Utility of Dairy Digestate as a Greenhouse Fertilizer

by

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Abstract

Newfoundland and Labrador is currently unable to satisfy the food demand for the population of the province mainly due to climatic and geologic restrictions. Controlled environment agriculture requires consistent conditions and a cost-effective supply of inputs, principally nutrients. Dairy, as the main agricultural industry in the province, does produce significant waste-streams which contains significant nutrient concentrations. Therefore, I proposed the application of dairy digestate to soil systems under controlled greenhouse conditions to grow high value crops in Newfoundland to increase the food self-sufficiency of the province. I assessed the utility of local farm soil as a growth substrate. This study quantified the nitrogen, phosphorus and other nutrients in locally available dairy digestate, assessed nutrient budget within a soil system, and thus evaluated nutrient uptake and the quality of spent soil when dairy digestate was employed as a fertilizer to lettuce crops under controlled greenhouse conditions. It was hypothesized that dairy digestate is a suitable source of fertilizer due to its high nutrient content and that application to local soils allows greenhouse production. This study thus provides novel information pertaining to the future of agriculture and food self-sufficiency in Newfoundland, bridging the gap between the current restrictions on crop growth in Newfoundland and local options for nutrient re-use for year round agricultural production.

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Table of contents

List of figures

List of tables

List of abbreviations

N – Nitrogen

P – Phosphorus

K – Potassium

WFNB – Whole farm nutrient budget

BNF – Biological nitrogen fixation

GHG – Greenhouse gas

DD – Dairy digestate

NS – Nutrient solution

NS+DD – Nutrient solution + dairy digestate

AD – Anaerobic digestion

NUE – Nutrient use efficiency

N-UE – Nitrogen use efficiency

P-UE – Phosphorus use efficiency

S-DD – Soil substrate + dairy digestate fertilizer treatment

S-NS – Soil substrate + nutrient solution fertilizer treatment

S-DD+NS – Soil substrate + 50% dairy digestate/50% nutrient solution fertilizer treatment

S+P – 50% soil + 50% promix substrate treatment

S+P-DD – 50% soil + 50% promix substrate + dairy digestate fertilizer treatment

S+P-NS – 50% soil + 50% promix substrate + nutrient solution fertilizer treatment

S+P – DD+NS - 50% soil + 50% promix substrate + 50% dairy digestate/50% nutrient solution fertilizer treatment

CEC – Cation exchange capacity

EC – Electrical conductivity

BD – Bulk density

FC – Field capacity

OM – Organic matter

SOM – Soil organic matter

Mg – Mega gram

mg – milligram

Kg – Kilogram

MW – Megawatt

NL – Newfoundland and Labrador

List of appendices

Chapter 1: Introduction

1.1. Fertilizers

1.1.1. History of fertilizers

There are two key defining moments in the history of nitrogenous fertilizers; the introduction of the mined fertilizer trade from South America in the 1840's and the discovery of the Haber-Bosh process in 1913 (Leigh 2004; Page 2016). Since then, fertilizers evolved from purely agricultural tools to indicators of global development with a central role to both the scientific development and to agricultural policies (Page 2016).

Application of organic fertilizer to agricultural fields dates as far back as 5900-2400 B.C. when farmers used animal manure to increase crop yields (Bogaard et al. 2013). Post Haber-Bosch process, during the period from World War-I and through World War-II research on synthetic fertilizers exploded as a consequence of widespread concerns about soil fertility and increased food demand (Soil Fertility 1941). The main targets for synthetic fertilizers are the three major macronutrients, nitrogen (N), phosphorus (P), and potassium (K) (Khaleel et al. 1981), central to increasing crop yields and thus supporting a rapidly growing population.

The crucial role of N in agricultural food quality and yield (Ju and Gu 2014) ensured the massive increase in global usage since the 1950's (Zhang et al. 2008). This trend continued with fertilizer inputs increasing by approximately 117% from 1998 to 2016 (Liang et al. 2019); as of 2014 approximately 110 Mg of N fertilizers were used globally (IFA 2016), an amount projected to increase to 236 Mg by 2050 (Tilman et al. 2001). Estimates from Food and Agriculture Organization (FAO) of the United Nations predicted that nutrient use would rise by 1.4% for N, 2.2% for PO_4^{3-}, and 2.6% for K each year from 2014 through 2018 (FAO 2015).

1.1.2. Benefits of inorganic fertilizer for soil quality

The application of inorganic fertilizer increases crop yield thus also increasing residual plant matter in surface soils, returning organic matter to soil (Haynes and Beare 1995). An increase in organic matter content associates with increased soil aggregation and stability, macroporosity, infiltration, water retention capacity, and hydraulic conductivity (Khaleel et al. 1981; Chawla and Chabra 1991). Soil stability can be related to organic matter fraction that also serves as a measure of the density of roots and hyphae in the soil (Tisdall and Oades 1982) which serves as habitats and substrates for microbes favouring the production of organic polymers, "glues" (Oades 1967). Various binding agents influence the size and stability of soil aggregates, such as microbial and root exudates (i.e., polysaccharides) (Swincer et al. 1968; Marshall 1976; Foster 1978), roots and hyphae (Hubbell and Chapman 1946; Tisdall and Oades 1979), organic polymers, and oxides that bind to clay surfaces and allow flocculation. Polysaccharides act as glues that hold soil particles together while roots capture fine soil particles into macroaggregates that are stabilized even after the root has died (Clarke et al. 1967; Forster 1979). Furthermore, humic substances, a form of stabilized organic matter, can bind to clay particles through interactions mediated by metal cations to aid in aggregation and thus contribute to soil stability (Marshall 1976; Turchenek and Oades 1978). Soil aggregates influence soil porosity, otherwise known as the fraction of the soil volume filled with air and water. The formation and distribution of soil aggregates and corresponding soil pores influence the movement of water through the soil profile (Camara and Klein 2005; Morais 2012).

Water infiltration, retention, and water activity are crucial for the growth of crops in soils. Infiltration is the process of vertical movement of water into the soil, where the force of gravity allows such movements through the soil profile as well as retention and storage in soil pores (Klein and Klein 2014). The rate of infiltration and amount of water retained within the soil profile is related to the size and distribution of soil pores. Macropores play a significant role in water infiltration and conductivity to deeper soil horizons while micropores are responsible for water retention and availability for plants (Mesquita and Moraes 2004).

In the long term fertilizers help to maintain, if not improve, crop yields. Increased organic matter returns to the soil due to higher crop yields resulting in increased soil organic matter and biological activity in comparison to unfertilized soils (Haynes and Naidu 1998).

1.1.3. Organic fertilizers

Organic fertilizers improve soil quality and benefit plant growth (Benitez et al. 1998; Kang et al. 2016; Table 1). A main effect is modifying the C: N ratio of soil's organic matter. Soil's C: N ratio directly influences the diversity and activity of microbial communities (Bowles et al. 2014), thus affecting rate of nutrient mineralization and nutrient cycling (Stark et al. 2008; Wortman et al. 2012). Microbial functions reach optimum levels at a ratio of 24:1 (24 equal parts carbon to 1 equal part nitrogen) - the amounts required by the microbe for energy and body maintenance. High C:N ratio leads to immobilization of soil N in microbial biomass. In contrast a lower ratio results in a temporary surplus of N in the soil which may be available for plant growth, but also a risk of losses in gaseous forms or through leaching.

Soil microbes are important in agricultural soils as they influence soil aggregation and organic matter stabilization, thus impacting oxygen availability, soil porosity, and water infiltration (Bronick and Lal 2005). Further, the microbial community governs the transformations and availability of many micro and macronutrients in soil (Hayat et al. 2010; Miransari 2013). Considering the previously mentioned benefits, an increase in microbial diversity is often considered a driver and indicator of soil health and quality. Interactions among soil microbes within the rhizosphere favour mycorrhizal fungi and growth promoting rhizomicrobes (Mendes et al. 2013). Organic fertilizers are well known to affect the activity of soil flora (Sparling 1985), with experimental sites showing an increase in earthworm (Edwards and Lofty 1982) and microbial (Dick 1992) numbers and biomass in direct relationship to the fertilizer's N content. Weil and Kroontje (1979) found that fields with heavy applications of poultry manure had both higher earthworm activity and that worm burrows increased infiltration rates in comparison to control plots. Enhanced biological activity accelerates decomposition, increasing humification, which ultimately leads to stable soil aggregates.

Table 1 Comparison of nutrient availability in solid and liquid forms of dairy manure (modified after Brown, 2013)

<table>
<tr><td colspan="3">Characteristics</td><td colspan="2">Types of organic fertilizers</td></tr>
<tr><td colspan="3"></td><td>Solid dairy Manure</td><td>Liquid dairy Manure</td></tr>
<tr><td colspan="3">Composition</td><td>Raw manures</td><td>Anaerobically digested manure</td></tr>
<tr><td colspan="3">Benefits</td><td>Gradual release of nutrients over a longer period of time in comparison to liquid fertilizer</td><td>Obtained from animal sources and readily absorbed by the plant therefore reducing the risk of runoff and contamination of nearby water bodies</td></tr>
<tr><td rowspan="4">Average total nutrient content</td><td>Total N</td><td rowspan="4">(%)</td><td>0.72</td><td>0.39</td></tr>
<tr><td>NH_4-N</td><td>0.15</td><td>0.16</td></tr>
<tr><td>P</td><td>0.2</td><td>0.09</td></tr>
<tr><td>K</td><td>0.61</td><td>0.25</td></tr>
<tr><td rowspan="4">Available nutrients</td><td>Average DM</td><td>(%)</td><td>25.9</td><td>8.6</td></tr>
<tr><td colspan="2">Usable N</td><td>2.0 (kg Mg^{-1})</td><td>1.7 (kg m^{-3})</td></tr>
<tr><td colspan="2">P_2O_5</td><td>1.8 (kg Mg^{-1})</td><td>0.8 (kg m^{-3})</td></tr>
<tr><td colspan="2">K_2O</td><td>6.6 (kg Mg^{-1})</td><td>2.7 (kg m^{-3})</td></tr>
</table>

1.2. Nutrient use and budgeting

1.2.1. Nutrient losses and nutrient use efficiency (NUE) in greenhouse systems

Organic greenhouse systems utilize large quantities of animal manures or composts originating as a base fertilizer (Cuijpers et al. 2008; Voogt et al. 2014) and supplemented with commercial organic fertilizers (Voogt et al. 2011). Composts are characterized by low N:P ratio with a gradual N release whereas the commercial organic fertilizers have a rapid N release (Zikeli et al. 2017). A soil N:P ratio lower than 14 indicates N limitation. Organic fertilizers applied to greenhouse soil systems can lead to surpluses of N, P, S, Ca, and Na, with Cl and Mg budgets nearly balanced, and a high K deficit (Cuijpers et al. 2008; Voogt et al. 2011; Zikeli et al. 2017). High P levels in soil can negatively impact the bioavailability of micronutrients in the soil system by increasing adsorption and precipitation (Pérez-Novo et al. 2011). To achieve a balanced N:P ratio when fertilizing the solid manures or compost can provide 15-25% of the N demand of a cropping system and N supplementation must originate from a P-free source to avoid a surplus (Moller and Schultheiß 2014).

A nitrogen balance describes the relationship between N inputs and losses in a system (Min et al. 2011). Any N surplus might lead to ammonia volatilization, gaseous losses due to nitrification/denitrification, and leaching (Ti et al. 2015). Excess nitrogen fertilization in greenhouses can be associated with lower nitrogen use efficiency (N-UE) and increased N losses to the environment (Ti et al. 2015; Zhu et al. 2005). In aerobic soils, nitrification can lead to excess NO_3^- which is highly soluble and thus readily leached; this can account to as much as 90% of N losses (Min et al. 2011). Zikeli et al. (2017) found an N-UE of about 60%. Nevertheless, conditions that are more favourable to plant growth increase N-UE; e.g. heated greenhouses (67%) and glasshouses (66%) have better N-UE than unheated greenhouses (44%) and polytunnels (50%) (Zikeli et al. 2017).

Typically, NUE can be increased through more efficient fertilization and irrigation management (Liang et al. 2019). A series of formulas outlined by Cassman et al. (2002) and Zikeli et al. (2017) can be used to calculate nutrient balance, nutrient input and output, and NUE:

1. Nutrient balance: NB [kg ha^{-1}] = $N_I - N_O$
    - Where N_I is the nutrient input and N_O is the nutrient output.
2. Total nutrient input for each macronutrient: N_I [kg ha^{-1}] = NCF + NCPP + NCH_2O
    - Where N_I is the nutrient input, NCF is the nutrient content of fertilizer, NCPP is the nutrient content of the pot substrates and NCH_2O is the nutrient content of the irrigation water.
3. Total nutrient output for each macronutrient: NO [kg ha^{-1}] = NCY + NCR
    - Where NO is the total nutrient offtake, NCY is the nutrient offtake of the harvested products, and NCR is the nutrient offtake of the crop residues
4. NUE: NUE (%) = 100 × total Nutrient output/total Nutrient input (Zikeli et al. 2017)
5. N-UE: NUE (%) = U_n-U_o/AN x 100
    - Where U_n is the total N uptake by vegetables from treatments with applied fertilizer, U_o is the total N uptake by vegetables from treatments without N fertilization. and AN is the amount of fertilizer applied (N in inorganic fertilizer + N in manure) (Cassman et al. 2002; Zikeli et al. 2017)

Several detrimental effects of large greenhouses have also been identified. High nutrient inputs in greenhouses leads to increased salt accumulation, soil acidification, and nutrient imbalances

(Guo et al. 2010). This has the potential to influence vegetable yield since vegetables such as lettuce, tomato, pepper, cabbage, spinach, and eggplant are all sensitive to salinity; an increase of 2-4 dS cm^{-1} could affect the crop yield (Tanji and Kielen 2002).

1.3. Dairy manures

1.3.3 Dairy manures as fertilizers

Typical dairy cattle manure accumulations average approximately 39.9 kg day^{-1} or 16.36 Mg $year^{-1}$. Slurry accumulations, which is a mixture of manure and water, are approximately 85.17 L/animal/day, thus totaling 2.39 kg/1000 L total N, 1.10 kg/1000 L NH_4-N, 1.65 kg/1000 L P_2O_5, and 2.39 kg/1000 L K_2O per 1400 lb animal unit each year (Barker, Hodges, and Walls 2002). Brown (2008) analyzed 2249 individual samples and concluded that on average, dairy manure contains 0.39% NH_4-N, 0.09% P, and 0.25% K (1.7 kg m^{-3} usable N, 0.8 kg m^{-3} P_2O_5, 2.7 kg m^{-3} K_2O). In total, the value of manure from a 1400 lb animal unit can be as much as $300 per year (Pennington et al. 2009). However, due to variations between farms, the most accurate way to determine nutrient content is to have a manure sample analyzed by a lab.

There are two main forms of N in manure, available (inorganic) and unavailable (organic), with available N being predominantly ammonium, nitrate and ammonia. Between 35-50% of organic N will transform to ammonium-N each consecutive year after the manure is applied to fields (Moller et al. 2008; Pennington et al. 2009; Gunnarsson et al. 2010). Generally, 70-80% of P and 70-90% of K in manure are plant available in the first year, but if manure is applied for several consecutive years it can be assumed that the full amount of P and K are available due to mineralization (Pennington et al. 2009; Massé et al. 2011).

Nutrient balances are important for assessing nutrient use efficiency, turnover, and utilization as well as monitoring overall nutrient losses at a farm level. The main components of a dairy farm nutrient cycle are the herd, soil/crop, and feed. Method of manure storage, application, animal diet, housing, bedding, and environmental temperature all influence the nutrient content of the manure (Pennington et al. 2009). A typical measure of whole farm nutrient budgets (WFNBs) is NUE, which is typically calculated over one calendar year, with N and P often the focus of dairy WFNBs as these nutrients add to costs of farming and can be a large contribution to non-point source pollution (Hutson et al. 1998). A surplus of nutrients in a farm budget can be considered in three components; the inputs not incorporated into outputs due to biological limitations, those that are wasted, and inputs that are used to reduce production risks such as a low crop yield (Powell et al. 2010). Losses through runoff, leaching, volatilization, and denitrification are typically not considered outputs in WFNBs due to difficulties in measurement (Oenema et al. 2003). For example, the main sources of nitrogen inputs on dairy farms are feed imports (Anderson and Magdoff 2000; Spears et al. 2003) and biological N fixation (BNF) (Roberts et al. 2008; Wattiaux et al. 2005). One of the largest sources of error in calculating an on-farm N budget is BNF (Watson et al. 2002), with the most prominent influencing factors being crop growth, soil environment, and fertilization causing difficulty in an accurate BNF measurement (Ledgard and Steele 1992). For phosphorus, the main inaccuracies are associated with the inaccurate evaluation of the proportion of total P to available P.

1.3.1. Losses of nutrients from dairy waste

The livestock and agricultural sectors are notable contributors to greenhouse gas (GHG) emissions, mainly through methane (CH_4) and nitrous oxide (N_2O) (Guerci et al 2013). Further, GHG emissions from agriculture are estimated to be 10-12% of total anthropogenic GHG emissions (Kristensen et al. 2011), and milk production contributing approximately 2-8% of total emissions (Opio et al. 2012). Higher emissions from ruminant livestock farming is due to CH_4 release from gastric fermentation, as well as manure storage and handling, and intense N cycling leading to both direct and indirect N_2O emissions (Olesen et al. 2006). Gastric fermentation and management of manure account for approximately 60% of GHG emissions related to milk production (Casey and Holden 2005). Agriculture contributes considerably to the release of nitrous oxides and NH_3 into the atmosphere as nitrogen volatilisation occurs both during and after the production, storage, and application of organic and mineral fertilizers (Bentrup et al. 2000). A study conducted on dairy farms in Germany showed that acidification of water and soils was due to the emission and deposition of ammonia from cattle keeping (Haas et al. 2001). On-farm activities contribute to eutrophication through deposition of volatilised ammonia, nitrate leaching, and phosphate run-off (Thomassen et al. 2008) leading to nutrient enrichment of surface waters (van Calker et al. 2004). Ammonia volatilization occurs during manure excretion, storage, and on-farm feed production thus contributing to 90% of the on-farm eutrophication potential (Thomassen et al. 2008; Rotz and Leytem 2015). Therefore, it is crucial that diary wastes are properly managed, processed, and applied under controlled conditions to reduce environmental impacts.

1.3.2. Anaerobic digestion of dairy manure

During the anaerobic digestion process, organic materials are decomposed using an anaerobic microbial community to recover a nutrient laden dairy digestate (DD) and a biogas (Pain et al. 1990). Anaerobic digestion is a well-established technology for biogas production (Wulf et al. 2006; Cantrell et al. 2008) with the resulting biogas consisting of 2/3 methane and 1/3 carbon dioxide. This gas can be combusted on-site and used as a renewable heat/ electricity source or sold as energy fuel (Bell et al. 2016). The first stage of the digestion is hydrolysis where fats, carbohydrates, and proteins are broken down into fatty acids, amino acids, and simple sugars. In the acidogenesis stage acidogenic bacteria convert the products from phase one into hydrogen, alcohols, organic acids, and CO_2. Next, the products of the acidogenesis phase are used as an energy source for acetogenic bacteria. The bacteria use these energy sources to create hydrogen, CO_2, and acetic acid. Finally, in the methanogenesis phase, the products formed by the previous phase are converted to methane, CO_2, and water by methanogen bacteria. This methane can then be collected and utilized as an energy source, and the remaining waste can be used as a nutrient source in soils (Chandra et al. 2012). Anaerobically digested wastes have a reduced odour and pathogen content (Hansen et al. 2005), an increase in nitrate and ammonium content (Moller and Stinner 2009), and an increase in pH, making them ideal for fertilizing acidic soils (Kvasauskas and Baltrėnas 2009; Table 1). Nevertheless, since ammonia content is increased in the digestate there is a greater chance of nitrogen loss through ammonia volatilisation. The high pH of the digestate provides favorable conditions for the thermodynamic conversion of ammonium to ammonia within the solution, therefore increasing ammonia emissions (Pain et al. 1990; Hansen et al. 2005).

1.3.3. Nutrient status of digestate

1.3.3.1. Nitrogen

In the digester, organic N compounds are mineralized as NH_4^+-N which is then used for growth by the digester's microbial community (Moller and Müller 2012). Remaining organic compounds in the waste stimulate biological processes that partially immobilize inorganic N

(Kirchmann and Lundvall 1993; Alburquerque et al. 2012). Reports on their utilisation as crop fertilizers conclude comparable NH_4 recoveries from both digestates and inorganic fertilizers (Fouda 2011; de Boer 2008; Gunnarsson et al. 2010). In pot experiments there was a higher NH_4 recovery from digested slurry than undigested, however when total N was equal there was equivalent uptake of N between both treatments - even with the higher NH_4 concentration of the digestate (Moller et al. 2008; Loria et al. 2007).

1.3.3.2. Phosphorus

Most reports from field experiments show no effect of digestion on P availability (Loria and Sawyer 2005; Moller and Stinner 2010; Bachmann et al. 2011); however, it could restrict P availability due to the increase in manure pH during the digestion process. This sways the equilibrium in favor of phosphate formation ($HPO_4^{2-} \rightarrow PO_4^{3-}$) and further, the precipitation as calcium or magnesium phosphate (Nelson et al. 2003; Burton 2007; Christensen et al. 2009; Hjorth et al. 2010). The mineralized P then becomes part of the suspended solids. A combination of the pH increase, and N, P, and Mg mineralization increases struvite crystallization (Suzuki et al. 2002; Le Corre et al. 2009; Hjorth et al. 2010). Other ionic species can react with struvite component ions and influence formation, thus leaving the digestate with only trace amounts of inorganic P, Ca^{2+}, and Mg^{2+} in solution (Sommer and Husted 1995; Hjorth et al. 2010).

1.3.3.3. Sulfur

Sulfate is the plant available form of sulfur, resulting from the degradation of organic matter. In anoxic conditions, such as those in the digester, sulfate reacts to form other compounds including H_2S (Beard and Guenzi 1983; Straka et al. 2007; Abatzoglou and Boivin 2009). This increases the pH of the digesting waste and causes a decrease in sulfate concentration and an increase in sulfide and other precipitated sulfur compounds (Beard and Guenzi 1983). However, there is limited information of plant available sulfur in digestate.

1.3.3.4. Micronutrients

The high pH inside the digester allows heavy metals to precipitate out of solution (Burton 2007; Callander and Barford 1983) as sulfates, carbonates, phosphates thus possibly reducing the heavy metal concentration in the digestate. There is conflicting data describing plant available micronutrients in digestate and the processes responsible are not well documented (Moller and Muller 2012). Several publications support a transition from mobile to more stable and less bioavailable forms during digestion (Bloomfield and McGrath 1982; Lake and Lester 1985; Lavado et al. 2005) while another study found no reduction in plant available micronutrients (Marcato et al. 2009).

1.4. Economic benefits of digestate use

Canada's largest anaerobic digester is situated in Lethbridge, Alberta. This particular digester, a $30-million project, can process over 100,000 Mg of raw organic material annually, thus producing 2.8 MW of power which is then sold to Alberta's open market, and approximately 100,000 GJ of thermal energy using the hot water that is used to heat the internal 12×10^6 L of digestate. The power output is enough to run 2,800 homes and reduce GHG equivalent emissions by over 224,000 Mg by 2020 (Our Plant | Lethbridge BioGas, n.d.).

A study was conducted by Morin et al. (2010) focusing on the assessment of an anaerobic waste digestion plant in Quebec, Canada. After analyzing several digestion scenarios it was found that a co-digestion of the municipal waste and cow/steer manure was one of the most profitable as the digestion products could be used for agricultural purposes and the addition of animal manure would increase biogas production by 37%. Products of this operation include 5,691,000 m^3 of biogas, a net electricity production of 9,614,000 kWh, 118,500 m^3 of liquid digestate, and 25,900 Mg of solid phase digestate (30% d.w.) annually. Finally, the economic payback time was estimated to be approximately 6.8 years, and the energetic payback time was estimated to be 3.5 years (Hartmann and Ahring 2005; Berglund and Börjesson 2006).

1.4.1. Agriculture in Newfoundland and Labrador

The agricultural sector is a crucial part of global economy, providing an important contribution to address concerns surrounding food security for an increasing global population through a direct supply of nutrient rich food. Indirect economic contributions include employment and a supply of products such as fertilizer, fibre, and renewable energy (Idel and Reichert 2013).

In Newfoundland and Labrador (NL) agriculture is considered to be a priority sector as it has the capacity to contribute considerably to the economy of the island. Over time increased energy and feed costs have impacted agricultural operations (Agrifoods | Department of Fisheries and Land Resources) and since food has become more readily available people moved away from growing and harvesting their own crops. However, climate change, increasing food prices, and reliance on marine transport to carry food to the island have led to the realization that we need to begin our own crop production (Government of Newfoundland and Labrador n.d.). Newfoundland's poor soil and climate have not been conducive to agricultural practices, but the dairy industry has led to the growth of the agricultural sector through the processing of high-value dairy products. New World Dairy Inc., the third largest dairy farm in Canada and the largest in

NL, is located in the community of St. David's, found along the South-West coast of the Island. The company has recently installed an anaerobic digester for waste treatment, collecting solid waste and converting it to animal bedding, fertilizer, and green energy (NEIA 2016). This new equipment will reduce both economic and environmental costs connected with transporting manure as well as reduce the odour emitted from spreading manure. Further, it is estimated that this new equipment will reduce greenhouse gas emissions from the farm by approximately 11,090 tonnes per year (Saltwire 2010).

Hypotheses

1) It is hypothesized that dairy digestate is a source of nutrients equivalent to mineral fertilization and can thus be employed as a source of nutrients for greenhouse lettuce.
2) Local soil may be employed as growth substrate when digestate is used as a source of nutrients for greenhouse lettuce.

Objectives

Objective 1: Quantify nutrient availability in the dairy digestate.

- Identify the dominant form of N in the digestate so quantities can be adjusted to plant requirements. Assess the total and available P, the latter an essential management decision tool in cropping systems.

Objective 2: Assess nutrient uptake in the soil/digestate system.

- Plant uptake will primarily focus on N and P.

Objective 3: Evaluate the residual nutrients and thus the final soil quality.

- Fertility measurements of the spent soil/digestate substrate, i.e., soil after harvest to ascertain total nutrient utilization, inefficiencies, and the utility of the spent substrate for further re-use.

Chapter 2: Methodology

2.1. Experimental Site

The experiment was carried out in a polyethylene film covered greenhouse built on a metal pipe frame (Tech Construction, Newfoundland) secured into a cement knee-wall. The greenhouse was set-up near the New World Dairy farm in St. David's (48°12'01.5"N 58°52'31.5"W), along the South-West Coast of Newfoundland, Canada).

Figure 1 Experimental greenhouse site located in St. David's, Newfoundland

2.2. Soil

2.2.1. Soil collection

Soil used in the greenhouse pot experiments was collected from one of New World Dairy's agricultural fields used for corn cultivation (growth cycles 2 to 4) or from a non-managed field adjacent to the greenhouse (1^{st} growth cycle). Next soil was spread on large tarps and air dried at ambient temperatures (about 15 °C) for 2 weeks.

2.2.2. Soil analyses

Standard soil fertility parameters were measured at the Soil, Plant & Feed Laboratory in the Department of Fisheries and Land Resources in St. John's, NL (Table 2). It was recommended that at least half of the N be applied pre-plant and the balance applied 3 weeks after transplant.

Soil texture (Table 2) was determined using an automated particle size analyser (PARIO meter, METER Group Inc., Pullman, the USA): default parameters were used, with 1.0 L volume of suspension, 2.65 g cm^{-3} particle density, 30.0 g of oven dried soil, and 100.0 g of dispersant. Soil texture was determined by the PARIO using the US Soil Taxonomy (Soil Survey Staff 1999).

Table 2 Soil parameters

pH			Organic Matter (%)			Cation exchange capacity (CEC) (cmol kg^{-1})			Texture		
6.5			6.44			15.6			Sandy soil (93% sand, 7% silt)		
Nutrient Content (mg L^{-1})											
P	K	Ca	Mg	S	Zn	Cu	Na	Fe	B	Mn	Al
289	477	2,226	348	29	16.1	36	7	299	1.5	83	1,196

2.3. Promix

Professional Mix – VPW 30 (ASB Greenworld Inc., Mattaponi, VA, the USA) purchased from a local nursery supplier (Humber Nurseries, Corner Brook, Newfoundland) was used for the 50% mineral soil – 50% Promix growth substrate (Table 3).

Table 3 Details of ASB GreenWorld Professional-Mix type VPW 30

Characteristics							Components						
• High water and nutrient storage • Buffering capacity • Stable fibrous structure • High porosity for aeration and drainage							• Coarse grade sphagnum peat moss • Coarse perlite • Horticultural vermiculite • Dolomite and calcium limestone						
pH				Organic Matter (%)			CEC (cmol kg^{-1})			Texture			
6.2				N/A			10.1			N/A			
Nutrient Content (mg L^{-1})													
P	K	Ca	Mg	S	Zn	Cu	Na	Fe	B	Mn	Al	N (%)	C (%)
50	175	1,162	443	27	1.2	1.2	27	16	0.1	3	24	0.6	29.1

2.4. Experimental setup

2.4.1. Experimental design

The experimental design was fully randomized with a complete block design (Figure 2). Soil media type (2 levels) and fertilizer type (3 levels) were employed as factors. Given the 15 replicates per treatment (i.e., factor combinations) this produced 90 pots per run. This number was reduced for the final two runs to 7 replicates per treatment, producing 42 pots per cycle.

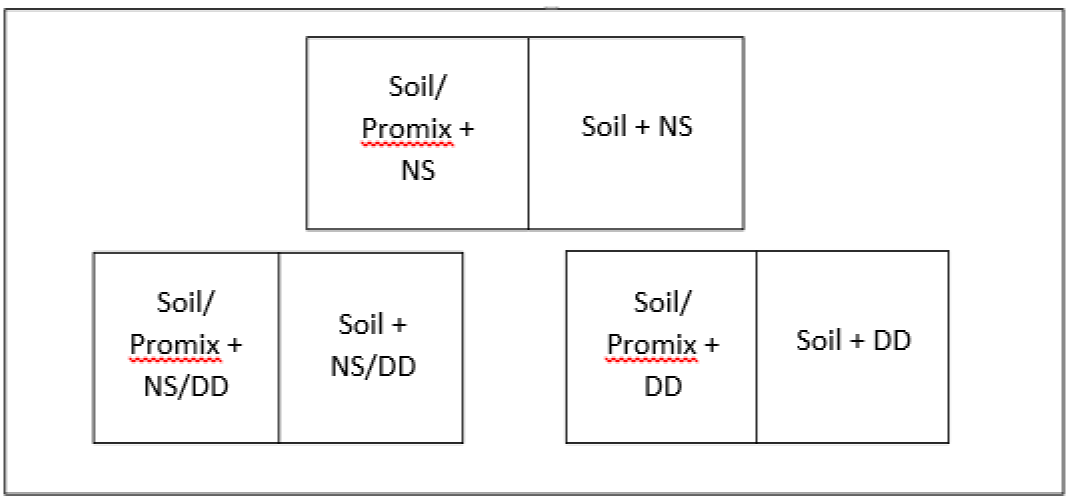


Figure 2 Illustration of greenhouse experimental design

2.4.2. Preparation of growth substrates

2.4.2.1. Soil

Soil was air dried for 2 weeks prior to use then sieved to 2 mm. By comparing the mass of samples before and after drying, air dried had an average moisture content of 1.83% while the *soil+promix* had a moisture content of 7.67%. Soil treatment further denoted as *soil*.

2.4.2.2. Soil+Promix

Soil was mixed with promix at volumetric ratios of 50% mineral soil and 50% promix. Treatment further denoted as *soil+promix*.

2.4.2.3. *Soil* and *soil+promix* bulk density (BD), porosity, and field capacity (FC)

Oven dried samples of *soil* or *soil+promix* were lightly packed in an open-ended canister of a known volume (269 cm^3); compaction was achieved by tapping the container 3 times against a hard, flat surface. One end of each canister was wrapped in a fine nylon mesh and held in place by an elastic band to prevent any soil loss. The mass of the empty canister was recorded as well as the mass of the canister containing soil to determine the mass of the soil. Three replicates were made for both the *soil* and the *soil+promix*. All 6 canisters were then placed in a tub filled with water (approximately ¾ of the height of the canister) and left for 2 days to absorb water from the bottom. This removes soil air while saturating. Once saturated each canister was weighed to determine water content at saturation. Canisters were then left to drain under gravity for 24 h (covered the top to avoid evaporation), then reweighed to calculate field capacity (Table 4).

Equations:

Bulk Density = $\frac{Mass\ of\ dry\ soil\ (g)}{Total\ canister\ volume\ (cm^3)}$

Porosity = $\frac{Volume\ of\ pores}{Total\ canister\ volume} = \frac{Volume\ of\ water\ at\ saturation}{Total\ canister\ volume}$

Field Capacity = $\frac{Mass\ of\ drained - Mass\ of\ dry\ soil}{Total\ canister\ volume}$

Table 4 Bulk density, porosity, and field capacity of soil media

Growth substrate	Field capacity (FC)	Bulk density (BD)	Porosity	Mass of substrate to fill 269 cm^3 canister (g)	Mass of substrate to fill 2 L pot (g)
Soil	0.51	0.98	0.64	6.15	1,960
Soil+Promix	0.44	0.57	0.57	3.59	1,142

2.4.2.4. Pot Preparation

Air-dried and sieved soil was added to pots. Each pot held approximately 2 L of soil; 30 pots were filled with 2 L of *soil* and another 30 were filled with *soil+promix*. Soil and promix were combined in a larger container before placed into pots to ensure mixing homogeneity among pots. Pots were filled with media and tapped on a table-top for compaction. Target bulk density was 0.98 g cm^{-3} for *soil* and 0.57 g cm^{-3} for *soil + promix* (Table 4).

Figure 3 Preparation of study site prior to crop transplant

2.4.3. Soil water content management

2.4.3.1. Estimating soil water potentials

A WP4C Dewpoint Potentiometer was used to determine the permanent wilting point of the soil (METER Group Inc., Pullman, the USA) (Figure 4). The mass of media used in the assessment was determined based on the repacked bulk density calculations. Three replicates were carried out for each media (i.e., *soil* or *soil+promix*). Water was gradually added to oven dried media using a pipette until a potential of -2.0 MPa was reached (slightly above the permanent wilting point), and again until -0.03 MPa (field capacity) and 0.00 MPa (saturation point). The mass of the media was recorded each time water was added to the sample. This mass was later used to determine volumetric water content.

Equations:

Gravimetric water content = $\frac{Mass\ of\ wet\ soil\ (g) - Mass\ of\ dry\ soil\ (g)}{Mass\ of\ dry\ soil\ (g)}$

Volumetric water content = $Gravimetric\ water\ content * Bulk\ density$

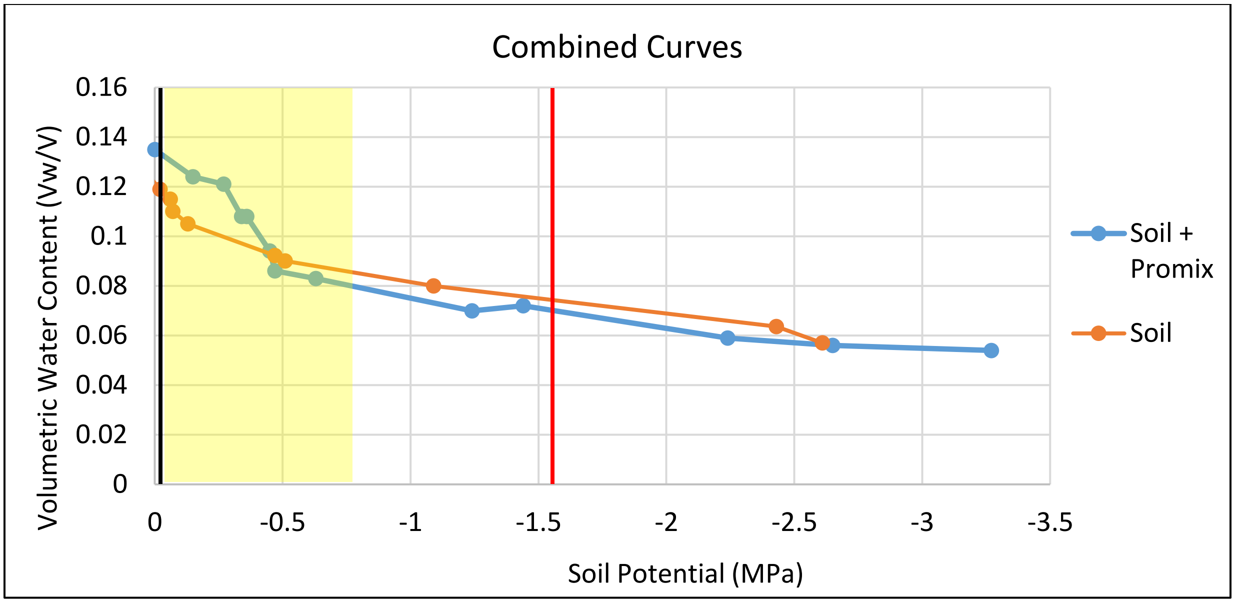


Figure 4 Average matric potential for 3 samples of soil and soil+promix used for the trial 2 experiment based on data collected a WP4C Dewpoint Potentiameter. Black line represents the field soil water potential, red line represents the permanent wilting point. Highlighted region represents where water levels were maintained for duration of experiment.

2.5. Fertilizers

The experiment compared dairy digestate (DD), with standardized nutrient solution (NS) and a 50% dairy digestate + 50% nutrient solution mix (DD+NS).

2.5.1. Dairy Digestate

DD parameters were analyzed at the Agriculture and Food Laboratory at the University of Guelph (Table 5).

Table 5 Chemical profile of the liquid dairy digestate

<table>
<tr><td colspan="11">Heavy metals panel (mg kg^{-1} dry soil)</td></tr>
<tr><td>As</td><td>Cd</td><td>Cr</td><td>Co</td><td>Cu</td><td>Pb</td><td>Me</td><td>Md</td><td>Ni</td><td>Si</td><td>Zn</td></tr>
<tr><td><MDL</td><td>0.24</td><td>6.7</td><td>1.7</td><td>620</td><td>0.73</td><td><MDL</td><td>4.8</td><td>9.6</td><td>2.5</td><td>390</td></tr>
<tr><td colspan="11">Non-agricultural source material (NASM)</td></tr>
<tr><td>Dry Matter (%)</td><td>K (% wet)</td><td>TKN (% wet)</td><td colspan="3">NH_4-N (mg kg^{-1} wet)</td><td colspan="2">NO_3 and NO_2 (mg kg^{-1} wet)</td><td colspan="2">P (% wet)</td><td>Na (% wet)</td></tr>
<tr><td>3.09</td><td>0.140</td><td>0.405</td><td colspan="3">2000</td><td colspan="2">2.50</td><td colspan="2">0.0260</td><td>0.0861</td></tr>
</table>

*TKN abbreviated for Total Kjeldahl Nitrogen

2.5.2. Nutrient solution

NS was prepared as per the recommendations from the provincial government Soil and Plant Laboratory (Department of Fisheries and Land Resources, Agriculture Production and Research Division) (Table 6) and P content of the digestate (Table 5). A diluted stock solution was prepared using potassium nitrate and potassium phosphate. Solution was mixed on site immediately before application (Appendix 1).

Table 6 Soil nutrient additions as per recommendations of Soil Test Report

Required nutrient applications (kg ha^{-1})		
Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)
150	0	0

2.5.3. Calculations of fertilizer applied nutrients

Fertilizers were adjusted to match the N recommendations as provided by the provincial laboratory: 150 kg ha^{-1} N, 0 kg ha^{-1} P_2O_5, and 0 kg ha^{-1} K_2O. The objective was to match the available N and P across the fertilizer treatments as they are most commonly the limiting factors in crop growth (Koerselman and Meuleman 1996). Micronutrients and K were not matched but were also not found to be in toxic excess or deficiency (Table 2; Table 5).

The depth of the pots was equivalent to the plough layer depth and thus relevant to the laboratory recommendation allowing a per area calculation. Given that the area of each pot was of 0.02 m^2, a total of 0.3g N was calculated as required from fertilizers.

Each pot required a total N input of 0.3 g as the digestate had an average N concentration of 2000 mg kg^{-1} or approximately 2.0 g L^{-1} (Table 6). This value was then diluted 14x to give an approximate mass of 0.14 g L^{-1} of N in the stock solution. Since fertigation occurred once during transplant and again after 3 weeks the total N application would meet the 0.3 g recommendation based on the Guelph report (Table 6; Appendix 1).

2.5.4. Nutrient solution/ dairy digestate (DD+NS) mixture

This DD+NS fertilizer was created to match the N and P content of the DD, which was provided equally by the NS and the DD (50% each).

During the first trial fertilizers were weighed on site using a portable balance however issues ensued regarding accuracy of fertilizer mass. Fertilizers for the final two trials were weighed on a calibrated balance in the BERI lab and stored in labeled Ziplock bags before being transported to the greenhouse and applied to soil media. All fertilizers were mixed on the day of application.

2.6. Crop

Newham lettuce (*Lactuca sativa*) cultivar was chosen due to its short growing season (45 days). This allowed multiple crops to be grown over a short period. Their short growing season also made them susceptible to unfavourable changes in their environment, thus quickly indicating signs of stress when exposed to nutrient excess/ deficiency.

2.6.1. Seedling preparation and transplanting

Seeds were sown in sanitized trays containing the same soil media as used in the greenhouse, and germination and seedling growth carried out in a growth chamber at the Boreal Ecosystems Research Facility of Grenfell Campus-Memorial University of Newfoundland. The growth chamber was pre-set on a 14 h:10 h day-night cycle. During the 10 h "night", relative humidity was lowered to approximately 63%, and temperature was lowered to 19 °C. For the 14 h "day", temperature was raised to 22 °C and the relative humidity was increased to approximately 70%. A HOBO® data logger (Onset Computer Corporation, Bourne, MA) placed in the chamber collected temperature, relative humidity, and CO_2 concentration at every 30 min for the entire duration of the germination process. Germination occurred 4 days after seeding. Seedlings were watered twice daily with a spray bottle and were visually assessed for signs of stress (i.e., wilting or discoloured leaves). Trays were covered and transported to the greenhouse for transplant 7 days after seeding (Figure 5).

Figure 5 Young lettuce plants – 6 days after sowing

2.6.2. Growing conditions

The greenhouse was equipped with a control panel that allowed maintaining the greenhouse at temperatures 16-23 °C using a combination of roll-up plastic sides and a large electrical fan. Sodium lights were on 14 h:10 h day: night cycle, respectively. On sunny days lights would be turned off in favour of natural sunlight.

2.6.3. Greenhouse management and in-growth data collection

A HOBO® data logger was suspended approximately 1 m above plant height, in the centre of the greenhouse to monitor ambient air temperature, CO_2 concentration, and relative humidity levels for the duration of the experiment (Figure 6). Five 5TE probes (5 cm) connected to an EM50 data logger (METER Group Inc., Pullman, the USA, former Decagon Devices Inc.,) was installed in 5 treatment units to record soil moisture, electrical conductivity (EC), and temperature during the growth period. As there were only 5 probes available for the 6 treatments it was decided that the *soil+promix*-DD+NS treatment would be omitted for each consecutive trial.

Figure 6 HOBO® data logger suspended in experimental greenhouse. Used to collect ambient air temperature, CO2 concentration, and relative humidity levels within the greenhouse.

2.6.4. Irrigation and fertigation

Upon transplant of seedlings pots were watered according to the pre-determined calculations for each media. Calculations were based on porosity and plant available water, determined using WP4C Dewpoint Potentiometer data (See Methodology, section 2.4), to maintain water levels close to the FC. Plants were irrigated 3 times a week. Upon irrigation media had typically dried to approximately 50% (+/- 10%) of the FC. The amount of irrigation water was dependent on average losses (Figure 7). To assess water losses three pots from each media treatment were randomly selected and weighed; this mass was then subtracted from the mass of the pot as weighed after the initial water addition at transplant. After the first week in the greenhouse water losses were monitored using 5TE probes with the EM50 data logger. Fertigation took place upon transplant and again after 3 weeks as per the suggestions from the initial soil report from the Soil and Plant

Laboratory of the Department of Fisheries and Land Resources in St. John's, Government of NL (See Methodology, section 2.2).

Figure 7 Irrigation of lettuce crop after transplant. Water was added based on moisture content provided by 5TE probes connected to an EM50 data logger

2.7. Data collection

Soil moisture, EC and temperature data were downloaded from the EM50 data logger weekly. The HOBOMobile® app (ver. 2.0) or EM50 the ECH20 Utility software (ver. 1.83, build 1.83.0.3) were used, as appropriate. Chlorophyll measurements were collected at transplanting and again at 3 weeks using a SPAD 502 chlorophyll meter (Tafolla et al. 2019). Light intensity was also periodically measured at plant height using a LUX meter (Mattson 2015, Fisher et al. 2001). Comparative photographs were also taken weekly for randomly selected pots to serve as visual assessment of crop development (Figure 8). Similarly, leaf emergence observations and signs of stress were verified weekly.

Figure 8 Comparative pictures of three fertilizer treatments in the mineral soil treatment

2.7.1. Harvesting and sampling

At harvest, 5 plants were randomly selected from each treatment (Figure 9). Shoots were separated from roots and placed in labelled paper bags. The detached shoots and their pots containing soil media and root systems, were then transported back to the Grenfell laboratory for processing (Figure 10).

Shoots were weighed on a calibrated analytical balance, rinsed with deionized water, shaken to remove excess water, placed back in the labelled paper bags, and then dried in a forced-air oven at 65 °C for 2 days.

Roots were 1) gently separated from the soil, 2) rinsed with tap water to remove larger debris, 3) placed in an ultrasonic bath for 5 min at 50 MHz, and 4) rinsed with tap water. The cycle was repeated once (Cuske 2014). Then, roots were thoroughly rinsed with distilled water. Tap water was used for first two rinses due to the limited amount of distilled water available in the lab. Roots were then placed in labelled paper bags and dried for 2 days in a forced-air oven at 65 °C.

Dried roots and shoots were ground using a Cryomill (manufactured by Retsch) and stored at 4 °C until further testing.

Pots were then emptied, and **growth media** was mixed to produce a representative sample. Samples were placed in labelled Ziploc bags and stored in a fridge at 4 $^{\circ}$C until analysis.

During all these activities, all surfaces and equipment were sterilized between samples by rinsing with water and methanol to prevent cross contamination.

Figure 9 Entire lettuce crop, consisting of 2 soil substrate types and 3 fertilizer treatments, prior to harvesting

A) B) C)

Figure 10 Crop harvesting process. A) Root system recovered from a mineral soil treatment, measured for total length, B) Root systems washed in an ultrasonic bath to remove fine debris, C) Separated lettuce shoot prepared for weighing

2.7.2. Laboratory analytical protocols

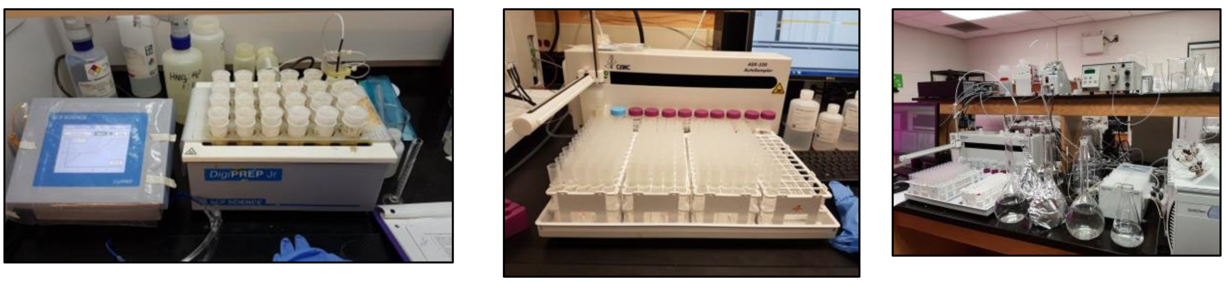
Soil media were analysed for:

- **Inorganic nitrogen** was extracted using the KCl method (Hofer 2003; Knepel 2003) and analyzed using Lachat Instruments QuikChem 8500 Series 2. Extraction was completed on soil samples the day after harvest following standard protocols. Extracts were frozen until they could be analyzed.
- **Orthophosphate** using the Mehlich 3 extraction protocol (Mehlich 1984) and analyzed using Lachat Instruments Quikchem 8500 Series 2. Extraction was completed on media samples the day after harvest following standard protocols. Extracts were frozen until they could be analyzed.
- **Heavy metals,** were analysed using ICP-OES (Hoobin and Vanclay 2012) on Mehlich 3 extracts. Total C and N were analysed on a CHNS instrument (Miller et al. 2013) at the

Soil, Plant & Feed Laboratory of the Department of Fisheries and Land Resources in St. John's, Newfoundland.

Plant material was analysed for:

- **Heavy metals** were analysed using ICP-OES (Hoobin and Vanclay 2012) on an HNO_3 extract. Total C and N were analysed on a CHNS instrument (Zaprjanova 2006) at the Soil, Plant & Feed Laboratory of the Department of Fisheries and Land Resources in St. John's, Newfoundland (Figure 11).



A) **B)** **C)**

Figure 11 Analytical processes. A) Acid digestion of plant and soil samples, B) ICP heavy metal and nutrient analysis, C) Inorganic nitrogen analysis using Lachat Instruments Quikchem 8500 Series 2

2.7.3. Statistical Analyses

<u>Normalization</u>

Crop biomass data from crops 1-4 and root, shoot, and post-harvest media nutrient data was tested for normality using the Shapiro-Wilks and Anderson-Darling tests at a significance level of 0.05 (PAST3 ver 3.22) (Hammer et al. 2001). The Shapiro-Wilks test selects a random sample to determine if it came from a normal distribution while the Anderson-Darling test identifies a specified distribution. Utilizing two commonly used tests would increase confidence in the final result. Normality testing took place to determine if data transformation was necessary before proceeding with further statistical analyses. If *p* values were below the determined significance level, the null hypothesis (data were normally distributed) was rejected in favour of the alternative hypothesis (data were not normally distributed) and the dependant variables were z-scored (i.e., standard units around the mean) for further analyses.

<u>Comparison of means</u>

Data normalised as z-scores was then analyzed using a MANOVA in RStudio (ver 1.1.463) to identify significant differences in measured parameters between treatments. Fertilizer treatment, soil substrate type, and crop number were used as independent variables while biomass parameters and nutrients were used as dependent variables. Test used a significance level of 0.05. A post-hoc Tukey HSD was then conducted to identify where differences existed.

<u>Drivers of variability</u>

A principal coordinate analysis (PCoA) was conducted in PAST 3 (ver 3.22) to condense the dataset into a series of eigenvectors (i.e. “components”) to help identify the dominant drivers of the variability in the response variables. While the output of PCA and PCoA is comparable, PCoA was selected as it is better able to handle complex and missing data points. Further, PCoA is able to represent dis/similarities while PCA is mainly used for similarities.

A canonical correspondence analysis (CCA) was then conducted using PAST 3 to identify correlations between the dependent and independent variables. Soil media and fertilizer treatments were used as independent (environmental) variables while root, shoot, and post-harvest soil nutrient concentration was used as the dependent variable. Data was normalized as z-score.

Correlation in post-harvest soil quality and crop shoot/root nutrient content

A correlation matrix was generated using the Pearson correlation in R (ver 1.1.463). The matrix compared post-harvest nutrient content in both soil substrate types to the nutrient content of crop shoots and roots.

Calculation of nutrient use efficiency (NUE)

The NUE was compared for crops between soil media and fertilizer treatments to identify the ability of the crop to utilize the added nutrients in each treatment. The total nutrient output was calculated as the average concentration of 5 crop and root samples taken from each treatment, and nutrient input was calculated as the combined nutrient input of two fertilizations during the crop cycle. Due to slight discrepancies in fertilizer nutrient content during each crop cycle, the NUE was calculated for each of the 3 cropping cycles then averaged for each treatment. NS + *soil*, and NS+ *soil+promix* treatments were used as a control.

The NUE was calculated using the following equations:

NUE (%) = 100 × total nutrient output/total nutrient input (Zikeli et al. 2017)

Nutrient content in plant (mg) = plant nutrient content (mg kg^{-1})*plant dry mass (kg)

Nutrient content in soil (mg) = soil nutrient content (mg kg^{-1})*soil media mass per pot (kg)

As per the calculations, outputs were calculated as above ground plant biomass. Inputs were calculated as nutrient already present in the soil media in addition to the fertilizer amendments.

Comparison of NUE between soil and fertilizer treatments

Crop N and P use efficiency (N-UE and P-UE, respectively) as well as crop N:P ratio were tested against the dependent variables (soil substrate type and fertilizer treatment) using a

MANOVA and post-hoc Tukey HSD to identify any significant effect ($p < 0.05$) of the dependent variables on the nutrient use efficiency or N:P ratio.

Chapter 3: Results and Discussion

3.1. Yield and biomass

Means comparisons have shown that there was no influence of fertilizer treatment on dry biomass and root length parameters (Table 7; Table 8; Figure 12). A PCA supported these results, as data points were not scattered in any obvious pattern around the environmental variables (Figure 13).

These findings correlate with results from Walsh et al. (2012), where digested and undigested cattle slurry were compared to N and NPK inorganic fertilizer application in grass leys in a greenhouse system. In their study, grasses that received liquid cattle digestate had yields that were equal to or higher than those fertilized with either N or NPK fertilizers. It was speculated that the liquid digestate applications may have led to higher yields than inorganic N applications since the digestate incorporated other nutrients such as P and K, which would also suggest why the NPK and digestate treatments had similar yields. It has also been suggested that the application of digestate could potentially increase microbial diversity, in turn benefitting soil through disease suppression (Garbeva et al. 2004) increased resilience to disturbances (Naeem and Li 1997), and increased plant growth (Lau and Lennon 2012). However, since microbial community was not measured in this experiment it can only be speculated that any change to the microbial community structure was either not significantly different or not significantly beneficial, as there was no statistical difference in biomass between crops grown with chemical fertilizer or digestate. Further, it was stated by Möller and Müller (2012) that there have been contradictions in findings between field and pot experiments, whereby field experiments often report either a non-existent (Möller et al. 2008; Loria and Sawyer 2005) or positive (Odlare 2005) effect on crop yield when digestate is applied. Meanwhile, the effects of digestate on crop yield are almost consistently positive in pot experiments (Dahlberg et al. 1988; Kirchmann and Lundvall 1993; Morris and Lathwell 2004; Möller and Müller 2012). This was suggested to be due to application method, as crops grown in pot experiments typically have a short growing season and the volume of soil used is often small. This would mean that there is less possibility of nutrient reallocation (Stinner et al. 2008; Gunnarsson et al. 2010). Although many studies support an increase in crop biomass when fertilized with digestate in a pot system, the results of this experiment did not support such a trend as we found no significant difference in biomass between any of our treatments.

Table 7 Impact of fertilizer and soil substrate type on crop growth parameters via means comparisons (post-hoc Tukey HSD; p_{H0} values). Data were cumulative of 3 crop cycles with combinations of two soil media and three fertilizer treatments. Data were normalized by parameter using z-scores. N=90.

Biomass parameters	Treatments			
	Soil media treatment	Crop cycle	Fertilizer treatment	Soil * fertilizer treatment interaction
Root length	<0.001	<0.001	0.884	0.115
Shoot mass (wet)	<0.001	<0.001	0.001	0.117
Shoot mass (dry)	<0.001	<0.001	0.082	0.867
Root mass (wet)	<0.001	<0.001	0.213	0.982
Root mass (dry)	<0.001	<0.001	0.760	0.997

Table 8 Impact of fertilizer and soil substrate type on crop growth parameters(post-hoc Tukey HSD; p_{H0} values). Data were cumulative of 3 crop cycles with combinations of two soil media and three fertilizer treatments. Data were normalized by parameter using z-scores. N=90.

Biomass parameters	Treatments			
	DD-DD+NS	NS-DD+NS	NS-DD	Crop cycle
Root length	0.883	0.928	0.994	<0.001
Shoot mass (wet)	0.006	0.003	0.978	<0.001
Shoot mass (dry)	0.193	0.090	0.926	<0.001
Root mass (wet)	0.190	0.788	0.518	<0.001
Root mass (dry)	0.740	0.943	0.910	<0.001

Crop cycle data					
Crop Cycle	Root length (cm)	Root mass (wet)	Root mass (dry)	Shoot mass (wet)	Shoot mass (dry)
3 – 4	<0.001	0.004	0.993	<0.001	<0.001
2 – 4	<0.001	<0.001	<0.001	<0.001	<0.001
1 – 4	<0.001	0.250	0.002	<0.001	<0.001
3 – 1	0.481	0.358	0.004	<0.001	<0.001
2 – 1	0.133	<0.001	0.125	<0.001	<0.001
2 – 3	0.875	0.034	<0.001	<0.001	0.075

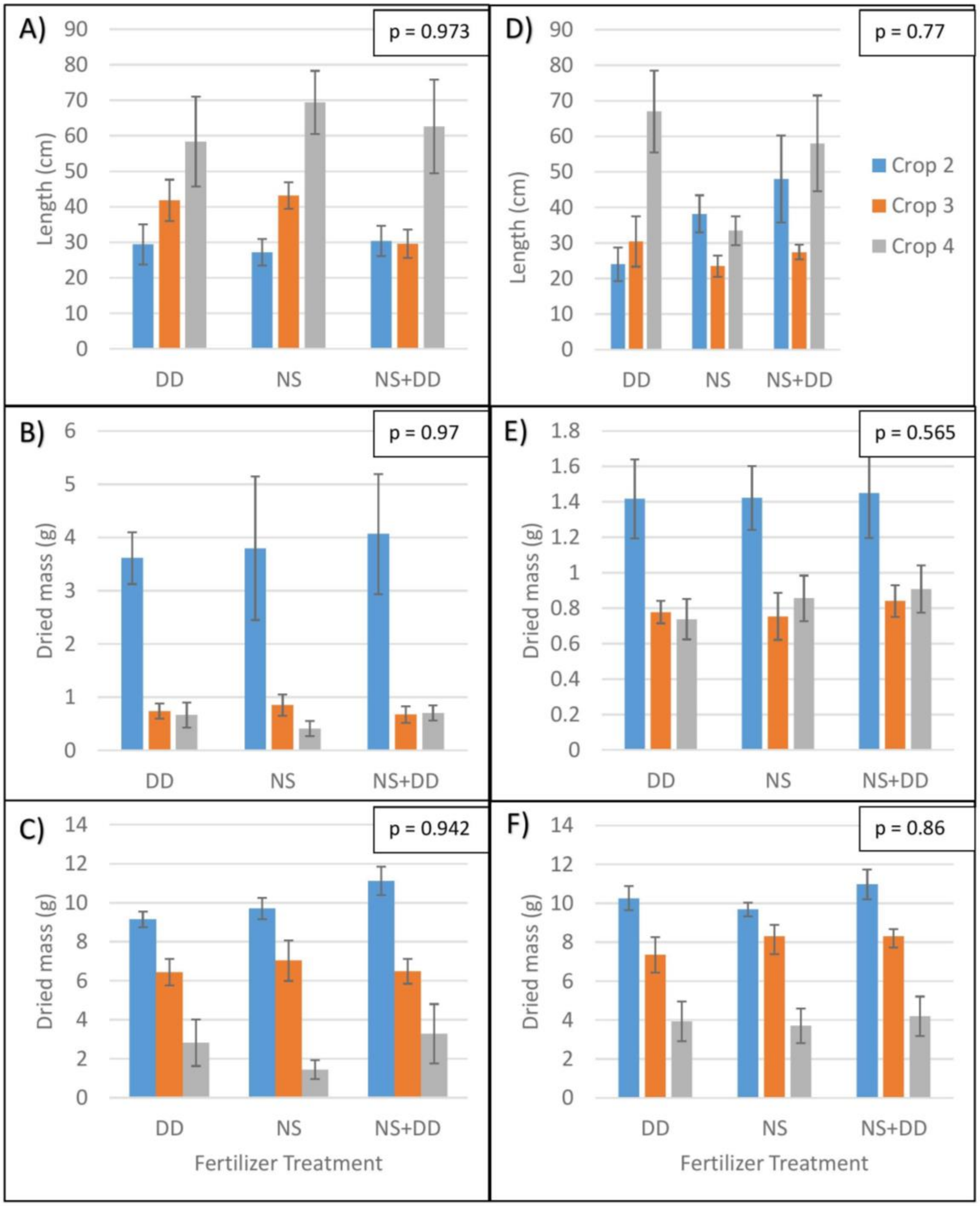


Figure 12 Comparison of growth parameters measured from crop cycles 2, 3, and 4. Root length in soil (A), Dried root mass in soil+promix (B), Dried shoot mass in soil (C), Root length in soil+promix (D), Dried root mass in soil+promix (E), Dried shoot mass in soil+promix (F). Error bars represent one standard deviation. Corresponding p values indicate significance of fertilizer treatment per crop on Y-axis parameter. H_o = there is no significant effect of fertilizer treatment on measured growth parameter. N = 30.

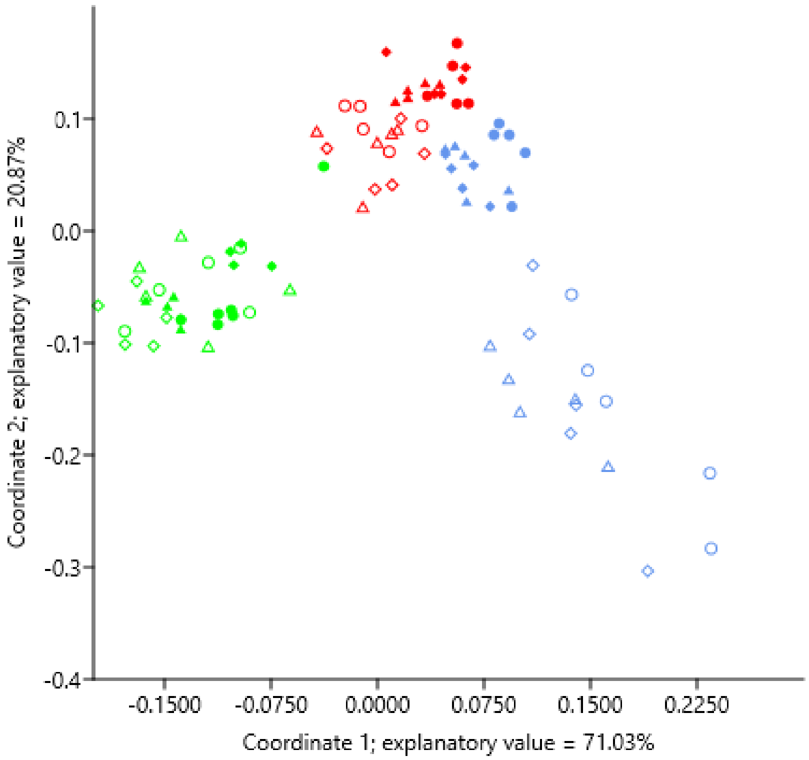


Figure 13 Scatterplot of growth parameter data. Data is cumulative of 3 crop cycles. Symbols and color represent crop number and soil media/ fertilizer treatment. Blue = Crop 2, Red = Crop 3, Green = Crop 4. Filled symbols represent soil+promix treatment, hollow symbols represent mineral soil treatment. Triangle = DD fertilizer, diamond = DD+NS fertilizer, Circle = NS (control). Data were normalized by parameter using z-scores. N=90.

3.2. Impact of soil substrate

While there was no significant effect of fertilizer treatment on growth parameters, there was an effect of the soil substrate type (Table 9). A means comparison concluded that there was a consistent significant effect of soil substrate type on each of the parameters measured; crop yield and biomass from each soil substrate type were statistically different (Table 10).

A 3 year-long field experiment has shown that the incorporation of *Sphagnum* peat increased the water holding capacity, organic matter (SOM), total porosity, and decreased bulk density of sandy soils, thus increasing potato and barley yields (Campagna and Simard 1967; Li et al. 2004). The decrease in bulk density was a result of diluting the denser mineral fraction with the organic material (Khaleel et al. 1981), thus increasing soil porosity and aeration in the root zone. These tilled soil layers are able to fill with both air and water, facilitating root penetration, water and nutrient availability, and microbial activity within the soil (Khaleel et al. 1981; Pulleman et al. 2000; Lampurlanés and Cantero-Martinez 2003). These findings correlate with our laboratory results, where *soil+promix* had a lower bulk density, and higher soil water holding capacity, SOM, and porosity in comparison to the *soil* treatment. This could also explain the difference in root length, as well as root and shoot mass seen between the soil substrate types.

Crop micronutrient content was also found to be significantly influenced by soil substrate type (Table 9; Table 10), and when compared to fertilizer as a factor, it was determined to be an influential driver in crop nutrient content (Figure 14; Appendix 7; Appendix 9). Peat has a high cation exchange capacity (CEC), and therefore has an increased ability to hold nutrients when compared to mineral soil due to the increased number of charged bonding sites on the peat particle (Maher et al. 2008). Nutrients are then available for plants for a longer period of time in comparison to mineral soil, allowing more time for uptake and higher nutrient accumulations within the crop.

Table 9 Impact of fertilizer and soil substrate type on post-harvest soil nutrient concentration via means comparisons (post-hoc Tukey HSD; p_{H0} values). Data were cumulative of 3 crop cycles with combinations of two soil media and three fertilizer treatments (Appendix 13). Data were normalized by parameter as z-scores. N=90.

Nutrient concentration	Soil substrate type	Crop number	Fertilizer treatment	Soil * fertilizer treatment interaction
Ca (mg L^{-1})	<0.001	<0.001	0.128	0.854
Mg (mg L^{-1})	<0.001	<0.001	0.664	0.324
K (mg L^{-1})	0.014	<0.001	<0.001	0.837
P (mg L^{-1})	<0.001	<0.001	0.050	0.801
Fe (mg L^{-1})	<0.001	<0.001	0.181	0.719
Cu (mg L^{-1})	<0.001	<0.001	0.146	0.860
Mn (mg L^{-1})	<0.001	<0.001	0.160	0.884
Zn (mg L^{-1})	<0.001	<0.001	0.078	0.982
B (mg L^{-1})	<0.001	<0.001	0.268	0.808
Na (mg L^{-1})	<0.001	<0.001	0.858	0.421
Al (mg L^{-1})	<0.001	<0.001	0.247	0.688
S (mg L^{-1})	<0.001	0.001	0.333	0.333
PO_4^{3-} (mg L^{-1})	0.017	<0.001	0.046	0.626
NH_3 (mg L^{-1})	0.647	<0.001	0.987	0.604
NO_3^- (mg L^{-1})	0.837	0.081	0.241	0.191
OM%	<0.001	<0.001	0.096	0.708
pH	0.018	<0.001	0.046	0.897
%N	<0.001	<0.001	0.782	0.695
%C	<0.001	<0.001	0.372	0.802

Table 10 Impact of fertilizer type on post-harvest soil media nutrient concentration (post-hoc Tukey HSD; p_{H0} values). Data were cumulative of 3 crop cycles with combinations of two soil media and three fertilizer treatments (Appendix 13). Data were normalized by parameter using z-scores. N=90.

Nutrient concentration	DD-DD+NS	NS-DD+NS	NS-DD
Ca (mg L^{-1})	0.333	0.121	0.838
Mg (mg L^{-1})	0.851	0.641	0.932
K (mg L^{-1})	<0.001	<0.001	<0.001
P (mg L^{-1})	0.039	0.521	0.347
Fe (mg L^{-1})	0.710	0.156	0.534
Cu (mg L^{-1})	0.466	0.125	0.710
Mn (mg L^{-1})	0.213	0.228	0.999
Zn (mg L^{-1})	0.147	0.102	0.983
B (mg L^{-1})	0.999	0.343	0.331
Na (mg L^{-1})	0.953	0.964	0.845
Al (mg L^{-1})	0.281	0.357	0.987
S (mg L^{-1})	0.943	0.333	0.518
PO_4^{3-} (mg L^{-1})	0.038	0.644	0.250
NH_3 (mg L^{-1})	0.995	0.986	0.998
NO_3^- (mg L^{-1})	0.272	0.358	0.983
OM%	0.103	0.221	0.920
pH	0.120	0.059	0.958
%N	0.855	0.786	0.991
%C	0.350	0.881	0.635
Crop cycle data			
Nutrient	2-3	2-4	3-4
Ca (mg L^{-1})	0.346	<0.001	<0.001
Mg (mg L^{-1})	0.714	<0.001	<0.001

Nutrient	2-3	2-4	3-4
K (mg L^{-1})	0.426	<0.001	<0.001
P (mg L^{-1})	0.086	<0.001	<0.001
Fe (mg L^{-1})	0.488	<0.001	<0.001
Cu (mg L^{-1})	0.386	<0.001	<0.001
Mn (mg L^{-1})	0.999	<0.001	<0.001
Zn (mg L^{-1})	0.629	<0.001	<0.001
B (mg L^{-1})	<0.001	<0.001	<0.001
Na (mg L^{-1})	<0.001	<0.001	<0.001
Al (mg L^{-1})	0.831	<0.001	<0.001
S (mg L^{-1})	0.958	<0.001	<0.001
PO_4^{3-} (mg L^{-1})	0.993	<0.001	<0.001
NH_3 (mg L^{-1})	<0.001	<0.001	0.039
NO_3^- (mg L^{-1})	0.150	0.107	0.985
OM%	0.011	<0.001	<0.001
pH	0.120	<0.001	<0.001
%N	<0.001	<0.001	<0.001
%C	<0.001	<0.001	0.100

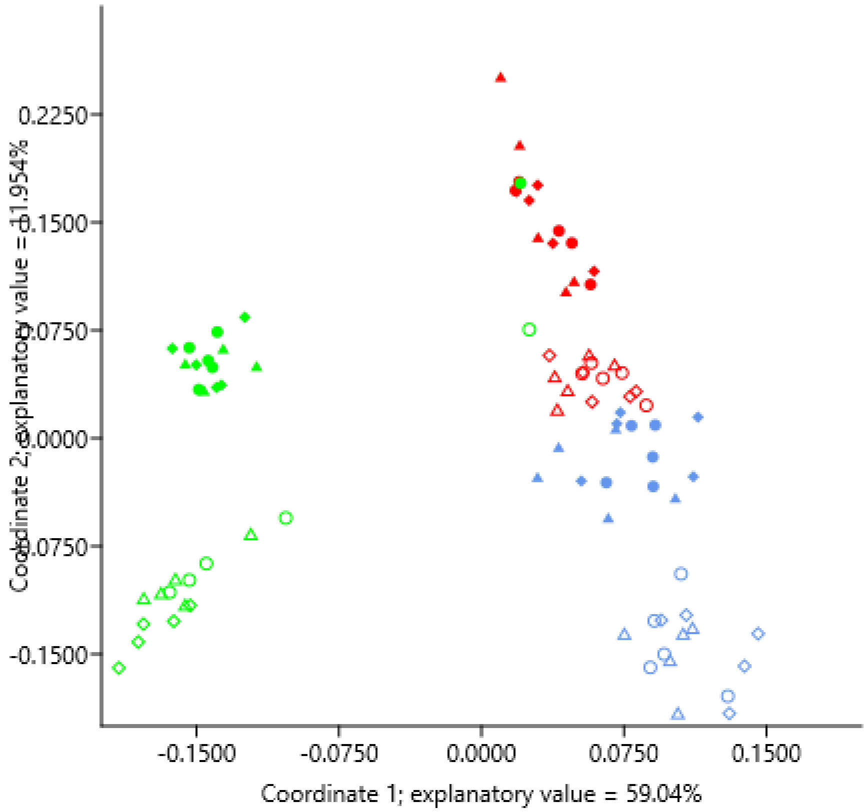


Figure 14 Scatterplot of post-harvest soil media nutrient content. Symbols and color represent crop number and soil media/ fertilizer treatment (Appendix 13). Blue = Crop 2, Red = Crop 3, Green = Crop 4. Filled symbols represent soil+promix treatment, hollow symbols represent mineral soil treatment. Triangle = DD fertilizer, diamond = DD+NS fertilizer, Circle = NS (control). Data were normalized by parameter using z-scores. N=90.

3.3. Soil media quality post-harvest

A comparison of means indicated that in most cases there was no statistically significant effect of fertilizer treatment on post-harvest, final soil substrate nutrient contents. There was one exception, the post-harvest concentrations of K, which were dissimilar between fertilizer treatments (Table 9; Table 10).

However when the soil substrate type as factor had a statistically significant impact on post-harvest nutrient concentrations, with the exception of NH_3, and NO_3^- (Table 9; Table 10). Thus the null hypothesis was rejected. Further investigation using a PCoA (Figure 14) and CCA (Appendix 5) showed clustering of data points based on soil substrate type, confirming trends identified in the MANOVA. This could be due to the increased organic matter content and nutrient holding capacity of peat in comparison to sandy soil (Davis and Whiting 2013). In reference to Gyllenberg and Eklund (1974) and Jenkinson (1981) the microbes responsible for the immobilization of N and P are typically scarce when nutrient content is low, but thrive with nutrient addition. Further, the chemical and physical properties of peat play an important role in nutrient retention- a large specific area (>200 m^2 g^{-1}) and high porosity (90-97%) (Puustjärvi 1983) lead to an increased CEC and nutrient retention capacity in comparison to mineral soils (Heikkinen et al. 1995). For example, the pH dependent formation of P complexes with Al^{3+}, Fe^{3+} or Ca^{2+} largely contribute to the retention of P in the peat matrix (Kaila 1959; Black 1968; Nieminen and Jarva, 1996) comparable to mineral soils (Nichols 1983). The relationship between P and Fe illustrated in Figure 18 has also been found in studies by Nieminen and Jarva (1996) and Silvan (2004), where strong correlations between P and Fe concentrations; it was concluded that the formation of iron phosphate complexes play a significant role in the retention of P in the peat matrix.

Bigelow et al. (2001) concluded that NH_4^+-N and NO_3^--N leaching is higher in sandy soils than in the same soils amended with peat. However, no such trend was identified in this study as post-harvest means comparisons in soils determined statistically similar concentrations of NH_3-N and NO_3^--N between soil treatments. It has been noted that nitrogen dynamics are mainly governed by microbial processes (i.e., fixation, denitrification) (Barnard et al. 2005) whereas phosphorus is governed by mechanisms of precipitation and sorption (Qualls and Richardson 1995; Bridgham et al. 2001, Zak et al. 2004). This, in combination with the findings of Kaila (1959), Black (1968), Nieminen and Jarva (1996), could explain the difference in phosphate concentration between soil treatments identified in this experiment.

A decline in substrate pH was consistent among all treatments during the final experimental crop (Appendix 13). While exact cause was not investigated it could be speculated that rapid mineralization and ammonium uptake could be a factor.

3.4. Crop Nutrient Content

Differences in crop N and P content existed between fertilizer treatments where nutrients in crops from the DD treatment significantly varied from the DD+NS treatment and control. Crop K content only differed between the DD and DD+NS treatments. With the exception of C and Fe content, all other discrepancies in nutrient content could be accounted for by comparison of the NS crop treatment to the DD and DD+NS treatments (Table 12; Table 13; Table 14; Table 15; Figure 15; Figure 16). This would be due to the experimental layout, as no micronutrients were added to the NS treatment. Pot experiments confirmed that in situations where N content was equal between AD animal slurry and undigested slurry N uptake by crops was higher when fertilized with the digested slurry (Morris and Lathwell 2004; de Boer 2008). These findings conflict with those of this experiment as N content in crops fertilized with DD was significantly lower when compared to those in the control and DD+NS treatment. In field experiments where digested animal manure and mineral fertilizer with equal N content were applied to crops there was comparable N recovery (Gunnarsson et al. 2010; Fouda 2011). Our results supported this finding as there was no statistically significant difference in post-harvest soil N content among fertilizer treatments.

Further, studies show that AD would improve P availability to crops (Massé et al. 2011), or have no effect (Loria and Sawyer 2005; Moller and Stinner 2010; Bachmann et al. 2011). In this case P content in crops was lowest in the DD treatment (Table 11), a result however supported by other previous reports (Nelson et al. 2003; Burton 2007; Christensen et al. 2009, Hjorth et al. 2010) that concluded that changes in pH during the AD process influence P solubility and favor the formation of precipitates such as magnesium or calcium phosphate. A correlation was also detected between soil pH and P accumulation in the crop: a negative correlation was identified in the DD treatment (lowest P accumulation) and DD+NS treatment (highest P accumulation) (Figure 17; Figure 18).

Tissue analysis of the fourth experimental crop showed low P and C content, potentially explaining the low yield of the crop. It is speculated that the low soil pH allowed the formation of P complexes in the soil leaving it immobilized and unavailable to plants. Thus, restricting photosynthetic activity and C accumulation by the plant (Pampolino et al. 2008; Sinsabaugh et al. 2009) (Appendix 13; Appendix 14).

Table 11 Average lettuce tissue nutrient content calculated using 3 crop cycles and 5 replicates per treatment, per cycle (Appendix 14). N=90.

Soil substrate type	Fertilizer treatment	N (%)	C (%)	S (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)	B (ppm)
Soil	DD	3.82	40.1	0.25	0.34	6.88	0.71	0.27	0.36	302	7.9	53.8	63.7	41.9
Soil	NS	4.07	40.0	0.24	0.35	6.96	0.64	0.25	0.34	371	7.6	54.6	58.3	38.1
Soil	DD+NS	4.12	38.8	0.26	0.38	7.44	0.71	0.29	0.35	573	10.7	59.5	66.3	43.3
Soil+ Promix	DD	3.86	39.9	0.24	0.34	6.68	0.70	0.32	0.33	293	8.1	60.3	67.9	39.1
Soil+ Promix	NS	4.09	39.7	0.24	0.41	7.38	0.64	0.29	0.32	274	6.9	54.9	61.3	36.9
Soil+ Promix	DD+NS	4.00	39.6	0.25	0.39	7.37	0.65	0.31	0.34	259	7.8	54.7	64.6	38.1

Table 5 Impact of fertilizer and soil substrate type on shoot nutrient concentration via means comparisons (post-hoc Tukey HSD; p_{H0} values). Data were cumulative of 3 crop cycles with combinations of two soil media and three fertilizer treatments (Appendix 14). Data were normalized by parameter using z-scores. N=90.

Nutrient concentration	Soil substrate type	Crop number	Fertilizer treatment	Soil*fertilizer treatment interaction
N (%)	0.776	<0.001	0.009	0.550
P (%)	0.489	<0.001	0.001	0.020
K (%)	0.501	<0.001	0.122	0.393
C (%)	0.066	<0.001	0.006	0.118
S (%)	0.742	<0.001	0.004	0.210
Ca (%)	0.04	<0.001	<0.001	0.104
Mg (%)	<0.001	<0.001	0.001	0.084
Na (%)	0.003	<0.001	0.057	0.610
Mn (ppm)	0.000	<0.001	0.029	0.004
Fe (ppm)	0.036	<0.001	0.012	0.068
Cu (ppm)	0.783	<0.001	0.622	0.127
Zn (ppm)	0.512	<0.001	0.230	0.670
B (ppm)	<0.001	<0.001	0.001	0.089

Table 13 Impact of fertilizer type on shoot nutrient concentration (post-hoc Tukey HSD; p_{H0} values). Data were cumulative of 3 crop cycles with combinations of two soil media and three fertilizer treatments (Appendix 14). Data were normalized by parameter using z-scores. N=90.

Nutrient concentration	DD-DD+NS	NS-DD+NS	NS-DD
N (%)	0.028	0.971	0.015
P (%)	0.008	0.894	0.028
K (%)	0.003	0.414	0.097
C (%)	0.001	0.013	0.641
S (%)	0.228	0.141	0.964
Ca (%)	0.359	0.006	0.000
Mg (%)	0.789	0.001	0.008
Na (%)	0.974	0.121	0.076
Mn (ppm)	0.999	0.668	0.683
Fe (ppm)	0.032	0.108	0.859
Cu (ppm)	0.159	0.009	0.462
Zn (ppm)	1.00	0.297	0.297
B (ppm)	0.965	0.003	0.006
Crop cycle data			
Nutrient	2-3	2-4	3-4
N (%)	<0.001	<0.001	<0.001
P (%)	<0.001	<0.001	<0.001
K (%)	<0.001	<0.001	<0.001
C (%)	<0.001	<0.001	<0.001
S (%)	<0.001	<0.001	<0.001
Ca (%)	<0.001	<0.001	<0.001
Mg (%)	<0.001	<0.001	<0.001
Na (%)	<0.001	<0.001	<0.001

Mn (ppm)	0.117	<0.001	<0.001
Fe (ppm)	0.997	<0.001	<0.001
Cu (ppm)	0.011	<0.001	<0.001
Zn (ppm)	0.001	<0.001	<0.001
B (ppm)	<0.001	<0.001	<0.001

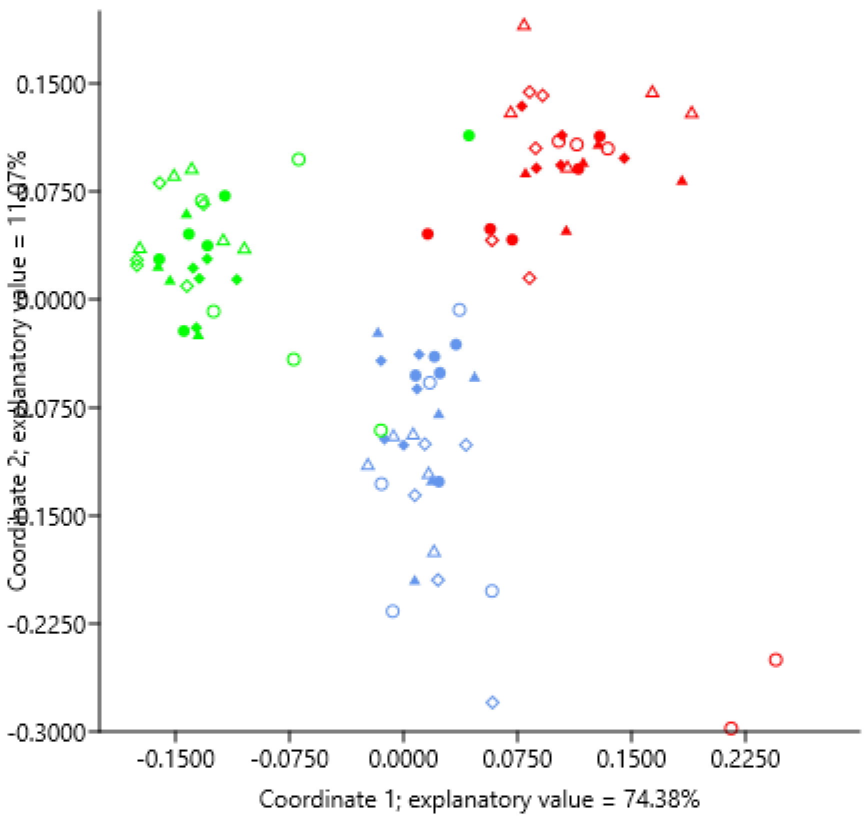


Figure 15 Scatterplot of shoot nutrient content. Symbols and color represent crop number and soil media/ fertilizer treatment (Appendix 14). Blue = Crop 2, Red = Crop 3, Green = Crop 4. Filled symbols represent soil+promix treatment, hollow symbols represent mineral soil treatment. Triangle = DD fertilizer, diamond = DD+NS fertilizer, Circle = NS (control). Data were normalized by parameter using z-scores. N=90.

Table 14 Impact of fertilizer and soil substrate type on post-harvest root nutrient concentration via means comparisons (post-hoc Tukey HSD; p_{H0} values). Data were cumulative of 3 crop cycles with combinations of two soil media and three fertilizer treatments (Appendix 12). Data were normalized by parameter using z-scores. N=90.

Nutrient	Soil substrate type	Crop number	Fertilizer treatment	Soil*fertilizer treatment interaction
N (%)	0.023	<0.001	0.142	0.883
C (%)	<0.001	<0.001	0.480	0.989
S (%)	0.645	<0.001	0.010	0.437
P (%)	0.653	<0.001	0.980	0.106
K (%)	0.507	<0.001	0.935	0.565
Ca (%)	0.002	<0.001	0.997	0.739
Mg (%)	0.205	0.169	0.006	0.173
Na (%)	0.850	<0.001	<0.001	0.122
Cu (mg L^{-1})	<0.001	<0.001	0.288	0.335
Fe (mg L^{-1})	<0.001	<0.001	0.136	0.607
Mn (mg L^{-1})	<0.001	<0.001	0.5	0.363
Zn (mg L^{-1})	0.699	0.091	0.297	0.653
B (mg L^{-1})	<0.001	<0.001	0.059	0.547

Table 15 Impact of fertilizer and soil substrate type on post-harvest root nutrient concentration (post-hoc Tukey HSD; p_{H0} values). Data were cumulative of 3 crop cycles with combinations of two soil media and three fertilizer treatments (Appendix 12). Data were normalized by parameter using z-scores. N=90.

Nutrient	DD-DD+NS	NS-DD+NS	NS-DD
N (%)	0.347	0.845	0.134
C (%)	0.692	0.466	0.933
S (%)	0.113	0.536	0.008
P (%)	0.897	0.841	0.992

K (%)	0.916	0.995	0.973
Ca (%)	0.911	0.846	0.989
Mg (%)	0.527	0.033	0.001
Na (%)	<0.001	0.532	<0.001
Cu (mg L^{-1})	0.999	0.250	0.241
Fe (mg L^{-1})	0.837	0.209	0.493
Mn (mg L^{-1})	0.781	0.432	0.836
Zn (mg L^{-1})	0.715	0.174	0.563
B (mg L^{-1})	0.915	0.013	0.038
Crop cycle data			
N (%)	<0.001	0.3	<0.001
C (%)	<0.001	<0.001	<0.001
S (%)	<0.001	0.010	<0.001
P (%)	<0.001	0.109	<0.001
K (%)	<0.001	<0.001	<0.001
Ca (%)	<0.001	<0.001	0.017
Mg (%)	0.370	0.576	0.936
Na (%)	0<0.001	<0.001	<0.001
Cu (mg L^{-1})	<0.001	<0.001	<0.001
Fe (mg L^{-1})	<0.001	<0.001	0.979
Mn (mg L^{-1})	<0.001	<0.001	0.333
Zn (mg L^{-1})	0.158	0.010	0.499
B (mg L^{-1})	<0.001	<0.001	<0.001

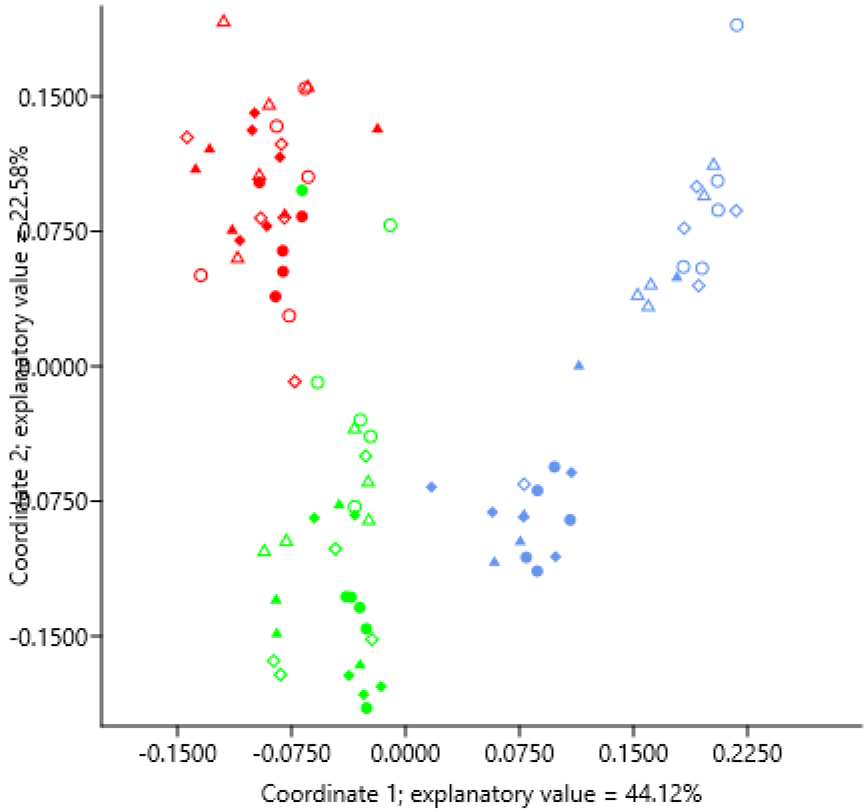


Figure 16. Scatterplot of root nutrient content. Symbols and color represent crop number and soil media/ fertilizer treatment (Appendix 12). Blue = Crop 2, Red = Crop 3, Green = Crop 4. Filled symbols represent soil+promix treatment, hollow symbols represent soil treatment. Triangle = DD fertilizer, diamond = DD+NS fertilizer, Circle = NS (control). Data were normalized by parameter using z-scores. N=90.

a)

b)

c)

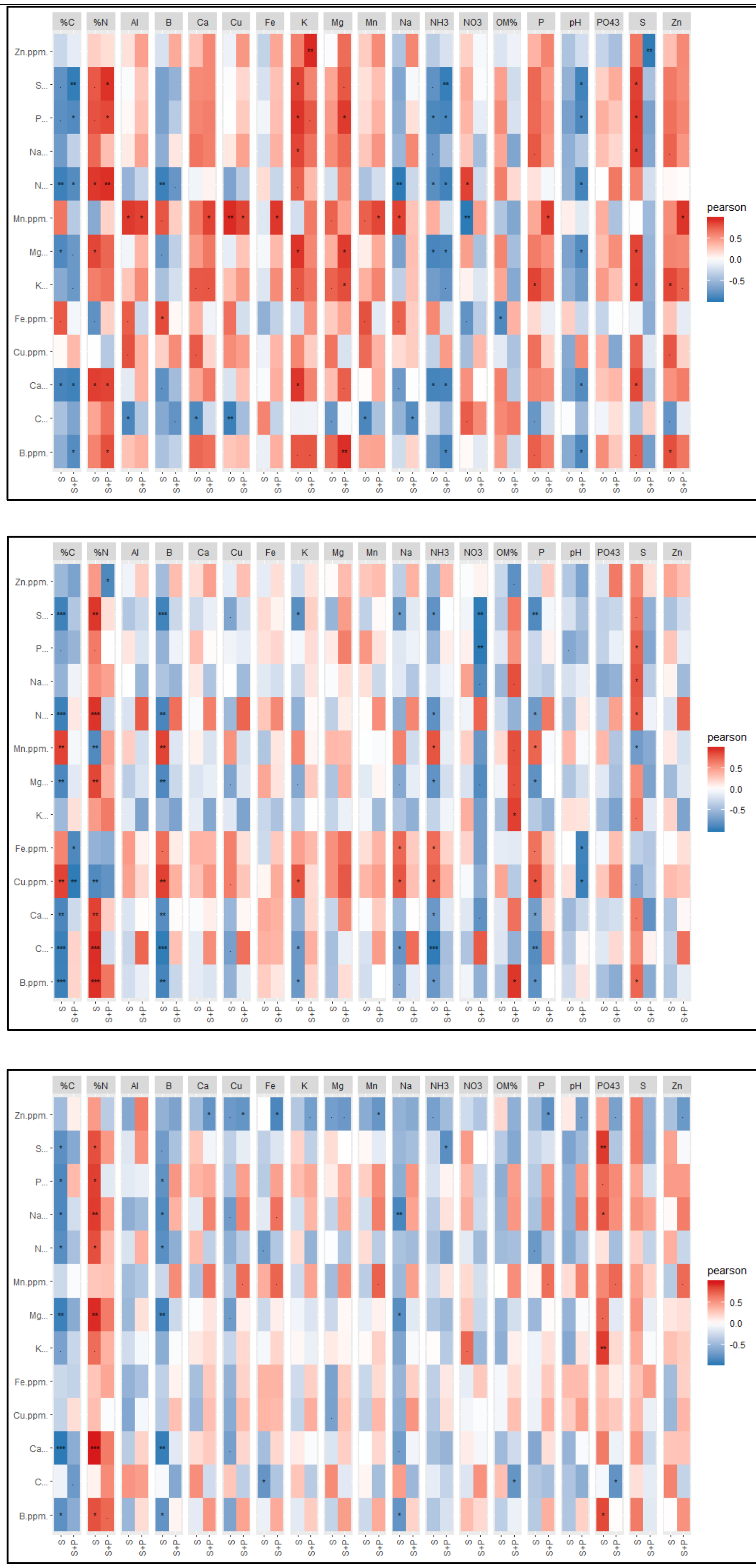


Figure 17 Correlation between lettuce shoot nutrient data and post-harvest media nutrient data (Appendix 14; Appendix 13). Data were normalized using z-score and grouped based on soil substrate type. A) DD fertilizer treatment, B) NS fertilizer treatment, C) DD+NS fertilizer treatment. Data were normalized by parameter using z-scores. N=90. Row labels describe plant tissue parameters, while column labels describe soil parameters; all plant and soil data has been obtained after harvest.

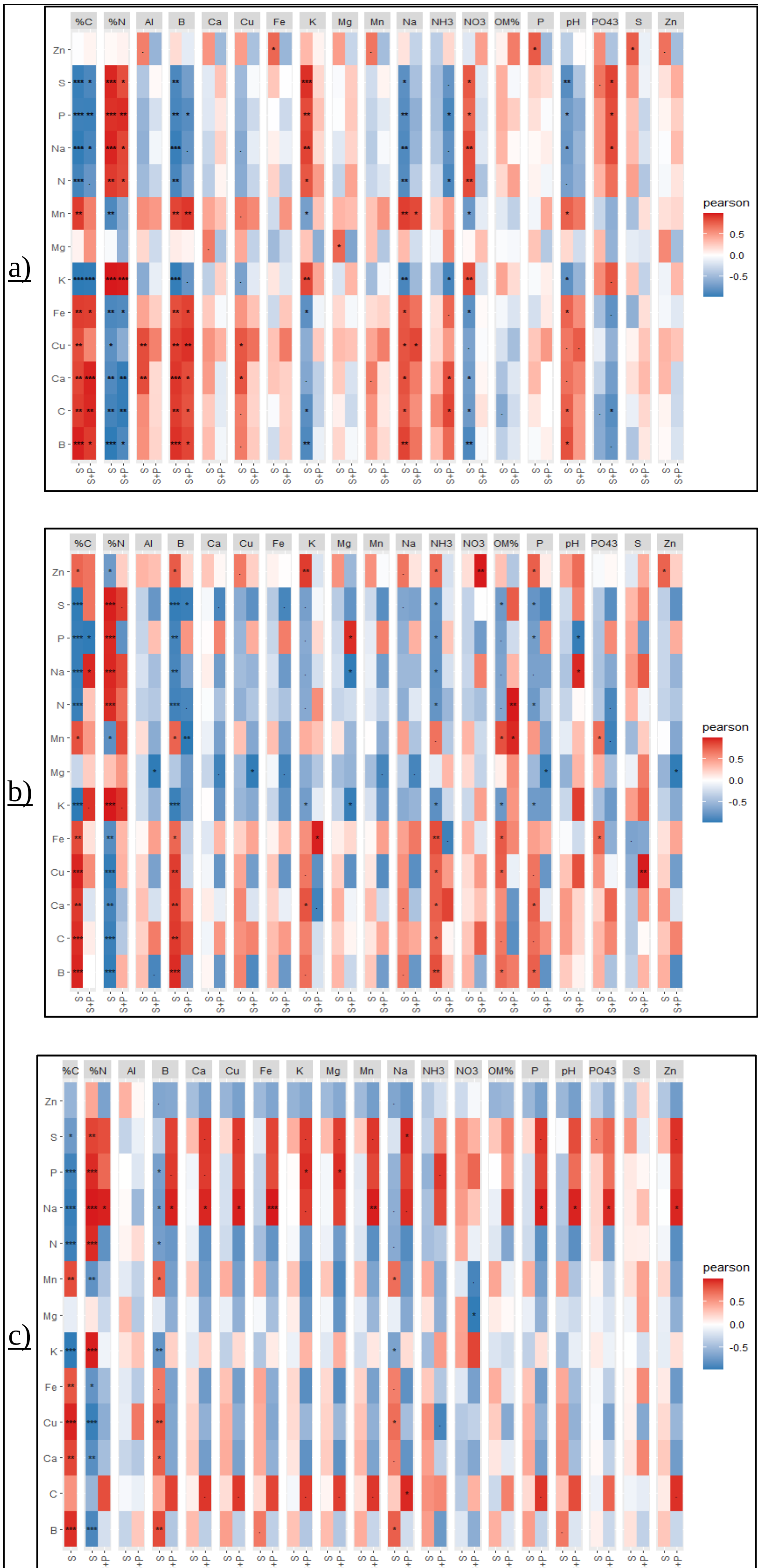


Figure 18 Correlation between lettuce root nutrient data and post-harvest media nutrient data (Appendix K; Appendix L). Data were normalized using z-score and grouped based on soil substrate type. A) DD fertilizer treatment, B) NS fertilizer treatment, C) DD+NS fertilizer treatment. Data normalized by parameter using z-scores. N=90. Row labels describe plant tissue parameters, while column labels describe soil parameters; all plant and soil data has been obtained after harvest.

3.5. Nutrient Use Efficiency (NUE, %)

N-UE ranged from 0.67%- 14.84% for NS, 2.32%- 25.45% for DD, and 2.50%- 23.15% for DD+NS. P-UE ranged from 0.181%- 9.637% for NS, 0.632%- 15.746% for DD, and 0.850%- 11.850% for DD+NS. There was a significant effect of soil substrate treatment on both nitrogen and phosphorus use efficiency (Table 15; Table 16), where the *soil+promix* treatment had consistently higher use efficiency in comparison to the *soil* treatment. While there was no effect of fertilizer treatment on phosphorus use efficiency there was a significant difference in nitrogen use efficiency between the control and DD+NS fertilizer treatment. In this case, the DD+NS treatment had a consistently higher nitrogen use efficiency in comparison to the control (Table 15; Table 16; Figure 19; Appendix 10; Appendix 11). De Boer (2008) reported that pig digestate often had a similar nitrogen use efficiency to mineral nitrogen fertilizer and in a pot experiment using ryegrass, the applied digestate also had a similar nitrogen use efficiency when compared to mineral fertilizer (Gunnarsonn et al. 2010). While there is little data available concerning P use efficiency in dairy digestate results from Bachmann et al. (2011) and Bachmann et al. (2016) conclude that P use efficiency of dairy slurry and maize silage digestate as well as maize silage, cereal whole plant silage, and grass silage digestate was significantly greater than that of chemical fertilizer, and no such trend was present in this study.

As previously mentioned, peat has a high CEC and therefore has an increased ability to hold nutrients when compared to mineral soil due to the increased number of charged bonding sites on the peat particle (Maher et al. 2008). This could explain the higher nitrogen and phosphorus use efficiency in the *promix+soil* treatment than the *soil* treatment, as the promix has a higher number of binding sites for added nutrients. Nutrients are then available for plants for a longer period of time in comparison to mineral soil, reducing losses and increasing nutrient usage efficiency. Studies by Solaiman et al. (2007), Akhtar et al. (2008), and Hammond et al. (2009) using *B. oleracea*, canola, and *B. napus* cultivars, respectively, agreed that longer total root lengths correlated with an increased P-UE as the roots were able to explore a greater volume of soil. Lettuce crops cultivated in the *soil+promix* treatment were found to have longer root lengths in comparison to those cultivated in the *soil* treatment (Table 7)(Table 8)(Figure 12), which could provide further explanation toward the discrepancies in N-UE and P-UE.

Crop cycle had a significant effect on nitrogen and phosphorus use efficiency where N-UE in crops 2 and 3 was significantly different from crop 4, and P-UE was significantly different in crops 3 and 4 (Table 15; Table 16).

Table 6 Impact of soil media and fertilizer on nutrient use efficiency via means comparisons (post-hoc Tukey HSD; p_{H0} values). Data were cumulative of 3 crop cycles with combinations of two soil media and three fertilizer treatments (Appendix 10). Data were normalized by parameter using z-scores. N=90.

Parameter	Soil substrate type	Crop cycle	Fertilizer treatment	Soil*Fertilizer treatment interaction
N use efficiency (N-UE)	<0.001	<0.001	0.029	0.103
P use efficiency (P-UE)	0.014	0.006	0.100	0.392
N:P	0.829	<0.001	0.133	0.442

Table 7 Impact of soil media and fertilizer on nutrient use efficiency (post-hoc Tukey HSD; p_{H0} values). Data were cumulative of 3 crop cycles with combinations of two soil media and three fertilizer treatments (Appendix 10). Data were normalized by parameter using z-scores. N=90.

Parameter	DD-DD+NS	NS-DD+NS	NS-DD
N use efficiency (N-UE)	0.437	0.024	0.183
P use efficiency (P-UE)	0.310	0.090	0.694
N:P	0.198	0.992	0.166

Crop cycle data			
Parameter	2-3	2-4	3-4
N use efficiency (N-UE)	0.369	<0.001	0.002
P use efficiency (P-UE)	0.147	0.120	0.004
N:P	0.999	<0.001	<0.001

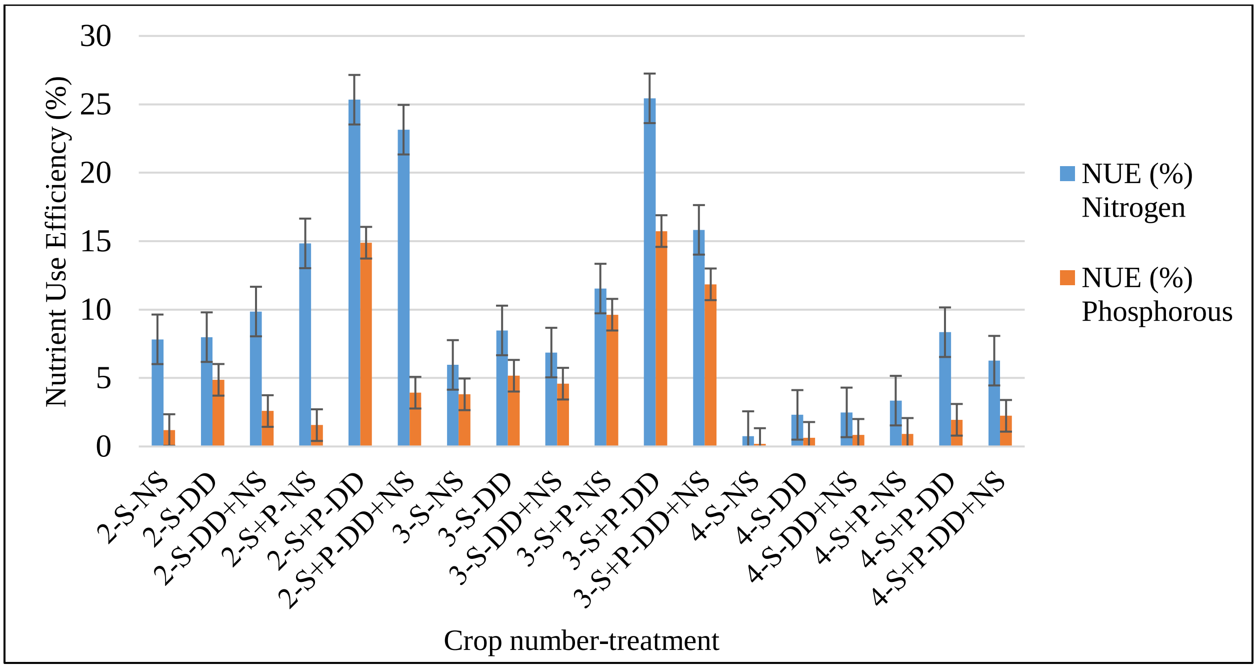


Figure 19 Nitrogen and phosphorus use efficiency in lettuce crops. Data consists of 3 crop cycles, 2 soil substrate types, and 3 fertilizer treatments (Appendix 10). Data normalized by parameter using z-scores. Error bars represent standard error. N=90.

3.6. Plant N:P ratios

Crops 2 and 3 maintained a N:P ratio between 8:1-10:1 (Appendix 10) which is relatively close to the 9:1 ratio outlined by Nemali (n.d.) as the optimal nutrient composition present in the dry leaf, indicating healthy growth. While there was no effect of media or fertilizer treatment on

N:P ratio, there was a significant effect of crop cycle. Crop 4 had N:P ratios approximately 3 times larger for each treatment in comparison to the previous 2 crop cycles. An increase in N:P ratio could be caused by a low P supply in comparison to N, thus resulting in a luxury uptake of N in the crop tissues. Reflecting on the biomass production of crop cycle 4, average mass from each treatment was notably lower in comparison to crop cycles 2 and 3. Findings by Koerselman and Meuleman (1996) indicate that a N:P ratio >16 indicate a P limitation and ultimately limitations in crop growth and biomass, thus possibly explaining the trend identified in this study. Johnstone et al. (2005), Sanchez and Burdine (1988), and Sanchez et al. (1988) also support that lettuce quality and crop yield are influenced in response to P availability. Since lettuce has been reported to have a higher P requirement in comparison to other vegetables (Cleaver and Greenwood 1975), a suboptimal N:P ratio leads to slowed leaf growth and low leaf area index through cell expansion and photosynthetic limitations (Sanchez and Burdine 1988). Further, high N accumulation in leaves can be beneficial as it increases leaf length and width however it also impacts leaf thickness (Tittonell et al. 2001) and can reduce crop quality, which leads to issues with crop storage and rapid crop decay post-harvest (David et al. 1992).

3.7. Conclusion

Results support the hypothesis that soil based utilisation of digestate as fertilizer is a viable and likely an economical option. There was no effect of fertilizer treatment on crop P-UE, however significant differences in N-UE existed between the control and DD+NS treatment. Crop N and P content significantly varied between the DD+NS and DD treatments, likely due to pH changes of the digestate during the digestion process. The majority of other differences in nutrient content can be accounted for by differences between the control and DD+NS/ DD treatments - an expected outcome resulting from experimental layout. There was also no significant effect of fertilizer treatment on post-harvest soil media nutrient content. Nevertheless, the selection of the substrate to which the digestate is added is critical. Local soils that might have undesirable chemical properties might need to be amended with substrates that can mitigate soil acidity, tendency to compact and low water holding capacity. The high quantities of Fe and Al from the experimental soil employed here could indicate that the CEC is primarily driven by these elements and thus the chemistry of nutrient availability, especially P, is governed by them. Soils amended with promix have been found to produce yields significantly higher than crops in unamended soils. Crops fertilized with DD have been found to be equivalent to those fertilized with NPK fertilizer, however crops in the *soil+promix* treatment had a higher yield in comparison to those from the *soil* treatment. Soil substrate type had a statistically significant impact on post-harvest nutrient concentrations, with the exception of NH_3, and NO_3^-, as well as N-UE and P-UE. Soil media pH was found to decrease in the final experimental crop and is speculated to be caused by rapid ammonium consumption by plants or mineralization of available nutrients. Further research concerning the maintenance of soil media pH is recommended.

In summary dairy digestate can be employed as an effective source of nutrients in greenhouse settings, but attention needs to be paid to the type and quality of the soil substrates. If local Newfoundland soils are considered, then pH and water holding capacity management practices must be employed.

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Appendix 1: Fertilizer Preparation Calculations

<u>Conversion of soil quantity</u>

1 ha = 10,000 m^2 = 100,000 L – not clear how did you get this 100,000 L? how did you convert area (m^2) to volume (L)?

1 L = 0.01 m^2

2 L soil/pot = 0.02 m^2 soil/pot

Nitrogen requirement per pot

150 kg/ha total N = 15 g/m^2 total N

15 g/m^2 total N * 0.02 m^2 soil per pot = **0.3 g total N required per pot**

Nutrient Solution Preparation

Nitrogen content:

N requirement to match soil report recommendation: 0.3 g

Fertilizer used: Potassium nitrate (KNO_3)

Molar mass of KNO_3 = 101.1032 g/ mol

Percent composition by mass: N: $\frac{(14.0067\frac{g}{mol})}{(101.1032\frac{g}{mol})} x\ 100$ = 13.85%

K: $\frac{(39.0983\frac{g}{mol})}{(101.1032\frac{g}{mol})} x\ 100$ = 38.67%

Mass of KNO_3 required per pot: $\frac{Mass\ of\ nitrogen\ required\ (g)}{Percent\ N\ of\ \text{KNO3}} = \frac{0.3\ g}{0.1385}$ = 2.2 g KNO_3 per pot (to reach total N requirement)

Since there are 30 pots per treatment, each requiring the same nitrogen input:

Total KNO_3 requirement for stock solution = 30 pots * 2.2 g KNO_3 per pot

= (66 g)/ 2 fertilizations

= 33 g KNO_3 required for stock solution per fertilization

Phosphorus and Potassium content:

P requirement to match diluted digestate: 0.018 g

K requirement to match diluted digestate: 0.097 g

Fertilizer used: Monopotassium phosphate (KH_2PO_4 g/mol)

Molar mass of KH_2PO_4: 136.086 g/mol

Percent composition by mass: P: $\frac{(30.97\frac{g}{mol})}{(136.086\frac{g}{mol})} x\ 100$ = 22.75%

K: $\frac{(39.0983\frac{g}{mol})}{(136.086\frac{g}{mol})} x\ 100$ = 28.73%

Mass of KH_2PO_4 required per pot: P: $\frac{Mass\ of\ P\ required\ (g)}{Percent\ P\ of\ \text{KH2PO4}} = \frac{0.018g}{0.2275}$ = 0.079 g * 30 pots = 2.38 g KH_2PO_4 for stock solution.

Digestate dilution calculations

Stock digestate = ~2000 mg/kg total N (2 g/L)

Target N mass in diluted digestate = 0.14 g/L

Molarity of Nitrogen in stock digestate = (Parts per million (ppm)* 0.001)/ (N atomic weight)

= (2 g/L)/ (14.0067 g/mol)

= 0.1428 mol/L

Target molarity of diluted digestate = (Parts per million (ppm)* 0.001)/ (N atomic weight)

= (0.14 g/L)/ (14.0067 g/mol)

= 0.01 mol/ L

Initial volume of stock digestate necessary to meet soil nutrient requirements

$M_1V_1 = M_2V_2$ (where M represents molarity and V represents volume)

(0.1428 mol/L)(V_1) = (0.01 mol/ L)(3 L)

V_1 = 0.210 L stock digestate is necessary to meet a final volume of 3 L of fertilizer

Dilution factor (DF) of the digestate

$$DF = C_f/C_i$$

$$DF = \frac{3L}{0.210L}$$

$$DF = 14.29$$

Appendix 2: Soil Nutrient Test Report

Newfoundland Labrador

Soil Test Report
Soil & Plant Laboratory
Dept. of Fisheries and Land Resources
Provincial Agriculture Building
308 Brookfield Road
P.O. Box 8700
St. John's, NL A1B 4J6

Name: Dr. M Nadeem
Farm Name:
Address: Grenfell Campus
MUN
Corner Brook, NL
A2H 6P9

Samples Received: 2019/05/07
Samples Reported: 2019/05/21
Unit Code: 1
Agric. Rep.: Not Applicable
Crop Specialist: Not Applicable
CC:

LR - Limestone Recommendations
C.E.C. - Cation Exchange Capacities
Lab Numbers: 205-205

Note: Soil test ratings and required nutrient applications are for crops specified. A change of crop will require new soil test ratings and may require different nutrient applications.

Sample Information				Crop To Be Grown	Soil pH	LR (t/ha)	Soil Test Values (mg/L) and Ratings				Organic Matter (%)	Soluble Salts (mS/cm)	Required Applications (kg/ha)			C.E.C. (cmol/kg)
Lab #	Field ID	UTM	Field Size (ha)				Phosphorus P	Potassium K	Calcium Ca	Magnesium Mg			Nitrogen N	Phosphate P_2O_5	Potash K_2O	
205	Pot Expt- Vanessa Mauel			Lettuce	6.8	0.0	289 E	477 E	2,226 H-	348 H	6.44		150	0	0	15.6

Nutrient Recommendations and Comments:

For lettuce, apply at least 1/2 of required nitrogen pre-plant and the balance 3 weeks after transplant. Phosphate requirements are based on broadcast. Banding can be used with a subsequent reduction in phosphate requirements. Apply the required potash pre-plant. Where crops are grown under fertigation, apply half of the required potash pre-plant and the remainder through fertigation system.

Other Tests					
Nitrogen:	%	**Carbon:**	%	**Total Sulphur:**	%
Sulphur:	29 mg/L	**Iron:**	299 mg/L	**Manganese:**	83 mg/L
Zinc:	16.1 mg/L	**Boron:**	1.5 mg/L	**Aluminum:**	1,196 mg/L
Copper:	36.0 mg/L	**Nitrate-N:**	mg/L	**Ammonium-N:**	mg/L
Sodium:	71 mg/L				

Appendix 3: Normality testing – Crop biomass parameters

Results of Shapiro-Wilks and Anderson-Darling normality tests conducted in PAST 3 using non-transformed biomass data. Data were cumulative of 4 crop cycles treated with combinations of two soil substrate types and three fertilizer treatments.

	Root Length (cm)	Root Mass(Wet)	Root Mass(Dry)	Shoot Mass(Wet)	Shoot Mass(Dry)
N	120	120	120	120	120
Shapiro-Wilk W	0.888	0.940	0.821	0.918	0.960
p(normal)	<0.001	<0.001	<0.001	<0.001	0.001
Anderson-Darling A	4.636	1.975	7.726	3.616	1.355
p(normal)	<0.001	<0.001	<0.001	<0.001	0.002
p(Monte Carlo)	0 1	0 1	0 1	0 1	0.0023

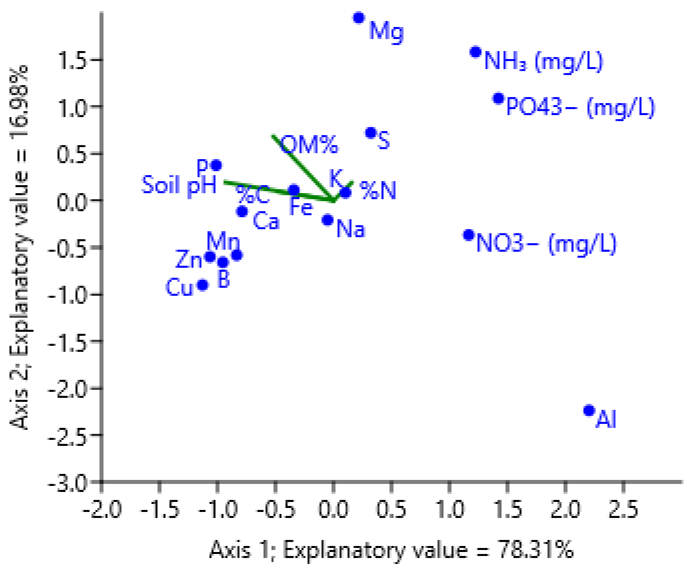
Appendix 4: Normality testing - Post-harvest soil nutrient content

Results of Shapiro-Wilks and Anderson-Darling normality tests conducted in PAST 3 using non-transformed, post-harvest media nutrient data. Data were cumulative of 4 crop cycles treated with combinations of two soil substrate types and three fertilizer treatments (Appendix 13).

	N	Shapiro-Wilk W	*p*(normal)	Anderson-Darling A	*p*(normal)	*p*(Monte Carlo)
Soil pH	90	0.841	<0.001	5.92	<0.001	0.1
Ca	90	0.896	<0.001	3.361	<0.001	0.1
Mg	90	0.919	<0.001	2.532	<0.001	0.1
K	90	0.971	0.042	0.540	0.162	0.168
P	90	0.809	<0.001	7.591	<0.001	0.1
Fe	90	0.829	<0.001	6.936	<0.001	0.1
Cu	90	0.918	<0.001	2.42	<0.001	0.1
Mn	90	0.905	<0.001	2.842	<0.001	0.1
Zn	90	0.909	<0.001	2.944	<0.001	0.1
B	90	0.939	0.373	1.551	0 504	0.001
Na	90	0.979	0.165	0.47	0.242	0.235
Al	90	0.977	0.104	0.630	0.098	0.095
S	90	0.887	<0.001	3.869	<0.001	0.1
OM%	90	0.963	0.011	1.114	0.006	0.005
%C	90	0.657	<0.001	15.46	<0.001	0.1
%N	90	0.855	<0.001	5.096	<0.001	0.1
PO_4^{3-} (mg/L)	90	0.826	<0.001	7.111	<0.001	0.1
NH_3 (mg/L)	90	0.778	<0.001	6.854	<0.001	0.1
NO^{3-} (mg/L)	90	0.952	0.002	1.115	0.006	0.006

Appendix 5: Canonical correspondence – Post-harvest media nutrient content

CCA scatterplot generated using PAST3. Post-harvest soil nutrient concentration was cumulative of 3 crop cycles (Appendix 13). Soil media and fertilizer treatments used as independent (environmental) variables and nutrient concentration as the dependent variables. Data was normalized by parameter to 0-1 range. N=90.



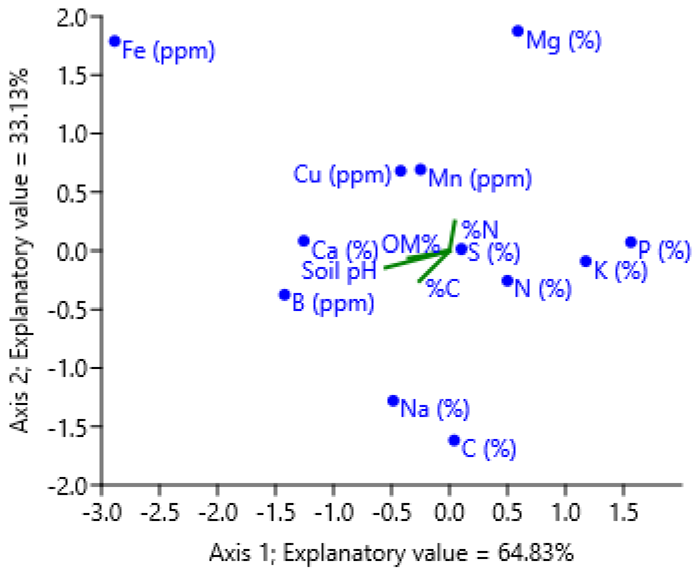
Appendix 6: Normality testing – Shoot nutrient content

Results of Shapiro-Wilks and Anderson-Darling normality tests conducted in PAST 3 using non-transformed shoot nutrient data. Data was cumulative of 4 crop cycles treated with combinations of two soil substrate types and three fertilizer treatments (Appendix 14).

Nutrient	N	Shapiro-Wilk W	p(normal)	Anderson-Darling A	p(normal)	p(Monte Carlo)
N (%)	90	0.945	0.001	1.657	<0.001	<0.001
C (%)	90	0.871	<0.001	5.053	<0.001	<0.001
S (%)	90	0.939	<0.001	2.044	<0.001	<0.001
P (%)	90	0.881	<0.001	4.189	<0.001	<0.001
K (%)	90	0.898	<0.001	3.867	<0.001	<0.001
Ca (%)	90	0.915	<0.001	3.128	<0.001	<0.001
Mg (%)	90	0.968	0.025	0.835	0.03	0.029
Na (%)	90	0.974	0.068	0.667	0.079	0.077
Fe (ppm)	90	0.725	<0.001	5.51	<0.001	<0.001
Cu (ppm)	90	0.949	0.001	1.163	<0.001	<0.001
Mn (ppm)	90	0.969	0.028	0.617	0.105	0.11
Zn (ppm)	90	0.924	<0.001	2.082	<0.001	<0.001
B (ppm)	90	0.935	<0.001	1.885	<0.001	<0.001

Appendix 7: Canonical correspondence – Shoot nutrient content

CCA scatterplot generated using PAST3. Shoot nutrient concentration was cumulative of 3 crop cycles (Appendix 14). Soil media and fertilizer treatments used as independent (environmental) variables and nutrient concentration as the dependent variables. Data was normalized by parameter to 0-1 range. Samples with missing data omitted. N=77.



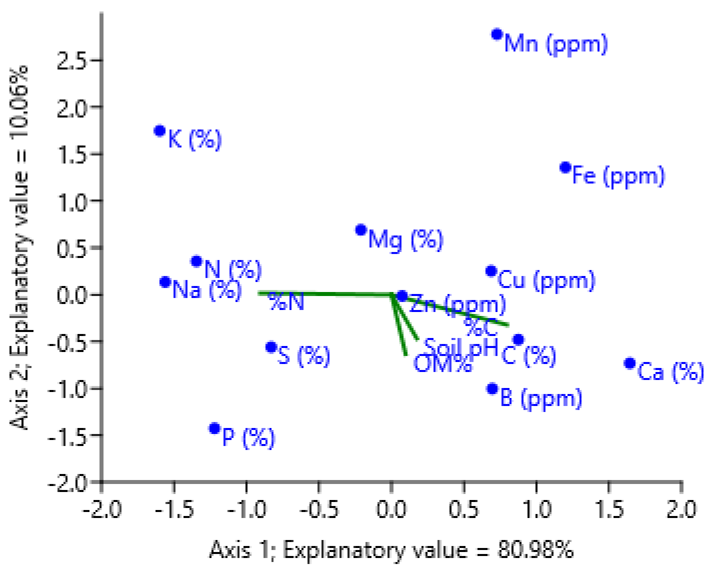
Appendix 8: Normality testing – Root nutrient content

Results of Shapiro-Wilks and Anderson-Darling normality tests conducted in PAST 3 using non-transformed root nutrient data. Data was cumulative of 4 crop cycles treated with combinations of two soil substrate types and three fertilizer treatments (Appendix 12).

	N	Shapiro-Wilk W	p(normal)	Anderson-Darling A	p(normal)	p(Monte Carlo)
N (%)	77	0.905	<0.001	2.665	<0.001	0.1
C (%)	77	0.94	0.001	1.493	0.693	0.6
S (%)	77	0.906	<0.001	3.31	<0.001	0.1
P (%)	90	0.871	<0.001	4.733	<0.001	0.1
K (%)	90	0.897	<0.001	3.099	<0.001	0.1
Ca (%)	90	0.831	<0.001	6.039	<0.001	0.1
Mg (%)	90	0.976	0.1004	0.798	0.03723	0.04
Na (%)	90	0.943	0 640	1.561	0.477	0.6
Fe (ppm)	90	0.736	<0.001	8.187	<0.001	0.1
Cu (ppm)	90	0.905	<0.001	2.922	<0.001	0.1
Mn (ppm)	90	0.702	<0.001	9.933	<0.001	0.1
Zn (ppm)	90	0.958	0.005	1.113	0.006	0.006
B (ppm)	90	0.968	0.024	0.859	0.026	0.027

Appendix 9: Canonical correspondence – Root nutrient content

CCA scatterplot generated using PAST3. Root nutrient concentration was cumulative of 3 crop cycles. Soil media and fertilizer treatments used as independent (environmental) variables and nutrient concentration as the dependent variables (Appendix 12). Data was normalized by parameter in 0-1 range. N=90.



Appendix 10: N and P nutrient use efficiency data

N and P nutrient use efficiency and N:P crop ratio calculated for 3 lettuce crop cycles grown under two soil substrate types and three fertilizer treatments. N=90.

Crop-treatment	NUE (%) nitrogen	NUE (%) phosphorus	Nutrient use N:P ratio	Plant N content (mg)	Plant P content (mg)	Plant content N:P ratio
2-S-NS	7.83	1.20	6.5 : 1	390.8	41.9	9.3 : 1
2-S-DD	7.99	4.87	1.6 : 1	311.7	31.2	9.9 : 1
2-S-DD+NS	9.86	2.59	3.8 : 1	417.8	45.5	9.1 : 1
2-S+P-NS	14.84	1.56	9.5 : 1	389.6	48.1	8.0 : 1
2-S+P-DD	25.34	14.89	1.7 : 1	388.9	35.6	10.8 : 1
2-S+P-DD+NS	23.15	3.93	5.8 : 1	433.5	53.3	8.1 : 1
3-S-NS	5.96	3.81	1.5 : 1	352.6	34.5	10.1 : 1
3-S-DD	8.48	5.17	1.6 : 1	318.0	33.9	9.3 : 1
3-S-DD+NS	6.86	4.59	1.4 : 1	324.7	34.2	9.4 : 1
3-S+P-NS	11.54	9.63	1.1 : 1	409.7	48.6	8.4 : 1
3-S+P-DD	25.44	15.74	1.6 : 1	352.3	40.1	8.7 : 1
3-S+P-DD+NS	15.83	11.85	1.3 : 1	374.3	40.7	9.1 : 1
4-S-NS	0.76	0.18	4.2 : 1	45.7	1.6	26.9 : 1

4-S-DD	2.31	0.63	4.6 : 1	87.4	4.0	21.8 : 1
4-S-DD+NS	2.49	0.85	2.9 : 1	118.0	6.4	18.3 : 1
4-S+P-NS	3.35	0.92	3.6 : 1	122.1	4.9	24.5 : 1
4-S+P-DD	8.35	1.95	6.9 : 1	118.1	4.5	25.8 : 1
4-S+P-DD+NS	6.27	2.24	2.7 : 1	148.2	7.9	18.5 : 1

Appendix 11: Soil, crop mass and nutrient content used to calculate N and P nutrient use efficiency (%) for lettuce crops grown in combinations of two soil media and three fertilizer treatments

Nitrogen									
Crop-treatment	Soil content (mg/kg)	Substrate mass (kg)	Total nutrient in soil (mg)	Total nutrient in fertilizer (mg)	Plant content (mg/kg)	Plant biomass (g)	Plant biomass (kg)	Plant content (mg)	NUE (%)
2-S-NS	1700	1.96	3332	1656	40280	9.7	0.0097	390.8	7.83
2-S-DD	1700	1.96	3332	566	34100	9.1	0.0091	311.7	7.99
2-S-DD+NS	1700	1.96	3332	904	37580	11.1	0.0111	417.8	9.86
2-S+P-NS	850	1.14	969	1656	40260	9.6	0.0097	389.6	14.84
2-S+P-DD	850	1.14	969	566	37920	10.2	0.0103	388.9	25.34
2-S+P-DD+NS	850	1.14	969	903.7	39520	10.9	0.0110	433.5	23.15
3-S-NS	1700	1.96	3332	2580	50160	7	0.0070	352.6	5.96
3-S-DD	1700	1.96	3332	415	49420	6.4	0.0064	318	8.48
3-S-DD+NS	1700	1.96	3332	1396	50060	6.4	0.0065	324.7	6.86
3-S+P-NS	850	1.14	969	2580	49360	8.3	0.0083	409.7	11.54
3-S+P-DD	850	1.14	969	415	47960	7.3	0.0073	352.3	25.44
3-S+P-DD+NS	850	1.14	969	1396	45040	8.3	0.0083	374.3	15.83

4-S-NS	1700	1.96	3332	2670	31600	1.4	0.0014	45.7	0.76
4-S-DD	1700	1.96	3332	446	30960	2.8	0.0028	87.4	2.31
4-S-DD+NS	1700	1.96	3332	1393	35940	3.2	0.0033	118	2.49
4-S+P-NS	850	1.14	969	2670	32960	3.7	0.0037	122.1	3.35
4-S+P-DD	850	1.14	969	446	30040	3.9	0.0039	118.1	8.35
4-S+P-DD+NS	850	1.14	969	1393	35320	4.1	0.0042	148.2	6.27
Phosphorus									
2-S-NS	289	1.96	566.4	2920	4320	9.7	0.0097	41.9	1.2
2-S-DD	289	1.96	566.4	75	3420	9.1	0.0091	31.2	4.87
2-S-DD+NS	289	1.96	566.4	1190	4100	11.1	0.0111	45.5	2.59
2-S+P-NS	144.5	1.14	164.7	2920	4980	9.6	0.0097	48.1	1.56
2-S+P-DD	144.5	1.14	164.7	75	3480	10.2	0.0103	35.6	14.81
2-S+P-DD+NS	144.5	1.14	164.7	1190	4860	10.9	0.0110	53.3	3.93
3-S-NS	289	1.96	566.4	340	4920	7	0.0070	34.5	3.81
3-S-DD	289	1.96	566.4	90	5280	6.4	0.0064	33.9	5.17
3-S-DD+NS	289	1.96	566.4	179	5280	6.4	0.0065	34.2	4.59
3-S+P-NS	144.5	1.14	164.7	340	5860	8.3	0.0083	48.6	9.63

3-S+P-DD	144.5	1.14	164.7	90	5460	7.3	0.0073	40.1	15.74
3-S+P-DD+NS	144.5	1.14	164.7	179	4900	8.3	0.0083	40.7	11.85
4-S-NS	289	1.96	566.4	370	1172	1.4	0.0014	1.6	0.18
4-S-DD	289	1.96	566.4	213	1420	2.8	0.0028	4	0.51
4-S-DD+NS	289	1.96	566.4	191	1960	3.2	0.0033	6.4	0.85
4-S+P-NS	144.5	1.14	164.7	370	1340	3.7	0.0037	4.9	0.92
4-S+P-DD	144.5	1.14	164.7	213	1160	3.9	0.0039	4.5	1.2
4-S+P-DD+NS	144.5	1.14	164.7	191	1900	4.1	0.0042	7.9	2.24

Appendix 12: Untransformed root nutrient data

Crop Number	Sample ID	Soil substrate type	Fertilizer treatment	N (%)	C (%)	S (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Fe (ppm)	Cu (ppm)
two	S+P-D+N-11	Soil+Promix	DD+NS	2.26	46	0.2	0.15	0.52	1.16	0.28	0.078	600	28
two	S+P-D+N-2	Soil+Promix	DD+NS	2.27	45.5	0.2	0.22	0.85	1.07	0.26	0.098	881	31
two	S+P-D+N-3	Soil+Promix	DD+NS	2.19	45.8	0.2	0.23	1.03	0.95	0.25	0.1	644	31
two	S+P-D+N-8	Soil+Promix	DD+NS	2.19	46	0.2	0.17	0.95	0.88	0.28	0.08	502	27
two	S+P-D+N-9	Soil+Promix	DD+NS	2.23	46.4	0.2	0.15	0.66	0.98	0.29	0.079	479	25
two	S+P-DD-11	Soil+Promix	DD	2.08	45.8	0.19	0.18	0.79	0.89	0.31	0.14	613	27
two	S+P-DD-13	Soil+Promix	DD	2.32	44.8	0.22	0.18	0.68	1.32	0.3	0.082	2080	62
two	S+P-DD-5	Soil+Promix	DD	2.16	46.1	0.2	0.18	0.79	0.89	0.33	0.15	545	26
two	S+P-DD-6	Soil+Promix	DD	2.2	46.2	0.2	0.18	0.76	0.97	0.33	0.15	457	26
two	S+P-DD-9	Soil+Promix	DD	2.31	45	0.21	0.21	0.76	1.15	0.41	0.13	1690	36
two	S+P-NS-11	Soil+Promix	NS	2.47	46.5	0.21	0.18	0.58	1.23	0.27	0.066	462	33
two	S+P-NS-2	Soil+Promix	NS	2.4	46	0.21	0.27	1.24	0.88	0.24	0.091	634	25
two	S+P-NS-4	Soil+Promix	NS	2.54	46	0.22	0.34	1.59	0.77	0.24	0.14	331	23
two	S+P-NS-6	Soil+Promix	NS	2.22	45.9	0.2	0.21	1.17	0.88	0.27	0.099	603	31
two	S+P-NS-8	Soil+Promix	NS	2.17	46	0.17	0.17	0.85	1.05	0.26	0.086	596	28
two	S-D+N-13	Soil	DD+NS	2.07	42.5	0.19	0.2	0.78	1.12	0.29	0.074	3510	61
two	S-D+N-2	Soil	DD+NS	2.21	38	0.23	0.24	0.6	0.92	0.31	0.053	4840	65
two	S-D+N-4	Soil	DD+NS	2.59	45.3	0.23	0.18	0.46	1.38	0.25	0.061	2010	62
two	S-D+N-8	Soil	DD+NS	2.33	43	0.22	0.18	0.66	1.04	0.31	0.063	3240	66
two	S-D+N-9	Soil	DD+NS	2.33	45.5	0.22	0.17	0.59	1.45	0.27	0.073	2020	63
two	S-DD-1	Soil	DD	2.23	39.1	0.2	0.15	0.3	1.41	0.26	0.062	2180	56
two	S-DD-10	Soil	DD	2.55	45.4	0.25	0.19	0.43	1.51	0.26	0.086	2020	70
two	S-DD-14	Soil	DD	2.21	43.5	0.2	0.22	1.05	0.86	0.29	0.091	2980	49
two	S-DD-2	Soil	DD	2.45	45.2	0.22	0.17	0.69	1.17	0.31	0.093	1990	58
two	S-DD-8	Soil	DD	2.21	43.2	0.22	0.19	0.71	1.2	0.36	0.096	3020	70

two	S-NS-11	Soil	NS	2.29	43.9	0.22	0.17	0.92	0.97	0.32	0.098	2720	63
two	S-NS-3	Soil	NS	2.3	45.6	0.21	0.18	0.65	1.48	0.25	0.072	1470	63
two	S-NS-4	Soil	NS	2.6	44.1	0.24	0.2	0.62	1.42	0.27	0.062	2560	71
two	S-NS-5	Soil	NS	2.31	45.8	0.2	0.2	0.85	1.02	0.33	0.15	719	28
two	S-NS-6	Soil	NS	2.36	44.8	0.22	0.18	0.44	1.6	0.26	0.059	2260	62
three	S+P-D+N-1	Soil+Promix	DD+NS	3.23	40.5	0.32	0.4	6.32	0.57	0.29	0.3	420	26
three	S+P-D+N-2	Soil+Promix	DD+NS	2.62	41.3	0.33	0.39	5.6	0.52	0.29	0.31	218	29
three	S+P-D+N-4	Soil+Promix	DD+NS	2.95	40.5	0.32	0.36	4.98	0.59	0.32	0.29	536	28
three	S+P-D+N-4	Soil+Promix	DD+NS	3.01	41.4	0.33	0.33	4.75	0.64	0.33	0.31	374	23
three	S+P-D+N-5	Soil+Promix	DD+NS				0.36	5.83	0.78	0.37	0.3	644	30
three	S+P-DD-1	Soil+Promix	DD	2.9	40.2	0.37	0.39	5.44	0.54	0.27	0.38	415	25
three	S+P-DD-2	Soil+Promix	DD	3.17	39.9	0.36	0.41	6.55	0.51	0.29	0.42	336	23
three	S+P-DD-3	Soil+Promix	DD	2.52	41.2	0.36	0.34	5.27	0.53	0.33	0.4	491	34
three	S+P-DD-5	Soil+Promix	DD	3.01	41.6	0.3	0.34	5.61	0.64	0.29	0.3	1160	45
three	S+P-DD-7	Soil+Promix	DD	2.74	40.8	0.42	0.39	5.98	0.55	0.33	0.52	284	28
three	S+P-NS-1	Soil+Promix	NS	3.48	39.1	0.35	0.44	6.08	0.59	0.31	0.26	482	24
three	S+P-NS-2	Soil+Promix	NS	3.24	41.2	0.31	0.44	5.96	0.6	0.25	0.24	486	22
three	S+P-NS-3	Soil+Promix	NS	3.38	40.5	0.36	0.38	6.31	0.6	0.3	0.35	466	30
three	S+P-NS-4	Soil+Promix	NS				0.4	7.13	0.61	0.27	0.35	891	33
three	S+P-NS-6	Soil+Promix	NS	3.19	40.7	0.33	0.43	6.05	0.63	0.3	0.27	390	30
three	S-D+N-2	Soil	DD+NS	3.48	40.8	0.35	0.37	6.21	0.68	0.31	0.28	581	42
three	S-D+N-4	Soil	DD+NS	3.27	40.1	0.3	0.33	5.88	0.57	0.28	0.29	717	37
three	S-D+N-5	Soil	DD+NS	2.86	41	0.31	0.32	4.82	0.58	0.32	0.28	403	28
three	S-D+N-6	Soil	DD+NS	3.56	39.1	0.31	0.38	6.26	0.57	0.28	0.3	1230	32
three	S-D+N-7	Soil	DD+NS				0.37	6.82	0.56	0.28	0.43	529	23
three	S-DD-1	Soil	DD	3.26	39.2	0.37	0.34	6.51	0.58	0.28	0.37	1180	40
three	S-DD-2	Soil	DD	3.32	40.2	0.41	0.47	6.28	0.62	0.35	0.42	433	33
three	S-DD-4	Soil	DD	2.85	39.7	0.38	0.38	6.45	0.59	0.29	0.31	1060	48
three	S-DD-5	Soil	DD	3.33	41.5	0.34	0.39	6.9	0.56	0.27	0.35	760	31
three	S-DD-6	Soil	DD				0.4	5.64	0.6	0.29	0.37	711	34

three	S-NS-1	Soil	NS	3.45	38.2	0.32	0.33	6.07	0.54	0.29	0.3	1420	39
three	S-NS-2	Soil	NS	3.6	40.6	0.31	0.34	6.2	0.6	0.28	0.29	657	34
three	S-NS-4	Soil	NS	3.33	39.9	0.32	0.3	6.46	0.62	0.3	0.27	834	38
three	S-NS-5	Soil	NS	3.98	38.2	0.32	0.38	6.78	0.58	0.28	0.38	667	31
three	S-NS-6	Soil	NS	2.48	41.7	0.28	0.27	4.45	0.56	0.37	0.35	344	29
four	S+P-D+N-3	Soil+Promix	DD+NS	2.4	42.2	0.16	0.13	3.72	0.51	0.32	0.13	387	18
four	S+P-D+N-4	Soil+Promix	DD+NS	2.52	41.9	0.18	0.15	2.95	0.48	0.29	0.17	632	14
four	S+P-D+N-1	Soil+Promix	DD+NS	3.52	39.7	0.31	0.34	5.62	0.59	0.31	0.18	535	30
four	S+P-D+N-7	Soil+Promix	DD+NS	2.57	42	0.16	0.15	3.69	0.5	0.35	0.18	545	11
four	S+P-D+N-5	Soil+Promix	DD+NS	2.5	40.8	0.17	0.14	3.58	0.52	0.34	0.15	533	9.2
four	S-NS-1	Soil	NS				0.13	3.39	0.4	0.22	0.16	297	9.4
four	S-NS-3	Soil	NS	2.91	40.5	0.17	0.24	3.96	0.6	0.26	0.17	1200	18
four	S-NS-7	Soil	NS				0.15	3.73	0.41	0.22	0.16	559	11
four	S-NS-6	Soil	NS	2.34	40	0.12	0.14	3.14	0.41	0.21	0.17	848	14
four	S-NS-4	Soil	NS				0.14	3.85	0.42	0.26	0.16	981	24
four	S-D+N-7	Soil	DD+NS	3.1	40.6	0.22	0.3	4.97	0.56	0.3	0.2	1230	41
four	S-D+N-3	Soil	DD+NS	2.8	41.2	0.18	0.2	3.98	0.55	0.29	0.23	1040	26
four	S-D+N-1	Soil	DD+NS	2.75	42.6	0.18	0.18	3.6	0.55	0.3	0.27	723	19
four	S-D+N-2	Soil	DD+NS				0.2	4.56	0.54	0.33	0.32	1310	20
four	S-D+N-4	Soil	DD+NS				0.21	3.99	0.54	0.3	0.18	1380	32
four	S-DD-5	Soil	DD	2.73	42.9	0.23	0.22	4.24	0.58	0.3	0.28	930	20
four	S-DD-1	Soil	DD	2.46	42.8	0.22	0.19	4.46	0.48	0.28	0.22	782	26
four	S-DD-4	Soil	DD	2.45	41.2	0.17	0.17	3.48	0.49	0.3	0.26	966	17
four	S-DD-2	Soil	DD				0.16	3.42	0.46	0.27	0.32	629	15
four	S-DD-3	Soil	DD				0.18	3.53	0.5	0.25	0.27	610	15
four	S+P-DD-5	Soil+Promix	DD				0.13	3.25	0.43	0.3	0.2	327	8.7
four	S+P-DD-1	Soil+Promix	DD				0.13	3.17	0.46	0.37	0.23	386	8.1
four	S+P-DD-2	Soil+Promix	DD	2.8	42.7	0.2	0.18	3.86	0.54	0.37	0.23	435	14
four	S+P-DD-3	Soil+Promix	DD	2.21	43.3	0.17	0.14	2.94	0.41	0.32	0.19	318	11
four	S+P-DD-7	Soil+Promix	DD	2.61	42.4	0.19	0.15	3.63	0.47	0.36	0.24	333	23

four	S+P-NS-6	Soil+Promix	NS	3.03	42	0.22	0.17	4.17	0.52	0.35	0.19	557	9.7
four	S+P-NS-7	Soil+Promix	NS	2.3	43.5	0.17	0.14	3.15	0.44	0.27	0.13	397	8.7
four	S+P-NS-5	Soil+Promix	NS	2.41	42.5	0.16	0.13	3.52	0.41	0.3	0.14	373	8
four	S+P-NS-1	Soil+Promix	NS	2.3	43.2	0.15	0.13	3.06	0.47	0.3	0.12	475	9.7
four	S+P-NS-2	Soil+Promix	NS	2.34	43.6	0.16	0.13	3.27	0.45	0.28	0.11	298	8

Crop Number	Sample ID	Soil substrate type	Fertilizer treatment	Mn (ppm)	Zn (ppm)	B (ppm)
two	S+P-D+N-11	Soil+Promix	DD+NS	60	181	36
two	S+P-D+N-2	Soil+Promix	DD+NS	62	164	37
two	S+P-D+N-3	Soil+Promix	DD+NS	49	154	38
two	S+P-D+N-8	Soil+Promix	DD+NS	54	137	35
two	S+P-D+N-9	Soil+Promix	DD+NS	54	136	35
two	S+P-DD-11	Soil+Promix	DD	39	154	36
two	S+P-DD-13	Soil+Promix	DD	164	141	40
two	S+P-DD-5	Soil+Promix	DD	42	128	31
two	S+P-DD-6	Soil+Promix	DD	39	165	38
two	S+P-DD-9	Soil+Promix	DD	82	158	38
two	S+P-NS-11	Soil+Promix	NS	44	240	34
two	S+P-NS-2	Soil+Promix	NS	47	102	34
two	S+P-NS-4	Soil+Promix	NS	27	121	30
two	S+P-NS-6	Soil+Promix	NS	60	110	37
two	S+P-NS-8	Soil+Promix	NS	55	126	38
two	S-D+N-13	Soil	DD+NS	209	128	44
two	S-D+N-2	Soil	DD+NS	336	83	43
two	S-D+N-4	Soil	DD+NS	162	164	39
two	S-D+N-8	Soil	DD+NS	285	77	41

two	S-D+N-9	Soil	DD+NS	155	219	38
two	S-DD-1	Soil	DD	156	193	33
two	S-DD-10	Soil	DD	135	240	40
two	S-DD-14	Soil	DD	177	87	42
two	S-DD-2	Soil	DD	161	129	39
two	S-DD-8	Soil	DD	235	128	41
two	S-NS-11	Soil	NS	263	77	41
two	S-NS-3	Soil	NS	148	208	41
two	S-NS-4	Soil	NS	177	169	37
two	S-NS-5	Soil	NS	56	133	37
two	S-NS-6	Soil	NS	139	269	42
three	S+P-D+N-1	Soil+Promix	DD+NS	33	210	26
three	S+P-D+N-2	Soil+Promix	DD+NS	30	142	29
three	S+P-D+N-4	Soil+Promix	DD+NS	45	177	29
three	S+P-D+N-4	Soil+Promix	DD+NS	39	55	28
three	S+P-D+N-5	Soil+Promix	DD+NS	55	75	31
three	S+P-DD-1	Soil+Promix	DD	45	72	26
three	S+P-DD-2	Soil+Promix	DD	34	177	27
three	S+P-DD-3	Soil+Promix	DD	47	163	27
three	S+P-DD-5	Soil+Promix	DD	117	173	33
three	S+P-DD-7	Soil+Promix	DD	36	69	27
three	S+P-NS-1	Soil+Promix	NS	46	165	34
three	S+P-NS-2	Soil+Promix	NS	37	183	23
three	S+P-NS-3	Soil+Promix	NS	45	190	29
three	S+P-NS-4	Soil+Promix	NS	64	80	27
three	S+P-NS-6	Soil+Promix	NS	38	179	30
three	S-D+N-2	Soil	DD+NS	61	216	31

three	S-D+N-4	Soil	DD+NS	60	183	30
three	S-D+N-5	Soil	DD+NS	37	65	27
three	S-D+N-6	Soil	DD+NS	76	139	30
three	S-D+N-7	Soil	DD+NS	42	116	28
three	S-DD-1	Soil	DD	75	138	28
three	S-DD-2	Soil	DD	53	201	29
three	S-DD-4	Soil	DD	83	180	27
three	S-DD-5	Soil	DD	47	82	30
three	S-DD-6	Soil	DD	45	68	30
three	S-NS-1	Soil	NS	105	80	27
three	S-NS-2	Soil	NS	49	59	29
three	S-NS-4	Soil	NS	74	47	28
three	S-NS-5	Soil	NS	43	80	28
three	S-NS-6	Soil	NS	36	62	23
four	S+P-D+N-3	Soil+Promix	DD+NS	26	135	16
four	S+P-D+N-4	Soil+Promix	DD+NS	40	82	19
four	S+P-D+N-1	Soil+Promix	DD+NS	43	220	29
four	S+P-D+N-7	Soil+Promix	DD+NS	26	118	19
four	S+P-D+N-5	Soil+Promix	DD+NS	31	113	20
four	S-NS-1	Soil	NS	13	88	21
four	S-NS-3	Soil	NS	55	113	24
four	S-NS-7	Soil	NS	26	68	18
four	S-NS-6	Soil	NS	43	99	20
four	S-NS-4	Soil	NS	65	86	22
four	S-D+N-7	Soil	DD+NS	75	235	29
four	S-D+N-3	Soil	DD+NS	52	164	23
four	S-D+N-1	Soil	DD+NS	33	107	25

four	S-D+N-2	Soil	DD+NS	58	127	30
four	S-D+N-4	Soil	DD+NS	56	118	25
four	S-DD-5	Soil	DD	41	108	28
four	S-DD-1	Soil	DD	43	128	24
four	S-DD-4	Soil	DD	44	83	28
four	S-DD-2	Soil	DD	24	104	22
four	S-DD-3	Soil	DD	29	104	24
four	S+P-DD-5	Soil+Promix	DD	23	111	21
four	S+P-DD-1	Soil+Promix	DD	28	107	23
four	S+P-DD-2	Soil+Promix	DD	23	131	24
four	S+P-DD-3	Soil+Promix	DD	21	89	21
four	S+P-DD-7	Soil+Promix	DD	28	136	24
four	S+P-NS-6	Soil+Promix	NS	51	85	19
four	S+P-NS-7	Soil+Promix	NS	25	89	17
four	S+P-NS-5	Soil+Promix	NS	23	80	19
four	S+P-NS-1	Soil+Promix	NS	39	88	19
four	S+P-NS-2	Soil+Promix	NS	29	87	17

Appendix 13: Untransformed post-harvest media nutrient data

Crop number	Field ID	Soil pH	Ca (%)	Mg (%)	K (%)	P (%)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)	B (ppm)	Na (%)	Al (%)	S (%)	OM%	%C	%N
2	S+P-D+N-8	6.3	2083	438	313	392	270	22.0	101	17.1	1.40	109	969	37.0	9.0	7.15	0.5
2	S-NS-4	6.5	2351	355	527	440	279	30.1	140	17.9	1.72	110	1155	34.0	7.4	6.28	0.53
2	S+P-DD-9	6.2	1868	437	154	282	259	17.6	88	10.8	1.26	102	812	35.5	9.7	7.26	0.5
2	S+P-DD-11	6.3	1913	427	165	299	259	18.8	93	11.6	1.27	98	858	36.9	10.6	7.59	0.51
2	S+P-NS-6	6.3	1810	447	484	401	268	17.1	97	11.0	1.19	101	826	37.0	11.8	7.49	0.5
2	S+P-DD-6	6.3	2099	499	163	339	272	20.0	104	12.8	1.36	104	957	42.5	10.1	7.72	0.51
2	S+P-D+N-3	6.3	2172	501	339	424	284	21.4	110	13.5	1.44	121	1020	41.2	9.4	8.09	0.54
2	S-D+N-9	6.5	2539	359	317	434	281	34.5	148	20.2	1.79	115	1267	38.7	6.0	6.32	0.52
2	S+P-NS-2	6.3	2230	539	549	477	288	22.0	115	13.3	1.47	116	1038	41.8	10.6	8.21	0.55
2	S-D+N-13	6.6	2401	341	325	410	374	32.2	139	17.6	1.73	112	1228	35.7	6.1	6.05	0.5
2	S+P-NS-11	6.3	1727	393	498	352	241	16.8	85	10.4	1.12	99	755	36.0	9.5	7.39	0.52
2	S-D+N-8	6.5	2700	393	412	475	289	38.7	158	21.1	1.99	119	1317	38.9	6.3	6.57	0.55
2	S+P-D+N-11	6.4	2036	453	332	372	259	20.8	105	12.8	1.33	111	933	38.6	10.4	7.92	0.54
2	S-D+N-2	6.5	2518	372	373	439	285	35.1	145	19.2	1.90	123	1242	39.9	7.9	6.37	0.53
2	S-DD-8	6.6	2785	409	241	424	281	40.3	145	21.3	2.02	126	1334	38.8	6.6	6.34	0.52
2	S-NS-11	6.4	2442	362	491	454	286	33.8	146	18.1	1.83	117	1230	37.7	7.6	6.42	0.54
2	S+P-NS-8	6.4	2285	480	593	504	288	26.1	123	15.3	1.59	119	1148	41.4	9.1	7.38	0.52
2	S+P-D+N-2	6.3	2088	473	281	390	282	21.5	101	12.2	1.50	111	986	39.2	12.4	8.22	0.54
2	S+P-D+N-9	6.3	2014	489	307	368	265	19.7	95	11.4	1.36	112	882	40.9	12.5	8.41	0.52
2	S-DD-14	6.5	2411	351	199	382	275	33.4	141	17.4	1.84	117	1182	36.0	6.6	5.99	0.49
2	S-NS-3	6.5	2869	415	568	533	289	43.8	169	23.4	2.13	125	1398	41.0	6.6	6.3	0.52
2	S+P-NS-4	6.3	1942	456	525	399	262	19.3	91	11.4	1.36	106	871	39.6	10.4	7.95	0.54
2	S+P-DD-5	6.4	2011	443	164	310	261	21.5	100	12.1	1.45	109	931	39.8	9.0	7.51	0.5
2	S-DD-10	6.5	2614	368	221	437	293	39.7	152	20.4	2.06	118	1373	41.5	6.2	6.20	0.52

2	S-D+N-4	6.5	2426	347	335	424	280	34.4	140	18.1	1.88	116	1209	38.8	6.3	6.09	0.52
2	S+P-DD-15	6.4	2363	513	195	396	292	27.5	124	14.8	1.73	123	1167	45.2	8.2	6.91	0.49
2	S-NS-6	6.5	2629	387	586	486	273	37.9	163	27.0	1.92	123	1259	38.8	6.5	6.24	0.52
2	S-DD-1	6.6	2598	363	215	427	283	39.6	148	20.6	2.02	121	1350	38.7	6.0	6.14	0.51
2	S-DD-2	6.5	2458	356	233	397	279	35.7	147	18.7	1.96	124	1246	39.1	5.0	5.96	0.5
2	S-NS-5	6.5	2596	387	552	480	275	38.7	150	19.9	2.04	129	1288	37.6	6.0	6.6	0.55
3	S-D+N-7	6.4	2825	407	442	412	270	35.8	160	23.1	1.27	122	1304	40.0	6.8	0.47	6.04
3	S-D+N-4	6.4	2603	369	367	395	272	33.5	145	21.0	1.15	107	1263	39.9	6.9	0.50	6.37
3	S+P-NS-3	6.4	2004	413	359	299	255	19.3	93	12.9	0.74	101	883	39.8	9.5	0.53	8.33
3	S-DD-1	6.4	2302	323	274	380	284	29.3	137	18.1	1.05	102	1200	39.3	6.9	0.49	6.27
3	S+P-D+N-4	6.4	2393	477	316	347	265	24.1	107	15.5	0.93	108	1037	40.2	9.2	0.51	7.77
3	S-NS-6	6.5	2355	333	493	383	281	28.9	144	18.2	1.08	102	1182	38.9	6.8	0.50	6.24
3	S+P-D+N-3	6.3	2035	420	255	304	259	18.8	94	12.4	0.77	94	880	40.4	9.4	0.47	7.49
3	S-NS-4	6.5	2541	355	432	398	282	31.9	139	19.8	1.14	106	1255	39.7	5.8	0.52	6.61
3	S-D+N-5	6.5	2489	339	367	399	283	30.3	148	19.0	1.09	97	1191	39.6	6.2	0.49	6.26
3	S+P-D+N-5	6.3	2078	449	292	316	265	18.4	89	12.0	0.78	100	845	40.3	8.9	0.46	7.18
3	S-NS-1	6.4	2716	384	504	431	276	34.7	161	21.5	1.24	113	1272	40.4	5.8	0.51	6.48
3	S-NS-5	6.4	2711	381	504	420	285	33.1	163	20.9	1.21	116	1265	40.4	6.5	0.50	6.47
3	S-DD-5	6.4	2510	341	305	417	281	32.0	142	19.7	1.18	97	1220	40.3	5.7	0.45	5.92
3	S-DD-6	6.5	2353	319	257	396	278	29.9	131	18.2	1.09	97	1170	39.5	6.2	0.46	6.12
3	S-NS-2	6.5	2235	332	412	376	272	27.4	130	17.1	1.04	94	1097	38.9	6.1	0.50	6.39
3	S+P-DD-7	6.2	2520	536	206	418	285	25.6	119	16.9	1.04	109	1138	37.1	7.4	0.46	7.15
3	S+P-NS-4	6.2	2278	487	403	342	264	22.0	106	14.3	0.91	108	941	39.6	7.8	0.46	6.99
3	S+P-DD-1	6.2	2063	503	170	292	249	17.7	90	11.7	0.75	103	793	40.1	8.3	0.49	8.68
3	S+D+N-2	6.4	2619	387	390	432	283	34.8	151	21.1	1.23	104	1251	40.3	6.6	0.49	6.41
3	S-DD-2	6.4	2704	403	311	429	277	35.2	152	21.3	1.24	108	1248	40.3	6.5	0.47	6.27
3	S+P-D+N-2	6.3	2628	539	344	442	283	28.6	131	18.7	1.08	109	1217	35.7	8.4	0.48	7.57
3	S+P-NS-1	6.2	2135	516	415	328	263	18.9	100	12.6	0.79	103	853	37.3	9.8	0.46	7.76
3	S+P-DD-3	6.3	2213	462	190	360	274	22.7	107	14.4	0.93	97	993	40.3	8.5	0.47	7.30
3	S-DD-4	6.4	2506	371	274	420	286	33.4	136	19.8	1.24	103	1214	40.2	6.8	0.48	6.50

3	S-D+N-6	6.3	2569	389	370	422	280	33.1	151	20.2	1.19	103	1197	40.2	6.2	0.48	6.31
3	S+P-DD-2	6.2	1896	484	175	276	244	15.7	80	11.1	0.70	96	705	39.7	11.7	0.50	8.95
3	S+P-D+N-1	6.2	2372	503	314	374	272	23.9	113	15.4	0.99	100	1011	39.1	8.5	0.45	7.06
3	S+P-NS-2	6.2	2522	555	428	409	277	25.1	126	16.3	1.04	114	1086	36	8.7	0.45	7.22
3	S+P-NS-6	6.3	2097	493	231	325	264	19.7	95	12.5	0.98	99	841	39.3	8.3	0.45	7.14
3	S+P-DD-5	6.2	2498	569	274	426	280	25.2	118	16.6	1.24	111	1105	31	8.6	0.50	8.14
4	S+P-D+N-3	5.8	1326	381	242	45	113	2.2	16	2.5	0.12	84	1338	37.1	7.0	0.26	5.50
4	S+P-D+N-4	5.8	1185	344	195	40	119	2.0	16	2.2	0.11	77	1275	36.6	6.5	0.23	4.80
4	S+P-D+N-1	6.1	2185	459	364	327	229	21.3	98	15.3	0.74	90	932	40.0	8.9	0.54	7.47
4	S+P-D+N-7	5.9	1228	333	214	52	129	2.9	23	2.9	0.14	79	1305	35.1	5.6	0.26	5.29
4	S+P-D+N-5	5.7	1240	365	221	41	123	2.0	22	2.5	0.11	85	1409	37.4	7.2	0.23	4.95
4	S-NS-1	5.5	1129	151	319	41.3	184	3.7	44	3.2	0.27	96	1535	29.1	4.0	0.22	3.55
4	S-NS-3	5.4	1165	160	329	45.6	166	4.4	43	3.9	0.27	98	1593	31.0	4.5	0.26	4.15
4	S-NS-7	5.5	1187	145	271	26.7	179	3.0	34	2.4	0.25	90	1718	28.5	4.0	0.23	3.85
4	S-NS-6	5.5	1063	121	251	20.4	167	2.4	24	2.1	0.21	85	1727	26.6	3.6	0.21	3.83
4	S-NS-4	5.5	1032	140	259	31.5	180	3.1	25	3.0	0.26	86	1591	28.4	4.0	0.24	3.92
4	S-D+N-7	6.3	2375	355	399	368	247	29.0	120	18.6	1.00	86	1078	38.8	6.4	0.53	6.21
4	S-D+N-2	5.8	1639	221	240	121	190	13.3	67	8.2	0.52	88	1381	34.4	4.7	0.32	4.73
4	S-D+N-1	5.6	1168	151	133	57.7	185	6.2	45	4.3	0.36	78	1497	30.0	4.0	0.23	3.84
4	S-D+N-2	5.6	1284	180	205	68	180	7.5	53	5.3	0.42	89	1482	32.4	4.3	0.28	4.36
4	S-D+N-4	5.6	1234	169	209	56.3	185	6.4	40	5.1	0.41	89	1549	33.6	3.6	0.24	3.76
4	S-DD-7	5.5	1228	170	106	54.9	179	5.7	50	4.4	0.38	91	1602	33.6	3.4	0.27	4.38
4	S-DD-1	5.8	1546	206	121	109	206	11.8	67	7.5	0.55	83	1519	34.6	3.9	0.31	4.67
4	S-DD-4	5.5	1089	135	79	34	196	4.1	38	3.2	0.35	83	1519	29.3	4.1	0.20	3.63
4	S-DD-2	5.5	1147	148	104	43.2	192	5.1	41	3.9	0.38	87	1637	31.9	4.4	0.22	3.90
4	S-DD-3	5.4	1171	155	102	48	218	5.0	50	4.1	0.44	94	1581	32.3	4.3	0.22	3.72
4	S+P-DD-5	5.6	1411	410	139	37.8	139	3.0	24	2.6	0.25	86	1591	39.6	5.5	0.21	4.62
4	S+P-DD-7	5.8	1092	316	101	40.1	137	3.1	17	2.5	0.19	68	1184	34.2	6.4	0.24	5.25
4	S+P-DD-1	5.6	1187	341	103	35.6	133	2.8	21	2.5	0.20	79	1360	36.6	7.2	0.23	5.22
4	S+P-DD-2	5.8	1614	441	154	55	146	3.9	29	3.2	0.32	98	1560	40.0	6.4	0.23	5.05

4	S+P-DD-3	5.7	1441	406	129	49.6	137	3.6	24	3.2	0.27	88	1462	39.1	6.4	0.25	5.50
4	S+P-NS-6	5.6	1163	354	338	41.9	133	2.4	20	2.3	0.21	76	1342	36.4	6.2	0.25	5.31
4	S+P-NS-7	5.7	1203	347	288	51	132	3.1	24	2.7	0.20	72	1305	36.8	5.8	0.28	5.97
4	S+P-NS-5	5.7	1291	345	337	52	138	3.7	26	2.9	0.23	77	1430	37.8	5.3	0.28	5.83
4	S+P-NS-1	5.6	1343	396	356	50	133	2.7	23.3	2.6	0.25	84.0	1556	39.6	5.5	0.24	4.92
4	S+P-NS-2	5.8	1429	445	377	52.3	124	3.3	20.5	2.60	0.23	87.0	1419	40.0	6.3	0.26	5.47

Crop number	Field ID	PO_4^{3-} (mg/L)	NH_3 (mg/L)	NO_3^- (mg/L)
2	S+P-D+N-8	19.33	1.16	2.95
2	S-NS-4	20.77	1.19	5.23
2	S+P-DD-9	17.6	1.21	1.87
2	S+P-DD-11	20.43	3.35	15.1
2	S+P-NS-6	22.84	1.08	10.9
2	S+P-DD-6	24.69	0.66	19.5
2	S+P-D+N-3	25.89	0.86	22.13
2	S-D+N-9	19.8	0.9	24.63
2	S+P-NS-2	19.1	1.84	27.4
2	S-D+N-13	23.35	0.93	20.37
2	S+P-NS-11	2.81	0.58	17.8
2	S-D+N-8	1.27	0.49	26.33
2	S+P-D+N-11	0.97	0.62	21.1

2	S-D+N-2	0.85	0.41	26.83
2	S-DD-8	1.28	0.58	26.6
2	S-NS-11	30.2	2.06	26.67
2	S+P-NS-8	21.03	1.23	13.5
2	S+P-D+N-2	29.63	1.74	9.04
2	S+P-D+N-9	22.73	3.45	28.6
2	S-DD-14	23.68	2.78	27.07
2	S-NS-3	24.91	0.83	24.47
2	S+P-NS-4	21.17	0.8	9.31
2	S+P-DD-5	22.31	0.74	6.32
2	S-DD-10	25.17	0.84	23.3
2	S-D+N-4	0.64	0.35	21.37
2	S+P-DD-15	0.78	0.44	2.42
2	S-NS-6	0.77	0.66	14.63
2	S-DD-1	1.43	0.56	16.7
2	S-DD-2	0.77	0.55	30.27
2	S-NS-5	16.17	1.88	17.77
3	S-D+N-7	21.87	0.54	7.01
3	S-D+N-4	22.17	1.19	2.11
3	S+P-NS-3	21.65	3.53	18.9
3	S-DD-1	17.33	1.88	1.97
3	S+P-D+N-4	27.72	1.26	25.17

3	S-NS-6	24.87	0.93	10.47
3	S+P-D+N-3	22.6	0.68	4.59
3	S-NS-4	24.28	0.78	24.63
3	S-D+N-5	23.03	0.72	5.57
3	S+P-D+N-5	23.17	0.91	25.27
3	S-NS-1	1.53	0.46	4.16
3	S-NS-5	2.81	0.59	1.25
3	S-DD-5	0.71	0.33	3.02
3	S-DD-6	1.74	0.51	30.17
3	S-NS-2	22.38	0.47	11.77
3	S+P-DD-7	22.6	1.9	16.23
3	S+P-NS-4	21.57	1.9	15.4
3	S+P-DD-1	22.17	3.03	10.6
3	S+D+N-2	22.4	1.94	1.76
3	S-DD-2	18.7	2.04	18.2
3	S+P-D+N-2	32.25	0.68	2.93
3	S+P-NS-1	27.12	0.9	15.1
3	S+P-DD-3	22.69	1.49	25.57
3	S-DD-4	22.63	0.78	11.53
3	S-D+N-6	27.75	0.77	9.56
3	S+P-DD-2	0.71	0.51	10.67

3	S+P-D+N-1	1.62	0.41	21.33
3	S+P-NS-2	1.17	0.56	32.73
3	S+P-NS-6	0.55	0.65	27.9
3	S+P-DD-5	29.63	3.31	33.5
4	S+P-D+N-3	33.7	1.35	8.49
4	S+P-D+N-4	24.08	1.02	2.44
4	S+P-D+N-1	33.27	2.18	18.63
4	S+P-D+N-7	29.29	1.13	22.83
4	S+P-D+N-5	21.9	0.76	4.07
4	S-NS-1	25.52	0.74	14.97
4	S-NS-3	21.01	0.74	20.47
4	S-NS-7	25.41	0.78	17.93
4	S-NS-6	26.75	0.84	13.77
4	S-NS-4	1.54	0.49	29.97
4	S-D+N-7	1.4	0.45	14.2
4	S-D+N-2	1.8	0.5	29.67
4	S-D+N-1	1.15	0.58	2.5
4	S-D+N-2	1.12	0.53	21.37
4	S-D+N-4	1.72	1.32	12.05
4	S-DD-7	37.23	1.37	17.73
4	S-DD-1	23.97	3.51	19

4	S-DD-4	27.1	1.02	4.57
4	S-DD-2	26.57	1.05	4.62
4	S-DD-3	29.2	2.97	10
4	S+P-DD-5	26.35	1.09	29.9
4	S+P-DD-7	25.34	0.81	27.63
4	S+P-DD-1	29.93	0.76	9.28
4	S+P-DD-2	22.75	1.51	24.3
4	S+P-DD-3	23.78	0.88	22.8
4	S+P-NS-6	30.28	0.56	4.73
4	S+P-NS-7	1.72	0.67	20.03
4	S+P-NS-5	1.13	0.41	18.83
4	S+P-NS-1	3.26	0.56	21.47
4	S+P-NS-2	0.45	0.56	12.37

Appendix 14: Untransformed shoot nutrient data

Crop number	Soil substrate type	Fertilizer treatment	Sample ID	N (%)	C (%)	S (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)	B (ppm)
2	Soil	DD	S DD 8	3.32	38.2	0.23	0.36	7.34	0.65	0.26	0.36	433	10	74	79	42
2	Soil	DD	S DD 2	3.37	38.1	0.22	0.35	7.36	0.65	0.26	0.35	563	12	78	71	42
2	Soil	DD	S DD 1	3.2	38.7	0.21	0.31	7.02	0.63	0.25	0.33	232	7.9	80	66	35
2	Soil	DD	S DD 14	3.45	38.1	0.22	0.35	7.69	0.64	0.26	0.34	335	8.5	69	60	38
2	Soil	DD	S DD 10	3.71	37.8	0.21	0.34	7.38	0.69	0.28	0.36	363	8.2	73	63	38
2	Soil+Promix	DD	S+P DD 13	3.34	38.3	0.2	0.31	6.37	0.63	0.31	0.32	636	11	76	81	39
2	Soil+Promix	DD	S+P DD 5	3.99	37.7	0.23	0.39	7.5	0.7	0.35	0.38	311	14	64	86	37
2	Soil+Promix	DD	S+P DD 11	3.86	38.5	0.23	0.34	7.03	0.61	0.3	0.34	187	5.4	66	64	34
2	Soil+Promix	DD	S+P DD 6	3.86	37.5	0.23	0.35	7.05	0.7	0.36	0.37	376	7.3	76	70	34
2	Soil+Promix	DD	S+P DD 9	3.91	37.4	0.22	0.35	6.84	0.65	0.34	0.34	503	8.8	75	64	38
2	Soil	NS	S NS 5	3.99	35.9	0.23	0.41	7.96	0.67	0.27	0.36	959	13	85	60	40
2	Soil	NS	S NS 4	3.9	37.4	0.22	0.4	7.63	0.62	0.27	0.31	540	13	81	70	36
2	Soil	NS	S NS 11	3.95	37.4	0.25	0.44	8.17	0.55	0.24	0.32	419	9	76	58	36
2	Soil	NS	S NS 3	4.02	37.3	0.24	0.43	8.36	0.6	0.26	0.34	357	7.7	76	57	38
2	Soil	NS	S NS 6	4.28	36.8	0.23	0.48	8.69	0.59	0.25	0.36	357	12	68	86	38
2	Soil+Promix	NS	S+P NS 2	3.93	37.8	0.23	0.5	7.88	0.61	0.3	0.34	331	6.4	66	69	34
2	Soil+Promix	NS	S+P NS 8	4.03	37.5	0.23	0.51	7.9	0.6	0.29	0.34	236	8.8	58	75	33
2	Soil+Promix	NS	S+P NS 11	4.06	37.6	0.23	0.48	8.06	0.55	0.28	0.32	278	6.3	56	49	33
2	Soil+Promix	NS	S+P NS 6	4.16	37.2	0.22	0.52	8.12	0.54	0.28	0.33	396	7.6	63	57	31
2	Soil+Promix	NS	S+P NS 4	3.95	37.6	0.21	0.48	7.53	0.54	0.26	0.34	335	7.8	60	75	27
2	Soil	DD+NS	S D+N 9	3.66	37	0.23	0.43	7.99	0.66	0.27	0.36	261	11	60	66	39
2	Soil	DD+NS	S D+N 4	3.56	36.9	0.2	0.37	7.5	0.58	0.25	0.31	761	8.4	66	58	37
2	Soil	DD+NS	S D+N 13	3.37	37.7	0.2	0.41	7.08	0.6	0.25	0.32	431	12	55	63	36
2	Soil	DD+NS	S D+N 8	4.22	37	0.26	0.45	8.5	0.69	0.3	0.36	340	9	55	66	40
2	Soil	DD+NS	S D+N 2	3.98	37.3	0.24	0.39	7.61	0.66	0.29	0.35	788	15	75	80	42

2	Soil+Promix	DD+NS	S+P D+N 3	3.81	37.1	0.25	0.5	7.54	0.62	0.3	0.31	514	10	68	65	37
2	Soil+Promix	DD+NS	S+P D+N 2	3.89	37.7	0.25	0.48	7.99	0.59	0.31	0.35	304	9.2	59	72	37
2	Soil+Promix	DD+NS	S+P D+N 8	4.06	37.2	0.24	0.48	8.08	0.59	0.3	0.36	263	11	60	71	35
2	Soil+Promix	DD+NS	S+P D+N 11	4.2	37	0.24	0.53	8.18	0.62	0.3	0.36	233	11	58	81	35
2	Soil+Promix	DD+NS	S+P D+N 9	3.8	37.8	0.22	0.44	7.68	0.6	0.31	0.36	210	8.8	65	76	33
3	Soil	DD	S-DD-1	4.91	39.6	0.28	0.47	7.95	0.86	0.34	0.38	308	10	49	73	49
3	Soil	DD	S-DD-5	5.41	38.4	0.35	0.55	8.88	0.96	0.38	0.42	449	15	50	128	51
3	Soil	DD	S-DD-6	4.99	39.2	0.32	0.49	8.41	0.89	0.35	0.4	269	7	44	72	48
3	Soil	DD	S-DD-2	4.65	38	0.38	0.62	10.41	1.01	0.41	0.45	410	14	72	81	65
3	Soil	DD	S-DD-4	4.76	38.7	0.31	0.51	8.89	0.88	0.35	0.4	289	13	64	76	51
3	Soil+Promix	DD	S+P-DD-7	4.57	38.4	0.31	0.54	9.24	0.88	0.42	0.4	262	10	71	85	50
3	Soil+Promix	DD	S+P-DD-1	5.09	38.3	0.31	0.55	9.09	0.88	0.42	0.43	334	12	64	76	49
3	Soil+Promix	DD	S+P-DD-3	4.53	39	0.3	0.51	8.75	0.87	0.38	0.39	266	15	73	80	46
3	Soil+Promix	DD	S+P-DD-2	4.91	39.5	0.29	0.51	7.97	0.81	0.38	0.36	342	8.9	62	85	46
3	Soil+Promix	DD	S+P-DD-5	4.88	38.3	0.32	0.62	9.37	0.9	0.42	0.44	389	14	72	150	55
3	Soil	NS	S-NS-6	5.28	39.1	0.29	0.52	8.62	0.89	0.36	0.37	294	9.9	53	76	49
3	Soil	NS	S-NS-4	4.7	39.2	0.28	0.44	8.58	0.73	0.3	0.35	372	10	59	79	47
3	Soil	NS	S-NS-1	4.98	39.1	0.27	0.53	8.35	0.81	0.32	0.36	529	10	64	89	45
3	Soil	NS	S-NS-5	5.09	38.8	0.28	0.51	8.13	0.89	0.36	0.37	402	11	49	78	47
3	Soil	NS	S-NS-2	5.03	38.9	0.31	0.46	8.73	0.82	0.35	0.38	255	8.3	53	82	49
3	Soil+Promix	NS	S+P-NS-3	4.97	38.7	0.3	0.54	9.55	0.78	0.36	0.39	262	5.6	57	61	49
3	Soil+Promix	NS	S+P-NS-4	4.96	38.9	0.3	0.55	8.49	0.74	0.34	0.37	330	12	48	105	44
3	Soil+Promix	NS	S+P-NS-1	4.67	38	0.34	0.66	10.67	0.86	0.4	0.44	343	12	66	75	51
3	Soil+Promix	NS	S+P-NS-2	5.15	38.9	0.31	0.59	8.62	0.83	0.37	0.38	311	11	59	79	49
3	Soil+Promix	NS	S+P-NS-6	4.93	38.2	0.31	0.59	9.24	0.8	0.36	0.39	307	11	58	81	47
3	Soil	DD+NS	S-D+N-7	5.33	38.8	0.33	0.54	8.61	0.91	0.35	0.39	495	11	56	75	49
3	Soil	DD+NS	S-D+N-4	4.96	39.2	0.31	0.49	8.86	0.86	0.35	0.41	377	10	60	78	51
3	Soil	DD+NS	S-D+N-5	5.07	35.3	0.3	0.52	8.7	0.94	0.38	0.43	1510	23	94	87	57
3	Soil	DD+NS	S-D+N-2	4.41	36	0.39	0.57	10.08	0.94	0.39	0.45	1310	21	115	85	65
3	Soil	DD+NS	S-D+N-6	5.26	37.6	0.33	0.52	9.32	0.89	0.37	0.43	428	12	60	74	53

3	Soil+Promix	DD+NS	S+P-D+N-4	4.46	39.5	0.25	0.46	8.34	0.69	0.35	0.4	303	11	56	79	45
3	Soil+Promix	DD+NS	S+P-D+N-3	4.83	37.8	0.3	0.53	9.94	0.8	0.4	0.45	250	9.5	68	79	46
3	Soil+Promix	DD+NS	S+P-D+N-5	4.42	39.4	0.27	0.47	8.35	0.75	0.36	0.41	418	12	56	71	46
3	Soil+Promix	DD+NS	S+P-D+N-2	4.74	38.6	0.32	0.57	9.37	0.86	0.4	0.42	276	13	64	79	54
3	Soil+Promix	DD+NS	S+P-D+N-1	4.07	39.7	0.28	0.42	8.01	0.67	0.31	0.35	258	6.2	59	68	39
4	Soil	DD	S-DD-5	3.11	42.9	0.2	0.16	4.51	0.55	0.18	0.35	257	3	35	38	36
4	Soil	DD	S-DD-1	3.3	42.1	0.21	0.19	5.05	0.57	0.19	0.3	206	4.5	36	55	34
4	Soil	DD	S-DD-4	2.58	43.7	0.16	0.1	3.96	0.49	0.15	0.3	143	2.4	26	29	34
4	Soil	DD	S-DD-2	3.19	43.6	0.19	0.13	4.15	0.57	0.17	0.35	144	2.1	29	27	35
4	Soil	DD	S-DD-3	3.3	43.7	0.2	0.13	4.26	0.53	0.17	0.32	139	1.3	28	28	30
4	Soil+Promix	DD	S+P-DD-5	2.92	43.4	0.18	0.11	4.05	0.54	0.2	0.24	133	2.3	45	27	35
4	Soil+Promix	DD	S+P-DD-1	2.92	43	0.17	0.11	4.13	0.59	0.22	0.26	198	3.4	52	42	31
4	Soil+Promix	DD	S+P-DD-2	3.17	43.2	0.19	0.13	4.43	0.59	0.23	0.25	154	2.6	32	32	31
4	Soil+Promix	DD	S+P-DD-3	2.92	43.2	0.18	0.11	4.23	0.54	0.21	0.23	150	2.2	34	36	28
4	Soil+Promix	DD	S+P-DD-7	3.09	43.1	0.2	0.12	4.21	0.6	0.22	0.25	158	4.6	42	40	33
4	Soil	NS	S-NS-1	3.21	43.8	0.2	0.12	3.97	0.53	0.18	0.29	362	3.2	35	28	32
4	Soil	NS	S-NS-3	3.38	43.5	0.22	0.15	4.62	0.55	0.19	0.3	219	2.3	33	33	31
4	Soil	NS	S-NS-7	2.94	44.1	0.17	0.098	4.05	0.45	0.14	0.32	205	1.4	30	27	28
4	Soil	NS	S-NS-6	3.23	44	0.19	0.12	4.33	0.47	0.14	0.37	138	‹ 1	27	22	29
4	Soil	NS	S-NS-4	3.04	44	0.17	0.098	4.18	0.47	0.14	0.29	154	2.4	30	30	27
4	Soil+Promix	NS	S+P-NS-6	3.63	42.6	0.21	0.16	5.25	0.54	0.22	0.25	195	2.7	51	49	33
4	Soil+Promix	NS	S+P-NS-7	3.25	42.4	0.2	0.14	5.61	0.53	0.22	0.24	200	2.1	40	32	30
4	Soil+Promix	NS	S+P-NS-5	3.23	43	0.18	0.13	4.73	0.54	0.22	0.25	130	4.6	40	30	32
4	Soil+Promix	NS	S+P-NS-1	3.21	43.4	0.2	0.12	4.49	0.53	0.21	0.22	213	2.1	55	45	31
4	Soil+Promix	NS	S+P-NS-2	3.16	43	0.18	0.12	4.52	0.54	0.22	0.21	237	2.9	46	38	30

4	Soil	D+N	S-D+N-7	3.85	39.7	0.25	0.3	7.37	0.61	0.28	0.27	575	8.5	59	64	37
4	Soil	D+N	S-D+N-3	3.7	41.2	0.2	0.22	4.99	0.61	0.22	0.26	526	6.1	41	64	39
4	Soil	D+N	S-D+N-1	3.25	42.9	0.18	0.13	4.41	0.57	0.19	0.31	421	3.9	34	36	33
4	Soil	D+N	S-D+N-2	3.79	42.5	0.23	0.19	5.75	0.65	0.23	0.33	212	5.5	34	61	37
4	Soil	D+N	S-D+N-4	3.38	43.2	0.2	0.14	4.78	0.51	0.19	0.29	167	3.3	29	38	35
4	Soil+Promix	D+N	S+P-D+N-3	3.07	43.2	0.19	0.13	4.43	0.6	0.23	0.26	143	1.6	40	33	30
4	Soil+Promix	D+N	S+P-D+N-4	3.47	42.9	0.23	0.13	4.9	0.61	0.23	0.28	192	1.1	41	34	32
4	Soil+Promix	D+N	S+P-D+N-1	4.78	40.1	0.3	0.43	8.34	0.71	0.35	0.31	224	8.5	48	98	39
4	Soil+Promix	D+N	S+P-D+N-7	3.02	43.1	0.18	0.12	4.55	0.54	0.22	0.23	155	1.5	34	31	27
4	Soil+Promix	D+N	S+P-D+N-5	3.32	42.9	0.2	0.14	4.78	0.56	0.22	0.24	145	2.7	44	32	36