughly 30 days after planting and was from a combination of AB2 and AB3. The first petiole measurement was 15 days after the second round of fertilization. There was a difference in petiole N uptake behavior by fertilizer treatment and by site. Figure 4-3 displays the total N taken in petioles from the CL and KF field sites at the low and recommended rates of fertilization. At the first measurement, the total petiole N in the AB treatments in CL was not different from the 0N. In KF the AB was higher than 0N, not different from the FM, and lower than UR at each rate. Two weeks later in CL at the second petiole measurement, the total N in the AB plots was still the same as the 0N while the FM was the same as the UR at each respective rate. In KF, both rates of each organic fertilizer were higher than 0N but lower than UR. One month later at the fourth petiole measurement, there was no difference in petiole N among low-rate treatments at either site. At the recommended rate at both sites the AB was the same as the 0N and the FM was the same as the UR. The third petiole N measurement in CL is not shown because it was not available from the KF site.

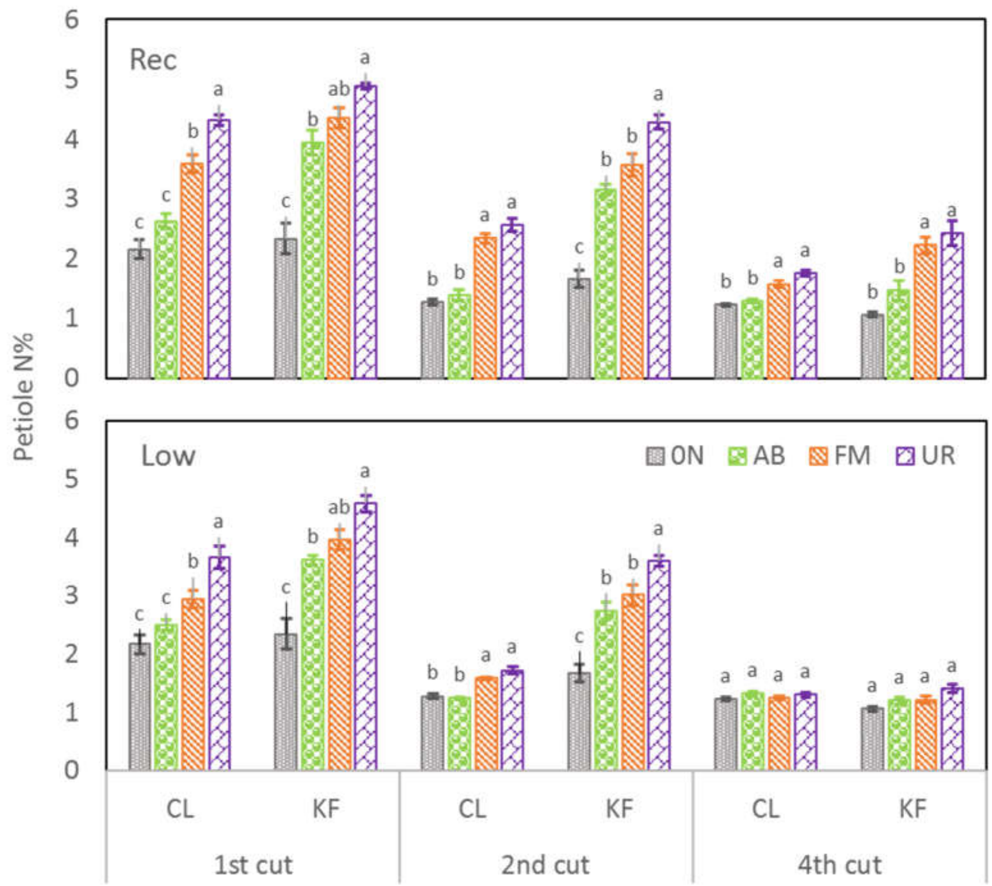


Figure 4-3 Petiole N Uptake - Differences by Site

AB=algal biomass, FM=feather meal, UR=urea, 0N=control, Low=50% of recommended rate of fertilization, Rec=100% of recommended rate of fertilization, CL=Corvallis, KF=Klamath Falls. Petiole cuttings were made on different dates at the two locations, but each group was within a couple of days of each other. Error bars represent the standard deviation with N=4. Grouping by letter compare fertilizer within each site for each cutting, means with the same letter are not significantly different at $p<0.05$ with Tukey HSD.

Fertilizer-by-Soil incubation

In the particle size-by-batch incubation there was a clear difference in N mineralization between AB1 and AB2. In the field trial there was a difference in petiole N uptake by site. In the fertilizer-by-soil incubation each of the soils generally behaved in a similar pattern with respect to fertilizer-induced CO_2-C respiration. However, there were significant differences between AB2 and AB3 on the third day of the incubation in KF soil alone and differences between the batches at both KF and CL on day 7.

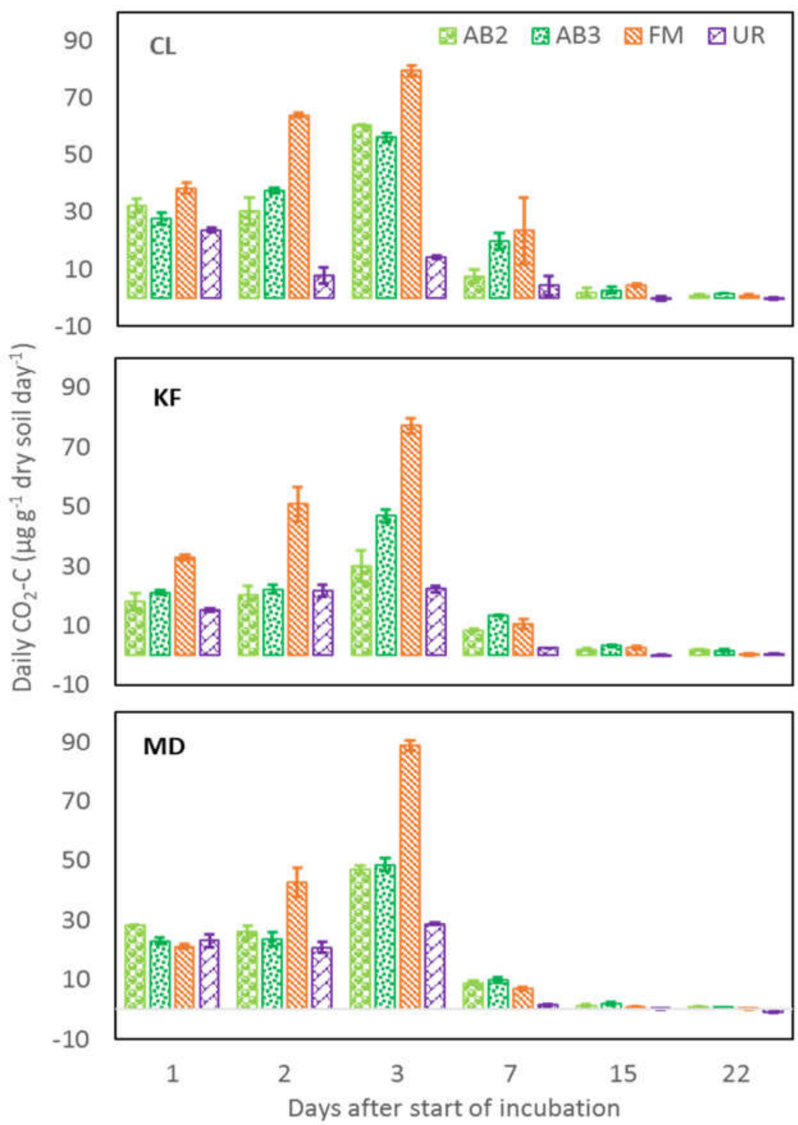


Figure 4-4 Daily CO_2-C Respiration Fertilizer-by-Site Incubation
AB2, AB32, FM, and UR are plots that received algal biomass from batch 2, algal biomass from batch 3, feather meal, or urea, respectively. CL, MD, and KF represent soils from Corvallis, Madras, and Klamath Falls respectively. Error bars represent the standard deviation with N=3. Emissions from the control treatment are subtracted from each replicate to yield CO_2-C produced as a result of the fertilizer application.

Respiration measurements provide snapshot data of microbial activity on the day the measurement is taken. However, NO_3^--N measurements are the cumulative impact of the induced microbial N mineralization activity. The NO_3^--N concentration at the end of the 22-day incubation was statistically the same for AB2 and AB3 with the exception of CL, where AB2 was higher than AB3. In the soil from both CL and MD, both of the AB treatments mineralized less NO_3^--N than either FM or UR. In CL, the FM and UR were not different. In KF, the UR was higher and in MD, the FM was higher.

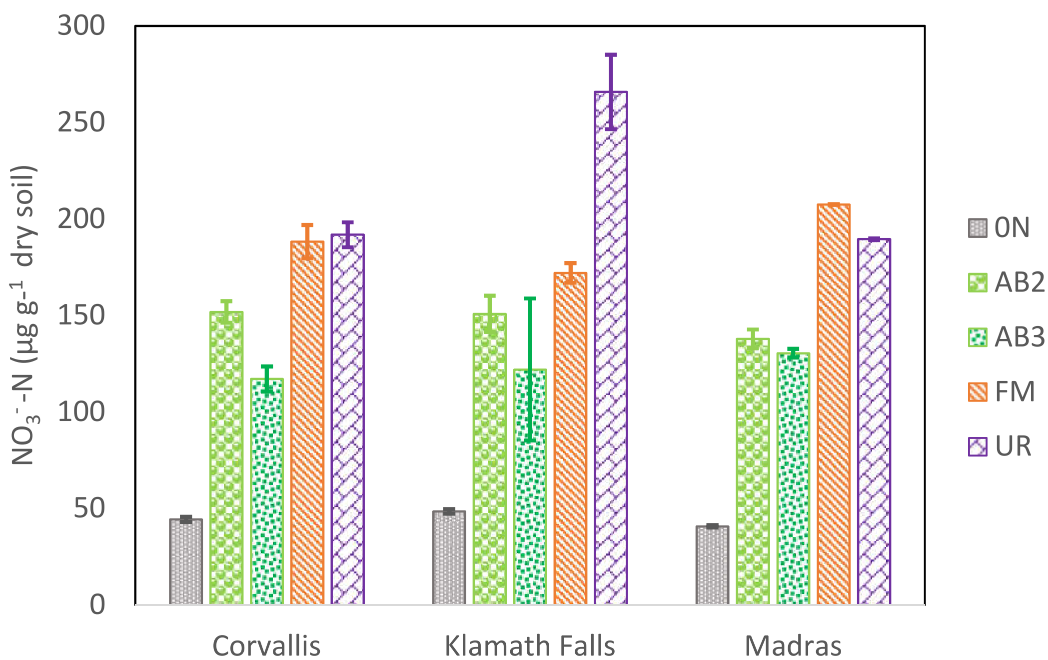


Figure 4-5 Soil Nitrate-N Fertilizer-by-Site Incubation

Soils incubated with fertilizers at 23°C and 50% water-filled pore space. Measurement taken 22 days after initiation. 0N=control, AB2=second batch of algal biomass, AB3=third batch of algal biomass, FM=feather meal, UR=urea. Error bars represent the standard deviation of three replicates.

Discussion

Particle Size

It has often been observed that small OM particles increase decomposition rate compared to similar material with a larger size particle (Nyhan, 1975; Sims, 1960). The surface of a soil particle is the reactive space, where microbes are sorbed, nutrients are exchanged and transformed, water is held, and plant roots and hyphae scavenge for nutrients. Therefore, a rate increase would be expected considering the surface area to volume ratio, which increases as the size of an object decreases, thereby allowing for a greater portion of the material to be in contact with the reactive surface. However, some reports have shown lower mineralization rates for fine textured residues (Bremer et al., 1991; Jensen, 1994). Jensen (1994) expects that the decelerating effect of grinding in N rich residues was due to stable associations between decomposing residues and soil mineral particles. As particle size decreased, the surface of residues potentially offered to contact soils particles increased, increasing mineralization for a time, but also increasing the likelihood for sorption to mineral surfaces. I found a pattern similar to Angers and Recous (1997) when assessing the mineralization dynamics of various materials with similar C:N ratios that differed by particle size, with higher mineralization rates for fine-textured amendments at the beginning of incubations followed by higher mineralization rates for coarse-textured materials after the first week. This is in accordance with current understanding of surface accessibility, surface reactivity, and sorption dynamics.

Variation in Process

The primary difference between AB batches used this trial was the temperature at which the materials were dried. Unfortunately, due to a non-disclosure agreement, the specific drying temperatures are not known, but the change in equipment was made so that the biomass would no longer be burnt. It can be expected that the material was not heated to more than 300^{o}C because the C content is not more than 50% (Keiluweit et al., 2010). However, we know material from the first batch induced a significantly lower C and N mineralization rate than the subsequent batches of AB. It has been shown that the C mineralization rate constant can decrease by an order of magnitude when wood is heated to greater than 200^{o}C (Baldock and Smernik, 2002). Biochars, OM burnt in the absence of oxygen (pyrolysis), have been investigated as a means of sequestering C because of their high C concentration and low C mineralization rates (Spokas, 2010). Literature on this thermally-altered OM demonstrate that as pyrolysis temperatures increase, the C:H, C:O, and H:O ratios all increase (Baldock and Smernik, 2002; Keiluweit et al., 2010). This means that as materials are pyrolyzed at progressively higher temperatures they become more reduced and have a lower oxidation state (LaRowe and Van Cappellen, 2011). Materials with a lower oxidation state are more likely to decompose at a slower rate under O_2 deplete conditions (Keiluweit et al., 2017). While the material we tested was not pyrolyzed, AB has been proposed as a biochar feedstock and if AB were pyrolyzed we would expect significant differences in mineralization. Further, the first batch of AB delivered had some degree of extreme-heat drying and demonstrated slower mineralization indicating that even minor thermal alteration could result in slow mineralization impacting fertilizer efficacy. Therefore, variations in drying/burning temperature must be considered when attempting to market a by-product for C utilization or storage. The ratio of C:O may be a good predictor of the persistence of C in soil (Spokas, 2010).

In a controlled environment, the manipulation of nutrient concentrations and environmental conditions allows for a higher degree of plasticity in AB. Redfield (1958) found N and P to be the primary limiting factors for phytoplankton growth, and recognized that local biochemical conditions can have a strong influence on the nutrient content of marine plankton. Table 4-6 summarizes the nutritive content of various algal materials grown on dairy manure effluent from the literature, N:P in the biomass ranges from 2.4 to 6.1. Although there was variability in available nutrients and mineralization rates between AB subsamples, the AB used in this trial is not representative of the general variability possible in AB grown on various wastewater streams. This particular material had over 1% iron. Though not problematic, it is a good reminder that algae are known to remove heavy metals from solution (Abdel-Raouf et al., 2012) and care must be taken to measure the concentration and calculate the total load prior to use as a fertilizer. Resources from the Washington State Department of Agriculture (http://www.aapfco.org/rules.html) provide means of calculating rates and current rules related to land application of OM with heavy metals. It is hard for producers to find organic fertilizers with specific nutrient concentrations. The plasticity of AB could be an opportunity to market various products as organic fertilizers with balanced macronutrient and specific micronutrient concentrations.

Table 4-5 Variation in Algal Biomass Nutrients

Author description of algal biomass	N loading rate	N	P	K	Ca	Mg	Fe	N:P	Citation
	g N m^{-2} day^{-1}	---------------------			%		----------------------		
Algae on dairy - anaerobic digester effluent - UF	0.64-1.03	7.1	1.47	1.72	1.8	0.42	0.08	4.8	Wilkie & Mulbry, 2002
Algae on dairy - anaerobic digester effluent - UF	0.78	3.5	1.25	0.53	0.62	0.14	0.04	2.8	Kebede-Westhead et al., 2004
Algae on dairy - anaerobic digester effluent - UF	1.48	4.6	1.42	0.66	0.68	0.16	0.04	3.3	Kebede-Westhead et al., 2004
Algae on dairy - anaerobic digester effluent - UF	2.41	6.5	1.47	0.84	0.97	0.23	0.06	4.4	Kebede-Westhead et al., 2004
Algae on dairy - anaerobic digester effluent - UF	3.22	6.9	1.38	0.80	0.85	0.19	0.05	5.0	Kebede-Westhead et al., 2004
Algae on dairy - anaerobic digester effluent USDA	0.64-1.03	4.9	1.54	1.13	0.8	0.45	0.11	3.2	Wilkie & Mulbry, 2002
Algae on dairy - anaerobic digester effluent USDA	1	4.5	0.73	0.91	0.55	0.19	0.12	6.2	Mulbry et al., 2005
Algae on dairy manure - separated liquid USDA	0.64-1.03	5.0	2.06	1.63	1.1	0.53	0.18	2.4	Wilkie & Mulbry, 2002
Algae on dairy manure - separated liquid USDA	0.51	4.8	0.69	-	-	-	-	7.0	Mulbry et al., 2008
Algae on dairy manure - separated liquid USDA	1.73	6.9	0.90	-	-	-	-	7.7	Mulbry et al., 2008
Algae on wastewater Batch 1	not reported	8.3	1.50	0.30	0.53	0.19	3.80	5.5	Current trial
Algae on wastewater batch 3	not reported	7.6	1.40	0.45	0.50	0.20	3.70	5.4	Current trial

UF is University of Florida was the source of the anaerobically digested effluent used for growing this algae. USDA refers to the Agriculural Research Service facility in Beltsville, MD

Interactions between Soil and Algal Biomass

Field plots at the two CL sites had a number of differing reactions to AB application. Related to cumulative gas emissions, CO_2-C respiration and N_2O-N emissions from CL corn plots receiving AB were nominally the lowest of any fertilizer treatment, whereas CL potato plots receiving AB demonstrated the highest emissions, (Cappellazzi, Chapter 3. Figure 3-3 and 3-7). In the agronomic trial, CL potatoes fertilized with AB demonstrate N uptake similar to 0N plots, in contrast to the other two locations where uptake was similar to FM (Figures 2-5, 4-3). In the laboratory incubation, CL potato plot soil mineralized a higher percentage of C added from the OF treatments but a lower percentage of C added from UR treatments than the other soils (Cappellazzi Chapter 3 Table 3-2). These inconsistencies indicate that an interaction between AB characteristics and soil edaphic features contribute to variation in utilization by the microbial community.

Increasing evidence indicates that the persistence of soil C should be considered on a continuum of decomposability with interactions related to soil and organic matter morphology, substrate availability, microbial accessibility, and thermodynamics driven by the chemical nature and physical architecture of the soil matrix (Baldock and Skjemstad, 2000; Chadwick et al., 2004; Lehmann and Kleber, 2015). In their work on the thermodynamics and kinetics of microbial metabolism, Jin and Bethke (2007) determined CO_2-C respiration is a function of the maximum reaction rate, microbial biomass, microbes ability to acquire reactants, and the catabolic energy yield, thereby taking all of the above-mentioned parameters into account. Building on this Keiluweit et al. (2016; 2017) showed, the rate of decomposition of a material with a low energetic quotient is a function of the percentage of anaerobic microsites in the soil, impacting the catabolic energy yield and microbial ability to acquire reactants. They were able to demonstrate a decline in mineralization rate of 60-95% of reduced materials in anaerobic microsites. This means that in addition to well-cited clay stabilization and physical protection, aggregate structure, distribution of pore spaces, and water management play a significant role in the rate of C utilization or storage.

Algae store between 10-70% of their biomass as lipids (Benemann and Oswald, 1996b), which is a highly reduced material. Marine phytoplankton typically have 10-20% lipids and their NOSC is estimated to be -0.45 (LaRowe and Van Cappellen, 2011). Algae grown for biodiesel production are regularly 30-60% lipids, consisting of various fatty acids that have a NOSC of -2 to -3 depending on the degree of saturation (Hanson, 1990). Organic matter quality has long been discussed as the major control for decomposition rate, with the idea that highly reduced organic matter is low quality and chemically recalcitrant (Nelson and Baldock, 2005; Sollins et al., 1996). However, empirical evidence provides data that a high lipid content does not always mean that the OM will be slow to degrade (Chadwick et al., 2004; Kleber et al., 2011; Marschner et al., 2008). In a controlled laboratory incubation with defatted and non-defatted meat and bone meal, Mondini et al., (2008) showed, that the non-defatted material actually resulted in higher CO_2-C respiration and N mineralization. It is important to note that these controlled experiments are performed under moderate moisture content with minimal anaerobic situations. Considering the bioenergetic potential of the materials, we would expect slower mineralization of these same products under anaerobic conditions.

I did not directly measure the percentage of anaerobic microsites in each of the soils; however, I can use soil physical characteristics to estimate this relative to the other sites in this trial. Aggregates build the soil structure that allows for a variation in pore sizes and reduces the likelihood that dispersed soil particles will collapse and clog pore spaces (Dighton and Adams Krumins, 2014). Soil from the CL potato plot had lower aggregate stability (20%) than CL corn (30%), likely due to a confluence of lower OM and clay content. It was also lower than either of the MD sites, 37% and 40% for corn and potato, respectively. It was slightly higher than KF sites (17%), but CL potato plots had less coarse sand than KF, which also helps to maintain large pore spaces. When preparing laboratory incubations, the dry, 2 mm sieved soils from CL and MD were each packed into a column with a D_b of 1g cm^{-3}, KF soil had D_b of 1.33 g cm^{-3}. However, after pouring water on the top of the soil to prepare the incubation, the volume that the CL soils occupied had dropped such that the bulk density was on average 1.15 g cm^{-3} while the MD and KF samples did not change after water addition. When removing the sample to mix for moisture measurements and KCl extractions, the top 2 cm of the CL samples were wetter than the rest of the sample and soil structure seemed to collapse with gentle mixing, leaving a rather uniform mud with no discernable aggregates. MD and KF samples seemed to have even moisture distribution through the column and maintained aggregate structure during mixing. The differential moisture and mixing characteristics are anecdotal observations, the differences in behavior among soil types were readily observable. The measured aggregate stability, texture, and changes in D_b along with my observations lead me to think that the CL potato soil has more anaerobic microsites than the other soils.

The potential variations in NOSC coupled with the variations in the soil pore oxygen availability between field sites could explain the variation in mineralization rates of both C and N. In addition to the C:N ratio, the C:O and C:H ratios of AB should be tested prior to marketing these materials as fertilizers. Edaphic characteristics such as bulk density, aggregate stability, and texture should also be used to better describe the timing and availability of organic nutrients added to the soil. It has long been recognized that the temperature and moisture dynamics of a system affect the microbially mediated cycling rates of nutrients in an agroecosystem (Singh, 2018). In order for a producer to increase their nutrient use efficiency by synchronizing the availability of nutrients with the plant requirements, formulas that take all of these factors into account must be accessible.

Conclusions

The C:N ratio alone of the algal biomass used in this trial would not have predicted a difference in mineralization rate. Organic matter mineralization is a function of the substrates contained therein, the soil it is applied to, and the climate in which it exists. As new facilities develop algae for energy production or incorporate algae to capture nutrients from their effluent, a framework that accurately predicts mineralization rates needs to be accessible so growers can have confidence that the product they select will help to meet the goals of their operation. In addition to measuring plant available nutrients, I expect that quantifying the C, H, and O to calculate the NOSC, characterizing the edaphic characteristics that control the O_2 content of pore gasses, and using climatic conditions will allow site-specific models to better estimate the dynamics of N and C mineralization. Understanding these dynamics will allow for proper fertilizer application rates and timing and thereby increase nutrient use efficiency and yield, moving organic production toward goals of sustainably feeding our growing population.

It has been argued that scientists must simplify information for farmers to understand and apply the knowledge. However, I argue that if soil mineralization dynamics are simplified at the expense of accuracy a producer is less likely to use testing and the resulting mineralization predictions because their results are inconsistent and they lose confidence in the science. Extension programs must understand that many producers are using smart farming tools to track everything from the growing degree days for insecticide application, to variations in electrical conductivity to determine where and when fertilizer application will be most beneficial. Each large agricultural business organization has proprietary software and predictive models and producers are ready to use complex models. As researchers move forward in extension work with producers, the best information available needs to be related to how multiple parameters interact to influence the mineralization dynamics of organic materials to ensure that organic producers have the tools they need to produce food efficiently.

Chapter 5 General Discussion

Algal biomass grown on wastewater can be an excellent source of fertilizer. The nitrogen mineralization rate is fast enough to meet the needs of both corn and potatoes during their respective periods of rapid nitrogen uptake. Under many conditions, it mineralizes organically bound nitrogen at a rate similar to feather meal, and results in yields similar to both feather meal and urea. I also demonstrated that algal biomass is the only one of the three fertilizers tested that is likely to increase soil carbon when used annually at an agronomic rate. Importantly, it was found that not all algal biomass products will mineralize at the same rate, even if they have a similar carbon to nitrogen ratio.

Beyond the traditionally quantifiable value of algal biomass as a fertilizer, growing algae on wastewater has the capacity to capture nutrients otherwise lost to the environment and atmospheric CO_2 and return them to the soil for further cycling. Harnessing this primary production and burying it into soil feeds microbial heterotrophs, enabling them to carry out vital ecosystem services. Any good cattleman will tell you a well-balanced ration is the best way to maintain a healthy, productive, and profitable herd. The same can be said for the herd of microbes living in the soil. If you feed them, they will cycle nutrients, store and filter water, build pore structure, combat pathogens, decrease erosion, and enhance agroecosystem resilience. Algal biomass grown on dairy wastewater can be characterized as a fertilizer with approximately 50% carbon, 4-8% nitrogen, 1-2% phosphorus, 1-2% potassium, and suite of micronutrients depending on the feedstock. Although we cannot say algal biomass is an ideal soil microbial feedstock, we did show efficient N utilization while demonstrating ample C utilization, and C storage for future use. The balance of macro and micronutrients, similar to what is used in microbiology laboratories, is worth consideration as a soil microbe feed.

Before this product is hailed as the next great savior, we must recognize that not all algal biomass behaves similarly in soil. The conditions under which algae is grown and processed affect soil carbon and nitrogen mineralization rates. Because there are many algal production systems and processes under consideration for commercialization, it is important to characterize algal biomass prior to fertilizer valuation and application rate calculations. Wastewater nutrient concentrations will vary. Even within the dairy manure sector, nutrient levels vary among herds, between seasons, and when their diet changes, resulting in the variable nutrient concentrations of the algal biomass. Algal biomass lipid concentrations will also vary by species, temperature, pH, and whether it has been extracted for biodiesel production. Each of these components will interact with the manufacturing process to determine the characteristics of the final product. Instead of categorizing materials by industry or process, I propose including total carbon, oxygen, and hydrogen in the traditional measurements of plant-available nutrients for any kind of organic amendment. This would allow for calculation of the carbon oxidation state, the energetic potential of the organic matter, and the likelihood of mineralization depending on the available terminal electron acceptors.

As we increase understanding of working with soil as a four-dimensional ecosystem, full of living, breathing, cycling organisms, we will dig deeper into the controls of these nutrient cycles. Algal biomass provides an interesting medium by which to characterize organic matter mineralization under various soil conditions. Nutrient content can be manipulated through laboratory growing conditions, allowing us to manipulate nutrient ratios to test the influence on mineralization rate. Extracting lipids, as is done for biodiesel production, would be another means of altering concentrations of functional groups that might influence microbial accessibility. By altering the oxidation state of carbon and concentrations of other nutrients, we could test the new paradigms related to the interactions of a material's energetic potential and the oxygenation of the soil environment. Further, isotopic-labelling of algal biomass using ^{13}C-CO_2 or ^{15}N-urea could enable detailed tracking of the fate of carbon and nitrogen in the environment, as well as the rate at which they are stored and cycled by the microbial community. The resulting mineralization dynamic models will also need to be tested in the presence of plants to account for their influence.

We are at an exciting time of scientific collaboration. There is so much knowledge available and the work currently underway involves integrating specific knowledge into whole systems. By coming together and crossing disciplines, we can gain a better understanding of the complex, living, soil system. Soils contain myriad microbial populations interdependent on each other, which require organic carbon for nutrients and energy to carry out the ecosystem services we rely on. As I move forward with this understanding I want to work to quantify the benefits of increasing soil organic carbon in terms of its contribution to: increased water holding capacity, buffering changes in pH, providing a substrate for and modulation of nutrient cycling rates, erosion reduction, surface and groundwater purification, and building resilience. These tangible benefits will build value and be the driving force behind increasing producer adoption of practices that increase the application of carbon-rich products to soil, having ancillary benefits in our fight to mitigate climate change. Until then, the agronomic value of algal biomass will be based on its ability to provide nitrogen to crops. It has become increasingly clear through my studies of soil science that every reaction depends on many components. In order to provide producers with the information they need to make the best management decisions, we will continue to work to describe the relationships of multiple interacting variables in soil systems.

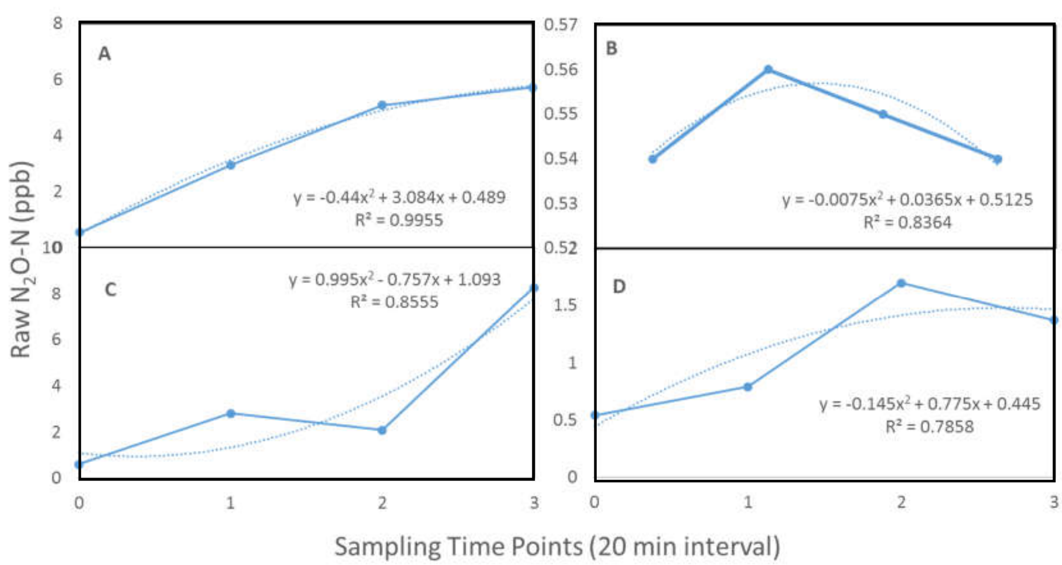
Appendix 1. Determination of Appropriate Flux calculations

In Chapter 3 I discussed our attempt to use the Hutchinson Mosier 4-point flux model (HM4) on all data. This formula only works if:

$[(C_{a1,2}-C_0)/(C_3-C_{a1,2})] > 0$ and $1 < [(C_{a1,2}-C_0)/(C_3-C_{a1,2})] > 0$ Eq. 6-1

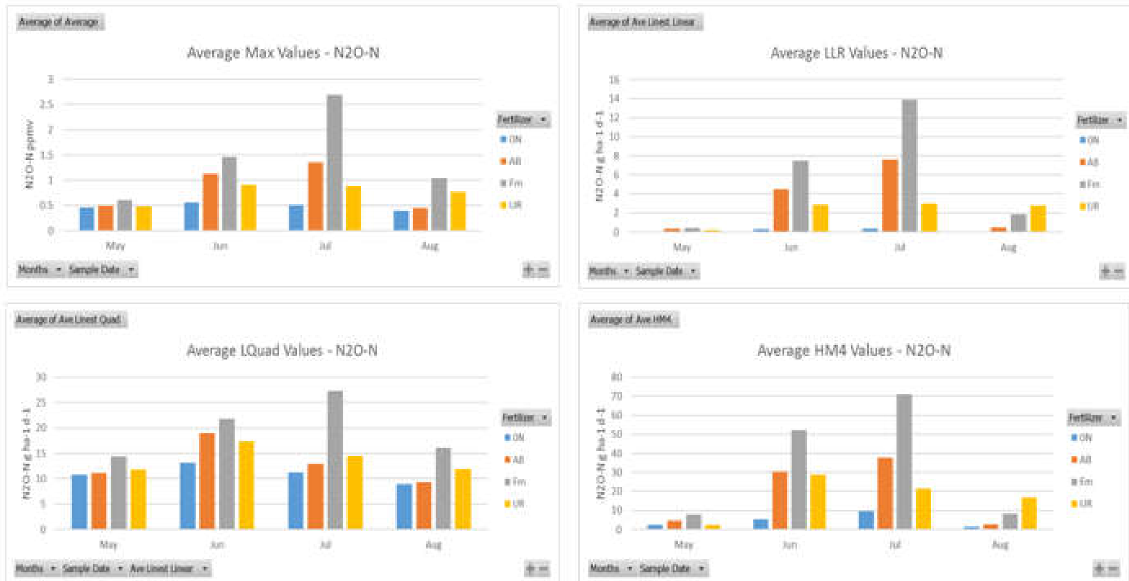
In the initial analysis it was found that only 48% of the sets of N_2O data and 57% of the CO2 data sets fit the requirements of this formula (set here is the 4 points used to calculate one flux measurement). It has been observed that very small changes one value in the t0 data point, from 297.1 to 297.0 ppbv can cause a major change in the flux rate, from 1.19x10^8 to "no flux" (Parkin et al., 212). This was also found in our data. Testing this in a random set of four time points, with the t1 data point at 260ppmv the function returned an error, when adjusted to 265 the flux was 15 g N2O-N ha-1 d-1, and when adjusted to 270 the function returned and error. The difference between these numbers would be considered insignificant because they are within the coefficient of variance of the standards run by the technician. However, the difference in the result is substantial.

Other formulas have also been used to estimate the flux. A linear regression using the LINEST function (LLR) in excel, will return a value for any data set with a minimum of two time points, and is not as sensitive to slight changes in individual values (Parkin et al., 2012). The LINEST function in Excel can also be used to fit a second order polynomial (LQuad) to any set with a minimum of three time points. The R^2 for the fitting of the polynomial function to the data is on average 0.3 better than the R^2 for the fit of the data to the linear regression. However, the formula has the ability to fit a line to any pattern of data. When the data follows an expected behavior pattern (panel A), the formula can return an R^2 of 0.995, while it can also return an high R^2 with patterns similar to those displayed in B, C, and D in Figure 6-1. This mean that this formula does not take into account the assumed upward linear efflux of CO_2 and N_2O from soil under natural circumstances, nor does it take into account the decrease in diffusion rate imposed by limited chamber space. Therefore the flux rate for data that does not fit a normal pattern may return unrealistic flux values.



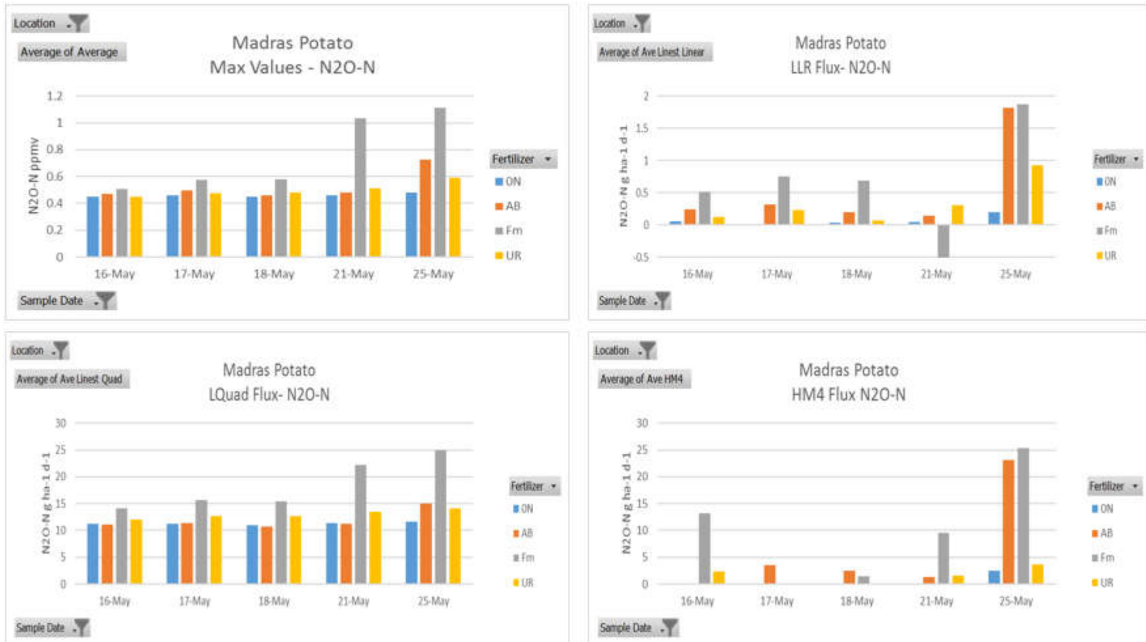
Appendix Figure 5-1 Examples of Quadratic Fitting to Variety of Measurement Patterns
Empirical measurements from N2O data in this trial. Panel A represents expected efflux measurements, Panels, B, C, and D, represent common patterns found that also provide a relatively strong correlation coefficient.

Considering how a slight variation in a value can change the flux rate significantly in the HM4 model I considered the standard deviation and the coefficient of variance of the eight standards used while running our samples on the GC mass spectrophotometer. The CVs ranged from 0.02 to 0.19 on various sampling dates. A technical report by Parkin, Venterea, and Hargreaves in 2012 detailed the process to calculate the detection limits of chamber-based soil greenhouse gas flux measurements. In this paper they provided regression coefficients for the most common flux calculations, (HM4, LLR, and LQuad were all included) for various deployment times that can be used in addition to analytical variance, and atmospheric concentrations to calculate the minimum detection limits (MDL) of a data set for a given gas. Flux measurements below the detection limit have a high chance of committing a Type 1 error in which I might say there is a flux, but I really should be accepting the null hypothesis that there is no flux. If applying these formulas most of the samples from the beginning and end the field trial would not be used, as well as a large portion of the 0N and UR samples. Applying the MDL would allow me to minimize reporting errors due to type one error but also skewed the data so that only values above a certain threshold were reported at all. Figure 6-2 shows that the pattern of emissions over the time coarse of the experiment is distorted and the relative comparison of the gas emissions resulting from the various fertilizers is skewed to include only high emission rates.



Appendix Figure 5-2 Flux Calculation Method Comparison

These pivot tables use all data that passed the minimum detection limit tests. Average Max uses the highest measurement from each sample date for each sample, no flux is calculated. LLR uses the linear regression from the four data points to calculate flux rates that range from 0 to 14. LQuad uses a second order polynomial to fit a line to the data, calculating flux rates from 10 to 27. HM4 uses the Hutchinson Mosier four point formula that takes into account idealized gas flux behavior, with values ranging from 3 to 71. Figure demonstrates that both the LLR, and HM4 limit data that can be reported and LQuad returns flux rates intermediate to the other methods.



Appendix Figure 5-3 Individual Dates Demonstrating Variation in Results based on Calculation Methods

The dates right after fertilization in Madras Potatoes demonstrate problems with the different flux calculation methods. These are the only dates in the Madras potato N_2O set that show statistical differences. Various methods, described in Fig 6-2, result in differences in total season long flux estimation. Max values track well with LQuad values but do not provide flux rate.

Table 6-1 displays the percentage of data sets that passed each of the flux calculations. The HM4 and LLR models both reject data when the overall flux of the data set appeared very low, within the standard deviation of the standards measured in the lab, as the model would suggest. However, the LQuad model passed the conditions 90% of the time, and often passed when there was no significant difference between the maximum gas measurement and t0. This solves the problem of reporting a limited, skewed data set but increases the chances of reporting type one errors. As stated by Gilbert (1987) and reiterated by Parkins (2010, 2012) there are several ways to deal with this data below detection limits; (i) report values as “below detection limit,” (ii) report the values as zero flux, (iii) report some value between zero and MDL, or (iv) report the actual measured value even if it falls below the MDL. Gilbert recommends reporting the measured value along with the stated MDL. Parkins et al. (2012) also points out that no one flux model is always the best to use, and a hybrid system could be implemented where the LLR is used if the data do not meet the requirements of the HM4 or LQuad models. However, in our data, the maximum value for the LLR flux is 13 and while the HM4 flux for that same data is 118. The coefficient of determination between these two models is 0.5112 for the data sets that meet the MDL for each flux calculation. If I inserted LLR value whenever the HM4 model did not work, it would also bias the reporting and the correlation is not good enough to use a multiplication factor to adjust the LLR values relative to HM4.

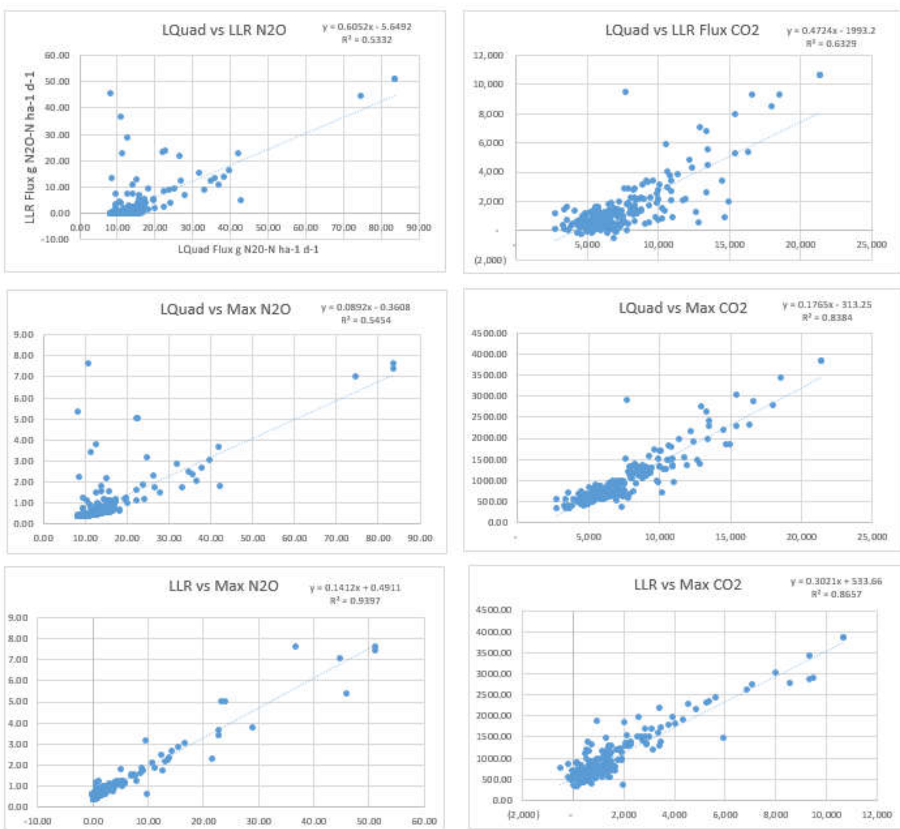
Appendix Table 5-1 Summary of Various Flux Calculations

	CO2 flux			N2O Flux		
	HM4	LLR	Lquad	HM4	LLR	Lquad
	--------------------------------			%-------------------------------		
Average	12473	1531	7496	32.9	3.63	15.6
Pass	56	60	90	30	32	95
Fail	0.8	35	5	18	65	2
No Calc	43	5	5	52	3	3

n=992 for each gas, each flux calculation consists of 4 data points
HM4 Hutchinson Mosier Flux Calculation revised for 4 point data with average t1,t2
LLR Linear Regression using Excel LINEST Array
Lquad 2nd order polynomial regression using Excel LINEST array
Pass - percent of flux values that are above the minimum detection limits
Fail - calculation made but flux value below the MDL
No Calc - no calculation possible with given formula
*10% of the LLR values returned negative slopes which were included in the failure

In the USDA-ARS GRACEnet Project Protocols, Chapter 3 (2010), the authors point out that there is currently an inability to “precisely assess the extent of bias associated with a given chamber design and sampling protocol,” so they have adopted a best guess protocol. The best I can do is to select a technique which minimizes potential problems. Several of the recommended protocols from the GRACEnet procedure were not followed due to funding limitations. I did try to minimize soil disturbance by leaving the cans in the field throughout the growing season but it was not the recommended anchor and chamber system. The can was inserted to recommended depth, but it extended up 8-10cm above the ground. This can cause a microclimate effect where water can become trapped after irrigation and the shading can affect the temperature. While I did try to reduce temperature perturbations, I did not have a thermocouple in the chamber lid to monitor temperature. Humidity was not controlled for. There was an attempt to take weekly measurements in a pattern with irrigation to minimize sampling of freshly wetted soil, but the irrigation schedule changed through the season and the moisture (measured) varied among sampling dates. I did not place chambers both in and out of the fertilizer band which preludes us from extrapolating our data to the entire field. A high degree of variability is to be expected in chamber-based soil gas measurements with CVs often exceeding 100% (Parkins, 2012). This can be minimized by using many chambers with a large footprint. I only had one chamber per plot instead of the recommended minimum of two and they were exactly the minimum recommended area 182cm^2. I do show a high degree of variability within plots when using the LLR and HM4 calculations. Calculating for each treatment, on each sampling date, the average

LLR flux was 3.65 g N2O-N ha^{-1} d^{-1}. When calculating the CV of the four blocks in one treatment on one day, 35% of the flux calculations had CV values over 100 with an average CV of 82%. The HM4 showed similarly high variability. However, the LQuad had an average CV of 24%. For most of the data the maximum data point also showed a low average CV of 28% and was well correlated to each of the flux calculations. The max values also required us to throw out the fewest outliers, but picked up on several outliers that the flux calculations did not that had the tendency to skew the data.



Appendix Figure 5-4 Relationship between Flux Calculation Measurements
Relationships show the strongest correlation between Max value and LLR flux calculations because the influence that the maximum value has on the linear formula compared to a second order polynomial. The points that were far from the regression line were assessed individually for abnormal flux patterns, and determined to be useable measurements.

In summary I have chosen to display data here using the coefficients determined by the Linest formula in excel fit with second order polynomial.

=LINEST(y1:y4,x1:x4^{1,2},,true) Eq. 6-2

The LLR flux calculation is known to underestimate values, the HM4 requirements are not met roughly half of the time, the maximum value data cannot be compared to any other data set. The variation between plots of the same treatment on the same date is significantly smaller when using the LQuad than any of the flux calculations. I recognize that the formula does not follow assumptions related to the behavior of gas diffusion. I also recognized that I have limited power to extrapolate this data to field scale for comparison with other trials because of our limited ability to control for bias. A table of the minimum detection limits (MDL) for each treatment, site, crop, and date is available in Appendix Table 2, separated by treatment within site and crop.

Appendix Table 5-2 Minimum Detection Limits and Flux Calculations

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2
					N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}			
06/15/15	C	C	0N	A	5.42	12.19	pass	0.40	1.57	0.05	fail	0.07	4.31			0.10
06/15/15	C	C	0N	B	5.42	11.92	pass	0.90	1.57	0.14	fail	0.90	4.31			0.10
06/15/15	C	C	0N	C	5.42	12.00	pass	0.64	1.57	0.20	fail	0.60	4.31	1.12	fail	0.10
06/15/15	C	C	0N	D	6.78	15.03	pass	0.98	1.97	0.20	fail	0.89	5.39	1.40	fail	0.10
06/17/15	C	C	0N	A	1.90	11.90	pass	1.00	0.55	0.00	fail	1.00	1.51			0.03
06/17/15	C	C	0N	B	1.90	11.73	pass	0.55	0.55	0.11	fail	0.45	1.51	0.12	fail	0.03
06/17/15	C	C	0N	C	1.90	11.90	pass	1.00	0.55	0.00	fail	0.00	1.51			0.03
06/17/15	C	C	0N	D	2.38	14.84	pass	0.93	0.69	0.08	fail	0.60	1.89			0.03
06/18/15	C	C	0N	A	2.10	12.71	pass	0.98	0.61	0.78	pass	0.98	1.67	1.82	pass	0.04
06/18/15	C	C	0N	B	2.10	12.28	pass	0.93	0.61	0.07	fail	0.60	1.67			0.04
06/18/15	C	C	0N	C	2.10	12.77	pass	1.00	0.61	0.45	fail	1.00	1.67	1.33	fail	0.04
06/18/15	C	C	0N	D	2.62	17.40	pass	0.80	0.76	1.04	pass	0.62	2.09	172.98	pass	0.04
06/23/15	C	C	0N	A	3.65	12.36	pass	0.47	1.06	0.13	fail	0.30	2.90			0.06
06/23/15	C	C	0N	B	3.65	12.59	pass	0.47	1.06	0.13	fail	0.30	2.90			0.06
06/23/15	C	C	0N	C	3.65	12.27	pass	0.20	1.06	0.09	fail	0.20	2.90			0.06
06/23/15	C	C	0N	D	4.56	16.01	pass	0.64	1.32	0.17	fail	0.20	3.63			0.06
06/24/15	C	C	0N	A	3.93	11.90	pass	0.93	1.14	0.20	fail	0.60	3.13			0.07
06/24/15	C	C	0N	B	3.93	12.20	pass	0.80	1.14	0.27	fail	0.80	3.13	0.67	fail	0.07
06/24/15	C	C	0N	C	3.93	12.53	pass	0.65	1.14	0.49	fail	0.65	3.13	1.11	fail	0.07
06/24/15	C	C	0N	D	4.91	15.19	pass	0.90	1.43	0.17	fail	0.90	3.91			0.07
06/26/15	C	C	0N	A	3.04	11.72	pass	0.80	0.88	-0.09	fail	0.80	2.42			0.06
06/26/15	C	C	0N	B	3.04	12.39	pass	0.86	0.88	0.11	fail	0.14	2.42			0.06
06/26/15	C	C	0N	C	3.04	12.51	pass	0.99	0.88	0.31	fail	0.70	2.42			0.06
06/26/15	C	C	0N	D	3.80	15.17	pass	0.84	1.10	-0.05	fail	0.04	3.02			0.06
07/03/15	C	C	0N	A	2.85	12.89	pass	0.96	0.83	1.63	pass	0.95	2.27	3.38	pass	0.05
07/03/15	C	C	0N	B	2.85	12.09	pass	0.84	0.83	-0.02	fail	0.02	2.27			0.05
07/03/15	C	C	0N	C	2.85	11.92	pass	0.36	0.83	0.09	fail	0.16	2.27			0.05
07/03/15	C	C	0N	D	3.56				1.03				2.83	109.51	pass	0.05
07/10/15	C	C	0N	A	2.93	13.24	pass	0.96	0.85	1.68	pass	0.95	2.33	3.47	pass	0.05
07/10/15	C	C	0N	B	2.93	12.42	pass	0.84	0.85	-0.02	fail	0.02	2.33			0.05
07/10/15	C	C	0N	C	2.93	12.25	pass	0.36	0.85	0.09	fail	0.16	2.33			0.05
07/10/15	C	C	0N	D	3.66				1.06				2.91	112.50	pass	0.05
07/16/15	C	C	0N	A	1.24	12.84	pass	0.99	0.36	0.92	pass	0.97	0.99	4.28	pass	0.02
07/16/15	C	C	0N	B	1.24	12.99	pass	0.96	0.36	0.63	pass	0.87	0.99	4.51	pass	0.02
07/16/15	C	C	0N	C	1.24	12.33	pass	1.00	0.36	0.38	pass	0.86	0.99	3.30	pass	0.02
07/16/15	C	C	0N	D	1.55	15.56	pass	0.93	0.45	0.17	fail	0.60	1.23			0.02
07/17/15	C	C	0N	A	3.16	12.66	pass	0.97	0.92	0.91	fail	0.95	2.51	1.74	fail	0.06
07/17/15	C	C	0N	B	3.16	13.00	pass	1.00	0.92	1.13	pass	0.98	2.51	4.87	pass	0.06
07/17/15	C	C	0N	C	3.16	12.64	pass	1.00	0.92	0.96	pass	1.00	2.51	3.36	pass	0.06
07/17/15	C	C	0N	D	3.95				1.15				3.14	111.93	pass	0.06
07/18/15	C	C	0N	A	0.92	12.27	pass	0.99	0.27	0.52	pass	0.99	0.73	1.55	pass	0.02
07/18/15	C	C	0N	B	0.92	12.20	pass	1.00	0.27	0.44	pass	0.95	0.73	2.42	pass	0.02
07/18/15	C	C	0N	C	0.92	11.89	pass	0.91	0.27	0.20	fail	0.85	0.73	0.30	fail	0.02
07/18/15	C	C	0N	D	1.15	14.63	pass	0.99	0.33	0.44	pass	0.75	0.92	0.07	fail	0.02
07/20/15	C	C	0N	A	0.74	12.26	pass	0.90	0.22	0.27	pass	0.90	0.59	0.88	pass	0.01
07/20/15	C	C	0N	B	0.74	11.91	pass	0.93	0.22	0.07	fail	0.60	0.59			0.01
07/20/15	C	C	0N	C	0.74	12.23	pass	0.90	0.22	0.09	fail	0.40	0.59			0.01
07/20/15	C	C	0N	D	0.93	15.02	pass	0.90	0.27	0.11	fail	0.40	0.74			0.01
07/22/15	C	C	0N	A	1.02	8.59	pass	0.80	0.30	0.09	fail	0.80	0.81			0.02
07/22/15	C	C	0N	B	1.02	8.70	pass	0.60	0.30	0.09	fail	0.10	0.81			0.02
07/22/15	C	C	0N	C	1.02	8.59	pass	0.90	0.30	0.09	fail	0.40	0.81			0.02
07/22/15	C	C	0N	D	1.27	10.45	pass	0.93	0.37	-0.17	fail	0.60	1.01			0.02
07/24/15	C	C	0N	A	0.55	9.39	pass	0.76	0.16	0.25	pass	0.17	0.44			0.01
07/24/15	C	C	0N	B	0.55	8.38	pass	0.40	0.16	0.02	fail	0.07	0.44			0.01
07/24/15	C	C	0N	C	0.55	9.92	pass	1.00	0.16	0.76	pass	0.86	0.44	6.62	pass	0.01
07/24/15	C	C	0N	D	0.68	10.55	pass	0.90	0.20	0.17	fail	0.90	0.54			0.01
07/29/15	C	C	0N	A	3.53	8.17	pass	0.84	1.02	0.17	fail	0.64	2.81			0.06
07/29/15	C	C	0N	B	3.53	8.23	pass	0.99	1.02	0.28	fail	0.97	2.81	1.39	fail	0.06
07/29/15	C	C	0N	C	3.53	8.48	pass	1.00	1.02	0.22	fail	0.56	2.81			0.06
07/29/15	C	C	0N	D	4.41	10.78	pass	0.40	1.28	-0.08	fail	0.07	3.51			0.06
08/07/15	C	C	0N	A	4.23	8.47	pass	0.99	1.23	0.16	fail	0.52	3.37			0.08
08/07/15	C	C	0N	B	4.23	8.77	pass	0.55	1.23	0.22	fail	0.45	3.37			0.08
08/07/15	C	C	0N	C	4.23	8.49	pass	0.55	1.23	0.11	fail	0.45	3.37	0.12	fail	0.08
08/07/15	C	C	0N	D	5.29	10.58	pass	0.70	1.54	0.22	fail	0.53	4.21	2.79	fail	0.08
08/14/15	C	C	0N	A	1.27	8.73	pass	0.72	0.37	0.20	fail	0.46	1.01			0.02
08/14/15	C	C	0N	B	1.27	8.68	pass	0.93	0.37	0.07	fail	0.60	1.01			0.02
08/14/15	C	C	0N	C	1.27	8.81	pass	0.84	0.37	0.04	fail	0.04	1.01			0.02
08/14/15	C	C	0N	D	1.59	10.74	pass	0.40	0.46	0.03	fail	0.07	1.26			0.02
08/21/15	C	C	0N	A	14.52	8.25	fail	0.98	4.21	0.07	fail	0.16	11.55			0.26
08/21/15	C	C	0N	B	14.52	8.13	fail	0.90	4.21	0.09	fail	0.40	11.55			0.26
08/21/15	C	C	0N	C	14.52	8.31	fail	0.64	4.21	0.18	fail	0.64	11.55			0.26
08/21/15	C	C	0N	D	18.15	10.40	fail	0.98	5.27	0.20	fail	0.89	14.43	1.38	fail	0.26

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2
					N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}			
06/15/15	C	C	AB	A	6.78	15.16	pass	0.80	1.97	0.23	fail	0.80	5.39			0.10
06/15/15	C	C	AB	B	5.08	11.30	pass	0.80	1.48	0.08	fail	0.80	4.04			0.10
06/15/15	C	C	AB	C	5.42	12.08	pass	0.90	1.57	0.27	fail	0.90	4.31			0.10
06/15/15	C	C	AB	D	5.42	12.08	pass	0.90	1.57	0.27	fail	0.90	4.31			0.10
06/17/15	C	C	AB	A	2.38	14.72	pass	0.40	0.69	0.03	fail	0.07	1.89			0.03
06/17/15	C	C	AB	B	1.78	11.22	pass	0.80	0.52	0.08	fail	0.80	1.42			0.03
06/17/15	C	C	AB	C	1.90	11.71	pass	0.98	0.55	0.16	fail	0.89	1.51	0.12	fail	0.03
06/17/15	C	C	AB	D	1.90	11.87	pass	0.93	0.55	0.07	fail	0.60	1.51			0.03
06/18/15	C	C	AB	A	2.62	16.28	pass	1.00	0.76	1.04	pass	1.00	2.09	2.55	pass	0.04
06/18/15	C	C	AB	B	1.97	11.72	pass	0.77	0.57	0.29	fail	0.70	1.56	0.40	fail	0.04
06/18/15	C	C	AB	C	2.10	12.46	pass	0.91	0.61	0.60	fail	0.78	1.67	0.45	fail	0.04
06/18/15	C	C	AB	D	2.10	12.65	pass	0.94	0.61	0.90	pass	0.93	1.67	1.67	fail	0.04
06/23/15	C	C	AB	A	4.56	15.61	pass	0.74	1.32	0.14	fail	0.26	3.63			0.06
06/23/15	C	C	AB	B	3.42	12.39	pass	1.00	0.99	0.00	fail	0.00	2.72			0.06
06/23/15	C	C	AB	C	3.65	14.53	pass	0.88	1.06	0.49	fail	0.29	2.90			0.06
06/23/15	C	C	AB	D	3.65	13.68	pass	0.84	1.06	0.40	fail	0.26	2.90			0.06
06/24/15	C	C	AB	A	4.91	15.32	pass	0.98	1.43	0.19	fail	0.89	3.91	1.37	fail	0.07
06/24/15	C	C	AB	B	3.69	11.36	pass	0.91	1.07	0.19	fail	0.85	2.93	0.29	fail	0.07
06/24/15	C	C	AB	C	3.93	12.22	pass	1.00	1.14	0.22	fail	1.00	3.13	0.66	fail	0.07
06/24/15	C	C	AB	D	3.93	12.15	pass	0.99	1.14	0.36	fail	0.91	3.13	0.42	fail	0.07
06/26/15	C	C	AB	A	3.80	14.63	pass	0.20	1.10	-0.05	fail	0.20	3.02			0.06
06/26/15	C	C	AB	B	2.85	11.23	pass	0.40	0.83	0.04	fail	0.07	2.27			0.06
06/26/15	C	C	AB	C	3.04	12.92	pass	0.90	0.88	0.35	fail	0.40	2.42			0.06
06/26/15	C	C	AB	D	3.04	12.66	pass	0.51	0.88	0.22	fail	0.12	2.42			0.06
07/03/15	C	C	AB	A	3.56	16.64	pass	0.94	1.03	1.25	pass	0.90	2.83	6.71	pass	0.05
07/03/15	C	C	AB	B	2.67	13.36	pass	0.80	0.78	2.04	pass	0.78	2.12	9.21	pass	0.05
07/03/15	C	C	AB	C	2.85	11.89	pass	0.97	0.83	1.02	pass	0.70	2.27	0.09	fail	0.05
07/03/15	C	C	AB	D	2.85	23.79	pass	0.75	0.83	1.59	pass	0.06	2.27			0.05
07/10/15	C	C	AB	A	3.66	17.10	pass	0.94	1.06	1.29	pass	0.90	2.91	6.89	pass	0.05
07/10/15	C	C	AB	B	2.74	13.72	pass	0.80	0.80	2.10	pass	0.78	2.18	9.46	pass	0.05
07/10/15	C	C	AB	C	2.93	12.21	pass	0.97	0.85	1.05	pass	0.70	2.33	0.09	fail	0.05
07/10/15	C	C	AB	D	2.93	24.44	pass	0.75	0.85	1.63	pass	0.06	2.33			0.05
07/16/15	C	C	AB	A	1.55	18.86	pass	0.95	0.45	3.63	pass	0.95	1.23	10.65	pass	0.02
07/16/15	C	C	AB	B	1.16	14.53	pass	1.00	0.34	4.25	pass	0.98	0.92	8.88	pass	0.02
07/16/15	C	C	AB	C	1.24	22.99	pass	0.98	0.36	6.10	pass	0.85	0.99	54.33	pass	0.02
07/16/15	C	C	AB	D	1.24	21.79	pass	0.82	0.36	5.81	pass	0.70	0.99	56.31	pass	0.02
07/17/15	C	C	AB	A	3.95	16.02	pass	0.80	1.15	1.58	pass	0.79	3.14	4.05	pass	0.06
07/17/15	C	C	AB	B	2.96	17.47	pass	0.98	0.86	4.25	pass	0.90	2.36	27.30	pass	0.06
07/17/15	C	C	AB	C	3.16	15.58	pass	0.99	0.92	4.87	pass	0.98	2.51	11.11	pass	0.06
07/17/15	C	C	AB	D	3.16	19.11	pass	0.99	0.92	6.03	pass	0.97	2.51	26.15	pass	0.06
07/18/15	C	C	AB	A	1.15	15.92	pass	0.98	0.33	0.57	pass	0.77	0.92	7.90	pass	0.02
07/18/15	C	C	AB	B	0.86	12.02	pass	1.00	0.25	1.08	pass	1.00	0.69	3.70	pass	0.02
07/18/15	C	C	AB	C	0.92	13.77	pass	0.78	0.27	2.09	pass	0.75	0.73	4.42	pass	0.02
07/18/15	C	C	AB	D	0.92	13.57	pass	0.99	0.27	1.20	pass	0.95	0.73	6.39	pass	0.02
07/20/15	C	C	AB	A	0.93	15.49	pass	1.00	0.27	0.28	pass	0.83	0.74	2.78	pass	0.01
07/20/15	C	C	AB	B	0.70	12.05	pass	0.82	0.20	0.58	pass	0.74	0.55	4.08	pass	0.01
07/20/15	C	C	AB	C	0.74	12.92	pass	0.97	0.22	0.27	pass	0.30	0.59			0.01
07/20/15	C	C	AB	D	0.74	13.04	pass	0.88	0.22	0.24	pass	0.29	0.59			0.01
07/22/15	C	C	AB	A	1.27	10.99	pass	0.81	0.37	0.45	pass	0.75	1.01	2.77	pass	0.02
07/22/15	C	C	AB	B	0.95	8.45	pass	0.66	0.28	0.34	pass	0.61	0.76	0.58	fail	0.02
07/22/15	C	C	AB	C	1.02	8.89	pass	0.95	0.30	1.05	pass	0.93	0.81	1.76	pass	0.02
07/22/15	C	C	AB	D	1.02	8.64	pass	0.98	0.30	0.43	pass	0.96	0.81	0.94	pass	0.02
07/24/15	C	C	AB	A	0.68	11.28	pass	0.98	0.20	0.11	fail	0.08	0.54			0.01
07/24/15	C	C	AB	B	0.51	9.48	pass	0.59	0.15	0.99	pass	0.53	0.41	7.52	pass	0.01
07/24/15	C	C	AB	C	0.55	9.46	pass	0.55	0.16	0.11	fail	0.05	0.44			0.01
07/24/15	C	C	AB	D	0.55	9.78	pass	0.78	0.16	0.58	pass	0.45	0.44			0.01
07/29/15	C	C	AB	A	4.41	10.80	pass	0.90	1.28	0.41	fail	0.88	3.51	1.74	fail	0.06
07/29/15	C	C	AB	B	3.31	8.39	pass	1.00	0.96	0.35	fail	0.86	2.63	3.01	pass	0.06
07/29/15	C	C	AB	C	3.53	8.73	pass	1.00	1.02	0.37	fail	0.98	2.81	1.59	fail	0.06
07/29/15	C	C	AB	D	3.53	8.41	pass	0.98	1.02	0.35	fail	0.98	2.81	1.09	fail	0.06
08/07/15	C	C	AB	A	5.29	11.81	pass	0.79	1.54	0.80	fail	0.61	4.21			0.08
08/07/15	C	C	AB	B	3.97	8.47	pass	0.79	1.15	1.58	pass	0.70	3.16	1.86	fail	0.08
08/07/15	C	C	AB	C	4.23	8.66	pass	1.00	1.23	0.22	fail	1.00	3.37	0.68	fail	0.08
08/07/15	C	C	AB	D	4.23	9.09	pass	0.86	1.23	0.69	fail	0.82	3.37	3.53	pass	0.08
08/14/15	C	C	AB	A	1.59	10.87	pass	0.72	0.46	0.61	pass	0.69	1.26	1.28	pass	0.02
08/14/15	C	C	AB	B	1.19	8.75	pass	0.55	0.35	0.10	fail	0.05	0.95			0.02
08/14/15	C	C	AB	C	1.27	8.53	pass	0.98	0.37	0.16	fail	0.89	1.01	0.12	fail	0.02
08/14/15	C	C	AB	D	1.27	8.94	pass	1.00	0.37	0.67	pass	1.00	1.01	2.17	pass	0.02
08/21/15	C	C	AB	A	18.15	10.44	fail	0.80	5.27	0.11	fail	0.80	14.43			0.26
08/21/15	C	C	AB	B	13.61	7.85	fail	0.60	3.95	0.04	fail	0.10	10.82			0.26
08/21/15	C	C	AB	C	14.52	8.24	fail	0.36	4.21	0.09	fail	0.16	11.55			0.26
08/21/15	C	C	AB	D	14.52	8.25	fail	0.99	4.21	0.29	fail	0.97	11.55	1.43	fail	0.26

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL (N_2O-N g ha^{-1} d^{-1})	Measured Flux	Pass/Fail	R^2	MDL (N_2O-N g ha^{-1} d^{-1})	Measured Flux	Pass/Fail	R^2	MDL (N_2O-N g ha^{-1} d^{-1})	Measured Flux	Pass/Fail	R^2
06/15/15	C	C	FM	A	6.10	13.41	pass	0.90	1.77	0.15	fail	0.90	4.85			0.10
06/15/15	C	C	FM	B	5.08	11.18	pass	0.93	1.48	0.13	fail	0.60	4.04			0.10
06/15/15	C	C	FM	C	5.42	12.35	pass	0.90	1.57	0.18	fail	0.40	4.31			0.10
06/15/15	C	C	FM	D	5.42	11.85	pass	0.20	1.57	0.05	fail	0.20	4.31			0.10
06/18/15	C	C	FM	A	2.36	14.29	pass	0.97	0.69	0.15	fail	0.30	1.88			0.04
06/18/15	C	C	FM	B	1.97	11.82	pass	0.98	0.57	0.29	fail	0.89	1.56	2.08	pass	0.04
06/18/15	C	C	FM	C	2.10	12.36	pass	0.92	0.61	0.58	fail	0.89	1.67	0.82	fail	0.04
06/18/15	C	C	FM	D	2.10	12.37	pass	0.90	0.61	0.34	fail	0.88	1.67	0.73	fail	0.04
06/23/15	C	C	FM	A	4.11	14.84	pass	0.54	1.19	0.55	fail	0.33	3.27			0.06
06/23/15	C	C	FM	B	3.42	17.78	pass	0.85	0.99	1.39	pass	0.20	2.72			0.06
06/23/15	C	C	FM	C	3.65	15.61	pass	0.89	1.06	2.37	pass	0.84	2.90	13.68	pass	0.06
06/23/15	C	C	FM	D	3.65	14.18	pass	0.83	1.06	0.99	fail	0.66	2.90	15.03	pass	0.06
06/24/15	C	C	FM	A	4.42	15.26	pass	0.94	1.28	0.47	fail	0.44	3.52			0.07
06/24/15	C	C	FM	B	3.69	15.39	pass	0.68	1.07	1.29	pass	0.42	2.93	31.41	pass	0.07
06/24/15	C	C	FM	C	3.93	41.78	pass	0.99	1.14	14.00	pass	0.83	3.13	139.68	pass	0.07
06/24/15	C	C	FM	D	3.93	15.09	pass	0.99	1.14	2.71	pass	0.99	3.13	9.36	pass	0.07
06/26/15	C	C	FM	A	3.42	14.00	pass	0.50	0.99	0.49	fail	0.50	2.72	2.04	fail	0.06
06/26/15	C	C	FM	B	2.85	15.00	pass	0.95	0.83	0.49	fail	0.10	2.27			0.06
06/26/15	C	C	FM	C	3.04	18.29	pass	0.53	0.88	0.52	fail	0.04	2.42			0.06
06/26/15	C	C	FM	D	3.04	14.24	pass	0.99	0.88	3.38	pass	0.98	2.42	7.06	pass	0.06
07/03/15	C	C	FM	A	3.21	26.31	pass	0.79	0.93	8.32	pass	0.69	2.55	72.57	pass	0.05
07/03/15	C	C	FM	B	2.67	88.13	pass	0.66	0.78	9.14	pass	0.07	2.12			0.05
07/03/15	C	C	FM	C	2.85	28.96	pass	0.86	0.83	48.47	pass	0.74	2.27	42.79	pass	0.05
07/03/15	C	C	FM	D	2.85	11.05	pass	0.97	0.83	26.85	pass	0.77	2.27	8.85	pass	0.05
07/10/15	C	C	FM	A	3.29	27.03	pass	0.79	0.96	8.55	pass	0.69	2.62	74.55	pass	0.05
07/10/15	C	C	FM	B	2.74	90.54	pass	0.66	0.80	9.39	pass	0.07	2.18			0.05
07/10/15	C	C	FM	C	2.93	29.75	pass	0.86	0.85	49.80	pass	0.74	2.33	43.95	pass	0.05
07/10/15	C	C	FM	D	2.93	11.35	pass	0.97	0.85	27.58	pass	0.77	2.33	9.09	pass	0.05
07/16/15	C	C	FM	A	1.39	47.80	pass	0.70	0.40	10.26	pass	0.26	1.11			0.02
07/16/15	C	C	FM	B	1.16	43.25	pass	0.97	0.34	30.84	pass	0.97	0.92	90.29	pass	0.02
07/16/15	C	C	FM	C	1.24	120.24	pass	1.00	0.36	69.95	pass	0.95	0.99	388.19	pass	0.02
07/16/15	C	C	FM	D	1.24	87.15	pass	1.00	0.36	68.19	pass	1.00	0.99	228.70	pass	0.02
07/17/15	C	C	FM	A	3.56	53.36	pass	1.00	1.03	31.62	pass	0.99	2.83	127.53	pass	0.06
07/17/15	C	C	FM	B	2.96	86.20	pass	1.00	0.86	52.53	pass	0.96	2.36	266.39	pass	0.06
07/17/15	C	C	FM	C	3.16	124.81	pass	1.00	0.92	81.25	pass	0.97	2.51	379.54	pass	0.06
07/17/15	C	C	FM	D	3.16	69.67	pass	1.00	0.92	39.22	pass	0.95	2.51	215.14	pass	0.06
07/18/15	C	C	FM	A	1.04	17.52	pass	1.00	0.30	6.64	pass	0.96	0.82	10.25	pass	0.02
07/18/15	C	C	FM	B	0.86	23.75	pass	0.86	0.25	15.83	pass	0.82	0.69	28.06	pass	0.02
07/18/15	C	C	FM	C	0.92	67.89	pass	1.00	0.27	40.08	pass	0.98	0.73	179.78	pass	0.02
07/18/15	C	C	FM	D	0.92	33.98	pass	0.73	0.27	6.12	pass	0.41	0.73			0.02
07/20/15	C	C	FM	A	0.84	17.93	pass	1.00	0.24	8.69	pass	0.95	0.67	12.30	pass	0.01
07/20/15	C	C	FM	B	0.70	34.69	pass	0.71	0.20	11.10	pass	0.63	0.55	86.48	pass	0.01
07/20/15	C	C	FM	C	0.74	73.12	pass	0.96	0.22	25.44	pass	0.66	0.59			0.01
07/20/15	C	C	FM	D	0.74	18.26	pass	0.90	0.22	6.84	pass	0.89	0.59	16.75	pass	0.01
07/22/15	C	C	FM	A	1.14	10.09	pass	1.00	0.33	1.01	pass	0.99	0.91	2.12	pass	0.02
07/22/15	C	C	FM	B	0.95	8.65	pass	0.97	0.28	4.56	pass	0.80	0.76	2.10	pass	0.02
07/22/15	C	C	FM	C	1.02	7.38	pass	0.97	0.30	21.57	pass	0.77	0.81	6.28	pass	0.02
07/22/15	C	C	FM	D	1.02	11.55	pass	0.77	0.30	2.02	pass	0.76	0.81	9.13	pass	0.02
07/24/15	C	C	FM	A	0.62	12.52	pass	0.71	0.18	3.17	pass	0.69	0.49	7.21	pass	0.01
07/24/15	C	C	FM	B	0.51	24.25	pass	0.93	0.15	5.23	pass	0.44	0.41			0.01
07/24/15	C	C	FM	C	0.55	41.25	pass	1.00	0.16	26.98	pass	0.99	0.44	107.09	pass	0.01
07/24/15	C	C	FM	D	0.55	17.65	pass	0.69	0.16	3.20	pass	0.33	0.44			0.01
07/29/15	C	C	FM	A	3.97	9.87	pass	0.96	1.15	1.05	fail	0.96	3.16	2.47	fail	0.06
07/29/15	C	C	FM	B	3.31	8.31	pass	0.94	0.96	5.61	pass	0.78	2.63	3.23	pass	0.06
07/29/15	C	C	FM	C	3.53	29.12	pass	0.74	1.02	8.28	pass	0.44	2.81			0.06
07/29/15	C	C	FM	D	3.53	12.99	pass	0.89	1.02	2.50	pass	0.70	2.81	38.52	pass	0.06
08/07/15	C	C	FM	A	4.76	11.57	pass	1.00	1.38	2.35	pass	0.98	3.79	4.39	pass	0.08
08/07/15	C	C	FM	B	3.97	21.44	pass	0.99	1.15	8.95	pass	0.94	3.16	49.69	pass	0.08
08/07/15	C	C	FM	C	4.23	42.58	pass	0.73	1.23	13.43	pass	0.42	3.37			0.08
08/07/15	C	C	FM	D	4.23	13.66	pass	0.96	1.23	2.89	pass	0.84	3.37	24.13	pass	0.08
08/14/15	C	C	FM	A	1.43	10.46	pass	0.58	0.41	0.70	pass	0.58	1.14	1.54	pass	0.02
08/14/15	C	C	FM	B	1.19	10.94	pass	1.00	0.35	2.43	pass	0.97	0.95	11.08	pass	0.02
08/14/15	C	C	FM	C	1.27	12.86	pass	1.00	0.37	29.03	pass	0.87	1.01	18.42	pass	0.02
08/14/15	C	C	FM	D	1.27	22.92	pass	0.96	0.37	2.44	pass	0.15	1.01			0.02
08/21/15	C	C	FM	A	16.33	9.92	fail	0.93	4.74	0.30	fail	0.60	12.99			0.26
08/21/15	C	C	FM	B	13.61	9.19	fail	0.93	3.95	0.50	fail	0.60	10.82			0.26
08/21/15	C	C	FM	C	14.52	12.58	fail	0.89	4.21	9.99	pass	0.75	11.55	7.51	fail	0.26
08/21/15	C	C	FM	D	14.52	11.82	fail	0.94	4.21	4.79	pass	0.94	11.55	9.93	fail	0.26

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2
					N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}			
06/15/15	C	C	UR	A	5.42	11.95	pass	1.00	1.57	0.29	fail	0.79	4.31	3.59	fail	0.10
06/15/15	C	C	UR	B	6.10	13.55	pass	0.55	1.77	0.13	fail	0.45	4.85	0.14	fail	0.10
06/15/15	C	C	UR	C	5.76	13.16	pass	0.74	1.67	0.12	fail	0.26	4.58			0.10
06/15/15	C	C	UR	D	6.10	13.33	pass	0.60	1.77	0.05	fail	0.10	4.85			0.10
06/18/15	C	C	UR	A	2.10	12.81	pass	0.66	0.61	0.36	fail	0.61	1.67	2.48	pass	0.04
06/18/15	C	C	UR	B	2.36	14.10	pass	0.91	0.69	0.53	fail	0.82	1.88	0.62	fail	0.04
06/18/15	C	C	UR	C	2.23	13.15	pass	0.55	0.65	0.12	fail	0.45	1.77	1.18	fail	0.04
06/18/15	C	C	UR	D	2.36	15.52	pass	0.23	0.69	0.20	fail	0.04	1.88			0.04
06/23/15	C	C	UR	A	3.65	12.83	pass	0.99	1.06	0.54	fail	0.87	2.90	4.40	pass	0.06
06/23/15	C	C	UR	B	4.11	15.75	pass	0.95	1.19	0.25	fail	0.05	3.27			0.06
06/23/15	C	C	UR	C	3.88	13.05	pass	0.93	1.13	0.07	fail	0.60	3.08			0.06
06/23/15	C	C	UR	D	4.11	15.87	pass	1.00	1.19	1.51	pass	0.98	3.27	6.89	pass	0.06
06/24/15	C	C	UR	A	3.93	13.07	pass	0.92	1.14	0.53	fail	0.70	3.13	7.06	pass	0.07
06/24/15	C	C	UR	B	4.42	15.05	pass	0.60	1.28	0.15	fail	0.10	3.52			0.07
06/24/15	C	C	UR	C	4.18	12.86	pass	0.93	1.21	0.26	fail	0.90	3.32	1.31	fail	0.07
06/24/15	C	C	UR	D	4.42	16.02	pass	0.30	1.28	0.20	fail	0.23	3.52			0.07
06/26/15	C	C	UR	A	3.04	12.41	pass	1.00	0.88	0.28	fail	0.79	2.42	3.47	pass	0.06
06/26/15	C	C	UR	B	3.42	13.41	pass	0.80	0.99	0.20	fail	0.80	2.72			0.06
06/26/15	C	C	UR	C	3.23	12.65	pass	0.91	0.94	0.21	fail	0.85	2.57	0.32	fail	0.06
06/26/15	C	C	UR	D	3.42	15.86	pass	0.44	0.99	1.67	pass	0.44	2.72	6.74	pass	0.06
07/03/15	C	C	UR	A	2.85	16.11	pass	0.86	0.83	1.50	pass	0.59	2.27	28.41	pass	0.05
07/03/15	C	C	UR	B	3.21	14.24	pass	0.60	0.93	0.15	fail	0.10	2.55			0.05
07/03/15	C	C	UR	C	3.03	12.66	pass	0.77	0.88	0.58	fail	0.64	2.41	0.46	fail	0.05
07/03/15	C	C	UR	D	3.21	14.05	pass	0.80	0.93	0.78	fail	0.79	2.55	3.13	pass	0.05
07/10/15	C	C	UR	A	2.93	16.55	pass	0.86	0.85	1.54	pass	0.59	2.33	29.18	pass	0.05
07/10/15	C	C	UR	B	3.29	14.63	pass	0.60	0.96	0.15	fail	0.10	2.62			0.05
07/10/15	C	C	UR	C	3.11	13.00	pass	0.77	0.90	0.59	fail	0.64	2.47	0.48	fail	0.05
07/10/15	C	C	UR	D	3.29	14.43	pass	0.80	0.96	0.80	fail	0.79	2.62	3.21	pass	0.05
07/16/15	C	C	UR	A	1.24	19.41	pass	0.99	0.36	9.01	pass	0.98	0.99	20.25	pass	0.02
07/16/15	C	C	UR	B	1.39	15.84	pass	0.89	0.40	1.26	pass	0.69	1.11	21.08	pass	0.02
07/16/15	C	C	UR	C	1.32	15.13	pass	1.00	0.38	2.75	pass	1.00	1.05	7.40	pass	0.02
07/16/15	C	C	UR	D	1.39	18.23	pass	0.98	0.40	5.28	pass	0.98	1.11	13.16	pass	0.02
07/17/15	C	C	UR	A	3.16	21.37	pass	1.00	0.92	9.74	pass	1.00	2.51	28.03	pass	0.06
07/17/15	C	C	UR	B	3.56	16.90	pass	1.00	1.03	2.73	pass	0.98	2.83	12.32	pass	0.06
07/17/15	C	C	UR	C	3.36	18.44	pass	0.94	0.97	1.87	pass	0.48	2.67			0.06
07/17/15	C	C	UR	D	3.56	21.89	pass	1.00	1.03	7.50	pass	1.00	2.83	27.01	pass	0.06
07/18/15	C	C	UR	A	0.92	19.08	pass	0.98	0.27	5.86	pass	0.97	0.73	24.26	pass	0.02
07/18/15	C	C	UR	B	1.04	15.91	pass	0.84	0.30	1.27	pass	0.62	0.82			0.02
07/18/15	C	C	UR	C	0.98	13.58	pass	0.96	0.28	1.32	pass	0.96	0.78	3.26	pass	0.02
07/18/15	C	C	UR	D	1.04	19.47	pass	0.99	0.30	4.46	pass	0.98	0.82	18.58	pass	0.02
07/20/15	C	C	UR	A	0.74	15.53	pass	0.99	0.22	7.88	pass	0.93	0.59	10.33	pass	0.01
07/20/15	C	C	UR	B	0.84	16.53	pass	0.57	0.24	1.79	pass	0.55	0.67	10.44	pass	0.01
07/20/15	C	C	UR	C	0.79	13.41	pass	0.98	0.23	1.15	pass	0.98	0.63	2.84	pass	0.01
07/20/15	C	C	UR	D	0.84	17.77	pass	0.94	0.24	2.04	pass	0.75	0.67	22.53	pass	0.01
07/22/15	C	C	UR	A	1.02	10.02	pass	0.30	0.30	0.36	pass	0.10	0.81			0.02
07/22/15	C	C	UR	B	1.14	9.99	pass	0.68	0.33	1.21	pass	0.56	0.91	1.01	pass	0.02
07/22/15	C	C	UR	C	1.08	9.03	pass	0.10	0.31	0.05	fail	0.10	0.86			0.02
07/22/15	C	C	UR	D	1.14	13.38	pass	0.88	0.33	0.98	pass	0.26	0.91			0.02
07/24/15	C	C	UR	A	0.55	14.94	pass	0.66	0.16	1.68	pass	0.34	0.44			0.01
07/24/15	C	C	UR	B	0.62	14.55	pass	0.96	0.18	2.90	pass	0.84	0.49	23.56	pass	0.01
07/24/15	C	C	UR	C	0.58				0.17				0.46	2.65	pass	0.01
07/24/15	C	C	UR	D	0.62	13.00	pass	0.62	0.18	1.71	pass	0.56	0.49	13.24	pass	0.01
07/29/15	C	C	UR	A	3.53	15.21	pass	0.92	1.02	5.24	pass	0.88	2.81	27.07	pass	0.06
07/29/15	C	C	UR	B	3.97	10.16	pass	0.96	1.15	0.22	fail	0.38	3.16			0.06
07/29/15	C	C	UR	C	3.75	9.60	pass	0.96	1.09	0.21	fail	0.38	2.98			0.06
07/29/15	C	C	UR	D	3.97	13.92	pass	0.79	1.15	1.27	pass	0.27	3.16			0.06
08/07/15	C	C	UR	A	4.23	7.71	pass	0.88	1.23	23.23	pass	0.68	3.37	8.10	pass	0.08
08/07/15	C	C	UR	B	4.76	13.68	pass	0.40	1.38	-0.87	fail	0.08	3.79			0.08
08/07/15	C	C	UR	C	4.50	10.71	pass	0.99	1.31	0.52	fail	0.40	3.58			0.08
08/07/15	C	C	UR	D	4.76	13.44	pass	0.90	1.38	2.10	pass	0.70	3.79	33.54	pass	0.08
08/14/15	C	C	UR	A	1.27	29.84	pass	1.00	0.37	8.94	pass	0.71	1.01	227.21	pass	0.02
08/14/15	C	C	UR	B	1.43	17.88	pass	0.86	0.41	5.23	pass	0.84	1.14	24.63	pass	0.02
08/14/15	C	C	UR	C	1.35	8.55	pass	0.90	0.39	2.37	pass	0.62	1.07	0.18	fail	0.02
08/14/15	C	C	UR	D	1.43	10.56	pass	0.73	0.41	3.02	pass	0.61	1.14	2.56	pass	0.02
08/21/15	C	C	UR	A	14.52	27.07	pass	0.93	4.21	24.67	pass	0.90	11.55	46.73	pass	0.26
08/21/15	C	C	UR	B	16.33	16.31	fail	0.68	4.74	4.16	fail	0.56	12.99	53.52	pass	0.26
08/21/15	C	C	UR	C	15.42				4.48				12.27	1.23	fail	0.26
08/21/15	C	C	UR	D	16.33	10.82	fail	0.77	4.74	0.28	fail	0.56	12.99	4.00	fail	0.26

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2
					N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}			
05/22/15	C	P	0N	A	2.52	8.97	pass	1.00	0.73	0.00	fail	1.00	2.00			0.05
05/22/15	C	P	0N	B	2.88	10.22	pass	0.93	0.83	0.07	fail	0.60	2.29			0.05
05/22/15	C	P	0N	C	2.88	10.48	pass	1.00	0.83	0.00	fail	0.00	2.29			0.05
05/22/15	C	P	0N	D	3.23	11.42	pass	0.40	0.94	-0.03	fail	0.07	2.57			0.05
05/23/15	C	P	0N	A	3.89	8.96	pass	1.00	1.13	0.00	fail	1.00	3.09			0.08
05/23/15	C	P	0N	B	4.44	10.21	pass	0.93	1.29	0.07	fail	0.60	3.53			0.08
05/23/15	C	P	0N	C	4.44	10.54	pass	0.90	1.29	0.09	fail	0.40	3.53			0.08
05/23/15	C	P	0N	D	5.00	11.60	pass	0.80	1.45	0.10	fail	0.80	3.98			0.08
05/24/15	C	P	0N	A	3.44	9.00	pass	0.80	1.00	0.08	fail	0.80	2.74			0.07
05/24/15	C	P	0N	B	3.93	10.18	pass	0.93	1.14	0.07	fail	0.60	3.13			0.07
05/24/15	C	P	0N	C	3.93	10.51	pass	0.90	1.14	0.09	fail	0.40	3.13			0.07
05/24/15	C	P	0N	D	4.42	11.60	pass	0.20	1.28	0.05	fail	0.20	3.52			0.07
05/25/15	C	P	0N	A	2.71	8.89	pass	0.90	0.79	0.12	fail	0.90	2.15			0.05
05/25/15	C	P	0N	B	3.09	10.35	pass	0.40	0.90	-0.02	fail	0.07	2.46			0.05
05/25/15	C	P	0N	C	3.09	10.52	pass	0.90	0.90	0.09	fail	0.40	2.46			0.05
05/25/15	C	P	0N	D	3.48	11.62	pass	0.40	1.01	0.03	fail	0.07	2.77			0.05
05/26/15	C	P	0N	A	2.68	9.04	pass	0.40	0.78	0.02	fail	0.07	2.13			0.05
05/26/15	C	P	0N	B	3.06	10.22	pass	1.00	0.89	0.00	fail	1.00	2.44			0.05
05/26/15	C	P	0N	C	3.06	10.55	pass	0.84	0.89	0.02	fail	0.02	2.44			0.05
05/26/15	C	P	0N	D	3.45	11.50	pass	1.00	1.00	0.00	fail	1.00	2.74			0.05
06/02/15	C	P	0N	A	4.05	10.80	pass	0.96	1.18	0.08	fail	0.16	3.22			0.08
06/02/15	C	P	0N	B	4.63	12.31	pass	1.00	1.34	0.39	fail	0.70	3.68			0.08
06/02/15	C	P	0N	C	4.63	12.64	pass	0.97	1.34	0.41	fail	0.62	3.68			0.08
06/02/15	C	P	0N	D	5.21	13.26	pass	0.93	1.51	0.08	fail	0.60	4.14			0.08
06/18/15	C	P	0N	A	4.34	10.46	pass	0.84	1.26	0.04	fail	0.04	3.45			0.09
06/18/15	C	P	0N	B	4.96	11.75	pass	0.93	1.44	0.25	fail	0.90	3.95	1.24	fail	0.09
06/18/15	C	P	0N	C	4.96	12.10	pass	0.88	1.44	0.43	fail	0.87	3.95	1.63	fail	0.09
06/18/15	C	P	0N	D	5.58	13.28	pass	0.90	1.62	0.15	fail	0.90	4.44			0.09
06/19/15	C	P	0N	A	3.13	10.33	pass	0.91	0.91	0.18	fail	0.85	2.49	1.09	fail	0.06
06/19/15	C	P	0N	B	3.58	11.91	pass	1.00	1.04	0.00	fail	0.00	2.85			0.06
06/19/15	C	P	0N	C	3.58	12.18	pass	0.81	1.04	0.36	fail	0.75	2.85	2.22	fail	0.06
06/19/15	C	P	0N	D	4.03	13.36	pass	0.93	1.17	0.08	fail	0.60	3.20			0.06
06/23/15	C	P	0N	A	6.45	10.64	pass	0.90	1.87	0.08	fail	0.40	5.13			0.13
06/23/15	C	P	0N	B	7.38	12.35	pass	0.99	2.14	0.16	fail	0.52	5.87			0.13
06/23/15	C	P	0N	C	7.38	12.47	pass	0.99	2.14	0.36	fail	0.91	5.87	2.32	fail	0.13
06/23/15	C	P	0N	D	8.30	13.60	pass	1.00	2.41	0.25	fail	1.00	6.60			0.13
06/24/15	C	P	0N	A	7.24	10.35	pass	0.80	2.10	0.08	fail	0.80	5.76			0.15
06/24/15	C	P	0N	B	8.27	11.92	pass	0.93	2.40	0.13	fail	0.60	6.58			0.15
06/24/15	C	P	0N	C	8.27	12.14	pass	0.93	2.40	0.13	fail	0.60	6.58			0.15
06/24/15	C	P	0N	D	9.31	13.77	pass	0.99	2.70	0.17	fail	0.52	7.40			0.15
06/25/15	C	P	0N	A	3.95	10.22	pass	1.00	1.15	0.19	fail	1.00	3.14			0.08
06/25/15	C	P	0N	B	4.52	11.87	pass	0.99	1.31	0.29	fail	0.97	3.59	0.51	fail	0.08
06/25/15	C	P	0N	C	4.52	11.83	pass	0.98	1.31	0.35	fail	0.98	3.59	1.10	fail	0.08
06/25/15	C	P	0N	D	5.08	13.29	pass	0.80	1.48	0.20	fail	0.80	4.04			0.08
06/26/15	C	P	0N	A	3.15	8.95	pass	0.64	0.91	0.17	fail	0.60	2.50	0.10	fail	0.07
06/26/15	C	P	0N	B	3.59	10.48	pass	0.28	1.04	0.13	fail	0.18	2.86	0.09	fail	0.07
06/26/15	C	P	0N	C	3.59	10.27	pass	0.97	1.04	0.54	fail	0.81	2.86	5.39	pass	0.07
06/26/15	C	P	0N	D	4.04	11.23	pass	0.42	1.17	0.29	fail	0.42	3.22	1.22	fail	0.07
07/03/15	C	P	0N	A	3.69	10.48	pass	0.98	1.07	0.06	fail	0.16	2.93			0.08
07/03/15	C	P	0N	B	4.21	11.79	pass	1.00	1.22	0.00	fail	0.00	3.35			0.08
07/03/15	C	P	0N	C	4.21	11.98	pass	0.98	1.22	0.07	fail	0.16	3.35			0.08
07/03/15	C	P	0N	D	4.74	13.38	pass	0.93	1.38	0.27	fail	0.90	3.77	1.36	fail	0.08
07/17/15	C	P	0N	A	4.07	10.19	pass	0.91	1.18	0.17	fail	0.85	3.24	0.27	fail	0.08
07/17/15	C	P	0N	B	4.65	11.83	pass	0.60	1.35	0.04	fail	0.10	3.70			0.08
07/17/15	C	P	0N	C	4.65	11.80	pass	0.55	1.35	0.11	fail	0.45	3.70	1.10	fail	0.08
07/17/15	C	P	0N	D	5.24	13.53	pass	0.98	1.52	0.35	fail	0.89	4.16	2.46	fail	0.08
07/28/15	C	P	0N	A	5.54	7.09	pass	0.97	1.61	0.12	fail	0.30	4.40			0.11
07/28/15	C	P	0N	B	6.33	8.13	pass	0.93	1.84	0.07	fail	0.60	5.03			0.11
07/28/15	C	P	0N	C	6.33	8.37	pass	0.72	1.84	0.24	fail	0.69	5.03	1.41	fail	0.11
07/28/15	C	P	0N	D	7.12	9.30	pass	0.40	2.07	0.02	fail	0.07	5.66			0.11
08/05/15	C	P	0N	A	5.09	7.39	pass	0.93	1.48	0.06	fail	0.60	4.05			0.10
08/05/15	C	P	0N	B	5.82	8.13	pass	0.95	1.69	0.25	fail	0.69	4.63			0.10
08/05/15	C	P	0N	C	5.82	8.67	pass	0.98	1.69	0.07	fail	0.16	4.63			0.10
08/05/15	C	P	0N	D	6.55	9.38	pass	0.15	1.90	0.08	fail	0.09	5.21			0.10
08/12/15	C	P	0N	A	2.53	7.72	pass	1.00	0.73	0.00	fail	0.00	2.01			0.05
08/12/15	C	P	0N	B	2.89	8.13	pass	0.93	0.84	0.07	fail	0.60	2.30			0.05
08/12/15	C	P	0N	C	2.89	8.38	pass	1.00	0.84	0.22	fail	1.00	2.30			0.05
08/12/15	C	P	0N	D	3.25	9.94	pass	0.64	0.94	0.22	fail	0.60	2.58	1.23	fail	0.05

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2
					N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}			
05/22/15	C	P	AB	A	2.88	10.67	pass	0.98	0.83	0.07	fail	0.16	2.29			0.05
05/22/15	C	P	AB	B	2.70	9.58	pass	0.93	0.78	0.06	fail	0.60	2.14			0.05
05/22/15	C	P	AB	C	3.23	11.61	pass	0.80	0.94	0.10	fail	0.80	2.57			0.05
05/22/15	C	P	AB	D	2.88	10.25	pass	1.00	0.83	0.00	fail	1.00	2.29			0.05
05/23/15	C	P	AB	A	4.44	10.17	pass	0.90	1.29	0.14	fail	0.90	3.53			0.08
05/23/15	C	P	AB	B	4.17	9.63	pass	0.98	1.21	0.15	fail	0.89	3.31	1.05	fail	0.08
05/23/15	C	P	AB	C	5.00	11.56	pass	0.93	1.45	-0.08	fail	0.60	3.98			0.08
05/23/15	C	P	AB	D	4.44	10.34	pass	0.40	1.29	0.02	fail	0.07	3.53			0.08
05/24/15	C	P	AB	A	3.93	10.32	pass	0.40	1.14	0.02	fail	0.07	3.13			0.07
05/24/15	C	P	AB	B	3.69	9.76	pass	0.93	1.07	0.06	fail	0.60	2.93			0.07
05/24/15	C	P	AB	C	4.42	11.83	pass	0.90	1.28	0.10	fail	0.40	3.52			0.07
05/24/15	C	P	AB	D	3.93	10.31	pass	0.60	1.14	0.05	fail	0.10	3.13			0.07
05/25/15	C	P	AB	A	3.09	10.26	pass	0.98	0.90	0.16	fail	0.89	2.46	1.12	fail	0.05
05/25/15	C	P	AB	B	2.90	9.56	pass	0.93	0.84	0.06	fail	0.60	2.31			0.05
05/25/15	C	P	AB	C	3.48	11.76	pass	1.00	1.01	0.00	fail	1.00	2.77			0.05
05/25/15	C	P	AB	D	3.09	10.52	pass	0.90	0.90	0.09	fail	0.40	2.46			0.05
05/26/15	C	P	AB	A	3.06	10.29	pass	0.90	0.89	0.09	fail	0.40	2.44			0.05
05/26/15	C	P	AB	B	2.87	9.62	pass	0.98	0.83	0.15	fail	0.89	2.28	0.12	fail	0.05
05/26/15	C	P	AB	C	3.45	11.84	pass	0.90	1.00	0.10	fail	0.40	2.74			0.05
05/26/15	C	P	AB	D	3.06	10.52	pass	0.90	0.89	0.09	fail	0.40	2.44			0.05
06/02/15	C	P	AB	A	4.63	48.64	pass	0.98	1.34	26.19	pass	0.94	3.68	134.17	pass	0.08
06/02/15	C	P	AB	B	4.34	40.44	pass	0.98	1.26	20.38	pass	0.93	3.45	113.93	pass	0.08
06/02/15	C	P	AB	C	5.21	34.21	pass	0.93	1.51	6.01	pass	0.45	4.14			0.08
06/02/15	C	P	AB	D	4.63	19.52	pass	0.83	1.34	2.11	pass	0.40	3.68			0.08
06/18/15	C	P	AB	A	4.96	20.58	pass	0.99	1.44	10.12	pass	0.98	3.95	24.93	pass	0.09
06/18/15	C	P	AB	B	4.65	13.13	pass	0.83	1.35	1.66	pass	0.78	3.70	9.51	pass	0.09
06/18/15	C	P	AB	C	5.58	15.13	pass	0.84	1.62	3.00	pass	0.79	4.44	4.99	pass	0.09
06/18/15	C	P	AB	D	4.96	15.26	pass	0.92	1.44	3.07	pass	0.90	3.95	13.07	pass	0.09
06/19/15	C	P	AB	A	3.58	37.39	pass	0.97	1.04	19.15	pass	0.93	2.85	95.43	pass	0.06
06/19/15	C	P	AB	B	3.35	19.18	pass	0.92	0.97	14.31	pass	0.86	2.67	20.85	pass	0.06
06/19/15	C	P	AB	C	4.03	77.55	pass	0.93	1.17	48.41	pass	0.93	3.20	198.23	pass	0.06
06/19/15	C	P	AB	D	3.58	22.45	pass	0.69	1.04	4.76	pass	0.59	2.85	44.38	pass	0.06
06/23/15	C	P	AB	A	7.38	56.16	pass	0.87	2.14	27.60	pass	0.78	5.87	215.57	pass	0.13
06/23/15	C	P	AB	B	6.92	28.03	pass	0.98	2.01	12.57	pass	0.95	5.50	61.30	pass	0.13
06/23/15	C	P	AB	C	8.30	49.72	pass	0.93	2.41	11.13	pass	0.43	6.60			0.13
06/23/15	C	P	AB	D	7.38	18.39	pass	0.85	2.14	5.31	pass	0.85	5.87	17.69	pass	0.13
06/24/15	C	P	AB	A	8.27	27.37	pass	0.99	2.40	13.41	pass	0.98	6.58	52.73	pass	0.15
06/24/15	C	P	AB	B	7.76	18.03	pass	0.99	2.25	6.18	pass	0.98	6.17	22.89	pass	0.15
06/24/15	C	P	AB	C	9.31	26.00	pass	0.98	2.70	10.44	pass	0.97	7.40	39.34	pass	0.15
06/24/15	C	P	AB	D	8.27	17.79	pass	0.99	2.40	3.71	pass	0.92	6.58	24.12	pass	0.15
06/25/15	C	P	AB	A	4.52	43.91	pass	0.97	1.31	13.09	pass	0.71	3.59	213.30	pass	0.08
06/25/15	C	P	AB	B	4.24	23.92	pass	1.00	1.23	11.86	pass	1.00	3.37	40.03	pass	0.08
06/25/15	C	P	AB	C	5.08	60.32	pass	0.99	1.48	32.30	pass	0.96	4.04	163.70	pass	0.08
06/25/15	C	P	AB	D	4.52	18.56	pass	0.94	1.31	7.38	pass	0.93	3.59	18.72	pass	0.08
06/26/15	C	P	AB	A	3.59	21.56	pass	0.80	1.04	0.59	fail	0.01	2.86			0.07
06/26/15	C	P	AB	B	3.37	11.25	pass	0.90	0.98	2.98	pass	0.81	2.68	3.27	pass	0.07
06/26/15	C	P	AB	C	4.04	14.02	pass	0.98	1.17	2.79	pass	0.97	3.22	6.99	pass	0.07
06/26/15	C	P	AB	D	3.59	12.68	pass	1.00	1.04	1.39	pass	0.85	2.86	12.95	pass	0.07
07/03/15	C	P	AB	A	4.21	12.76	pass	0.99	1.22	0.90	fail	0.99	3.35	3.08	fail	0.08
07/03/15	C	P	AB	B	3.95	12.68	pass	0.44	1.15	0.43	fail	0.09	3.14			0.08
07/03/15	C	P	AB	C	4.74	23.07	pass	0.37	1.38	0.29	fail	0.00	3.77			0.08
07/03/15	C	P	AB	D	4.21	12.94	pass	0.41	1.22	-0.11	fail	0.02	3.35			0.08
07/17/15	C	P	AB	A	4.65	12.72	pass	0.99	1.35	0.93	fail	0.98	3.70	3.86	pass	0.08
07/17/15	C	P	AB	B	4.36	11.42	pass	1.00	1.27	0.21	fail	1.00	3.47	0.62	fail	0.08
07/17/15	C	P	AB	C	5.24	14.13	pass	1.00	1.52	0.90	fail	0.98	4.16	3.87	fail	0.08
07/17/15	C	P	AB	D	4.65	12.15	pass	1.00	1.35	0.51	fail	0.99	3.70	2.04	fail	0.08
07/28/15	C	P	AB	A	6.33	8.24	pass	0.92	1.84	0.73	fail	0.75	5.03	0.38	fail	0.11
07/28/15	C	P	AB	B	5.93	7.86	pass	1.00	1.72	0.21	fail	1.00	4.72			0.11
07/28/15	C	P	AB	C	7.12	9.56	pass	0.17	2.07	0.00	fail	0.00	5.66			0.11
07/28/15	C	P	AB	D	6.33	9.07	pass	0.34	1.84	0.40	fail	0.32	5.03	2.82	fail	0.11
08/05/15	C	P	AB	A	5.82	8.51	pass	1.00	1.69	0.38	fail	0.98	4.63	1.63	fail	0.10
08/05/15	C	P	AB	B	5.46	8.13	pass	0.93	1.58	0.06	fail	0.60	4.34			0.10
08/05/15	C	P	AB	C	6.55	9.69	pass	0.84	1.90	0.20	fail	0.64	5.21			0.10
08/05/15	C	P	AB	D	5.82	8.65	pass	0.55	1.69	0.11	fail	0.45	4.63			0.10
08/12/15	C	P	AB	A	2.89	8.38	pass	1.00	0.84	0.22	fail	0.83	2.30	0.09	fail	0.05
08/12/15	C	P	AB	B	2.71	8.00	pass	0.93	0.79	0.12	fail	0.60	2.15			0.05
08/12/15	C	P	AB	C	3.25	9.90	pass	0.70	0.94	0.05	fail	0.03	2.58			0.05
08/12/15	C	P	AB	D	2.89	8.59	pass	0.72	0.84	0.24	fail	0.69	2.30	1.41	fail	0.05

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2
					N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}			
05/22/15	C	P	FM	A	2.88	10.32	pass	0.90	0.83	0.09	fail	0.40	2.29			0.05
05/22/15	C	P	FM	B	3.23	11.57	pass	0.98	0.94	0.18	fail	0.89	2.57	1.27	fail	0.05
05/22/15	C	P	FM	C	2.52	9.00	pass	0.98	0.73	0.14	fail	0.89	2.00	0.99	fail	0.05
05/22/15	C	P	FM	D	2.70	9.61	pass	1.00	0.78	0.00	fail	1.00	2.14			0.05
05/23/15	C	P	FM	A	4.44	10.47	pass	1.00	1.29	0.00	fail	0.00	3.53			0.08
05/23/15	C	P	FM	B	5.00	11.74	pass	0.93	1.45	0.08	fail	0.60	3.98			0.08
05/23/15	C	P	FM	C	3.89	8.90	pass	0.90	1.13	0.12	fail	0.90	3.09			0.08
05/23/15	C	P	FM	D	4.17	9.60	pass	1.00	1.21	0.00	fail	1.00	3.31			0.08
05/24/15	C	P	FM	A	3.93	10.34	pass	0.91	1.14	0.20	fail	0.85	3.13	1.26	fail	0.07
05/24/15	C	P	FM	B	4.42	11.56	pass	0.55	1.28	0.13	fail	0.45	3.52	1.26	fail	0.07
05/24/15	C	P	FM	C	3.44	9.11	pass	0.93	1.00	0.06	fail	0.60	2.74			0.07
05/24/15	C	P	FM	D	3.69	9.64	pass	0.80	1.07	0.09	fail	0.80	2.93			0.07
05/25/15	C	P	FM	A	3.09	10.68	pass	1.00	0.90	0.23	fail	0.83	2.46	2.29	fail	0.05
05/25/15	C	P	FM	B	3.48	11.70	pass	0.55	1.01	0.13	fail	0.45	2.77	16.79	pass	0.05
05/25/15	C	P	FM	C	2.71	9.12	pass	0.93	0.79	0.06	fail	0.60	2.15			0.05
05/25/15	C	P	FM	D	2.90	9.77	pass	0.93	0.84	0.06	fail	0.60	2.31			0.05
05/26/15	C	P	FM	A	3.06	10.60	pass	0.40	0.89	0.16	fail	0.36	2.44	1.26	fail	0.05
05/26/15	C	P	FM	B	3.45	11.82	pass	0.55	1.00	0.13	fail	0.45	2.74	1.26	fail	0.05
05/26/15	C	P	FM	C	2.68	9.23	pass	0.60	0.78	0.04	fail	0.10	2.13			0.05
05/26/15	C	P	FM	D	2.87	9.65	pass	0.80	0.83	0.09	fail	0.80	2.28			0.05
06/02/15	C	P	FM	A	4.63	16.35	pass	0.85	1.34	1.41	pass	0.49	3.68			0.08
06/02/15	C	P	FM	B	5.21	50.84	pass	0.93	1.51	12.92	pass	0.50	4.14			0.08
06/02/15	C	P	FM	C	4.05	15.44	pass	0.98	1.18	1.55	pass	0.47	3.22			0.08
06/02/15	C	P	FM	D	4.34	11.23	pass	0.93	1.26	0.13	fail	0.60	3.45			0.08
06/18/15	C	P	FM	A	4.96	12.03	pass	0.99	1.44	0.36	fail	0.91	3.95	2.32	fail	0.09
06/18/15	C	P	FM	B	5.58	45.45	pass	0.95	1.62	9.88	pass	0.43	4.44			0.09
06/18/15	C	P	FM	C	4.34	10.56	pass	0.94	1.26	1.02	fail	0.84	3.45	1.01	fail	0.09
06/18/15	C	P	FM	D	4.65	12.28	pass	0.97	1.35	1.26	fail	0.97	3.70			0.09
06/19/15	C	P	FM	A	3.58	22.38	pass	0.96	1.04	3.55	pass	0.50	2.85			0.06
06/19/15	C	P	FM	B	4.03	49.58	pass	0.74	1.17	19.16	pass	0.69	3.20	126.96	pass	0.06
06/19/15	C	P	FM	C	3.13	28.88	pass	0.79	0.91	6.15	pass	0.36	2.49			0.06
06/19/15	C	P	FM	D	3.35	37.63	pass	0.99	0.97	20.60	pass	0.97	2.67	93.55	pass	0.06
06/23/15	C	P	FM	A	7.38	28.47	pass	0.87	2.14	3.96	pass	0.41	5.87			0.13
06/23/15	C	P	FM	B	8.30	74.67	pass	0.95	2.41	30.75	pass	0.78	6.60	342.81	pass	0.13
06/23/15	C	P	FM	C	6.45	25.61	pass	0.86	1.87	3.43	pass	0.32	5.13			0.13
06/23/15	C	P	FM	D	6.92	26.02	pass	0.99	2.01	12.40	pass	0.99	5.50	43.01	pass	0.13
06/24/15	C	P	FM	A	8.27	15.59	pass	0.95	2.40	3.44	pass	0.94	6.58	14.17	pass	0.15
06/24/15	C	P	FM	B	9.31	52.36	pass	0.99	2.70	31.39	pass	0.98	7.40	124.06	pass	0.15
06/24/15	C	P	FM	C	7.24	13.61	pass	0.97	2.10	3.67	pass	0.97	5.76	9.82	pass	0.15
06/24/15	C	P	FM	D	7.76	17.00	pass	1.00	2.25	3.87	pass	0.93	6.17	23.89	pass	0.15
06/25/15	C	P	FM	A	4.52	36.08	pass	1.00	1.31	22.81	pass	1.00	3.59	75.08	pass	0.08
06/25/15	C	P	FM	B	5.08	50.67	pass	0.96	1.48	33.27	pass	0.96	4.04	110.85	pass	0.08
06/25/15	C	P	FM	C	3.95	24.91	pass	1.00	1.15	8.41	pass	0.89	3.14	64.47	pass	0.08
06/25/15	C	P	FM	D	4.24	55.93	pass	1.00	1.23	26.13	pass	0.91	3.37	184.68	pass	0.08
06/26/15	C	P	FM	A	3.59	17.33	pass	0.87	1.04	3.39	pass	0.82	2.86	21.53	pass	0.07
06/26/15	C	P	FM	B	4.04	17.99	pass	0.78	1.17	4.62	pass	0.75	3.22	10.04	pass	0.07
06/26/15	C	P	FM	C	3.15	19.21	pass	0.71	0.91	4.00	pass	0.39	2.50			0.07
06/26/15	C	P	FM	D	3.37	14.62	pass	0.93	0.98	4.79	pass	0.93	2.68	14.31	pass	0.07
07/03/15	C	P	FM	A	4.21	9.43	pass	0.93	1.22	4.72	pass	0.60	3.35			0.08
07/03/15	C	P	FM	B	4.74	14.49	pass	0.94	1.38	1.97	pass	0.93	3.77	3.66	fail	0.08
07/03/15	C	P	FM	C	3.69	16.97	pass	0.63	1.07	1.80	pass	0.19	2.93			0.08
07/03/15	C	P	FM	D	3.95	12.33	pass	0.76	1.15	0.92	fail	0.76	3.14	3.70	pass	0.08
07/17/15	C	P	FM	A	4.65	11.93	pass	0.99	1.35	0.29	fail	0.97	3.70	1.41	fail	0.08
07/17/15	C	P	FM	B	5.24	13.89	pass	0.96	1.52	0.62	fail	0.95	4.16	1.29	fail	0.08
07/17/15	C	P	FM	C	4.07	12.96	pass	0.99	1.18	3.35	pass	0.97	3.24	6.73	pass	0.08
07/17/15	C	P	FM	D	4.36	14.50	pass	0.99	1.27	2.16	pass	0.91	3.47	14.73	pass	0.08
07/28/15	C	P	FM	A	6.33	8.38	pass	1.00	1.84	0.00	fail	0.00	5.03			0.11
07/28/15	C	P	FM	B	7.12	9.15	pass	1.00	2.07	0.32	fail	0.79	5.66	0.08	fail	0.11
07/28/15	C	P	FM	C	5.54	7.20	pass	0.95	1.61	1.43	fail	0.77	4.40	0.62	fail	0.11
07/28/15	C	P	FM	D	5.93	8.11	pass	0.64	1.72	0.12	fail	0.20	4.72			0.11
08/05/15	C	P	FM	A	5.82	8.27	pass	0.64	1.69	0.20	fail	0.60	4.63	1.10	fail	0.10
08/05/15	C	P	FM	B	6.55	9.58	pass	0.93	1.90	-0.08	fail	0.60	5.21			0.10
08/05/15	C	P	FM	C	5.09	7.50	pass	0.60	1.48	0.04	fail	0.10	4.05			0.10
08/05/15	C	P	FM	D	5.46	8.69	pass	0.43	1.58	0.40	fail	0.39	4.34	3.33	fail	0.10
08/12/15	C	P	FM	A	2.89	8.47	pass	0.60	0.84	0.04	fail	0.10	2.30			0.05
08/12/15	C	P	FM	B	3.25	9.50	pass	0.90	0.94	0.10	fail	0.40	2.58			0.05
08/12/15	C	P	FM	C	2.53	7.29	pass	0.55	0.73	0.10	fail	0.45	2.01			0.05
08/12/15	C	P	FM	D	2.71	8.93	pass	0.97	0.79	0.95	pass	0.90	2.15	6.21	pass	0.05

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2
					N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}			
05/22/15	C	P	UR	A	2.88	10.32	pass	0.80	0.83	0.09	fail	0.80	2.29			0.05
05/22/15	C	P	UR	B	2.88	10.25	pass	1.00	0.83	0.00	fail	1.00	2.29			0.05
05/22/15	C	P	UR	C	3.23	11.45	pass	0.90	0.94	0.15	fail	0.90	2.57			0.05
05/22/15	C	P	UR	D	2.70	10.42	pass	0.77	0.78	0.30	fail	0.70	2.14	2.22	pass	0.05
05/23/15	C	P	UR	A	4.44	10.40	pass	0.93	1.29	0.14	fail	0.60	3.53			0.08
05/23/15	C	P	UR	B	4.44	10.21	pass	0.93	1.29	0.07	fail	0.60	3.53			0.08
05/23/15	C	P	UR	C	5.00	11.60	pass	0.80	1.45	0.10	fail	0.80	3.98			0.08
05/23/15	C	P	UR	D	4.17	9.99	pass	0.36	1.21	0.09	fail	0.16	3.31			0.08
05/24/15	C	P	UR	A	3.93	10.38	pass	0.93	1.14	0.14	fail	0.60	3.13			0.07
05/24/15	C	P	UR	B	3.93	10.09	pass	0.40	1.14	0.02	fail	0.07	3.13			0.07
05/24/15	C	P	UR	C	4.42	11.75	pass	1.00	1.28	0.00	fail	0.00	3.52			0.07
05/24/15	C	P	UR	D	3.69	10.16	pass	0.86	1.07	0.11	fail	0.14	2.93			0.07
05/25/15	C	P	UR	A	3.09	10.46	pass	1.00	0.90	0.23	fail	0.83	2.46	2.29	fail	0.05
05/25/15	C	P	UR	B	3.09	10.19	pass	0.93	0.90	0.07	fail	0.60	2.46			0.05
05/25/15	C	P	UR	C	3.48	11.61	pass	0.20	1.01	0.05	fail	0.20	2.77			0.05
05/25/15	C	P	UR	D	2.90	10.04	pass	0.70	0.84	0.17	fail	0.53	2.31	2.14	fail	0.05
05/26/15	C	P	UR	A	3.06	10.51	pass	0.55	0.89	0.11	fail	0.45	2.44	1.12	fail	0.05
05/26/15	C	P	UR	B	3.06	10.49	pass	0.93	0.89	-0.07	fail	0.60	2.44			0.05
05/26/15	C	P	UR	C	3.45	11.91	pass	0.84	1.00	0.20	fail	0.64	2.74			0.05
05/26/15	C	P	UR	D	2.87	10.13	pass	0.93	0.83	0.19	fail	0.60	2.28			0.05
06/02/15	C	P	UR	A	4.63	19.84	pass	0.65	1.34	2.61	pass	0.43	3.68	48.08	pass	0.08
06/02/15	C	P	UR	B	4.63	13.49	pass	0.97	1.34	0.98	fail	0.79	3.68	10.84	pass	0.08
06/02/15	C	P	UR	C	5.21	15.97	pass	0.84	1.51	0.54	fail	0.24	4.14			0.08
06/02/15	C	P	UR	D	4.34	49.97	pass	1.00	1.26	15.18	pass	0.67	3.45			0.08
06/18/15	C	P	UR	A	4.96	12.71	pass	0.99	1.44	1.01	fail	0.97	3.95	4.49	pass	0.09
06/18/15	C	P	UR	B	4.96	12.56	pass	0.96	1.44	0.63	fail	0.87	3.95	4.52	pass	0.09
06/18/15	C	P	UR	C	5.58	12.89	pass	1.00	1.62	0.18	fail	0.17	4.44			0.09
06/18/15	C	P	UR	D	4.65	25.05	pass	0.93	1.35	10.79	pass	0.93	3.70	43.40	pass	0.09
06/19/15	C	P	UR	A	3.58	15.11	pass	1.00	1.04	2.36	pass	0.96	2.85	12.13	pass	0.06
06/19/15	C	P	UR	B	3.58	16.11	pass	0.97	1.04	2.16	pass	0.77	2.85	27.99	pass	0.06
06/19/15	C	P	UR	C	4.03	17.03	pass	0.99	1.17	2.86	pass	0.96	3.20	14.31	pass	0.06
06/19/15	C	P	UR	D	3.35	37.49	pass	1.00	0.97	34.15	pass	0.99	2.67	73.47	pass	0.06
06/23/15	C	P	UR	A	7.38	20.55	pass	0.97	2.14	3.67	pass	0.73	5.87	63.80	pass	0.13
06/23/15	C	P	UR	B	7.38	24.87	pass	0.87	2.14	1.75	fail	0.09	5.87			0.13
06/23/15	C	P	UR	C	8.30	21.04	pass	0.94	2.41	3.00	pass	0.65	6.60			0.13
06/23/15	C	P	UR	D	6.92	56.91	pass	0.92	2.01	16.73	pass	0.65	5.50	283.59	pass	0.13
06/24/15	C	P	UR	A	8.27	12.82	pass	0.93	2.40	1.22	fail	0.92	6.58	2.80	fail	0.15
06/24/15	C	P	UR	B	8.27	13.43	pass	0.84	2.40	1.55	fail	0.84	6.58			0.15
06/24/15	C	P	UR	C	9.31	16.26	pass	0.92	2.70	2.20	fail	0.91	7.40	9.44	pass	0.15
06/24/15	C	P	UR	D	7.76	42.36	pass	0.94	2.25	18.29	pass	0.82	6.17	151.16	pass	0.15
06/25/15	C	P	UR	A	4.52	26.87	pass	0.96	1.31	5.97	pass	0.60	3.59			0.08
06/25/15	C	P	UR	B	4.52	44.77	pass	0.96	1.31	28.56	pass	0.96	3.59	97.97	pass	0.08
06/25/15	C	P	UR	C	5.08	18.00	pass	0.42	1.48	0.69	fail	0.08	4.04			0.08
06/25/15	C	P	UR	D	4.24	37.63	pass	1.00	1.23	25.97	pass	1.00	3.37	80.37	pass	0.08
06/26/15	C	P	UR	A	3.59	12.68	pass	1.00	1.04	1.17	pass	0.75	2.86	18.92	pass	0.07
06/26/15	C	P	UR	B	3.59	23.50	pass	0.80	1.04	4.30	pass	0.49	2.86	133.48	pass	0.07
06/26/15	C	P	UR	C	4.04	14.05	pass	0.95	1.17	2.47	pass	0.95	3.22	8.43	pass	0.07
06/26/15	C	P	UR	D	3.37	11.11	pass	0.92	0.98	8.36	pass	0.77	2.68	5.39	pass	0.07
07/03/15	C	P	UR	A	4.21	12.76	pass	0.98	1.22	0.24	fail	0.23	3.35			0.08
07/03/15	C	P	UR	B	4.21	36.11	pass	0.98	1.22	12.73	pass	0.83	3.35	124.92	pass	0.08
07/03/15	C	P	UR	C	4.74	17.32	pass	0.14	1.38	0.49	fail	0.03	3.77			0.08
07/03/15	C	P	UR	D	3.95	14.08	pass	0.68	1.15	0.90	fail	0.23	3.14			0.08
07/17/15	C	P	UR	A	4.65	11.93	pass	0.99	1.35	0.29	fail	0.97	3.70	1.41	fail	0.08
07/17/15	C	P	UR	B	4.65	14.43	pass	0.95	1.35	1.93	pass	0.92	3.70	9.14	pass	0.08
07/17/15	C	P	UR	C	5.24	13.88	pass	0.99	1.52	0.40	fail	0.91	4.16	2.59	fail	0.08
07/17/15	C	P	UR	D	4.36	11.71	pass	0.91	1.27	0.25	fail	0.80	3.47	2.05	fail	0.08
07/28/15	C	P	UR	A	6.33	8.32	pass	0.93	1.84	0.13	fail	0.60	5.03			0.11
07/28/15	C	P	UR	B	6.33				1.84				5.03			0.11
07/28/15	C	P	UR	C	7.12	9.40	pass	0.98	2.07	0.07	fail	0.16	5.66			0.11
07/28/15	C	P	UR	D	5.93	8.25	pass	0.70	1.72	0.04	fail	0.03	4.72			0.11
08/05/15	C	P	UR	A	5.82	9.24	pass	0.92	1.69	0.04	fail	0.02	4.63			0.10
08/05/15	C	P	UR	B	5.82	8.72	pass	0.64	1.69	0.18	fail	0.64	4.63	0.68	fail	0.10
08/05/15	C	P	UR	C	6.55	9.53	pass	0.11	1.90	0.03	fail	0.02	5.21			0.10
08/05/15	C	P	UR	D	5.46	8.14	pass	0.70	1.58	0.04	fail	0.03	4.34			0.10
08/12/15	C	P	UR	A	2.89	8.23	pass	0.96	0.84	0.09	fail	0.16	2.30			0.05
08/12/15	C	P	UR	B	2.89	8.27	pass	0.64	0.84	0.22	fail	0.36	2.30			0.05
08/12/15	C	P	UR	C	3.25	9.68	pass	1.00	0.94	0.00	fail	0.00	2.58			0.05
08/12/15	C	P	UR	D	2.71	7.91	pass	0.55	0.79	0.10	fail	0.45	2.15	1.02	fail	0.05

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2
					N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}			
06/10/15	M	C	0N	A	2.72	11.48	pass	0.93	0.79	0.07	fail	0.60	2.17			0.05
06/10/15	M	C	0N	B	2.58	11.06	pass	1.00	0.75	0.00	fail	1.00	2.05			0.05
06/10/15	M	C	0N	C	3.91	16.82	pass	0.80	1.13	-0.13	fail	0.80	3.11			0.05
06/10/15	M	C	0N	D	3.24	13.93	pass	1.00	0.94	0.00	fail	1.00	2.58			0.05
06/15/15	M	C	0N	A	4.76	13.67	pass	0.93	1.38	0.28	fail	0.60	3.79			0.08
06/15/15	M	C	0N	B	4.50	12.69	pass	0.98	1.31	-0.31	fail	0.98	3.58	-0.87	fail	0.08
06/15/15	M	C	0N	C	6.83	17.86	pass	0.80	1.98	0.13	fail	0.80	5.43			0.08
06/15/15	M	C	0N	D	5.67	18.57	pass	0.77	1.64	-0.47	fail	0.54	4.51			0.08
06/18/15	M	C	0N	A	4.23	11.89	pass	0.83	1.23	0.25	fail	0.41	3.36			0.07
06/18/15	M	C	0N	B	4.00	11.45	pass	0.80	1.16	0.17	fail	0.36	3.18			0.07
06/18/15	M	C	0N	C	6.06	19.38	pass	0.40	1.76	0.23	fail	0.36	4.82	0.45	fail	0.07
06/18/15	M	C	0N	D	5.03	14.32	pass	0.98	1.46	0.19	fail	0.89	4.00	0.15	fail	0.07
06/19/15	M	C	0N	A	5.75	12.33	pass	0.93	1.67	0.07	fail	0.60	4.57			0.10
06/19/15	M	C	0N	B	5.43	11.66	pass	0.93	1.58	0.07	fail	0.60	4.32			0.10
06/19/15	M	C	0N	C	8.25	17.68	pass	1.00	2.39	0.00	fail	1.00	6.56			0.10
06/19/15	M	C	0N	D	6.84	14.38	pass	0.98	1.99	0.19	fail	0.89	5.44	1.37	fail	0.10
06/20/15	M	C	0N	A	7.75				2.25				6.16			0.13
06/20/15	M	C	0N	B	7.33	12.62	pass	0.63	2.13	0.75	fail	0.55	5.83	0.90	fail	0.13
06/20/15	M	C	0N	C	11.12	18.42	pass	0.91	3.23	0.40	fail	0.80	8.84	0.37	fail	0.13
06/20/15	M	C	0N	D	9.22	14.97	pass	0.93	2.68	0.17	fail	0.60	7.34			0.13
06/22/15	M	C	0N	A	3.95	12.06	pass	0.91	1.15	0.28	fail	0.80	3.14	2.28	fail	0.07
06/22/15	M	C	0N	B	3.73	11.56	pass	0.98	1.08	0.15	fail	0.89	2.97	1.08	fail	0.07
06/22/15	M	C	0N	C	5.66	17.20	pass	0.90	1.64	0.13	fail	0.40	4.50			0.07
06/22/15	M	C	0N	D	4.70	14.35	pass	0.90	1.36	0.33	fail	0.90	3.74			0.07
06/23/15	M	C	0N	A	3.81	12.49	pass	0.90	1.11	0.09	fail	0.40	3.03			0.07
06/23/15	M	C	0N	B	3.60	11.84	pass	0.99	1.05	0.28	fail	0.97	2.87	1.40	fail	0.07
06/23/15	M	C	0N	C	5.47	18.16	pass	0.40	1.59	-0.13	fail	0.07	4.35			0.07
06/23/15	M	C	0N	D	4.54	14.88	pass	0.98	1.32	0.19	fail	0.89	3.61	1.36	fail	0.07
06/24/15	M	C	0N	A	5.10	8.77	pass	0.40	1.48	0.02	fail	0.07	4.05			0.09
06/24/15	M	C	0N	B	4.82	7.86	pass	0.93	1.40	0.24	fail	0.90	3.83	0.30	fail	0.09
06/24/15	M	C	0N	C	7.31	12.25	pass	0.84	2.12	0.03	fail	0.02	5.82			0.09
06/24/15	M	C	0N	D	6.07	9.90	pass	0.98	1.76	0.39	fail	0.89	4.82	2.73	fail	0.09
07/10/15	M	C	0N	A	2.87	8.56	pass	0.78	0.83	0.30	fail	0.45	2.28			0.05
07/10/15	M	C	0N	B	2.71	8.70	pass	0.87	0.79	0.18	fail	0.23	2.16			0.05
07/10/15	M	C	0N	C	4.12	12.68	pass	0.55	1.19	-0.17	fail	0.45	3.27	-1.66	fail	0.05
07/10/15	M	C	0N	D	3.41	10.03	pass	1.00	0.99	0.28	fail	1.00	2.71			0.05
07/23/15	M	C	0N	A	5.75	11.19	pass	0.91	1.67	0.43	fail	0.85	4.57	0.66	fail	0.10
07/23/15	M	C	0N	B	5.44	10.48	pass	0.93	1.58	0.25	fail	0.90	4.32	1.24	fail	0.10
07/23/15	M	C	0N	C	8.25	16.36	pass	0.20	2.39	0.07	fail	0.20	6.56			0.10
07/23/15	M	C	0N	D	6.84	13.64	pass	0.68	1.99	0.20	fail	0.19	5.44			0.10
07/29/15	M	C	0N	A	7.39	11.12	pass	0.91	2.14	0.21	fail	0.85	5.88	0.32	fail	0.13
07/29/15	M	C	0N	B	6.99	10.68	pass	0.80	2.03	0.09	fail	0.80	5.56			0.13
07/29/15	M	C	0N	C	10.60	16.26	pass	0.93	3.08	0.10	fail	0.60	8.43			0.13
07/29/15	M	C	0N	D	8.79	13.24	pass	0.99	2.55	1.07	fail	0.97	6.99	1.90	fail	0.13

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2
					N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}			
06/10/15	M	C	AB	A	2.93	12.58	pass	1.00	0.85	0.00	fail	1.00	2.33			0.05
06/10/15	M	C	AB	B	2.62	11.28	pass	1.00	0.76	0.00	fail	1.00	2.09			0.05
06/10/15	M	C	AB	C	3.09	13.22	pass	0.40	0.90	0.03	fail	0.07	2.45			0.05
06/10/15	M	C	AB	D	3.40	14.55	pass	0.40	0.99	0.03	fail	0.07	2.70			0.05
06/15/15	M	C	AB	A	5.12	15.60	pass	0.84	1.49	0.20	fail	0.64	4.07			0.08
06/15/15	M	C	AB	B	4.59	12.65	pass	0.91	1.33	-0.20	fail	0.85	3.65	-1.23	fail	0.08
06/15/15	M	C	AB	C	5.39	14.17	pass	0.84	1.57	-0.03	fail	0.02	4.29			0.08
06/15/15	M	C	AB	D	5.94	15.20	pass	0.55	1.72	0.14	fail	0.45	4.72			0.08
06/18/15	M	C	AB	A	4.54	12.92	pass	0.80	1.32	0.10	fail	0.80	3.61			0.07
06/18/15	M	C	AB	B	4.07	11.67	pass	0.40	1.18	-0.04	fail	0.07	3.24			0.07
06/18/15	M	C	AB	C	4.79	13.68	pass	0.83	1.39	1.26	fail	0.79	3.81	2.25	fail	0.07
06/18/15	M	C	AB	D	5.27	16.79	pass	0.98	1.53	0.99	fail	0.95	4.19	5.18	pass	0.07
06/19/15	M	C	AB	A	6.18	13.27	pass	0.93	1.79	0.08	fail	0.60	4.92			0.10
06/19/15	M	C	AB	B	5.54	11.66	pass	0.93	1.61	0.07	fail	0.60	4.41			0.10
06/19/15	M	C	AB	C	6.51	14.18	pass	0.61	1.89	0.55	fail	0.60	5.18	1.62	fail	0.10
06/19/15	M	C	AB	D	7.17	15.35	pass	0.99	2.08	0.41	fail	0.70	5.70			0.10
06/20/15	M	C	AB	A	8.33	13.18	pass	0.73	2.42	3.55	pass	0.72	6.63	13.22	pass	0.13
06/20/15	M	C	AB	B	7.47	12.60	pass	0.92	2.17	0.34	fail	0.76	5.94	0.21	fail	0.13
06/20/15	M	C	AB	C	8.78	16.32	pass	1.00	2.55	2.56	pass	1.00	6.98	6.16	fail	0.13
06/20/15	M	C	AB	D	9.67	16.11	pass	0.96	2.81	1.25	fail	0.96	7.69	2.93	fail	0.13
06/22/15	M	C	AB	A	4.24	19.71	pass	0.63	1.23	3.01	pass	0.62	3.38	12.40	pass	0.07
06/22/15	M	C	AB	B	3.80	11.84	pass	0.60	1.10	0.04	fail	0.10	3.02			0.07
06/22/15	M	C	AB	C	4.47	13.85	pass	1.00	1.30	1.23	fail	0.66	3.56			0.07
06/22/15	M	C	AB	D	4.92	15.24	pass	1.00	1.43	0.98	fail	1.00	3.92	2.88	fail	0.07
06/23/15	M	C	AB	A	4.10	13.40	pass	0.99	1.19	3.12	pass	0.98	3.26	8.30	pass	0.07
06/23/15	M	C	AB	B	3.67	12.13	pass	0.64	1.07	0.18	fail	0.64	2.92	0.66	fail	0.07
06/23/15	M	C	AB	C	4.32	14.85	pass	0.96	1.25	4.02	pass	0.87	3.43	30.13	pass	0.07
06/23/15	M	C	AB	D	4.76	15.55	pass	1.00	1.38	2.26	pass	0.99	3.78	7.88	pass	0.07
06/24/15	M	C	AB	A	5.48	9.23	pass	1.00	1.59	2.32	pass	0.99	4.36	8.59	pass	0.09
06/24/15	M	C	AB	B	4.91	8.62	pass	0.28	1.43	0.13	fail	0.18	3.91	0.09	fail	0.09
06/24/15	M	C	AB	C	5.77	9.96	pass	1.00	1.68	2.28	pass	0.97	4.59	11.27	pass	0.09
06/24/15	M	C	AB	D	6.36	10.83	pass	0.94	1.85	1.07	fail	0.94	5.06	2.92	fail	0.09
07/10/15	M	C	AB	A	3.08	8.94	pass	0.97	0.90	4.03	pass	0.95	2.45	7.74	pass	0.05
07/10/15	M	C	AB	B	2.76	8.97	pass	0.24	0.80	0.11	fail	0.08	2.20			0.05
07/10/15	M	C	AB	C	3.25	9.20	pass	0.89	0.94	3.50	pass	0.87	2.58	15.78	pass	0.05
07/10/15	M	C	AB	D	3.58	11.01	pass	1.00	1.04	6.48	pass	0.99	2.85	25.76	pass	0.05
07/23/15	M	C	AB	A	6.18	10.16	pass	0.98	1.79	36.55	pass	0.97	4.92	144.44	pass	0.10
07/23/15	M	C	AB	B	5.54	11.46	pass	0.87	1.61	2.01	pass	0.23	4.41			0.10
07/23/15	M	C	AB	C	6.51	19.29	pass	0.97	1.89	71.27	pass	0.96	5.18	155.72	pass	0.10
07/23/15	M	C	AB	D	7.17	2.14	fail	0.98	2.08	160.97	pass	0.98	5.71	457.08	pass	0.10
07/29/15	M	C	AB	A	7.94	2.57	fail	0.78	2.31	36.04	pass	0.78	6.32	110.94	pass	0.13
07/29/15	M	C	AB	B	7.12	11.08	pass	0.98	2.07	2.40	pass	0.76	5.66	31.05	pass	0.13
07/29/15	M	C	AB	C	8.37	12.40	pass	1.00	2.43	59.50	pass	0.81	6.66	668.87	pass	0.13
07/29/15	M	C	AB	D	9.22	6.47	fail	0.96	2.68	85.21	pass	0.96	7.33	257.55	pass	0.13

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2
					N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}			
06/10/15	M	C	FM	A	2.99	12.55	pass	0.90	0.87	0.10	fail	0.40	2.38			0.05
06/10/15	M	C	FM	B	2.93	12.29	pass	0.80	0.85	0.20	fail	0.80	2.33			0.05
06/10/15	M	C	FM	C	2.67	11.48	pass	0.93	0.78	-0.07	fail	0.60	2.13			0.05
06/10/15	M	C	FM	D	3.34	14.62	pass	0.93	0.97	-0.08	fail	0.60	2.66			0.05
06/15/15	M	C	FM	A	5.22	14.66	pass	0.99	1.52	-0.15	fail	0.10	4.15			0.08
06/15/15	M	C	FM	B	5.12	14.44	pass	0.40	1.49	-0.02	fail	0.07	4.07			0.08
06/15/15	M	C	FM	C	4.67	12.20	pass	0.60	1.36	-0.05	fail	0.10	3.72			0.08
06/15/15	M	C	FM	D	5.84	17.44	pass	0.31	1.69	-0.20	fail	0.28	4.64			0.08
06/18/15	M	C	FM	A	4.63	13.39	pass	0.98	1.35	2.86	pass	0.97	3.69	6.69	pass	0.07
06/18/15	M	C	FM	B	4.54	12.96	pass	0.93	1.32	0.07	fail	0.60	3.61			0.07
06/18/15	M	C	FM	C	4.15	12.31	pass	0.99	1.20	0.49	fail	0.33	3.30			0.07
06/18/15	M	C	FM	D	5.18	14.65	pass	1.00	1.50	6.30	pass	0.94	4.12	37.95	pass	0.07
06/19/15	M	C	FM	A	6.30	13.39	pass	0.97	1.83	1.27	fail	0.81	5.01	13.16	pass	0.10
06/19/15	M	C	FM	B	6.18	13.07	pass	0.55	1.79	0.13	fail	0.45	4.92	1.24	fail	0.10
06/19/15	M	C	FM	C	5.64	12.11	pass	0.99	1.64	0.30	fail	0.97	4.49	0.52	fail	0.10
06/19/15	M	C	FM	D	7.05	14.82	pass	0.98	2.05	3.91	pass	0.97	5.61	14.24	pass	0.10
06/20/15	M	C	FM	A	8.50	15.01	pass	1.00	2.47	18.64	pass	0.60	6.76			0.13
06/20/15	M	C	FM	B	8.33	14.24	pass	0.99	2.42	0.18	fail	0.52	6.63			0.13
06/20/15	M	C	FM	C	7.61	12.65	pass	0.93	2.21	2.60	pass	0.90	6.05	12.84	pass	0.13
06/20/15	M	C	FM	D	9.51	18.04	pass	1.00	2.76	30.37	pass	1.00	7.56	100.02	pass	0.13
06/22/15	M	C	FM	A	4.33	16.58	pass	0.99	1.26	29.05	pass	0.98	3.44	117.68	pass	0.07
06/22/15	M	C	FM	B	4.24	13.03	pass	0.99	1.23	3.15	pass	0.81	3.38	34.97	pass	0.07
06/22/15	M	C	FM	C	3.87	11.94	pass	0.98	1.12	1.11	fail	0.96	3.08	4.75	pass	0.07
06/22/15	M	C	FM	D	4.84	14.66	pass	1.00	1.40	10.91	pass	0.98	3.85	47.02	pass	0.07
06/23/15	M	C	FM	A	4.18	12.08	pass	0.99	1.21	61.57	pass	0.99	3.32	209.38	pass	0.07
06/23/15	M	C	FM	B	4.10	13.50	pass	0.99	1.19	0.47	fail	0.59	3.26			0.07
06/23/15	M	C	FM	C	3.74	12.65	pass	0.99	1.09	6.96	pass	0.98	2.98	29.79	pass	0.07
06/23/15	M	C	FM	D	4.67	16.13	pass	1.00	1.36	51.30	pass	0.99	3.72	211.52	pass	0.07
06/24/15	M	C	FM	A	5.59	10.16	pass	0.99	1.62	18.30	pass	0.99	4.44	52.44	pass	0.09
06/24/15	M	C	FM	B	5.48	8.97	pass	1.00	1.59	1.50	fail	0.99	4.36	5.56	pass	0.09
06/24/15	M	C	FM	C	5.00	8.68	pass	1.00	1.45	1.34	fail	1.00	3.98	4.57	pass	0.09
06/24/15	M	C	FM	D	6.25	10.46	pass	1.00	1.81	9.89	pass	0.99	4.97	39.67	pass	0.09
07/10/15	M	C	FM	A	3.15	6.87	pass	0.97	0.91	33.50	pass	0.72	2.50	674.18	pass	0.05
07/10/15	M	C	FM	B	3.08	9.69	pass	0.50	0.90	0.25	fail	0.50	2.45	0.50	fail	0.05
07/10/15	M	C	FM	C	2.82	8.75	pass	0.81	0.82	0.99	pass	0.81	2.24	3.93	pass	0.05
07/10/15	M	C	FM	D	3.52	20.23	pass	0.53	1.02	19.15	pass	0.53	2.80	85.71	pass	0.05
07/23/15	M	C	FM	A	6.31	11.70	pass	1.00	1.83	23.50	pass	0.97	5.01	109.76	pass	0.10
07/23/15	M	C	FM	B	6.18	11.46	pass	0.99	1.79	15.59	pass	0.92	4.92	99.47	pass	0.10
07/23/15	M	C	FM	C	5.65	7.70	pass	0.96	1.64	32.25	pass	0.96	4.49	98.00	pass	0.10
07/23/15	M	C	FM	D	7.05	19.15	pass	0.97	2.05	44.09	pass	0.69	5.61	779.40	pass	0.10
07/29/15	M	C	FM	A	8.10	9.84	pass	0.78	2.35	7.62	pass	0.48	6.44			0.13
07/29/15	M	C	FM	B	7.94	11.80	pass	0.99	2.31	5.71	pass	0.38	6.32			0.13
07/29/15	M	C	FM	C	7.25	12.19	pass	0.99	2.11	25.51	pass	0.98	5.77	52.59	pass	0.13
07/29/15	M	C	FM	D	9.06	19.53	pass	0.95	2.63	51.75	pass	0.95	7.21	150.66	pass	0.13

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2
					N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}			
06/10/15	M	C	UR	A	2.26	9.54	pass	0.93	0.66	0.06	fail	0.60	1.80			0.05
06/10/15	M	C	UR	B	3.34	14.38	pass	0.90	0.97	-0.11	fail	0.40	2.66			0.05
06/10/15	M	C	UR	C	3.81	16.03	pass	0.98	1.11	0.22	fail	0.89	3.03	1.59	fail	0.05
06/10/15	M	C	UR	D	3.19	13.69	pass	0.80	0.93	0.11	fail	0.80	2.54			0.05
06/15/15	M	C	UR	A	3.95	11.85	pass	0.24	1.15	0.10	fail	0.08	3.14			0.08
06/15/15	M	C	UR	B	5.84	15.93	pass	0.55	1.69	-0.14	fail	0.45	4.64			0.08
06/15/15	M	C	UR	C	6.66	17.85	pass	0.55	1.93	-0.16	fail	0.45	5.30			0.08
06/15/15	M	C	UR	D	5.58	18.45	pass	0.99	1.62	-0.84	fail	0.70	4.44			0.08
06/18/15	M	C	UR	A	3.51	9.82	pass	0.99	1.02	0.25	fail	0.97	2.79	1.20	fail	0.07
06/18/15	M	C	UR	B	5.18	14.77	pass	1.00	1.50	0.00	fail	1.00	4.12			0.07
06/18/15	M	C	UR	C	5.91	19.54	pass	0.88	1.72	0.64	fail	0.49	4.70			0.07
06/18/15	M	C	UR	D	4.95	15.67	pass	0.56	1.44	0.29	fail	0.18	3.94			0.07
06/19/15	M	C	UR	A	4.77	10.24	pass	1.00	1.39	0.39	fail	0.95	3.80	2.14	fail	0.10
06/19/15	M	C	UR	B	7.05	15.11	pass	1.00	2.05	0.00	fail	1.00	5.61			0.10
06/19/15	M	C	UR	C	8.04	16.96	pass	0.91	2.33	0.29	fail	0.85	6.39	1.80	fail	0.10
06/19/15	M	C	UR	D	6.74	14.44	pass	1.00	1.96	0.00	fail	1.00	5.36			0.10
06/20/15	M	C	UR	A	6.44	10.57	pass	0.92	1.87	0.62	fail	0.11	5.12			0.13
06/20/15	M	C	UR	B	9.51	16.68	pass	0.61	2.76	0.29	fail	0.04	7.56			0.13
06/20/15	M	C	UR	C	10.84	18.20	pass	1.00	3.15	2.50	fail	0.99	8.62	9.61	pass	0.13
06/20/15	M	C	UR	D	9.08	15.00	pass	0.98	2.64	0.08	fail	0.16	7.22			0.13
06/22/15	M	C	UR	A	3.28	10.13	pass	1.00	0.95	1.69	pass	1.00	2.61	5.80	pass	0.07
06/22/15	M	C	UR	B	4.84	14.86	pass	0.93	1.40	0.76	fail	0.60	3.85			0.07
06/22/15	M	C	UR	C	5.52	17.09	pass	0.99	1.60	0.78	fail	0.96	4.39	3.85	fail	0.07
06/22/15	M	C	UR	D	4.63	14.36	pass	0.93	1.34	0.08	fail	0.60	3.68			0.07
06/23/15	M	C	UR	A	3.17	10.32	pass	1.00	0.92	2.43	pass	0.98	2.52	9.71	pass	0.07
06/23/15	M	C	UR	B	4.67	15.59	pass	0.95	1.36	2.02	pass	0.94	3.72	5.98	pass	0.07
06/23/15	M	C	UR	C	5.33	17.50	pass	1.00	1.55	6.48	pass	0.99	4.24	25.13	pass	0.07
06/23/15	M	C	UR	D	4.47	14.69	pass	0.90	1.30	0.16	fail	0.90	3.55			0.07
06/24/15	M	C	UR	A	4.23	7.09	pass	1.00	1.23	0.98	fail	0.99	3.37	3.29	fail	0.09
06/24/15	M	C	UR	B	6.25	10.29	pass	0.99	1.81	1.19	fail	0.84	4.97	11.24	pass	0.09
06/24/15	M	C	UR	C	7.13	11.73	pass	0.97	2.07	0.71	fail	0.97	5.67	2.22	fail	0.09
06/24/15	M	C	UR	D	5.97	10.27	pass	0.84	1.73	0.22	fail	0.64	4.75			0.09
07/10/15	M	C	UR	A	2.38	8.82	pass	0.74	0.69	4.69	pass	0.70	1.89	8.32	pass	0.05
07/10/15	M	C	UR	B	3.52	10.65	pass	0.90	1.02	0.17	fail	0.90	2.80			0.05
07/10/15	M	C	UR	C	4.01	11.84	pass	0.98	1.16	0.62	fail	0.87	3.19	0.54	fail	0.05
07/10/15	M	C	UR	D	3.36	10.28	pass	0.40	0.98	0.19	fail	0.36	2.67	0.38	fail	0.05
07/23/15	M	C	UR	A	4.78	9.13	pass	0.99	1.39	3.67	pass	0.20	3.80			0.10
07/23/15	M	C	UR	B	7.05	14.58	pass	0.85	2.05	-0.15	fail	0.00	5.61			0.10
07/23/15	M	C	UR	C	8.04	15.25	pass	0.97	2.33	7.48	pass	0.96	6.40	28.54	pass	0.10
07/23/15	M	C	UR	D	6.74	16.59	pass	0.92	1.96	18.60	pass	0.79	5.36	14.49	pass	0.10
07/29/15	M	C	UR	A	6.14	6.13	fail	0.62	1.78	6.66	pass	0.44	4.88			0.13
07/29/15	M	C	UR	B	9.06	13.91	pass	1.00	2.63	1.59	fail	0.56	7.21			0.13
07/29/15	M	C	UR	C	10.33	17.88	pass	0.87	3.00	10.37	pass	0.81	8.22	14.41	pass	0.13
07/29/15	M	C	UR	D	8.66	12.14	pass	0.97	2.51	12.21	pass	0.96	6.89	27.80	pass	0.13

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2
					N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}			
05/16/15	M	P	0N	A	5.87	11.38	pass	1.00	1.71	0.00	fail	0.00	4.67			0.09
05/16/15	M	P	0N	B	6.53	12.49	pass	0.40	1.89	0.03	fail	0.07	5.19			0.09
05/16/15	M	P	0N	C	5.22	10.83	pass	0.87	1.52	0.18	fail	0.23	4.15			0.09
05/16/15	M	P	0N	D	5.22	10.12	pass	1.00	1.52	0.00	fail	0.00	4.15			0.09
05/17/15	M	P	0N	A	9.04	11.22	pass	0.80	2.62	-0.10	fail	0.80	7.19			0.14
05/17/15	M	P	0N	B	10.04	12.68	pass	0.40	2.91	0.03	fail	0.07	7.99			0.14
05/17/15	M	P	0N	C	8.03	10.86	pass	0.90	2.33	0.18	fail	0.40	6.39			0.14
05/17/15	M	P	0N	D	8.03	10.07	pass	0.10	2.33	-0.05	fail	0.10	6.39			0.14
05/18/15	M	P	0N	A	4.90	10.81	pass	0.40	1.42	0.03	fail	0.07	3.90			0.08
05/18/15	M	P	0N	B	5.45	12.29	pass	0.40	1.58	0.03	fail	0.07	4.33			0.08
05/18/15	M	P	0N	C	4.36	10.56	pass	0.68	1.26	0.16	fail	0.19	3.47			0.08
05/18/15	M	P	0N	D	4.36	9.99	pass	0.93	1.26	-0.07	fail	0.60	3.47			0.08
05/21/15	M	P	0N	A	4.18	11.45	pass	1.00	1.21	0.00	fail	1.00	3.32			0.07
05/21/15	M	P	0N	B	4.64	12.81	pass	0.80	1.35	0.11	fail	0.80	3.69			0.07
05/21/15	M	P	0N	C	3.71	10.60	pass	0.93	1.08	0.07	fail	0.60	2.95			0.07
05/21/15	M	P	0N	D	3.71	10.41	pass	1.00	1.08	0.00	fail	1.00	2.95			0.07
05/25/15	M	P	0N	A	7.65	11.41	pass	0.93	2.22	0.08	fail	0.60	6.09			0.12
05/25/15	M	P	0N	B	8.50	13.53	pass	0.98	2.47	0.08	fail	0.16	6.76			0.12
05/25/15	M	P	0N	C	6.80	11.17	pass	0.97	1.97	0.50	fail	0.83	5.41	4.45	fail	0.12
05/25/15	M	P	0N	D	6.80	10.34	pass	0.90	1.97	0.14	fail	0.90	5.41	0.45	fail	0.12
06/02/15	M	P	0N	A	5.47	11.69	pass	0.93	1.59	0.08	fail	0.60	4.35			0.09
06/02/15	M	P	0N	B	6.07	13.19	pass	0.91	1.76	0.26	fail	0.85	4.83	0.39	fail	0.09
06/02/15	M	P	0N	C	4.86	10.99	pass	0.64	1.41	0.23	fail	0.36	3.86			0.09
06/02/15	M	P	0N	D	4.86	10.49	pass	0.80	1.41	0.09	fail	0.80	3.86	0.23	fail	0.09
06/10/15	M	P	0N	A	6.97	12.32	pass	0.93	2.02	-0.08	fail	0.60	5.55			0.11
06/10/15	M	P	0N	B	7.75	13.96	pass	0.93	2.25	-0.08	fail	0.60	6.16			0.11
06/10/15	M	P	0N	C	6.20	16.10	pass	0.98	1.80	2.98	pass	0.88	4.93	21.92	pass	0.11
06/10/15	M	P	0N	D	6.20	11.74	pass	0.90	1.80	-0.09	fail	0.40	4.93			0.11
06/19/15	M	P	0N	A	5.96	28.45	pass	0.96	1.73	3.14	pass	0.55	4.74			0.10
06/19/15	M	P	0N	B	6.62	20.08	pass	0.88	1.92	1.77	fail	0.83	5.26	1.70	fail	0.10
06/19/15	M	P	0N	C	5.29	17.24	pass	1.00	1.54	2.77	pass	0.93	4.21	17.03	pass	0.10
06/19/15	M	P	0N	D	5.29	14.31	pass	1.00	1.54	1.44	fail	0.99	4.21	5.29	pass	0.10
07/02/15	M	P	0N	A	6.92	10.93	pass	1.00	2.01	1.09	fail	0.99	5.50	4.30	fail	0.11
07/02/15	M	P	0N	B	7.69	11.36	pass	0.99	2.23	0.85	fail	0.95	6.11	4.56	fail	0.11
07/02/15	M	P	0N	C	6.15	8.77	pass	1.00	1.78	0.88	fail	0.99	4.89	1.84	fail	0.11
07/02/15	M	P	0N	D	6.15	9.78	pass	0.99	1.78	1.05	fail	0.92	4.89	6.70	pass	0.11
07/08/15	M	P	0N	A	4.30	10.19	pass	0.78	1.25	0.32	fail	0.45	3.42			0.07
07/08/15	M	P	0N	B	4.78	11.16	pass	0.98	1.39	0.96	fail	0.98	3.80	3.32	fail	0.07
07/08/15	M	P	0N	C	3.82	8.88	pass	0.98	1.11	0.42	fail	0.87	3.04	3.25	pass	0.07
07/08/15	M	P	0N	D	3.82	9.27	pass	1.00	1.11	0.74	fail	0.98	3.04	3.20	pass	0.07
07/23/15	M	P	0N	A	9.74	11.94	pass	0.40	2.83	0.03	fail	0.07	7.75			0.15
07/23/15	M	P	0N	B	10.82	13.14	pass	1.00	3.14	0.28	fail	1.00	8.61	0.83	fail	0.15
07/23/15	M	P	0N	C	8.66	10.51	pass	1.00	2.51	0.00	fail	1.00	6.88			0.15
07/23/15	M	P	0N	D	8.66	10.67	pass	0.90	2.51	0.13	fail	0.90	6.88			0.15
07/31/15	M	P	0N	A	3.01	10.46	pass	0.40	0.87	0.17	fail	0.36	2.40	0.34	fail	0.05
07/31/15	M	P	0N	B	3.35	11.57	pass	0.84	0.97	0.03	fail	0.02	2.66			0.05
07/31/15	M	P	0N	C	2.68	9.00	pass	0.90	0.78	-0.33	fail	0.88	2.13	-1.39	fail	0.05
07/31/15	M	P	0N	D	2.68	8.97	pass	1.00	0.78	0.59	fail	0.94	2.13	0.72	fail	0.05
08/05/15	M	P	0N	A	4.44	9.76	pass	0.90	1.29	-0.10	fail	0.40	3.53			0.07
08/05/15	M	P	0N	B	4.94	10.85	pass	0.90	1.43	0.17	fail	0.90	3.93			0.07
08/05/15	M	P	0N	C	3.95	8.53	pass	0.11	1.15	-0.02	fail	0.02	3.14			0.07
08/05/15	M	P	0N	D	3.95	8.90	pass	0.93	1.15	0.13	fail	0.60	3.14			0.07
08/12/15	M	P	0N	A	5.27	9.36	pass	0.93	1.53	0.07	fail	0.60	4.19			0.08
08/12/15	M	P	0N	B	5.85	10.62	pass	0.15	1.70	-0.08	fail	0.09	4.65			0.08
08/12/15	M	P	0N	C	4.68	8.20	pass	0.80	1.36	0.09	fail	0.80	3.72			0.08
08/12/15	M	P	0N	D	4.68	8.53	pass	0.75	1.36	0.31	fail	0.75	3.72	1.10	fail	0.08
08/25/15	M	P	0N	A	0.61	9.30	pass	0.40	0.18	-0.05	fail	0.07	0.48			0.01
08/25/15	M	P	0N	B	0.67	10.39	pass	0.80	0.20	0.11	fail	0.80	0.54			0.01
08/25/15	M	P	0N	C	0.54	8.14	pass	0.84	0.16	-0.02	fail	0.02	0.43			0.01
08/25/15	M	P	0N	D	0.54	8.61	pass	0.40	0.16	-0.07	fail	0.07	0.43			0.01

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2
					N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}			
05/16/15	M	P	AB	A	4.57	10.06	pass	1.00	1.33	0.40	fail	0.44	3.63			0.09
05/16/15	M	P	AB	B	5.55	10.47	pass	0.93	1.61	0.07	fail	0.60	4.41			0.09
05/16/15	M	P	AB	C	5.87	12.43	pass	0.78	1.71	0.49	fail	0.47	4.67			0.09
05/16/15	M	P	AB	D	6.04	11.31	pass	0.40	1.75	-0.03	fail	0.07	4.80			0.09
05/17/15	M	P	AB	A	7.03	10.88	pass	0.95	2.04	0.40	fail	0.19	5.59			0.14
05/17/15	M	P	AB	B	8.53	10.63	pass	0.93	2.48	0.07	fail	0.60	6.79			0.14
05/17/15	M	P	AB	C	9.04	12.35	pass	0.96	2.62	0.72	fail	0.93	7.19	3.51	fail	0.14
05/17/15	M	P	AB	D	9.29	11.59	pass	0.10	2.70	0.05	fail	0.10	7.39			0.14
05/18/15	M	P	AB	A	3.81	9.56	pass	0.95	1.11	0.30	fail	0.45	3.03			0.08
05/18/15	M	P	AB	B	4.63	10.41	pass	0.80	1.34	0.10	fail	0.80	3.68			0.08
05/18/15	M	P	AB	C	4.90	11.56	pass	0.91	1.42	0.31	fail	0.80	3.90	2.52	fail	0.08
05/18/15	M	P	AB	D	5.04	11.48	pass	0.93	1.46	0.08	fail	0.60	4.01			0.08
05/21/15	M	P	AB	A	3.25	9.85	pass	0.95	0.94	0.30	fail	0.45	2.59			0.07
05/21/15	M	P	AB	B	3.95	10.89	pass	0.80	1.15	0.10	fail	0.80	3.14			0.07
05/21/15	M	P	AB	C	4.18	12.00	pass	0.98	1.21	0.18	fail	0.89	3.32	1.26	fail	0.07
05/21/15	M	P	AB	D	4.30	12.29	pass	1.00	1.25	0.00	fail	0.00	3.42			0.07
05/25/15	M	P	AB	A	5.95	11.30	pass	0.92	1.73	1.74	pass	0.91	4.73	7.48	pass	0.12
05/25/15	M	P	AB	B	7.23	11.13	pass	0.90	2.10	0.10	fail	0.40	5.75			0.12
05/25/15	M	P	AB	C	7.65	20.70	pass	0.77	2.22	3.89	pass	0.64	6.09	38.74	pass	0.12
05/25/15	M	P	AB	D	7.86	17.14	pass	0.93	2.28	1.54	fail	0.49	6.26			0.12
06/02/15	M	P	AB	A	4.25	11.95	pass	0.99	1.23	0.89	fail	0.53	3.38			0.09
06/02/15	M	P	AB	B	5.16	11.19	pass	0.40	1.50	0.02	fail	0.07	4.11			0.09
06/02/15	M	P	AB	C	5.47	17.67	pass	0.90	1.59	2.65	pass	0.74	4.35	27.83	pass	0.09
06/02/15	M	P	AB	D	5.62	12.36	pass	0.98	1.63	0.18	fail	0.89	4.47	1.30	fail	0.09
06/10/15	M	P	AB	A	5.42	10.55	pass	1.00	1.57	0.33	fail	0.70	4.31			0.11
06/10/15	M	P	AB	B	6.59	11.90	pass	0.90	1.91	0.09	fail	0.40	5.24			0.11
06/10/15	M	P	AB	C	6.97	16.23	pass	0.73	2.02	0.63	fail	0.14	5.55			0.11
06/10/15	M	P	AB	D	7.17	13.17	pass	0.98	2.08	0.18	fail	0.89	5.70	1.27	fail	0.11
06/19/15	M	P	AB	A	4.63	60.72	pass	1.00	1.34	28.38	pass	0.93	3.68	178.24	pass	0.10
06/19/15	M	P	AB	B	5.62	28.90	pass	0.96	1.63	9.56	pass	0.96	4.47	39.15	pass	0.10
06/19/15	M	P	AB	C	5.96	53.27	pass	0.98	1.73	28.26	pass	0.97	4.74	116.01	pass	0.10
06/19/15	M	P	AB	D	6.12	16.03	pass	0.40	1.78	-0.08	fail	0.07	4.87			0.10
07/02/15	M	P	AB	A	5.38	21.27	pass	0.93	1.56	9.27	pass	0.85	4.28	61.72	pass	0.11
07/02/15	M	P	AB	B	6.53	14.27	pass	1.00	1.90	5.01	pass	1.00	5.20	16.59	pass	0.11
07/02/15	M	P	AB	C	6.92	17.91	pass	0.97	2.01	8.34	pass	0.97	5.50	22.64	pass	0.11
07/02/15	M	P	AB	D	7.11	9.85	pass	0.93	2.06	0.08	fail	0.60	5.65			0.11
07/08/15	M	P	AB	A	3.35	17.24	pass	0.92	0.97	7.11	pass	0.87	2.66	40.49	pass	0.07
07/08/15	M	P	AB	B	4.06	10.63	pass	0.92	1.18	2.26	pass	0.90	3.23	4.62	pass	0.07
07/08/15	M	P	AB	C	4.30	14.20	pass	1.00	1.25	3.65	pass	0.98	3.42	16.62	pass	0.07
07/08/15	M	P	AB	D	4.42	9.51	pass	0.91	1.28	0.23	fail	0.85	3.52	1.40	fail	0.07
07/23/15	M	P	AB	A	7.57	10.71	pass	0.70	2.20	0.49	fail	0.30	6.02			0.15
07/23/15	M	P	AB	B	9.20	11.26	pass	0.20	2.67	0.05	fail	0.20	7.32			0.15
07/23/15	M	P	AB	C	9.74	12.27	pass	0.24	2.83	0.13	fail	0.08	7.75			0.15
07/23/15	M	P	AB	D	10.01	26.93	pass	0.87	2.91	3.80	pass	0.28	7.96			0.15
07/31/15	M	P	AB	A	2.34	9.19	pass	0.67	0.68	0.52	fail	0.67	1.86	2.32	pass	0.05
07/31/15	M	P	AB	B	2.85	10.16	pass	0.98	0.83	0.07	fail	0.16	2.26			0.05
07/31/15	M	P	AB	C	3.01	10.83	pass	0.99	0.87	0.17	fail	0.28	2.40			0.05
07/31/15	M	P	AB	D	3.10	12.86	pass	0.98	0.90	3.53	pass	0.98	2.46	9.11	pass	0.05
08/05/15	M	P	AB	A	3.46	8.12	pass	0.84	1.00	0.04	fail	0.04	2.75			0.07
08/05/15	M	P	AB	B	4.20	9.30	pass	0.64	1.22	0.21	fail	0.60	3.34	1.18	fail	0.07
08/05/15	M	P	AB	C	4.44	9.84	pass	1.00	1.29	0.25	fail	1.00	3.53	0.77	fail	0.07
08/05/15	M	P	AB	D	4.57	13.89	pass	1.00	1.33	4.38	pass	0.99	3.63	9.91	pass	0.07
08/12/15	M	P	AB	A	4.10	7.99	pass	0.96	1.19	0.17	fail	0.38	3.26			0.08
08/12/15	M	P	AB	B	4.97	9.30	pass	0.98	1.44	0.07	fail	0.16	3.96			0.08
08/12/15	M	P	AB	C	5.27	9.72	pass	0.90	1.53	0.10	fail	0.40	4.19			0.08
08/12/15	M	P	AB	D	5.41	12.23	pass	1.00	1.57	2.97	pass	0.99	4.31	6.58	pass	0.08
08/25/15	M	P	AB	A	0.47	7.72	pass	0.20	0.14	-0.04	fail	0.20	0.38			0.01
08/25/15	M	P	AB	B	0.57	8.83	pass	0.90	0.17	0.09	fail	0.40	0.46			0.01
08/25/15	M	P	AB	C	0.61	9.41	pass	0.40	0.18	-0.03	fail	0.07	0.48			0.01
08/25/15	M	P	AB	D	0.62	9.75	pass	0.93	0.18	0.08	fail	0.60	0.50			0.01

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2
					N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}			
05/16/15	M	P	FM	A	6.53	13.47	pass	1.00	1.89	0.37	fail	0.57	5.19			0.09
05/16/15	M	P	FM	B	5.87	12.99	pass	0.87	1.71	0.67	fail	0.59	4.67	13.24	pass	0.09
05/16/15	M	P	FM	C	7.18	15.67	pass	0.99	2.08	0.60	fail	0.47	5.71			0.09
05/16/15	M	P	FM	D	6.53	14.46	pass	1.00	1.89	0.40	fail	0.21	5.19			0.09
05/17/15	M	P	FM	A	10.04	13.57	pass	0.96	2.91	0.26	fail	0.38	7.99			0.14
05/17/15	M	P	FM	B	9.04	15.48	pass	0.77	2.62	1.39	fail	0.46	7.19			0.14
05/17/15	M	P	FM	C	11.05	18.34	pass	0.91	3.21	0.66	fail	0.13	8.78			0.14
05/17/15	M	P	FM	D	10.04	15.35	pass	0.97	2.91	0.68	fail	0.30	7.99			0.14
05/18/15	M	P	FM	A	5.45	12.49	pass	0.98	1.58	0.20	fail	0.89	4.33	1.40	fail	0.08
05/18/15	M	P	FM	B	4.90	16.37	pass	0.80	1.42	1.12	fail	0.27	3.90			0.08
05/18/15	M	P	FM	C	5.99	17.43	pass	1.00	1.74	0.62	fail	0.14	4.76			0.08
05/18/15	M	P	FM	D	5.45	15.45	pass	0.99	1.58	0.79	fail	0.32	4.33			0.08
05/21/15	M	P	FM	A	4.64	12.96	pass	0.93	1.35	0.08	fail	0.60	3.69			0.07
05/21/15	M	P	FM	B	4.18	15.20	pass	0.94	1.21	1.15	fail	0.55	3.32			0.07
05/21/15	M	P	FM	C	5.11	16.95	pass	0.96	1.48	1.56	pass	0.90	4.06	9.50	pass	0.07
05/21/15	M	P	FM	D	4.64	43.88	pass	0.38	1.35	-4.92	fail	0.05	3.69			0.07
05/25/15	M	P	FM	A	8.50	14.66	pass	0.81	2.47	1.22	fail	0.79	6.76	6.19	fail	0.12
05/25/15	M	P	FM	B	7.65	17.48	pass	1.00	2.22	1.43	fail	0.35	6.09			0.12
05/25/15	M	P	FM	C	9.35	22.44	pass	0.91	2.71	3.33	pass	0.69	7.44	44.48	pass	0.12
05/25/15	M	P	FM	D	8.50	45.06	pass	0.39	2.47	1.50	fail	0.01	6.76			0.12
06/02/15	M	P	FM	A	6.07	14.20	pass	0.93	1.76	0.51	fail	0.60	4.83			0.09
06/02/15	M	P	FM	B	5.47	14.78	pass	0.41	1.59	0.79	fail	0.25	4.35	15.36	pass	0.09
06/02/15	M	P	FM	C	6.68	19.73	pass	1.00	1.94	2.93	pass	0.87	5.31	24.50	pass	0.09
06/02/15	M	P	FM	D	6.07	53.37	pass	0.89	1.76	4.62	pass	0.08	4.83			0.09
06/10/15	M	P	FM	A	7.75	16.27	pass	0.95	2.25	1.98	fail	0.94	6.16	6.98	pass	0.11
06/10/15	M	P	FM	B	6.97	16.68	pass	1.00	2.02	0.73	fail	0.19	5.55			0.11
06/10/15	M	P	FM	C	8.52	47.20	pass	0.78	2.47	7.29	pass	0.30	6.78			0.11
06/10/15	M	P	FM	D	7.75	90.25	pass	0.83	2.25	9.94	pass	0.10	6.16			0.11
06/19/15	M	P	FM	A	6.62	39.12	pass	1.00	1.92	9.72	pass	0.94	5.26	57.06	pass	0.10
06/19/15	M	P	FM	B	5.96	23.80	pass	0.87	1.73	5.34	pass	0.86	4.74	14.48	pass	0.10
06/19/15	M	P	FM	C	7.28	36.26	pass	1.00	2.11	11.95	pass	0.97	5.79	56.81	pass	0.10
06/19/15	M	P	FM	D	6.62	101.19	pass	0.96	1.92	60.67	pass	0.94	5.26	273.86	pass	0.10
07/02/15	M	P	FM	A	7.69	14.31	pass	0.96	2.23	4.00	pass	0.96	6.11	12.37	pass	0.11
07/02/15	M	P	FM	B	6.92	11.71	pass	1.00	2.01	0.76	fail	0.53	5.50			0.11
07/02/15	M	P	FM	C	8.45	14.72	pass	1.00	2.45	3.74	pass	0.99	6.72	9.21	pass	0.11
07/02/15	M	P	FM	D	7.69	17.42	pass	0.40	2.23	-1.40	fail	0.08	6.11			0.11
07/08/15	M	P	FM	A	4.78	15.45	pass	0.97	1.39	1.70	pass	0.48	3.80			0.07
07/08/15	M	P	FM	B	4.30	10.96	pass	0.99	1.25	0.52	fail	0.42	3.42			0.07
07/08/15	M	P	FM	C	5.26	14.16	pass	0.95	1.53	2.71	pass	0.95	4.18	8.80	pass	0.07
07/08/15	M	P	FM	D	4.78	64.67	pass	0.54	1.39	1.01	fail	0.00	3.80			0.07
07/23/15	M	P	FM	A	10.82	14.31	pass	0.87	3.14	0.45	fail	0.51	8.61			0.15
07/23/15	M	P	FM	B	9.74	11.96	pass	0.98	2.83	0.48	fail	0.96	7.75	1.06	fail	0.15
07/23/15	M	P	FM	C	11.90	15.24	pass	0.98	3.46	0.58	fail	0.96	9.47	2.54	fail	0.15
07/23/15	M	P	FM	D	10.82	65.77	pass	0.47	3.14	-7.97	fail	0.06	8.61			0.15
07/31/15	M	P	FM	A	3.35	11.99	pass	1.00	0.97	0.55	fail	0.83	2.66	0.22	fail	0.05
07/31/15	M	P	FM	B	3.01	10.78	pass	0.72	0.87	0.27	fail	0.69	2.40	0.56	fail	0.05
07/31/15	M	P	FM	C	3.68	11.69	pass	1.00	1.07	0.30	fail	1.00	2.93	0.92	fail	0.05
07/31/15	M	P	FM	D	3.35	56.18	pass	0.42	0.97	-6.87	fail	0.05	2.66			0.05
08/05/15	M	P	FM	A	4.94	11.21	pass	1.00	1.43	0.00	fail	0.00	3.93			0.07
08/05/15	M	P	FM	B	4.44	9.66	pass	0.90	1.29	0.10	fail	0.40	3.53			0.07
08/05/15	M	P	FM	C	5.43	12.16	pass	0.95	1.58	0.34	fail	0.69	4.32			0.07
08/05/15	M	P	FM	D	4.94	58.31	pass	0.40	1.43	-7.85	fail	0.06	3.93			0.07
08/12/15	M	P	FM	A	5.85	10.93	pass	0.90	1.70	0.66	fail	0.87	4.65	1.26	fail	0.08
08/12/15	M	P	FM	B	5.27	9.63	pass	0.48	1.53	0.02	fail	0.01	4.19			0.08
08/12/15	M	P	FM	C	6.44	11.51	pass	0.70	1.87	0.24	fail	0.53	5.12	3.04	fail	0.08
08/12/15	M	P	FM	D	5.85	47.73	pass	0.40	1.70	-6.18	fail	0.06	4.65			0.08
08/25/15	M	P	FM	A	0.67	10.37	pass	0.55	0.20	0.14	fail	0.45	0.54	1.38	pass	0.01
08/25/15	M	P	FM	B	0.61	9.66	pass	0.40	0.18	-0.03	fail	0.07	0.48			0.01
08/25/15	M	P	FM	C	0.74	11.59	pass	0.93	0.22	0.09	fail	0.60	0.59			0.01
08/25/15	M	P	FM	D	0.67	52.93	pass	0.40	0.20	-7.29	fail	0.06	0.54			0.01

Parameters					Lquad Flux Calculation				LLR Flux Calculation				HM4 Flux Calculations			
Sample Date	Location	Crop	Fertilizer	Rep	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2	MDL	Measured Flux	Pass/Fail	R^2
					N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}				N_2O-N g ha^{-1} d^{-1}			
05/16/15	M	P	UR	A	6.53	13.12	pass	0.78	1.89	0.49	fail	0.77	5.19	2.37	fail	0.09
05/16/15	M	P	UR	B	6.53	12.36	pass	1.00	1.89	0.00	fail	1.00	5.19			0.09
05/16/15	M	P	UR	C	6.53	12.36	pass	1.00	1.89	0.00	fail	1.00	5.19			0.09
05/16/15	M	P	UR	D	5.22	10.01	pass	0.40	1.52	-0.02	fail	0.07	4.15			0.09
05/17/15	M	P	UR	A	10.04	15.29	pass	0.87	2.91	0.80	fail	0.39	7.99			0.14
05/17/15	M	P	UR	B	10.04	12.71	pass	0.40	2.91	-0.03	fail	0.07	7.99			0.14
05/17/15	M	P	UR	C	10.04	12.67	pass	0.20	2.91	0.06	fail	0.20	7.99			0.14
05/17/15	M	P	UR	D	8.03	10.24	pass	0.93	2.33	0.07	fail	0.60	6.39			0.14
05/18/15	M	P	UR	A	5.45	16.03	pass	0.73	1.58	0.20	fail	0.02	4.33			0.08
05/18/15	M	P	UR	B	5.45	12.32	pass	0.40	1.58	-0.03	fail	0.07	4.33			0.08
05/18/15	M	P	UR	C	5.45	12.41	pass	0.93	1.58	0.08	fail	0.60	4.33			0.08
05/18/15	M	P	UR	D	4.36	9.96	pass	1.00	1.26	0.00	fail	1.00	3.47			0.08
05/21/15	M	P	UR	A	4.64	15.89	pass	0.93	1.35	0.74	fail	0.32	3.69			0.07
05/21/15	M	P	UR	B	4.64	13.01	pass	1.00	1.35	0.00	fail	0.00	3.69			0.07
05/21/15	M	P	UR	C	4.64	13.42	pass	0.93	1.35	0.31	fail	0.90	3.69	1.57	fail	0.07
05/21/15	M	P	UR	D	3.71	11.23	pass	0.68	1.08	0.16	fail	0.19	2.95			0.07
05/25/15	M	P	UR	A	8.50	16.47	pass	0.79	2.47	0.99	fail	0.41	6.76			0.12
05/25/15	M	P	UR	B	8.50	13.40	pass	0.84	2.47	0.06	fail	0.04	6.76			0.12
05/25/15	M	P	UR	C	8.50	14.96	pass	0.97	2.47	0.62	fail	0.39	6.76			0.12
05/25/15	M	P	UR	D	6.80	11.43	pass	0.97	1.97	2.01	pass	0.95	5.41	3.67	fail	0.12
06/02/15	M	P	UR	A	6.07	16.15	pass	1.00	1.76	0.57	fail	0.20	4.83			0.09
06/02/15	M	P	UR	B	6.07	13.32	pass	1.00	1.76	0.00	fail	0.00	4.83			0.09
06/02/15	M	P	UR	C	6.07	14.63	pass	0.93	1.76	1.05	fail	0.79	4.83	10.15	pass	0.09
06/02/15	M	P	UR	D	4.86	12.48	pass	0.70	1.41	1.11	fail	0.66	3.86	6.84	pass	0.09
06/10/15	M	P	UR	A	7.75	17.16	pass	0.38	2.25	1.03	fail	0.35	6.16	7.94	pass	0.11
06/10/15	M	P	UR	B	7.75	16.52	pass	0.93	2.25	0.92	fail	0.60	6.16			0.11
06/10/15	M	P	UR	C	7.75	16.55	pass	0.99	2.25	0.58	fail	0.28	6.16			0.11
06/10/15	M	P	UR	D	6.20	12.27	pass	0.87	1.80	0.18	fail	0.23	4.93			0.11
06/19/15	M	P	UR	A	6.62	32.80	pass	0.88	1.92	5.47	pass	0.80	5.26	40.25	pass	0.10
06/19/15	M	P	UR	B	6.62	39.19	pass	1.00	1.92	15.58	pass	0.97	5.26	77.83	pass	0.10
06/19/15	M	P	UR	C	6.62	18.11	pass	0.64	1.92	0.27	fail	0.36	5.26			0.10
06/19/15	M	P	UR	D	5.29	21.07	pass	1.00	1.54	6.23	pass	0.99	4.21	25.56	pass	0.10
07/02/15	M	P	UR	A	7.69	10.70	pass	0.68	2.23	3.26	pass	0.52	6.11	1.85	fail	0.11
07/02/15	M	P	UR	B	7.69	21.66	pass	1.00	2.23	10.42	pass	1.00	6.11	32.91	pass	0.11
07/02/15	M	P	UR	C	7.69	10.31	pass	0.80	2.23	0.22	fail	0.80	6.11			0.11
07/02/15	M	P	UR	D	6.15	25.94	pass	1.00	1.78	9.30	pass	0.87	4.89	77.54	pass	0.11
07/08/15	M	P	UR	A	4.78	12.50	pass	0.98	1.39	2.11	pass	0.96	3.80	3.66	fail	0.07
07/08/15	M	P	UR	B	4.78	17.92	pass	0.97	1.39	6.87	pass	0.96	3.80	27.53	pass	0.07
07/08/15	M	P	UR	C	4.78	10.53	pass	0.93	1.39	0.30	fail	0.90	3.80	1.52	fail	0.07
07/08/15	M	P	UR	D	3.82	27.01	pass	1.00	1.11	11.26	pass	0.91	3.04	78.60	pass	0.07
07/23/15	M	P	UR	A	10.82	13.50	pass	0.90	3.14	0.11	fail	0.40	8.61			0.15
07/23/15	M	P	UR	B	10.82	12.97	pass	0.97	3.14	0.62	fail	0.83	8.61	0.41	fail	0.15
07/23/15	M	P	UR	C	10.82	17.37	pass	0.78	3.14	1.59	fail	0.43	8.61			0.15
07/23/15	M	P	UR	D	8.66	11.56	pass	1.00	2.51	2.37	fail	0.94	6.88	2.94	fail	0.15
07/31/15	M	P	UR	A	3.35	12.62	pass	0.93	0.97	-0.16	fail	0.60	2.66			0.05
07/31/15	M	P	UR	B	3.35	11.68	pass	0.99	0.97	0.35	fail	0.97	2.66	0.63	fail	0.05
07/31/15	M	P	UR	C	3.35	15.41	pass	0.85	0.97	2.15	pass	0.66	2.66	39.97	pass	0.05
07/31/15	M	P	UR	D	2.68	11.11	pass	0.98	0.78	0.89	pass	0.65	2.13			0.05
08/05/15	M	P	UR	A	4.94	11.34	pass	0.93	1.43	0.03	fail	0.01	3.93			0.07
08/05/15	M	P	UR	B	4.94	10.97	pass	0.98	1.43	0.20	fail	0.89	3.93	1.39	fail	0.07
08/05/15	M	P	UR	C	4.94	12.08	pass	0.83	1.43	0.78	fail	0.68	3.93	10.13	pass	0.07
08/05/15	M	P	UR	D	3.95	9.80	pass	1.00	1.15	0.81	fail	0.98	3.14	3.48	pass	0.07
08/12/15	M	P	UR	A	5.85	10.31	pass	0.40	1.70	-0.03	fail	0.07	4.65			0.08
08/12/15	M	P	UR	B	5.85	10.75	pass	0.99	1.70	0.19	fail	0.28	4.65			0.08
08/12/15	M	P	UR	C	5.85	11.32	pass	0.97	1.70	1.26	fail	0.97	4.65			0.08
08/12/15	M	P	UR	D	4.68	9.78	pass	0.98	1.36	1.54	pass	0.98	3.72			0.08
08/25/15	M	P	UR	A	0.67	10.72	pass	0.55	0.20	0.28	pass	0.45	0.54			0.01
08/25/15	M	P	UR	B	0.67	10.84	pass	0.50	0.20	0.31	pass	0.36	0.54			0.01
08/25/15	M	P	UR	C	0.67	10.64	pass	0.47	0.20	0.17	fail	0.30	0.54			0.01
08/25/15	M	P	UR	D	0.54	8.56	pass	0.93	0.16	0.25	pass	0.90	0.43	1.24	pass	0.01

Appendix 2. Details on Field Trials

Controls

Sites were assessed for heterogeneity prior to trial initiation using pH and moisture. Only the Madras sites varied significantly in moisture by from north to south. Plots were blocked according to gradients found in the preliminary testing. All soils were analyzed to determine if there were any nutrient deficiencies other than nitrogen. The soil test results for both Klamath Falls and Madras were near the cut off for needing phosphorus fertilizer, triple super phosphate was applied at a rate 129 lbs P acre^{-1} in Klamath Falls, and 25 lbs P acre^{-1} in Madras to minimize the chance of confounding results due to P deficiency. The fertilizer for Madras was donated by the Jefferson branch of Wilbur-Ellis. A routine application of micronutrients (Zn, Mn, Cu, and B) were applied aerially to all plots in Klamath Falls. While the ultimate goal of the project was to analyze the efficacy of organic fertilizers, none of the fields were managed organically. In order to minimize confounding results from crop damage, each site used herbicide, insecticide, and fungicide according to the management practices for each respective crop as advised by each farm manager. Irrigation was also managed by farm managers using their knowledge of the evaporation and evapotranspiration rates.

There were five rows in each plot with the exception of Klamath Falls potatoes where there were only 4 rows per plot. The two outer rows in each experimental unit (EU) at each location were not sampled for any measurements. Yukon gold potatoes were used for potato test plots while, potato buffer zones, 1.3m long, were planted to the Norcoda potato variety which is a dark red/purple in order to clearly mark plot boundaries during harvest. One row of buffer corn was planted between plots and 1.3m of buffer was used between plots within a continuous row.

Fertilizer application

The optimal rate of N fertilizer for each plot was determined using the soil test results in Table 2-1. The total substrate availability and organic matter content were used to estimate the N that would be supplied to the crop through soil N mineralization. This was subtracted from the total N needed for each crop to determine the recommended (R) rate. The medium rate (M) was 75% of the total recommended rate and the low rate (L) was 50% of the recommended rate. Fertilizers were separated into individual bags for each plot and each row. All N fertilizers were banded and incorporated into the soil. The corn received all N fertilizer in organic form at planting, banded in a row within 4 inches of the seed. In accordance with best management practices, the UR treatments received 30 lbs N acre^{-1} at planting and the remainder of the total N rate 30 days later. The potatoes received 50% of the N fertilizer at planting. The fertilizer was laid in a row, potato seed pieces were placed on top and soil was hilled over the seed and fertilizer. The other 50% was side-dressed 30 days later at which point they were re-hilled to incorporate the fertilizer and bury part of the initial growth to optimize yield.

Soil sampling

Soils for each site were sampled on the day of planting, roughly 30 days after planting, 60 days after planting, at harvest, and three weeks after harvest. They were taken from the middle of one row on each plot (taken from third row from the east), directly in line with the crop roots. (The exception to this was the day 60 sampling point in the Madras corn crop where a technician did not follow instructions so half of the samples were in row and half were between rows.) For the first four soil sampling points a 2.54 cm diameter soil corer was used to take five subsamples per plot to a depth of 15cm. These subsamples were combined in a bag and placed into a cooler, each with 15 minutes of collection. The post-harvest samples were taken using a 7.6cm diameter soil auger to take three subsamples per plot at each of four depths, 0-15cm, 15-30cm, 30-45cm, and 45-60cm. The subsamples for each depth were combined in a bucket, mixed, a portion was poured into a bag, and placed in a cooler within 15 minutes of collection.

Plant sampling

Potato petioles were sampled through the season to assess soil N uptake dynamics. The first sample was taken about 45 days after planting, with subsequent samples taken every 14 days. The second row from the east was sampled for each plot. The fourth fully-expanded leaf set from the top was plucked and leaflets were removed from the petiole in the field prior to placing the sample in a paper bag. Fifteen petioles per experimental unit were used. The bags were brought back to the lab, dried, and ground prior to analysis.

Roughly one week prior to harvest the above ground biomass for the potatoes was collected by cutting five plants in the third row from the east in Madras and Corvallis but because of the standard vine kill procedures used in Klamath Falls, above ground biomass was not collected. Plants were put into burlap bags, put in the drying oven, then a subsample was ground for analysis.

Below ground biomass was harvested using a potato digger and laid on the ground. Technicians then collected all of the potatoes from the second row from the east for each plot. Potatoes in Klamath Falls were processed on site with a team of technicians who showed us the procedure for assessing quality metrics, disease, and measuring specific gravity. Quality was assessed visually and scores were given on a scale from 0-5 with 5 being no damage, for greening, growth cracks, and presence of *Rhizoctonia solani*. Ten potatoes in the 10-14 oz size range were cut open to assess for hollow heart, the count of presence was recorded. Specific gravity was quantified by weighing potatoes in the air and then also in water.

Specific gravity = air weight/(air weight-wet weight) Eq 6-3

Potatoes that were misshapen were sorted as #2s, culls were rotten potatoes or those with virus or other damage that would make them inedible. Then sizes were sorted as <2oz, 2-4oz, 4-6oz, 6-10 oz, 10-14oz, and >14 oz by the potato harvest sorting equipment. This same procedure was used for potatoes harvested in Corvallis and Madras by the sorting equipment on site in Corvallis.

Sweet corn Anthem XR F1 was chosen because Klamath Falls has a short growing season for corn, with an estimated 70 frost free days. This variety is set to mature in 73 days and has resistance to new rust strains and Stewart's Bacterial Wilt (Harrisseeds.com). For the corn plots both ear and total biomass samples were taken at harvest. Because of a poor emergence rate in Madras and some marginal plot boundaries in Klamath Falls the harvest procedure was slightly modified. Plot buffers were mowed down prior to sample collection for clear demarcation of plot boundaries. The three middle rows of each plot were sampled at harvest and a total count of ears was tallied for the individual rows. Every third plant was sampled for ears and every sixth plant was cut with a machete for biomass. All corn harvest data was processed in Corvallis. Ears were assessed for the total count, total yield, count and yield for ears greater than 6 inches, and 9 inches. The average lengths, width, tip fill, and total kernel damage was assessed for each plot as quality parameters.

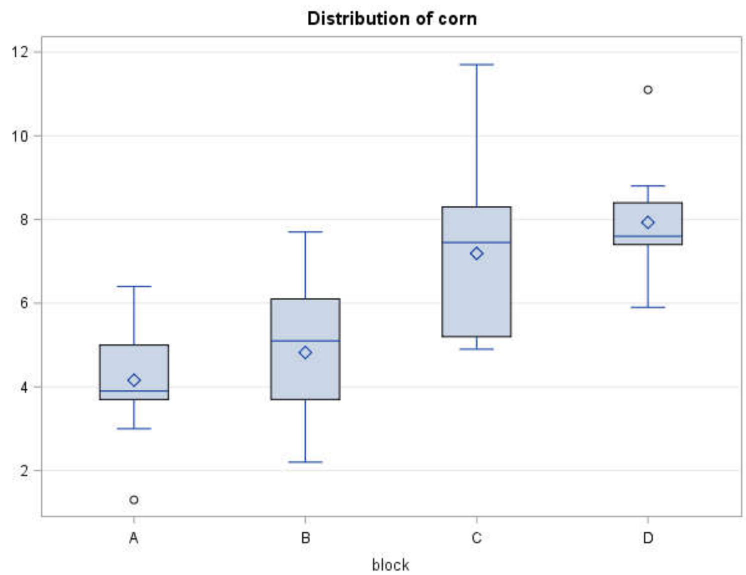
Total C and N of plant materials, petioles, total biomass, and produce, were analyzed using dry combustion with an Elementar vario MACRO cube (Elementar Langenselbold, Germany). It is more traditional to quantify the NO_3-N in potato petioles. However, the Lachat FIA was not in working order and the Elementar provided very reliable results.

Sources of Error

Some of the data collected for this trial was not used in this analysis. I took on a very ambitious trial design with limited funds and doing field work always results in lessons to be learned. The student technicians who were to collect petiole samples in Madras on July 1st, stripped the leaves off of the petiole and sent the leaves alone. The samples were not dried and analyzed because I was unable to find a reference to use the leaf N as a sufficiency level. In Klamath Falls, the field technicians did not have enough time to collect petiole samples at the third sampling date. The field sampling of corn 60 days after planting was not collected because when I was at the site there was a strong storm bringing thunder, lightning, and heavy rain. I did not give proper instructions to the crew to take the samples after I had left.

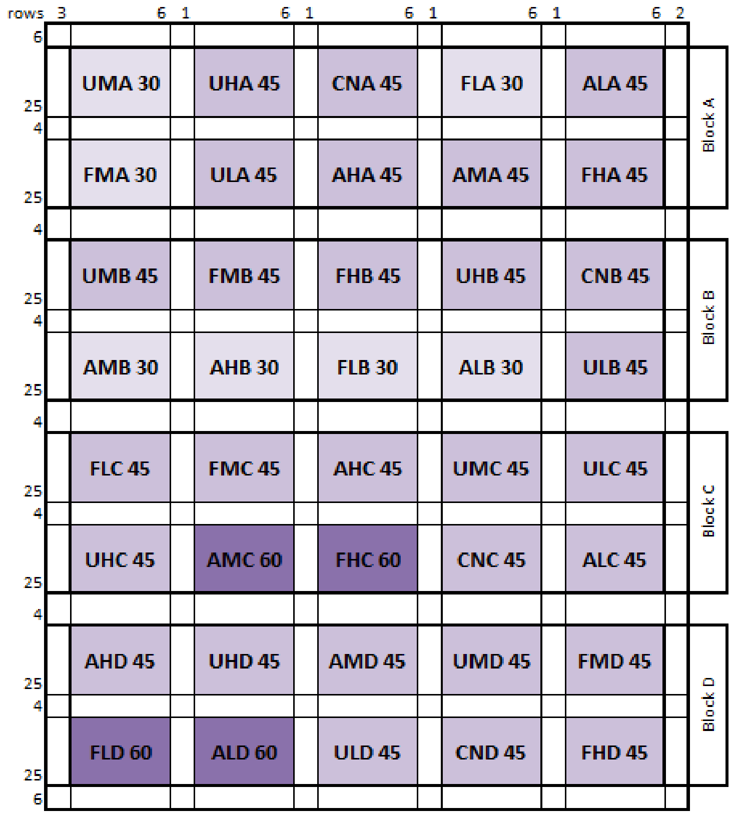
The corn trials had several complicating factors. In Madras there was a very poor emergence rate. It was expected that birds had eaten seed that had been planted too shallow. I was unaware of this problem until I arrived 30 days after planting and saw the crop. At this point, it was too late to replant. The emergence rate was assessed visually and ranged from 70-95% with no significant differences by block or treatment (Average = 85 Pr>F 0.4321). The emergence rate in Klamath Falls was better (90%), but while planting the corn I tried to maintain buffer zones within the row in which no corn was planted. There were several plots where I messed up the timing when pushing the button to engage in planting and so the plot size was smaller than it should have been. These two issues forced us to adjust our harvest data plan. I skipped the first three and last three corn plants in each row, and only used ears from every third stalk that had emerged. Typically all of the corn from a set length of row would be harvested. This adjustment was made to try to account for the poor emergence and the imperfect plot boundaries. In order to make sure that these problems did not cause significant differences, I counted the total number of plants in each plot that were harvested. I analyzed the yield in relation to the plant count and found that the our harvest plan adjustment did normalize the planting errors so that the total plants harvested was similar per plot and the yield per plot did not differ from the total yield.

There was also a weed problem in the Madras corn crop. At 30 days after planting weeds covered most of the soil, some weeds were as high as the corn plant. Herbicides were applied subsequently, but the crop continued to struggle (Image 6-1). While taking soil samples at day 60 one technician did not follow the instructions to take the samples in the middle of the corn row. This resulted in some of the samples in the row and some between rows. Since the fertilizer had been banded and the rhizosphere is the most active area of microbial activity, this resulted in soil NO3-N results that did not follow any expected pattern. At harvest, it was clear that the north end of the field was visibly dry and seemed to be different by yield. Appendix Figure 6-8 shows that there were yield differences by block with blocks D and C being significantly higher than blocks A and B. While I had assumed that this was due to poorly managed irrigation, I found that there was variation in depth to bedrock while taking the post-harvest nitrate samples. The north end of the field, blocks A and B, averaged 40 cm to bedrock, with several plots not more than 30cm deep, while blocks C and D averaged 48cm to bedrock (Appendix Figure 6-9). This impacted the total amount of water that the soil could hold between irrigation events and volume of soil the roots could explore and could be the cause for lower performance in these plots.



Appendix Figure 5-5 Corn Yield in Madras by Block
Among the problems with the corn crop was a significant difference by block regarding yield.

Appendix Image 1 Madras Corn Crop at 30 days after planting
Weeds were not controlled in the Madras corn plot. You can also see the poor emergence rate in several parts of the field



Appendix Figure 5-6 Depth to Bedrock (cm) in Madras Corn by Treatment Plot
While taking the post-harvest soil samples, I found that there is dramatic differences in the depth to bedrock. It is expected that this impacted the variability in performance by block. This is a plot map where the first letter represents the fertilizer, the second is the rate, and the third I the block.

In Corvallis the corn crop was likely over fertilized. The soil organic matter was at 2.5% and while the recommended rate in Corvallis was 50 lbs N acre^{-1} lower than the other sites. This adjustment was not enough. The control plots, which received no N fertilizer had the same yield and corn ear N as plots that received, the low, medium and high rates of both FM and UR. Looking at the plots it was impossible to tell which had been fertilized. It was curious however, that the plots that received the AB were actually lower in total yield and ear N.

In Corvallis, there was an irrigation blowout that primarily impacted one potato plot. The water gushed from the pipes overnight and was enough to saturate the local soil, lay the above ground biomass in the mud, and expose the potatoes. When assessing for outliers, this plot did not show a significant difference in total yield, but the quality parameter for greening was an outlier (scores for CPFL 4.5, 4, 5, and 0). This is to be expected because when potatoes are exposed to light they get green skins.

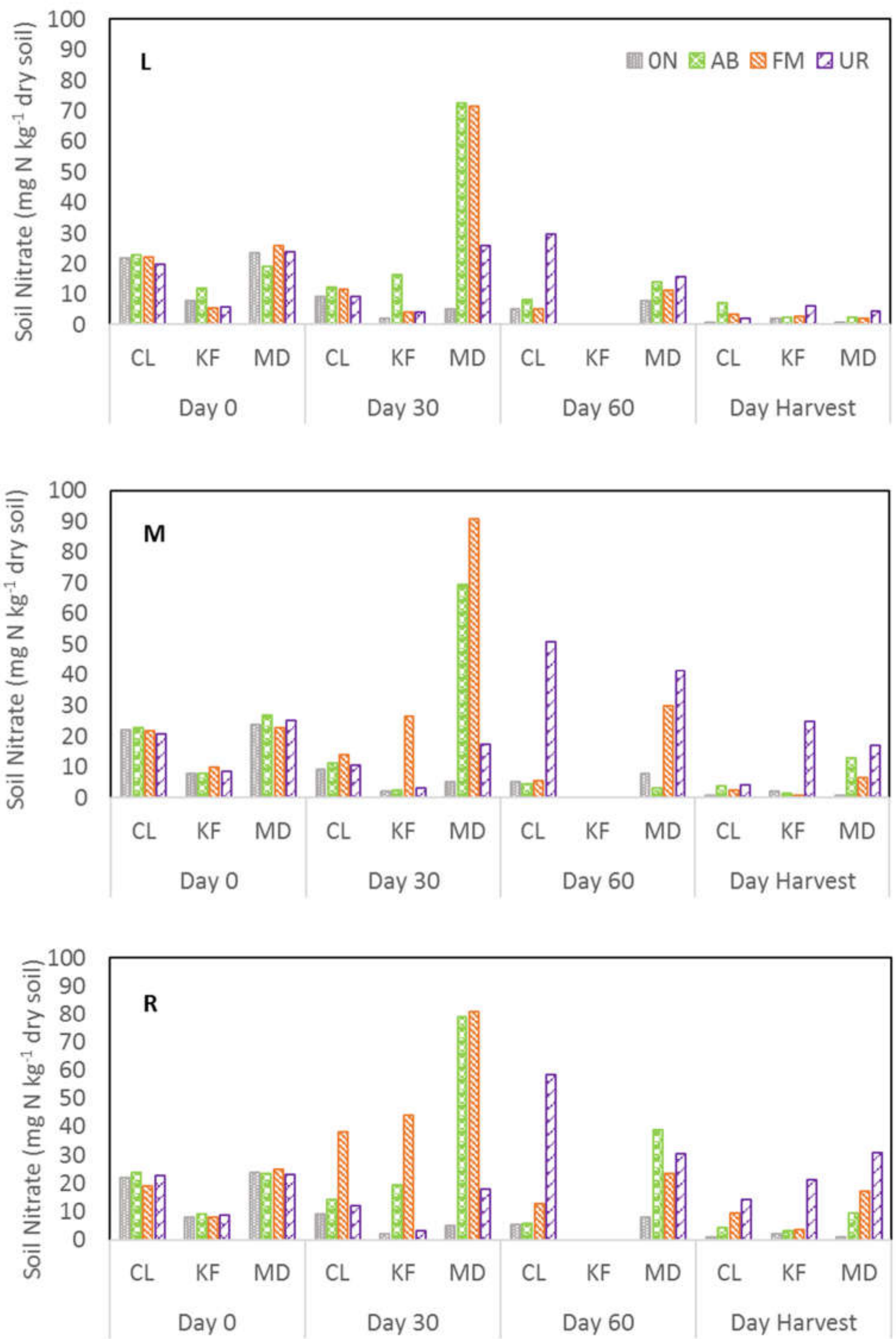
Appendix Image 2 Corvallis Potato Plot Irrigation Blowout
The pipe burst overnight and by morning the area around one plot was saturated, but the yield of this plot was not significantly lower than other plots. It did result in a higher percentage of green potatoes due to exposure to light.

In Klamath Falls the soil nitrate at planting for potatoes was significantly higher than it was for corn 13.7 and 7.8 mg kg^{-1} NO_3^--N respectively. This caught my attention because the potatoes were planted one month earlier than the corn and so I would expect lower temperatures to cause lower soil mineralization rates and therefore lower soil nitrate levels. It was later discovered that the pilot of the fertilizer application plane applied 6 lbs N acre^{-1} two weeks prior to potato planting while applying the other nutrients on this trial area. This is not enough to last through the season, but enough to elevate the day 0 samples.

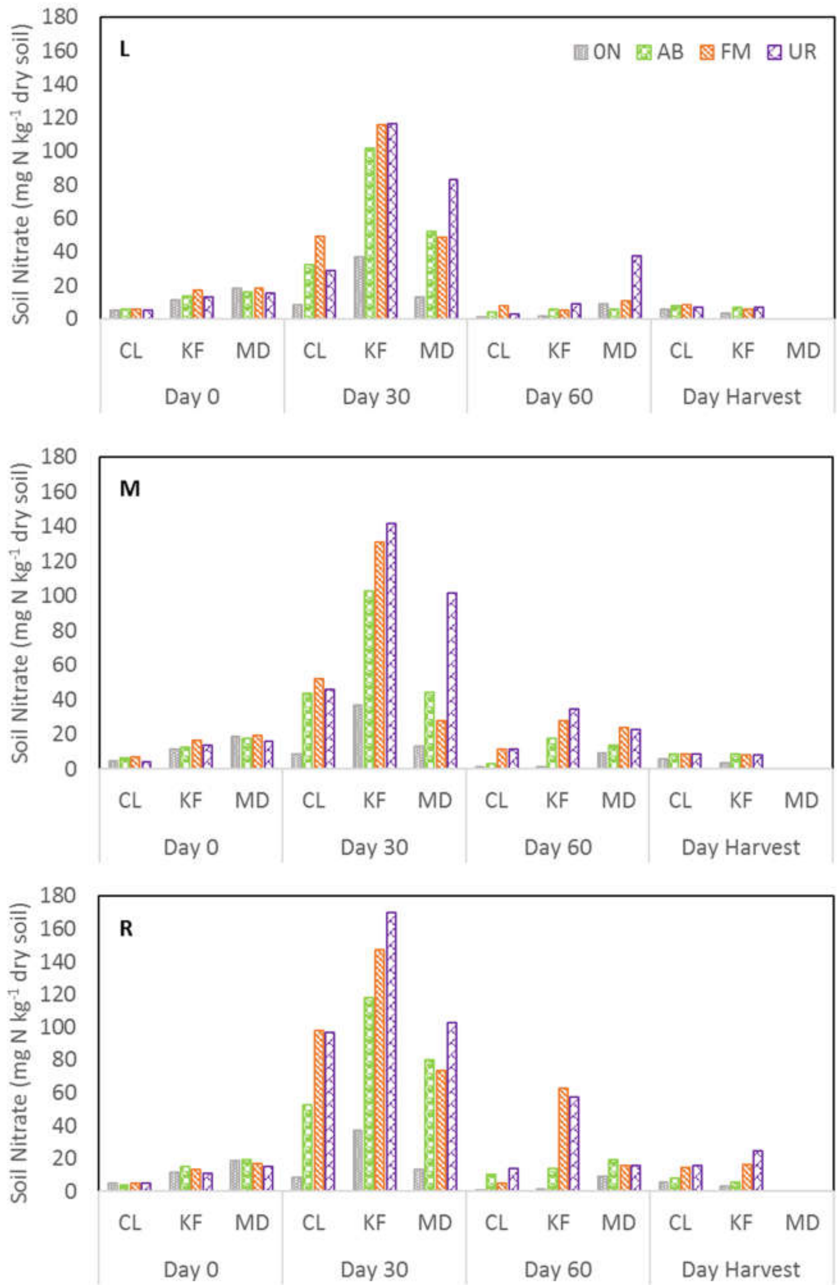
The algal biomass itself was also problematic. In Chapter 4, I discussed the variation in the shipments received. I did take subsamples from each of the shipments to assess for moisture and total N content. The total N applied at each location could have been adjusted for these variables. However, the deliveries were already late, I was on a tight time schedule, and stayed with the original calculations based on preliminary sample analysis. This likely caused variation in the total N applied to the plots receiving AB. The laboratory incubation comparing batch one and batch two of AB showed significant differences in C and N mineralization. I was unaware of this at the time of application. Luckily records show all potato plots received one half of their fertilizer from the slow mineralizing batch one, and applications were only mixed between batch two and three.

Additional Figures from Field Trial

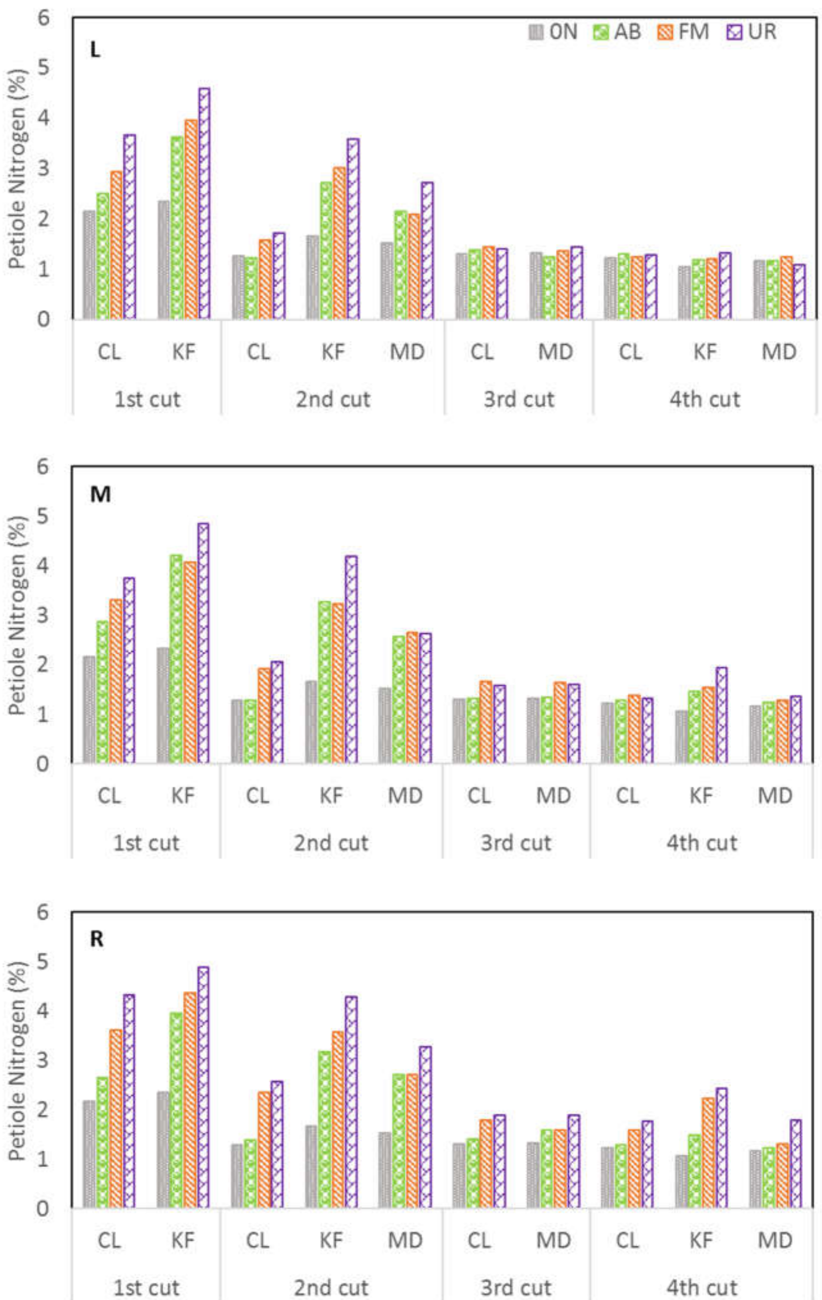
In many of the comparisons in the field trial we were able to combine either the rate or the site in order to compare the performance of the fertilizer. Additional data not presented in Chapter 2 are displayed below.



Appendix Figure ***5-7 All Soil Nitrate for Corn Plots by Rate, Date, Site, and Fertilizer***
CL=Corvallis, KF=Klamath Falls, MD=Madras, 0N=control, AB=algal biomass, FM=feather meal, UR=urea, L=50% of recommended fertilizer rate, M=75% of recommended fertilizer rate, R=recommended fertilizer rate. Days refer to time after planting.

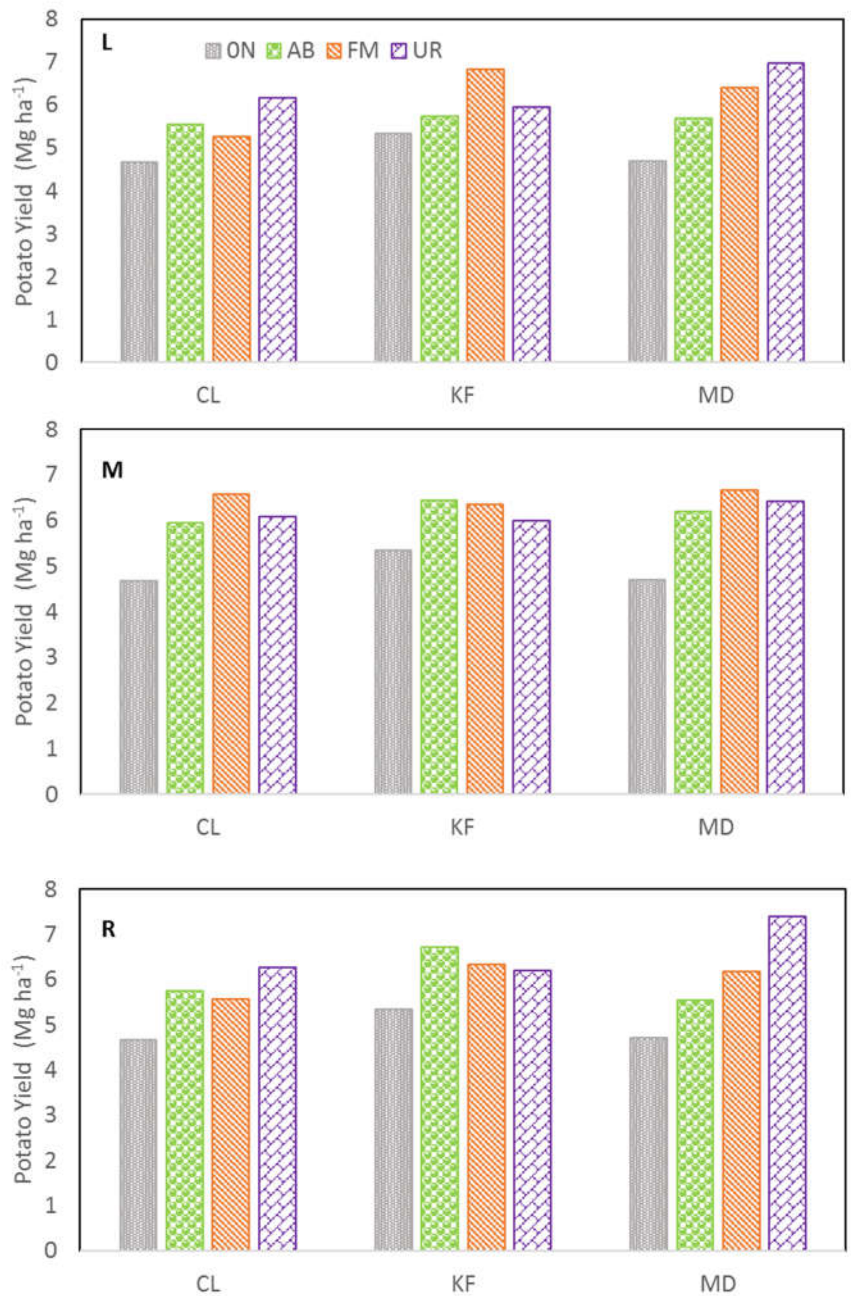


Appendix Figure 5-8 All Soil Nitrate for Potato Plots Rate, Date, Site, and Fertilizer
CL=Corvallis, KF=Klamath Falls, MD=Madras, 0N=control, AB=algal biomass, FM=feather meal, UR=urea, L=50% of recommended fertilizer rate, M=75% of recommended fertilizer rate, R=recommended fertilizer rate. Days refer to time after planting.

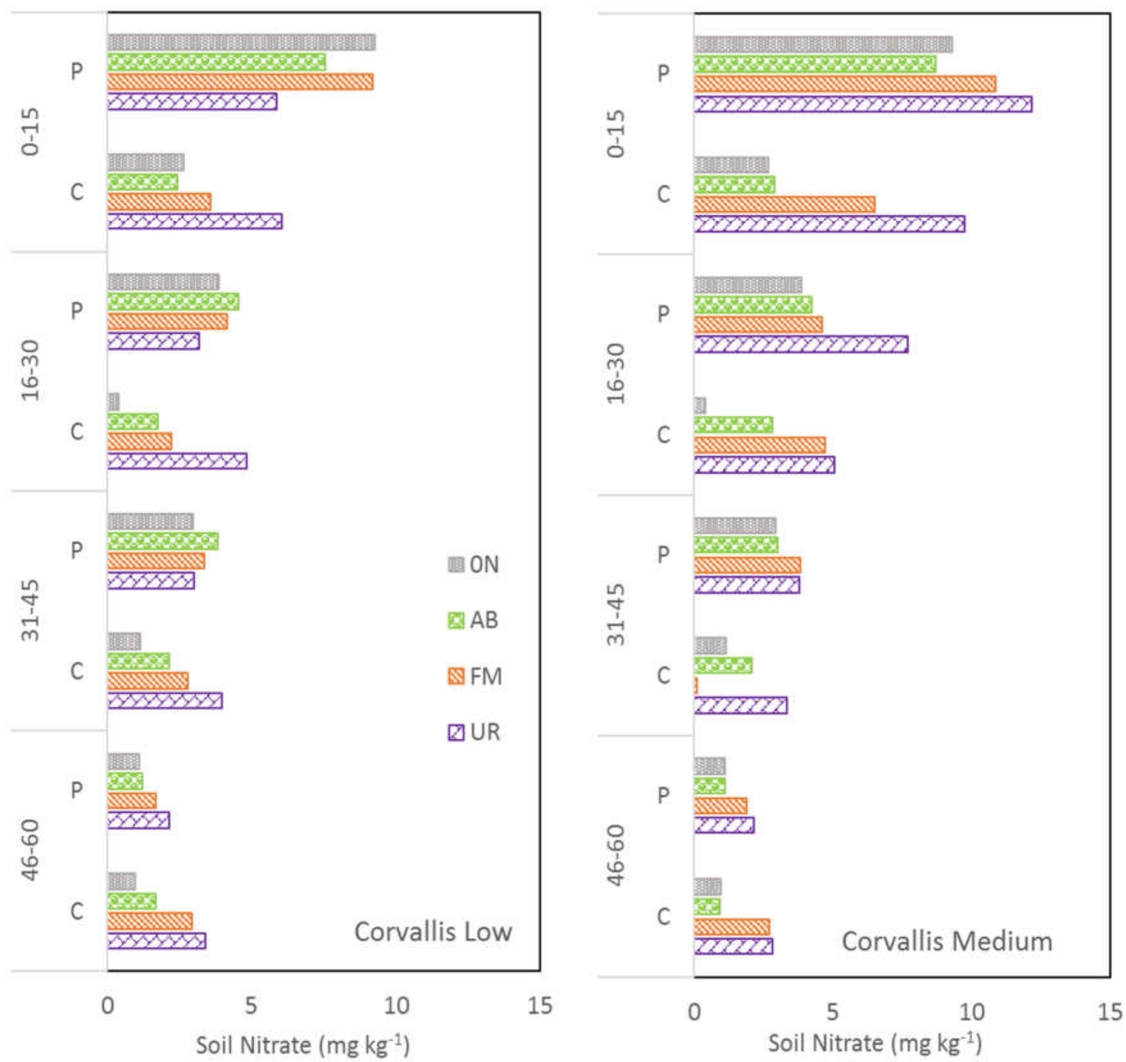


Appendix Figure 5-9 Potato Petiole Nitrogen by Rate, Date, Site, and Fertilizer

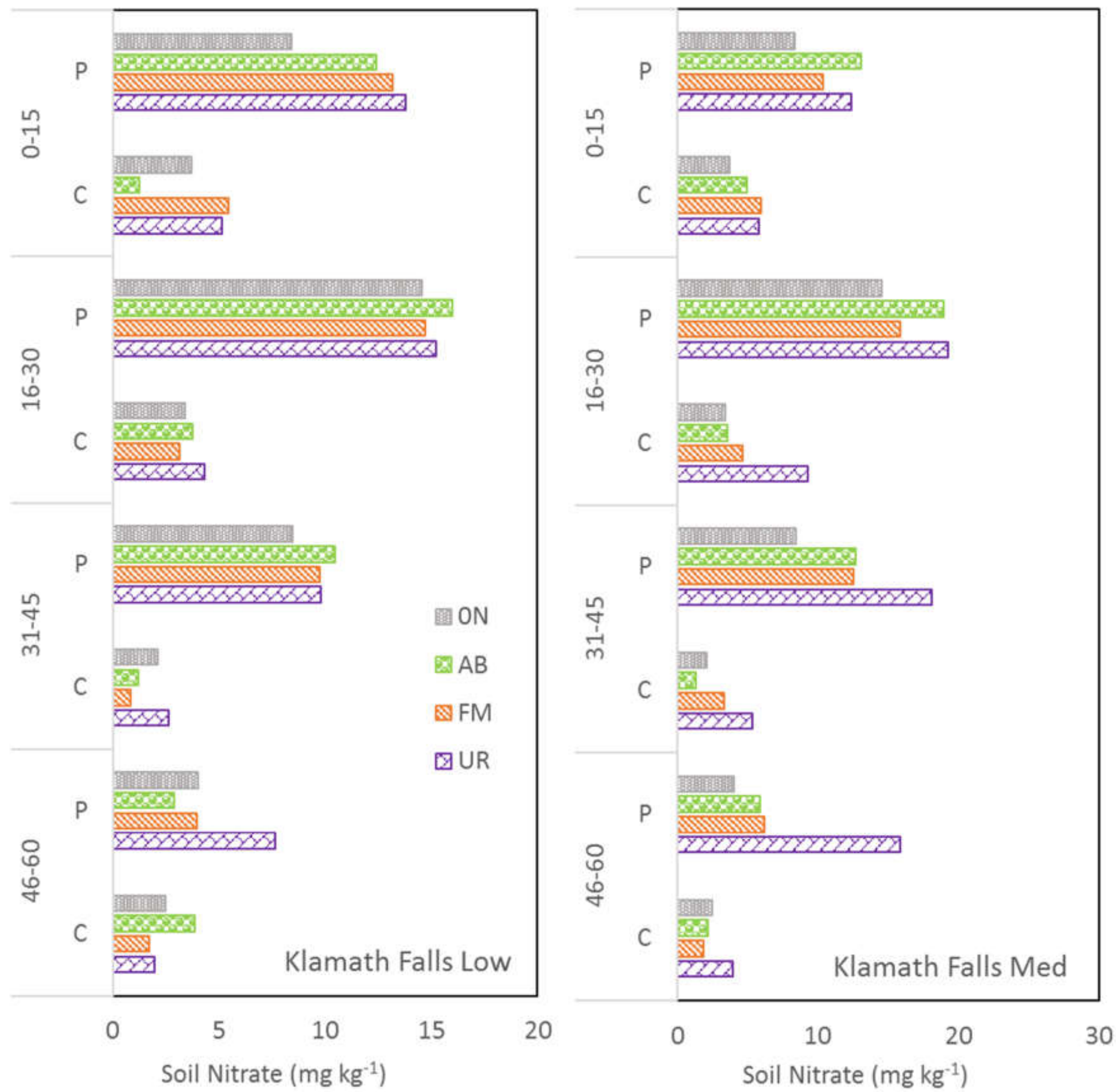
CL=Corvallis, KF=Klamath Falls, MD=Madras, 0N=control, AB=algal biomass, FM=feather meal, UR=urea, L=50% of recommended fertilizer rate, M=75% of recommended fertilizer rate, R=recommended fertilizer rate. 1st cut refers to first petiole cutting around 45 days after harvest, each consecutive cut was roughly 14 days later.



Appendix Figure 5-10 Total Potato Yield by Rate, Site, and Fertilizer
CL=Corvallis, KF=Klamath Falls, MD=Madras, 0N=control, AB=algal biomass, FM=feather meal, UR=urea, L=50% of recommended fertilizer rate, M=75% of recommended fertilizer rate, R=recommended fertilizer rate.

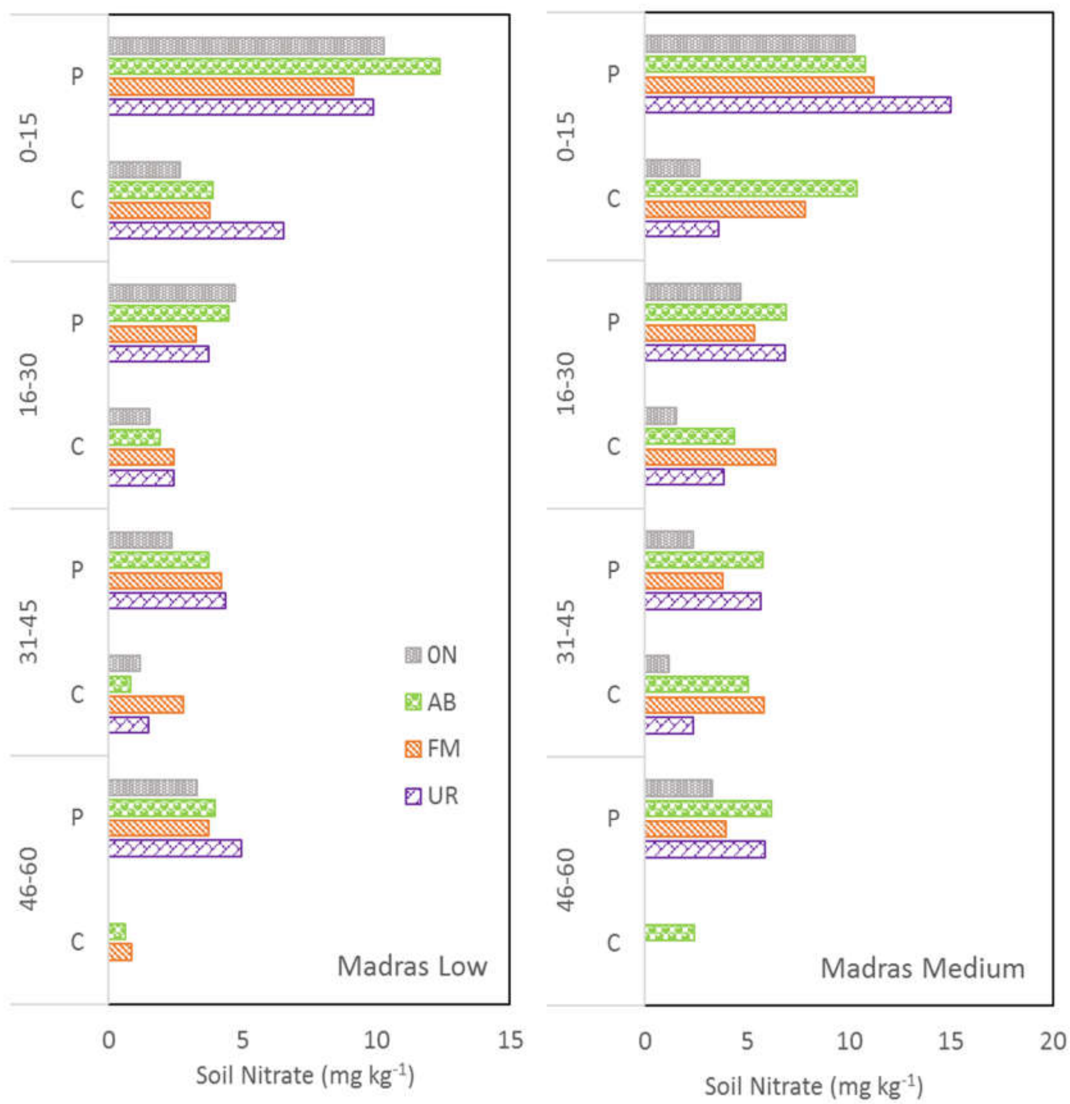


Appendix Figure 5-11 Post-Harvest Soil Nitrate in Corvallis by Depth, Crop, Rate, and Fertilizer
0N=control, AB=algal biomass, FM=feather meal, UR=urea, P=potato crop, C=corn crop, Low=50% of recommended fertilizer rate, M=75% of recommended fertilizer rate, recommended rate data in main text.



Appendix Figure 5-12 Post-Harvest Soil Nitrate in Klamath Falls by Depth, Crop, Rate, and Fertilizer

0N=control, AB=algal biomass, FM=feather meal, UR=urea, P=potato crop, C=corn crop, Low=50% of recommended fertilizer rate, M=75% of recommended fertilizer rate, recommended rate data in main text.



Appendix Figure 5-13 Post-Harvest Soil Nitrate in Madras by Depth, Crop, Rate, and Fertilizer
0N=control, AB=algal biomass, FM=feather meal, UR=urea, P=potato crop, C=corn crop, Low=50% of recommended fertilizer rate, M=75% of recommended fertilizer rate, recommended rate data in main text.

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