SOIL AMENDMENTS AND COVER CROPS IN WINE GRAPE PRODUCTION

by

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ABSTRACT

In 2011 and 2012, a study was conducted to evaluate the use of selected soil amendments (SA) and cover crops (CC) in Nova Scotia (NS) wine grape production to reduce synthetic fertilizer inputs, enhance soil quality and improve grape yield and quality. In 2011, increases in particulate organic matter nitrogen, carbon, and 205nm $NaHCO_3^-$- extractable nitrogen were attributed to CC establishment. In 2011, treatments with CC increased grape yield and cluster weight. Differences in selected soil nutrient concentrations, pH and whole leaf and petiole nitrogen were found between SA treatments in 2012. Interactions between SA, CC and year of amendment application led to significant differences in the number of clusters per vine and average of cluster weight per vine in 2012.

Soil amendment treatments provided comparable results to synthetic fertilizers while some also enhanced soil quality. Cover crops typically increased yield and soil quality compared with bare soil treatments.

LIST OF ABBREVIATIONS AND SYMBOLS USED

°C	Degrees Celsius
AAFRD	Alberta Agriculture, Food and Rural Development
ANOVA	Analysis of Variance
B	Boron
BS	Tilled Bare Soil
C	Carbon
C:N	Carbon to Nitrogen Ratio
Ca	Calcium
CC	Cover Crop variable encompassing OPV, ORC, TM and BS
CEC	Cation Exchange Capacity
DON	Dissolved Organic Nitrogen
Fe	Iron
FERT	Fertilizer
g	gram
GDD	Growing Degree Days
Ha	Alternative hypothesis
Ho	Null hypothesis
K	Potassium
kg	Kilogram
L	Liters
LSD	Least Significant Difference
LSmeans	Least Square Means
m	Meter
MBC	Microbial Biomass Carbon
Mg	Magnesium
Mn	Manganese
MS	Mussel Sediments
MSFW	Municipal Solid Food Waste
N	Nitrogen
$NaHCO_3^-$	Sodium Bicarbonate
NDEF	Nitrogen Deficient Fertilizer
NH_4^+-N	Ammonium-nitrogen
NM	Nutrient Management
nm	Nanometers
NO_3^--N	Nitrate-nitrogen
NS	Nova Scotia
NSDAF	Nova Scotia Department of Agriculture and Fisheries
NSLC	Nova Scotia Liquor Commission
OM	Organic Matter
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
OPV	Oats, Pea, Hairy Vetch
ORC	Oats, Red Clover

P	Phosphorous
PEAF	Prince Edward Aqua Farms
PEI	Prince Edward Island
POM	Particulate Organic Matter
POMC	Particulate Organic Matter Carbon
POMN	Particulate Organic Matter Nitrogen
ppm	Parts per million
SA	Soil Amendment variable encompassing FERT, NDEF, WA, MSFW and MS.
SAS	Statistical Analysis System
SE	Standard Error
SOM	Soil Organic Matter
t	Tonne
TE	Trolox Equivalent
TM	Triple Mix of 70% timothy, 15% alsike clover and 15% red clover
TSS	Total Soluble Solids
USDA	United States Department of Agriculture
WA	Wood ash
WANS	Winery Association of Nova Scotia

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Chapter 1.0 Introduction

1.1 Need for Research

Wine grape production is a rapidly growing but relatively young industry in Nova Scotia (NS). With the industry only blossoming, sustainable soil management practices have not been evaluated in NS vineyards. Soil nutrient management recommendations for grape production are not well developed. Further study is required on soil management in relation to the performance of wine grape yield and quality especially in the context of alleyway vegetation and soil fertility management. Alternatives to synthetic fertilizers need to be evaluated for their impact on grape productivity, fruit quality and soil quality indicators in NS vineyards. Although the effects of cover crops with legumes and grasses have been studied, the effect of selected cover crop (CC) and soil amendment (SA) combinations have not been studied in NS vineyards. This research will assist in developing sustainable management practices for wine grapes in NS.

1.2 Project Goal

The purpose of this project is to identify optimal sustainable soil management practices for Nova Scotia's viticulture industry. The effect of SA and CC on wine grape yield and quality and some indices of soil quality will be investigated. Treatments of interest in this project include mussel sediments (MS), municipal solid food waste compost (MSFW), wood ash (WA), and the use of alleyway cover cropping between vine rows.

1.3 Objectives

The specific objectives and hypotheses of this project are:

1. To assess the effect of selected SA and CC treatments on soil and grapevine nutrient status and soil quality.

Ho: There will be no significant effect of SA or CC or their combination on the soil or plant nutrient status and/or quality parameters of the soil.

Ha: Significant differences in treatment effects on grapevine nutrient status and/or soil quality will be observed.

2. To evaluate the effects of selected SA on the CC biomass and the CC tissue N concentration.

Ho: There will be no significant differences among SA treatments in their effect on CC tissue N concentration and/or above ground biomass.

Ha: Soil amendment treatments will result in significant differences in CC biomass and CC tissue N concentration.

3. To evaluate the response of wine grape yield and quality in relation to:

A) CC- oat/pea/hairy vetch mixture (OPV), oat underseeded with red clover (ORC), triple mix (TM), and tilled bare soil (BS).

B) SA- MS, MSFW, WA, inorganic fertilizer (FERT) and N deficient fertilizer (NDEF).

Ho: There will be no significant differences in yield components and/or quality of wine grapes due to CC, SA and/or SA x CC combinations.

Ha: Significant differences in treatment effects on wine grape yield components and quality will be observed.

4. To investigate the residual effects of SA on grape yield and quality and soil quality parameters in the year after application.

Ho: There will be no significant residual effects of SA on grape yield and quality and/or soil quality parameters.

Ha: At least one SA treatment will show a significant residual effect on grape yield and quality and/or soil quality parameters.

Chapter 2 will address objectives 1 and 2, Chapter 3 will address objective 3 and objective 4 will be covered in both chapters 2 and 3.

1.4 Scope of the Project

This project will evaluate the use of SA and CC in NS wine grape production to reduce synthetic fertilizer inputs, improve soil fertility, soil quality, yield, and yield quality.

1.5 Wine Grape Production

The grapevine is the most cultivated fruit tree in the world (Wrinkler 1974). There is a huge diversity in climates, soils and viticulture practices resulting in an extraordinary range of wines worldwide (Delrot et al. 2010). Nova Scotia is becoming recognized for its high quality wines made from locally grown grapes (Kittilsen 2008). It is the third most developed wine grape growing region in Canada following British Columbia and Ontario (Winery Association of Nova Scotia (WANS) 2009). Wine grape production is a relatively new industry in NS commencing in the early 1980's but it is growing rapidly with vineyard acreage expected to increase from a reported 162 ha in 2008 to 400 ha by 2020 (Kittilsen 2008; WANS 2009). With a rapidly growing industry, now is the time to explore the effects of sustainable soil management practices on soil fertility, vine growth, grape yield and grape quality in NS. The risk of nutrient loss in NS is high due to the rolling topography, light to medium textured shallow soils and the amount of precipitation experienced in the region. Implementing sustainable management practices in vineyards of the region, which are mainly located on light textured soils and sloping land, may reduce the potential risks conventionally managed vineyards pose to the environment. This project took a highly resourceful look at the use of biowaste compost and industrial by-products in combination with cover cropping in an attempt to protect the soil and improve its quality for wine grape production. These alternatives also were assessed in terms of sustainability in production by attempting to address some of the deficiencies that exist in NS soils.

1.6 Sustainable Soil Management Role in Viticulture

Soil is an important component in viticulture but unlike other cropping systems, a highly fertile soil is not always desired (Naugler and Wright 2006). Some soil properties are inherent such as texture, drainage and slope. These cannot be readily altered by management practices (Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) 1997). Other properties are significantly affected by cultural practices such as soil structure, organic matter content and moisture. A good understanding and management of a vineyard's soil will help vines develop good root systems and reduces crop stress during extreme weather events (OMAFRA 1997). Without proper management practices continuous wine grape production can reduce nutrient reserves in the soil. Over time, cumulative depletion of nutrients can decrease grape yields and soil fertility (OMAFRA n.d.). Although grapes can thrive in a variety of soils, intensive and unsustainable grape production, mainly over-cropping and stressing young vines, can result in soil degradation, deplete stored nutrients, and cause an overall reduction of soil quality and fertility (Cline and Fitts 2002; Agnew et al. 2005; OMAFRA n.d.).

Sustainable agriculture, the act of farming by understanding relationships between organisms and their environment, has emerged in response to concerns surrounding conventional farming practices (Ingels 1992). It is an agricultural system that is environmentally sound, economically viable and socially acceptable (Ingels 1992). Practices used to achieve the goal of being sustainable are variable and dependent upon specific factors such as climate, soil characteristics, and local availability of inputs for the system (Ingels 1992). In sustainable agricultural systems, the soil is viewed as a fragile living medium that must be protected and nurtured to ensure its long-term productivity and stability (Ingels 1992). To enhance soil quality and protect soil conditions a cover crop may be sown, a soil amendment applied and/or reduced tillage practices utilized.

The overall goal in vine nutrient management is to maintain a healthy and productive vine, getting the fruit ripe and allowing the wood to harden for winter as soon as possible (Naugler and Wright 2004). The best practice for each vineyard site is determined in part by vine age, vineyard design, soil type and climatic conditions (Guerra and Steenworth 2012).

1.7 History of the Nova Scotia Wine Grape Industry

Although some sources claim that French explorer Louis Hebert planted a vineyard in Bear River, NS in 1611, there are definite sources that say he was not even in NS during this time (Naugler and Wright 2006; Nova Scotia Liquor Commission (NSLC) 2011). The first recorded and documented vineyard in NS and in Canada was planted in LaHave, NS in 1632 (Naugler and Wright 2006). Due to the inexperience of early settlers on the NS climate, the vines did not survive (Naugler and Wright 2006). No production of wine grapes was recorded in the province for the next three centuries (NSLC 2011).

During this hiatus from wine grape production, settlers planted table grapes in place of wine grapes because European wine cultivars could not prosper in the NS climate (Naugler and Wright 2006). No one concerned themselves with commercial wine grape production. Research in grape production in NS first took place in 1913 where 175 wine and table grape cultivars were tested at the Kentville Agriculture and Agri-Food Canada's Research Station (Naugler and Wright 2006). The experiment continued until 1983 but unfortunately had discouraging results (Naugler and Wright 2006).

Nova Scotia's commercial wine grape industry is young, being just over 30 years old. The first farm winery was opened in 1981 by Dr. Roger Dial in Grand Pre, NS (Naugler and Wright 2006). Two years later in 1983, Hans W. Jost and Walter Warhur opened the second farm winery in Malagash (Naugler and Wright 2006). Together, these three men formed the Nova Scotia Grape Growers Association (WANS 2009). The years following have seen an increase in wine grape production in NS, which now has over 40 vineyards and 11 farm wineries across the province (Naugler and Wright 2006). Nova Scotia's commercial wine grape industry is based on short season, hardy French hybrid varieties which were originally bred in France to combine the natural hardiness and disease resistance of North American vines with *vinifera* wine quality (Lewis n.d.). In 2009, the NS Wine Industry Initiative Fund was created with the goal of increasing vineyard acreage from 400 to 1000 and increasing the number of wineries to 20 by 2020 (Kittleson 2008; WANS 2009).

1.8 Effect of Soil Type and Microclimate on Grape Production in Nova Scotia

Nova Scotia, bordered by the Atlantic Ocean, Bay of Fundy and the Northumberland Strait, has been divided into six distinct wine growing areas (Bell 2011).

These regions are the North Shore, Annapolis Valley, Avon River Valley, LaHave River Valley, Bear River and Cape Breton.

The climatic conditions in NS are the largest limiting factor affecting grape production in the province (Lewis 2008). Wine grapes are sensitive to extreme winter temperatures. The length of the growing season and accumulation of growing degree days (GDD) determine the cultivars that can grow in a location (Lewis 2008). GDD represent the sum of the average temperature above a growth baseline of 10°C in viticulture (Lewis 2008). For example, a day with a high of 25°C and a low of 15°C has an average temperature of 20°C which would be 10 GDD for that day. To maintain an acceptable level of maturing in earliest varieties, a vineyard site should have a heat accumulation of 900 GDD, a long frost free period of at least 150 days, and a location where winter temperatures rarely are below -26°C (Lewis 2008). These conditions are acceptable for ripening the earliest varieties (Naugler and Wright 2006). The timing of heat units and hours of sunshine are also very important with heat units before and after veraison being most important to wine quality (Naugler and Wright 2006). Average heat unit accumulation, temperature and precipitation over the growing season in NS premier wine growing regions are shown in Table 1-1, Table 1-2 and Table 1-3 respectively (Environment Canada 2014). Temperature has a distinct influence on the development of colour with warm days and cool nights making the colour of the grape darker (Wrinkler 1974; Delrot et al. 2010). Vine leaves can withstand frost to a temperature of -2°C (Naugler and Wright 2006). Successful viticulture in the province will depend on matching suitable varieties with climate and soil type (Naugler and Wright 2006). Along the northern coastline of NS, the area near the Northumberland Strait has an extended fall growing season but low winter temperatures due to the strait freezing over, poses a risk if there is no insulating snow cover (Naugler and Wright 2006). Although cooler spring temperatures can delay growth, the total heat unit accumulation is similar to that measured in the Annapolis Valley and Avon River Valley where the Minas Basin offers protection from early fall frosts and helps moderate winter temperatures (Naugler and Wright 2006). The south facing slopes of North Mountain, Gaspereaux Valley, and western Hants County are very suitable vineyard areas and are in rapid development (Naugler and Wright 2006). Near Digby, the Bear River Valley is developing into a wine region and with its milder winter temperatures, the risk of damaging cold temperatures is reduced (Naugler and Wright 2006). In the LaHave River Valley the moderating effect from the Atlantic Ocean in the winter months is a benefit to local wine growers. Spring frosts are rarely a problem but selecting a good site is crucial as heat unit accumulation in the area varies widely within a short area (Naugler and Wright 2006). The Lahave River Valley offers the best location for viticulture in the region due to its south facing glacial drumlins composed of slate till often consisting of a large gravel component (Cann and Hilchey 1958; Naugler and Wright 2006). The above five wine growing areas host most of the vineyard acreage in the province. There are other plantings throughout the province including Cape Breton where lower heat accumulation forces growers to use more hardy earlier ripening varieties (Naugler and Wright 2006).

Other obstacles that NS grape growers have encountered are low levels of soil organic matter and nutrient availability. Nova Scotia tends to have low levels of some essential nutrients required for vine growth along with acidic soils (Lewis 2008). Macronutrients are needed for high quality high yielding grapes. Without essential nutrients, the vine can experience deficiencies such as yellowing of leaves, reduced vine growth, smaller cluster sizes and decreased disease resistance (Naugler and Wright 2006; Lewis 2008). It is important to ensure that good soil management strategies are developed for the region with the goal of optimizing vineyard yields while also preserving soil and water resources for sustainable use (Lewis 2008). Many of the world's best wine comes from steep rocky slopes (Naugler and Wright 2006). Sloping terrain is important for drainage of soil water and air movement. A radiative cooling pattern is created on these slopes where cold air drains down slope and the temperature at the top of the slope is much warmer than at the bottom. A study in Lunenburg, NS showed a 4°C temperature difference from the top to the bottom of a slope (Naugler and Wright 2006). South facing slopes like those found with most wine regions of the province warm earlier in spring and experience the greatest amount of direct sunlight possible on the grapes.

A wide range of soil textures are found in the province. Soil texture in vineyards from the grape growing regions of the province varies widely (Naugler and Wright 2006). Fine textured soils high in clay or silt hold more water than coarse textured soils and resist the movement of water through the soil profile (Naugler and Wright 2006). Coarse textured soils high in sand and gravel have a low water holding capacity but allow rapid percolation (Naugler and Wright 2006). Rapidly draining soils warm earlier promoting early growth which is beneficial in climates such as NS (Naugler and Wright 2006). Damp cool soils restrict root growth, slow fruit maturation and encourage fungal disease. Slowly draining soils have a negative impact on cold hardiness as well (Naugler and Wright 2006). Percolation rates of 2.5 - 5 cm hr^{-1} is ideal. Stone and gravel can make the soil more difficult to cultivate but it can improve drainage and act as a surface mulch to limit evaporation (Naugler and Wright 2006). Stones can also absorb and transmit the sun's heat to and from the soil and radiate it back onto the vines at night (Naugler and Wright 2006).

For the purpose of this research project, the soil of Lunenburg County in the La Have grape growing region is of interest. Lunenburg County has a humid temperate climate (Cann and Hilchey 1958). Parent material of soils in Lunenburg County was developed from glacial ice depositions (Cann and Hilchey 1958). Drumlins composed of deep drifts are a landscape feature where the underlying rock is slate and where most agricultural activity occurs (Cann and Hilchey 1958). The till is thin and consists of yellowish brown sandy loam or gravelly sandy loam (Cann and Hilchey 1958). The soil used for viticulture on the drumlin formations are Bridgewater Loam-Drumlin phase (Cann and Hilchey 1958). In Lunenburg County much of the agricultural land is on the steep slopes of drumlins where the risk of erosion is increased (Cann and Hilchey 1958).

1.9 Nutrient Requirements and Their Role in Nova Scotia Wine Grape Production

Providing optimal vine nutrition is one of the most important determinants of wine grape yield and quality (Naugler and Wright 2006). Acceptable nutrient values may vary from vineyard to vineyard with published values often being conflicting (Naugler and Wright 2006). Keeping a record of soil and tissue nutrient testing is critical. Soil sampling should take place every three years in an established vineyard and tissue sampling can take place yearly (Lewis 2008). If vine shoots and leaves are left on the ground during pruning minimal amounts of nutrients are removed within the grapes during harvest (Naugler and Wright 2006).

Soil and tissue nutrient status may differ for many reasons and therefore both are necessary to give a true picture of the vines nutritional status. Tissue analysis provides information on the actual nutritional status of the vine where soil analysis provides details on which nutrients are available for the plant to uptake.

When looking at a soil test report the first thing to consider is pH. The optimal pH is 6 to 6.5. Most suitable vineyard locations in NS have soils that are too acidic (Naugler and Wright 2006). If a large change in pH is necessary, applications of liming products are split into several applications until pH reaches a satisfactory level. The pH will also affect the variability of available nutrients in the soil for the vine to uptake (Naugler and Wright 2006). Nutrient and pH balance must be at an appropriate level to encourage deep rooting up to 60 cm (Naugler and Wright 2006).

Increased organic matter content of soils is probably one of the most well documented benefits of the use of both cover crops and compost, making these practices highly desirable for vineyard management (Hirschfelt 1998; Pinamonti 1998; Ingels et al. 2005). Soil organic matter is a very small part of the soil but plays a large role. Soil organic matter should be within a range of 2 - 5% in vineyard soils for optimal growth (Naugler and Wright 2006). Excessive soil organic matter encourages vigorous growth late in the summer at the expense of fruit quality and winter hardiness (Naugler and Wright 2006). Soil temperature and moisture are inherently related to mineralization of soil organic matter (Davenport et al. 2012).

Nitrogen (N) is required by the grape vine at three main stages of production in the growing season (Patrick et al. 2004). The greatest N demand comes in early spring and at bloom to support shoot and leaf growth (Patrick et al. 2004). After spring, the vine has an increased N demand from the end of rapid shoot growth up to veraison where higher proportion of N goes into developing and ripening the fruit (Christensen et al. 1994; Bair et al. 2007). Nitrogen is an essential part of chlorophyll and is most important in vegetative vine growth (Naugler and Wright 2006). The roots and the aboveground permanent woody vine serve as important storage organs for N to support vine growth in the spring by remobilizing nutrients stored from the previous season (Christensen et al. 1994). The decomposition of organic materials such as vegetation, crop residues and amendments by soil organisms account for most of the residual N in the soil. Grapes do not have high N requirements compared to other crops (Spectrum Analytic 2011a). The recommended soil test N required on average per year is 40 kg ha^{-1} for most varieties in Nova Scotia (Nova Scotia Department of Agriculture and Fisheries (NSDAF) 2004). Nitrogen is best broadcast applied to the vine in a single application before bud break (Wrinkler et al. 1974; Lewis n.d.). Nitrogen deficiency reduces yields and vine growth (Wrinkler 1974). A continuous lack of N will affect growth in the next season as well because the allocation of N in storage compartments is reduced (Schultz et al. 2002). High applications of N fertilizer will not address deficiencies immediately because the plant's reserves need to be replenished first (Schultz et al. 2002). Nitrogen fertilizer application should be avoided during periods of low vine uptake to minimize leaching losses (Christensen et al. 1994). Excess N late in the season leads to excessive vine vigour and incomplete vine hardening effecting the vines ability to survive cold winters (Wrinkler 1974; Bell and Robson 1999; Chien n.d.). Excessive N during ripening tends to divert the sugar produced by the leaves to continued shoot growth instead of to the fruit

(Wrinkler 1974). Cover crops are commonly planted to take up and balance excess N in the vineyard (Hirschfelt 1998).

Phosphorus (P) is important in flowering, promotes early maturation of fruit and enhances root growth (Spectrum Analytic 2011b). Phosphorus plays an important role in energy transfer of the vine, as it is necessary for photosynthesis and transforming sugars to starch and starch to sugars (Wrinkler 1974; Spectrum Analytic 2011b; Chien n.d). A deficiency in P can cause stunted growth, dull gray-green leaves, premature defoliation and fruit ripening (Wrinkler 1974; Spectrum Analytic 2011b). Phosphorous requirements of grapes are not very high, so often vines can obtain adequate P from the soil without supplemental fertilization (Wrinkler 1974). Soil test (Mehlich III extraction) P_2O_5 levels of 274-360 kg ha^{-1} are considered adequate for vineyard production in NS (NSDAF 2004).

Potassium (K) is required by grapevines in a relatively high amount primarily for transport, production and storage of carbohydrates and sugars (Wrinkler 1974; Spectrum Analytic 2011c; Chien n.d.). Soil test K_2O values of 156-236 kg ha^{-1} are considered adequate for vineyard production in NS (NSDAF 2004). It also affects the acid balance in grape juice and the pH and colour of wine (Spectrum Analytic 2011c). Grapevines are not very efficient at obtaining K from the soil, as most K is a structural component in soil minerals and not available to uptake (Spectrum Analytic 2011c). Vines with K deficiency have small tight clusters of unevenly ripened various sized grapes and evidence of chlorosis on older plant leaves (Wrinkler 1974). During ripening K content of the grape increases which leads to the formation of potassium bitartrate, which reduces the acidity and increases the juice pH (Dharmadhikari 2010).

Grapes have a higher requirement for boron (B) than most other perennial deciduous fruit crops (Wrinkler 1974). Boron is most needed by the vine in early spring (Naugler and Wright 2006). Boron affects pollen tube growth, sugar accumulation and is essential for fruit set and carbohydrate metabolism (Spectrum Analytic 2011f; Naugler and Wright 2006). Boron deficiency in vineyards is commonly found on acidic soils in high rainfall areas where leaching occurs (Cook 1966). In addition, sandy and shallow soils have been shown to have a B deficiency (Christensen 1986). A deficiency prevents the normal development and germination of pollen drastically affecting fruit set (Delrot et al. 2010). A deficiency may be visible in the grape bunches where a large number of green berries on a mature cluster will be present which is referred to as millerandage (Naugler and Wright 2006). This will significantly affect the grape quality. Boron deficiency has also resulted in poor fruit set with clusters consisting of a very small number of berries, also known as coulure (Hayes 1989). Other symptoms are stunting and repetitive poor fruit set. Boron toxicity has similar signs to B deficiency but is not seen unless excessive B is applied (Naugler and Wright 2006).

Other nutrients are rarely found to be deficient in grapevines. Calcium (Ca) and magnesium (Mg) deficiencies are rare because these nutrients are contained in dolomitic or calcitic limestone applications used to adjust soil pH (Naugler and Wright 2006). On Lunenburg County drumlins, dolomitic limestone is commonly used because soils in the area have been shown to be deficient in Mg and acidic (Cann and Hilchey 1958). Sulfur (S) deficiency is rare in vineyards because it is commonly used as part of a fungicide spray program against powdery mildew. Other soil S sources are within organic matter or applied as elemental S where soil microbes have to convert it to sulfate (SO_4^{2-}) in a form available for the vine to uptake. A deficiency of S is indicated by paleness in younger leaves. Other nutrients are usually not found to be deficient in vineyard production (Wrinkler 1974; Naugler and Wright 2006).

1.10 Soil Amendments and Their Proposed Benefits

Alternative methods for disposing of industrial and other types of organic waste products with minimal environmental impact are constantly being considered. Land application is one alternative (Campbell 1990; Vance 1996; Cameron et al. 1997; Mitchell and Black 1997). Land application of municipal and industrial by-products present an opportunity as they may contain available nutrients required for plant growth and can be used while posing little or no risk to the environment when applied appropriately (Campbell 1990; Vance 1996; Mitchell and Black 1997). Soil amendments chosen for this project were used to test their use as suitable sustainable alternatives to conventional inorganic fertilizer and were locally available. The selected SA were not tested before in NS vineyards to our knowledge. Soil amendments may be added to manage soil fertility, organic matter, pH and bulk density along with other potential benefits. (Hirschfelt 1998; Pinamonti 1998; Ingels et al. 2005; Macleod et al. 2006). In contrast to fertilizer mineral N which is plant available and easy to quantify, the release of N from organic amendments is dependent on mineral N content and factors influencing mineralization rates.

1.10.1 Inorganic Fertilizer

Inorganic fertilizer (FERT) is the most commonly used substance for supplying nutrients to grapevines because the nutrients are readily available and convenient for the producer to access and use. As knowledge about sustainable agricultural production is increasing due to public concern for the environment, research has taken place on testing alternative nutrient sources to replace fertilizers (Ozores-Hampton et al. 1997; Andrews et al. 1999; Maynard 2004). In established vineyards, fertilizers should be banded in a 1 m swath under the vine rows (Naugler and Wright 2006). This avoids feeding any weeds in the alleyways between vine rows (Naugler and Wright 2006).

1.10.2 Wood ash

Wood ash (WA) is the ash byproduct of wood burning (6 - 10% of burnt wood) which is classified as a form of green energy production because it is both carbon neutral and renewable. (Mills 2009). Wood ash is essentially composed of fine particles that swell when they encounter water (Demeyer et al. 2001). Wood ash can obstruct soil pores and affect aeration, water holding capacity, salinity and hydraulic conductivity of the soil (Demeyer et al. 2001). Brooklyn Power Corporation was the supplier of the WA used in this project. This company provides WA to farmers as a spreadable soil amendment (Mills 2009). Farmers must have a nutrient management plan to use the product (Mills 2009). This product was formerly sent to landfill sites and now is used by farmers as both a source of fertility and as a soil neutralizer (Mills 2009). Wood ash contains very little N but can be a good source of K, P and other nutrients and can also be used as a liming agent in the soil (Alberta Agriculture, Food and Rural Development (AAFRD) 2002; Delong 2008; Mills 2009). Most of the N and S is released into the atmosphere during ash production while much of the P and K are retained in the ash (AAFRD 2002). A significant amount of P, Ca, Mg and K is added to the soil when WA is used (AAFRD 2002; Lickacz 2002; Mills 2009). The key determinants of wood ash chemistry are the tree species combusted, the nature of the burn process and the conditions at the application site (Pitman 2006). Hardwoods produce more macronutrients in their ash. A furnace temperature between 500 and 900˚C is critical for retention of nutrients (Pitman 2006). Wood ash also contains many nutrients, which vine roots take up from the soil so it may improve crop growth through improved nutrition as opposed to using limestone (AAFRD 2002). In Alberta wood ash applied to grasslands significantly increased microbial biomass carbon (MBC), microbial diversity and pH (Lupwayi et al. 2009). An increase in soil pH may increase the decomposition rate of soil organic matter by soil bacteria and thus accelerate the release of plant nutrients such as N (AAFRD 2002). Brooklyn Power produces 180 t of wood ash each week (Delong 2008). One 30 t load is typically spread over 4 ha of land and is estimated to be equal to $2000 in lime and fertilizer (Delong 2008). It takes about 3 - 4 weeks for the WA to begin to alter the soil pH levels (Delong 2008).

There is currently no published data available on the pH and nutrient status of soils in a NS climate after WA application (Delong 2008). After application of WA, increased yield, biomass and soil nutrient levels have been observed in many crops and soils, where the effect of WA can last for several years after application (Karsisto 1979; Vance 1996). Soil pH and nutrient values are usually higher in Alberta soils amended with WA (Lickacz 2002). Perucci et al. (2006) stated that the effect of WA on soil quality is poorly known but its use as a liming agent is beneficial to increasing soil pH. Perucci et al. (2006) also mentioned that Ca, K, Mg, Na, and P were supplied to the soil in addition to liming. Perucci et al. (2006) found that MBC was increased at WA application rates of 5 t ha^{-1} but decreased at higher rates of 20 t ha^{-1}. The soil pH levels increased with increasing application rates. Lickacz (2002) suggested that WA was a much better

SA than lime because it contains other nutrients along with adjusting pH. Increased biomass compared to lime and increased uptake of P, S and B in oats were found in a study using WA (Krejsl and Scanlon 1996). Muse and Mitchell (1995) found WA to increase forage yield and soil pH. Erich (1991) found WA to be an effective source of P and K for corn.

1.10.3 Mussel Sediments

An interest in using mussel sediments (MS) to produce and market a nutrient rich soil amendment has recently been established on Prince Edward Island (PEI) (Prince Edward Aqua Farms (PEAF) 2010). Mussel sediment has a history of usage on PEI farms since the early 18th century, as fertilizer and lime were too expensive to ship from the mainland (Carroll 1992). The MS used in this project were not the same as the sediment used many years ago, which was gathered by scraping mud off ocean inlets, but the benefits experienced from the product are anticipated to be similar. The benefits farmers claimed from using MS was the reduction of NPK fertilizer, the elimination of liming, the addition of micronutrients to the soil, and increasing the SOM (Carroll 1992; McLeod et al. 2006). Mussel sediments used in this project are an aqueous waste product produced from washing mussels before processing and consists of metabolic wastes of mussel and small biofouling organisms that would normally be discharged into local waters (PEAF 2010).

Since the PEAF product is new to the market little research has taken place on the company's 4,320,000 L of product that is produced of yearly (Sharifi et al. 2010). Sharifi et al. (2010) tested nutrient concentrations of MS and evaluated its use as a SA to improve crop growth of tomatoes and annual ryegrass. The result yielded a biomass 5.5

times greater in tomato and 1.9 times greater in ryegrass in treatments using 42,000 L ha^{-1} of MS compared with control plots. The bioavailability of total N in the sediments ranged from 23-30% for tomatoes and 34-41% for ryegrass over the duration of the study. The reported concentrations of nutrients in MS were N (1.29% +/- 0.20), Ca (11% +/- 3), Mg (0.64% +/- 0.17), S (0.58% +/- 0.11) and B (53ppm +/- 12). Since little research has taken place on this product, literature on other aqueous ocean bi-products being used as fertilizers are discussed here. Woodaed (1999) reported that a dredged lake sediment treatment led to an increase in plant biomass and N, P, K uptake in corn, soybean and sunflowers. Woodaed (1999) also reported shoot dry matter, shoot N, P and K concentration, and N, P and K uptake increased dramatically with increasing application rates of the sediment. Gallant (2005) found that composted mussel processing waste used in an oat crop required additional fertilizer N for optimal crop yield whereas fresh mussel processing waste did not require supplemental N fertilizer. Blatt (1991) compared various fish and ocean wastes with chemical fertilizers and found that broccoli and cabbage receiving the amendments produced crops of comparable yield and size to those from plants receiving chemical fertilizer. Blatt (1991) also found that broccoli and cabbage leaf N values were higher in liquid fish silage than in chemical fertilizer plots. Other research found that a fish soil drench showed no difference in taste in beets than using regular synthetic fertilizer (Blatt 1991). This is important for grape production because taste is a profound feature for a wine’s quality. Sandler et al. (2009) found that cluster weights, Brix and total phenolics were improved with a local seafood industry by-product.

1.10.4 Municipal Solid Food Waste

Municipal solid food waste compost (MSFW) is increasingly being used in agriculture as a SA and fertilizer (Mkhabela 2005; Hargreaves et al. 2008a). This amendment, like others being used in the research, prevent these products from being sent to landfill, creating an excellent recycling practice (Hargreaves et al. 2008a). Municipal solid food waste is primarily composed of kitchen and yard wastes. With a rising interest in sustainable and organic agriculture, high grade MSFW is becoming popular because of the reported biological, physical and chemical benefits provided to the soil (Iglesias-Jimenez and Alvarez 1993; Hargreaves et al. 2008a). Composting is the decomposition of heterogeneous OM by a mixed microbial population in a moist, warm, aerobic environment (Basnayake 2001).

Municipal solid food waste compost, currently used in agriculture as a SA and a source of nutrients for crops, has been found to increase soil organic matter levels, increase pH, improve soil structure and lower bulk densities of soils (He et al. 1995; Soumare et al. 2003). Recent studies have shown that MSFW compost in agriculture has many benefits to soil, crops and environment (Mkhabela 2005; Hargreaves et al. 2008a). None of the field experiments conducted however have studied the effects MSFW as a soil amendment in NS vineyards. It is safe to use in agriculture due to source separation as well as the development and implementation of standards that people must follow when disposing of waste (Hargreaves et al. 2008a). Odour issues can be a problem in MSFW composts from the release of S compounds (Basnayake 2001).

Research surrounding the use of MSFW in viticulture is not well documented. An increase in soil organic matter and lower bulk densities from MSFW applications were published (Said-Publlicino et al. 2004). Application in various California vineyards has improved soil structure and water retention (Farrell 2005). Some studies have shown that high input of inorganic N can be obtained from rates of 40-50 t ha^{-1} MSFW (Igesias-Jimenez and Alvarez 1993). A long-term study on MSFW compost showed that K availability in MSFW was comparable to that in mineral fertilizers (deHann 1981). A 2009 study on squash showed MSFW was a good source of nutrients however, the relatively low availability of these nutrients meant that high compost rates were needed to meet crop nutrient requirements or the use of supplementary N-P-K fertilizer (Warman et al. 2009). This study also showed higher soil pH with increased MSFW application rates. Increases in soil microbial biomass N, C and S have been observed in the soil immediately after compost application for up to one month after application (Warman et al. 2009). Perucci (1990) found MSFW to be a good source of available P; however, the low availability of N means that supplementary N in the form of inorganic fertilizer had to be used together with the compost. Application rates of MSFW compost have been found to consistently increase soil organic matter and C:N ratio to levels significantly greater than in unamended soil (Perucci 1990; Crecehio et al. 2004; Walter et al. 2006). Some studies have shown that MSFW has high water holding capacity due to its OM content (Hernando et al. 1989; Soumare et al. 2003). Murphy and Warman (2007) saw an increase in manganese (Mn) when MSFW was applied to the soil. Zheljazkov et al. (2006) reported increased yield of biomass in a timothy/red clover forage.

1.11 Cover Crops and their Role in Wine Grape Production

Vineyard floor management is an important part of vineyard operations (Olmstead 2006; Tesic et al. 2007). Principal goals of vineyard floor management include weed and pest management, soil conservation and improvement, soil nutrient and water management and habitat for beneficial insects (Celette et al. 2005; Jacometti et al. 2007; Steenworth and Belina 2008a; Ripoche et al. 2010;).

Cover crops are planted to protect the soil surface and to maintain soil structure (Hartwig and Ammon 2002). There are a variety of cover crop options available, each suited for specific uses. Species selection of cover crop is important in vineyards because the farmer wants to achieve a desired benefit without compromising yield and quality of grapes (Ingels et al. 2005; Walser et al. 2007). A cover crop can be purposely seeded or consist of resident species that cover the vineyard floor (Guerra and Steenworth 2012). If seeding a new cover crop, the existing vegetation should be removed, as it will be a source of competition for the desired cover crop (Olmstead 2006). Cover crops can affect soil properties including soil nitrate (NO_3^- - N) and ammonium (NH_4^+ - N) pools, increase soil organic matter and microorganism populations, offer soil protection from crusting and erosion, improve soil fertility, structure and water holding capacity (Hartwig and Ammon 2002; Morlat and Jacquet 2003; Celette et al. 2008; Steenworth and Belina 2008b; Fourie 2010). Cover crops also help tie up excess nutrients regulating vine growth, suppress weeds and control some pests while providing a habitat for beneficial organisms (Ingels et al. 2005; Tesic et al. 2007). Potential disadvantages include competition with vines for water and nutrients, cost of establishment, need for regular maintenance, increased risk of spring frost, and vine damage from increased rodent populations (Tan and Crabtree 1990; Carsoulle 1995; Ingels et al. 2005; Celette et al. 2008). Cover crops are essential to have included in vineyard management with benefits to the vine outweighing the disadvantages (Salazar and Melgarejo 2005). Tall cover crops can negatively affect temperatures in the fruiting zone due to transpirational cooling by the cover crop (Patrick et al. 2004). Mowing increases exposure to the soil surface allowing for a greater absorption of heat during the day (Patrick et al. 2004). At night, this heat is released into the atmosphere in the vineyard (Patrick et al. 2004). Mowing grasses leaves stubble in the alleyways, which reduces dust, provides traction for equipment and competes with weed species (Olmstead 2006).

Cover crops can be annual, biennial, or perennial herbaceous plants grown in a pure or mixed stand during all or part of the year (Sullivan 2003). The most commonly used cover crops belong to the *Poaceae* (cereal/grasses) and the *Fabaceae* (legumes) families (McGourty and Reganold 2005). In vineyards that would benefit from devigouration and yield reduction, a permanent cover crop can improve soil physical properties and juice quality (Morlat and Jacquet 2003). Cover crop effects on juice quality arises through competition for water and nutrients, which reduces vigor and enhances fruit exposure to the sun (David et al. 2001; Maigre and Aerny 2001). In an attempt to achieve several benefits simultaneously, vineyard cover crops are often a mix of grasses and legumes (Patrick et al. 2004; Olmstead, 2006).

Grasses have fibrous roots that effectively penetrate and aggregate the soil (Colugnati et al. 2004). Grass residue has a higher C:N ratio than that for legumes, resulting in a slower decomposition rate and lower supply of N in grasses for the vines (McGourty and Reganold 2005; Olmstead 2006). Grasses provide large amounts of biomass increasing soil organic matter and reduces soil compaction (Olmstead 2006).

Legumes are broad-leaved annual or perennial species known for their ability to fix N (Ingels et al. 2005; Olmstead 2006; Bair et al. 2008). The N-fixing bacteria that form symbiotic relationships with roots are found on root nodules (Olmstead 2006). A small number of organisms form nodules on roots of the leguminous plants (Olmstead 2006). The soil organisms oxidize the soil organic N compounds to NH_4^+ - N and NO_3^- - N, which are the most available forms of N to plants (Olmstead 2006). Legumes have a lower C:N ratio, allowing them to decompose rapidly after incorporation and better meet microbial N needs (Faria et al. 2004; McGourty and Reganold 2005). Optimum C:N ratios for rapid cover crop decomposition range from 15:1 to 25:1 (Sullivan 2003).

Legume seeds need to be inoculated with the proper strain of bacteria to effectively fix N (Olmstead 2006). Nitrogen is released and available for mineralization after the cover crop begins to decompose (Olmstead 2006). Temperature can be used as a predictor of N release after incorporation of a green manure in vineyard soils (Davenport et al. 2012). Nitrogen also is released when a portion of the roots die from mowing, which maintains a balance between the shoot and root system (Olmstead 2006). Legume root systems include a taproot, which aids in water infiltration (Olmstead 2006). Studies have shown that half of the N fixed by a legume will mineralize during the next growing season and be available to that seasons crop (Patrick et al. 2004).

During establishment, mowing legumes at the flowering stage, and grasses earlier than that, tends to enhance rapid soil coverage (Colugnati et al. 2004). Permanent cover crops that consist of grasses, tends to benefit from N fertilization (Carsoulle 1995; Spring and Mayor 1996; Colugnati et al. 2004). Permanent cover crops have the greatest potential for influencing vine growth and grape quality over time due to longevity of the cover crop planted in the alleyway (Guerra and Steenworth 2012). The fruit produced in cover cropped vineyards is cleaner, free of dust, ripens earlier, colours better and stores better than fruit from a vineyard maintained without cover through cultivation and herbicides (Wrinkler et al. 1974; Pinamonti 1998; Ingels, et al. 2005).

Cultivated rows allow an increased heat transfer of soil back into the air at night reducing the risk of frosts at temperatures close to zero (Naugler and Wright 2006). Cultivation is done to mix, loosen or turn the soil between and around vines (Wrinkler 1974). Although cultivation is detrimental to breaking down soil structure and causing erosion problems, it can be beneficial at controlling weeds, preparing the soil for a seedbed of cover crops and incorporating soil amendments or organic matter to the soil (Wrinkler 1974; Naugler et al. 2006; Steenworth and Belina 2008a). Tillage eliminates surface crusts leading to less surface runoff than when herbicides are the sole means of weed control (Merwin et al. 1994). Tillage reduces the need for chemical inputs on the vineyard (Gaviglio 2007). The main disadvantages of cultivation include soil compaction and loss of structure, cumulative loss of fertility and soil organic matter, risk of damage to vine roots and trunks and contributes to the spread of soil pests and pathogens (Guerra and Steenworth 2012). Cultivation is best kept shallow to avoid damage to vine roots (Lanini et al. 2011). Tillage increases decomposition and mineralization of existing soil organic N pools and plant residues, providing a pool of inorganic N for vine uptake (Guerra and Steenworth 2012).

Other research studies concerning cover cropping as a vineyard management practice have been well documented. A study in a France vineyard indicated that the permanent grass cover crop competed with the vine more strongly than the non-permanent cover crop for N and reduced vine vigor and leaf N (Celette et al. 2009). In South Wales, Australia, a permanent cover crop increased canopy openness and decreased shoot length (Tesic et al. 2007). Ingels et al. (2005) stated that the use of a cover crop would significantly increase organic matter content in vineyards soils overtime. A study in San Joaquin Valley showed that vetch significantly increased soil NO_3^- - N levels within five to six weeks of incorporation (Hirschfelt 1993). The vine N status in the vetch plots was concluded to be similar to treatments receiving 56 kg ha^{-1} of N fertilizer per year (Ingels et al. 2005). The same study also reported a bean/pea/vetch mixture yielded the greatest biomass when used as a green manure as opposed to a clover mixture and a cereal stand. Ingels et al. (2005) concluded the clover mixture produced the least biomass. The bean/pea/vetch mixture also had the highest vine leaf N content and it was significantly higher than clover and bare rows (Ingels et al. 2005). Bair et al. (2008) looked at a legume cover crop of hairy vetch that resulted in a greater supply of available N per unit of biomass to the soil than small grass cover crop used in the study. Tesic et al. (2007) concluded that an increase in floor cover resulted in decreased soil moisture content. Reeve et al. (2005) studied an oat/clover/mustard cover and concluded that it attracted beneficial vineyard insects and fertilized the soil when incorporated. In Boudreaux France, the use of cover crops increased phenolic compounds in the grape juice (Carsoulle, 1995).

Table 1-1. Long-term average (1981-2010) heat unit accumulation in selected Nova Scotia winegrowing regions during the growing season.

Location	Heat Units						
	Total	May	June	July	August	September	October
Bridgewater	1002	65	183	292	278	145	39
Wolfville	1078	71	203	310	290	180	24
Bear River	876	56	162	249	254	121	34
Malagash	1002	45	178	288	255	127	19

(Environment Canada, 2014)

Table 1-2. Long-term average (1981-2010) monthly temperatures in selected Nova Scotia winegrowing regions during the growing season.

Location	Average Monthly Temperature (℃)					
	May	June	July	August	September	October
Bridgewater	11.1	16.1	19.5	19	14.7	9.3
Wolfville	11.5	16.7	20	19.4	15.9	8.6
Bear River	10.9	15.4	18.4	18.3	14.3	9
Malagash	9.8	15.8	19.3	18.2	14	7.9

(Environment Canada, 2014)

Table 1-3. Long-term average (1981-2010) monthly precipitation in selected Nova Scotia winegrowing regions during the growing season.

Location	Average Monthly Precipitation (mm)					
	May	June	July	August	September	October
Bridgewater	105	101	100	81	111	128
Wolfville	85	78	93	79	97	98
Bear River	91	80	85	75	114	111
Malagash	85	81	78	71	118	118

(Environment Canada, 2014)

Chapter 2.0 The Effect of Selected Amendments and Cover Crops on Vineyard Soil Quality and Grapevine Nutrition

2.1 Introduction

Grapes can grow successfully in a wide range of soils, although certain soil properties are required for optimal growth including appropriate range of pH, reasonable rooting depth, moderate soil water holding capacity, and moderate fertility (Naugler et al. 2006; Lasko 2012). Soils that are limiting in some of these characteristics can be improved by modifications such as installing drainage tiles, deep ripping of soil to break up restrictive layers, irrigation, lime application to modify soil pH, and appropriate fertilization (Naugler et al. 2006; Lasko 2012). With soil being the foundation of wine grape production, proper management will result in consistent quality yields with a lower frequency of required inputs and sustained soil quality. Soil fertility needs to be improved and maintained in order to ensure high productivity of grapevines. Vines require adequate nutrients from the soil to be able to grow a healthy canopy that can properly mature the grape clusters (Lasko 2012).

Uncertainty in optimal fertilizer rates can lead to economic losses and harmful consequences to the environment. The sustainable management practices implemented in this project aim at improving soil physical, chemical and biological characteristics of vineyard soils. Effective nutrient management is a critical component of wine grape production not only to improve financial returns, but also to maintain soil quality, and reduce the likelihood of impact on the environment. Almost no natural soils have the characteristics necessary for optimal growth, which means that in nearly all cases soils need to be modified, maintained and managed so that optimal characteristics are enhanced and preserved.

Wine grape production is a relatively young industry in Nova Scotia (NS) but is growing rapidly. With the industry only blossoming, sustainable soil management practices have not been evaluated in NS vineyards. Soil nutrient management recommendations for grape production are not well developed. Further study is required on soil management in relation to the performance of wine grape yield and quality especially in the context of alleyway and soil fertility management. Non-synthetic amendments of interest have not been assessed for their performance on grape quality and productivity and fruit quality or soil quality indicators in NS vineyards. Although the effect of cover cropping with legumes and grasses has been studied, the effect of cover cropping combined with soil amendment application has not been studied in NS vineyards. This research will result in developing research expertise in the area of wine grape nutrient management in NS.

Municipal and industrial by-products may be valuable soil amendments since they contain nutrients required for plant growth and pose little or no risk to the environment when applied appropriately (Campbell 1990; Vance 1996; Mitchell and Black 1997). Soil amendments may be added to manage soil fertility, organic matter, pH and bulk density along with other potential benefits (Hirschfelt 1998; Pinamonti 1998; Ingels et al. 2005; Macleod et al. 2006). In contrast to fertilizer N, which is plant available and easy to quantify, the release of N from organic amendments is dependent on both mineral N content and factors influencing mineralization rates of organic N.

Ground cover management is an important part of vineyard operations (Olmstead 2006; Tesic et al. 2007). Cover crops are planted to protect the soil surface and to maintain soil structure (Hartwig and Ammon 2002). There are a variety of cover crop options available, each suited for specific uses. Species selection of cover crop is important in vineyards because the farmer wants to achieve a desired benefit without compromising yield and quality of grapes (Ingels et al. 2005; Walser et al. 2007). Cover crops can affect soil properties including soil nitrate (NO_3^- - N) and ammonium (NH_4^- - N) pools, increase soil organic matter and microorganism populations, offer soil protection from crusting and erosion and improve soil fertility, structure and water holding capacity (Hartwig and Ammon 2002). The most commonly used cover crops belong to the *Poaceae* (cereal/grasses) and the *Fabaceae* (legumes) families (McGourty and Reganold 2005).

Some soil properties are inherent such as texture, drainage and slope, which cannot readily be altered by management practices (OMAFRA, 1997). Other properties are affected by cultural practices such as soil structure, organic matter, moisture content and ecology. Obstacles grape growers face in Nova Scotia besides the climate are low levels of organic matter and nutrient availability in the soils in part due the acidic soils in the region (Lewis 2008). Without an optimal soil, vines can experience nutrient deficiencies, reduced canopy growth and yield (Naugler and Wright 2006; Lewis 2008). As soils vary widely over the province, each vineyard site needs a specific strategy to build an ideal soil that will promote optimal growth, yield and quality to the vine. This project takes a highly resourceful look at the use of biowaste compost and industrial bi-products in combination with cover cropping in an attempt to protect the soil and improve its quality.

The purpose of this project is to identify optimal sustainable soil management practices for the NS viticulture industry. The effect of soil amendments and cover crops on wine grape yield and quality and selected indices of soil quality will be investigated. Treatments of interest in this project include mussel sediments (MS), municipal solid food waste compost (MSFW), wood ash (WA), and the use of alleyway cover cropping between vine rows.

The specific objectives and hypothesis of this chapter are:

1. To assess the effect of selected soil amendments (SA) and cover crops (CC) on soil and grapevine nutrient status and soil quality.

Ho: There will be no significant effect of SA or CC treatment or their combination on the soil or plant nutrient status and/or quality parameters of the soil.

2. To evaluate the effects of selected SA on the CC above ground biomass and tissue N concentration.

Ho: There will be no significant difference among SA treatments in their effect on CC tissue N concentration and/or above ground biomass.

3. To investigate the residual effects of selected SA on grape yield, quality and soil quality parameters in the year after application.

Ho: There will be no significant residual effects of SA on grape yield, quality and soil quality parameters.

2.2 Experimental Design

The research took place in Crousetown, NS in the LaHave River Valley area of Lunenburg County (Naugler et al. 2004). This study, initiated in 2011, was conducted in a slightly concave section of a 3.24 ha field planted with Léon Millot wine grapes in 1999 at a 1.8 m row spacing. Although the vineyard is located relatively close to the ocean, it lies above the fog line and grapes ripen here at about the same time as areas of the region with more growing degree-days during the growing season (Naugler et al. 2004; Environment Canada, 2014). Spring frosts are rarely a problem but heat unit accumulation in the area varies widely within a short distance (Naugler and Wright 2006). In the LaHave River Valley the moderating effect from the Atlantic Ocean in the winter months is a benefit to vineyards.

The most prominent geological feature of the research site is the south facing glacial drumlin composed of slate till consisting of a large gravel component which contributes to the unique terroir of the wines produced from the grapes (Cann and Hilchey 1958; Naugler and Wright 2006). The till consists of yellowish brown sandy loam or gravelly sandy loam (Cann and Hilchey 1958). The soil type is a Bridgewater loam-drumlin phase soil (Cann and Hilchey 1958). Baseline soil characteristics were taken from composite core samples (0 - 15 cm) in 2011 before the project began and analyzed at the NS Department of Agriculture Analytical Laboratory (Table 2-1). These soil test results are compared to a study done by the Grape Growers of Nova Scotia in 2002, which gave a range of soil test values over six NS vineyards and literature values for adequate levels for each soil nutrient (Table 2-1).

Léon Millot was the grape variety used in this study. It was chosen because it is one of the most vigorous and productive vines in the vineyard that was most consistent over the entire research plot. Léon Millot is a hardy red variety French hybrid grape used for winemaking (Smiley 2010; Lewis n.d.). It ripens mid-season with a nice sugar content and moderate acid making it a popular grape among wine producers (Lewis n.d.). It is a sister to the Marechal Foch grape with the differences being Millot ripens a week earlier on average and has a higher vigour but smaller grape bunch size (Lewis n.d.). Léon Millot is grown on its own rootstock like most hybrid vines. The grape variety was created in 1911 by the French viticulturist Eugene Kuhlmann (Waterkeyn n.d.). It was created from crossing the hybrid grape Millardet et Grasset 101-14 O.P. (*Vitis riparia x Vitis rupestris*) with Goldriesling (*Vitis vinifera*) (Smiley 2010; Waterkeyn n.d.).

The experiment was conducted in 2011 and 2012 as a nested design with four cover crop (CC) treatments as main effects done in triplicate with five soil amendment (SA) factors. In order to evaluate residual effects, each SA subplot had a split for application year (i.e. first year treatment only versus first and second year) giving 120 experimental units. Each experimental unit contained three vines in production. Each sub-plot size was slightly different due to factors such as dead or unhealthy vines. To eliminate variability, three productive vines were chosen for measurable vine characteristics. Vine rows were 1.8 m apart and spacing within the row was 1.0 m between plants. The CC and SA treatments were applied to each side of the measurable vine row in the alleyway with a guard row separating each main effect. Within the measurable vine row, each treatment was separated by single guard vine.

The four CC treatments included: i) an oats, pea and hairy vetch mixture (OPV), ii) oats underseeded with double cut red-clover (ORC), iii) a triple mix of forages which consists of 70% timothy, 15% alsike clover and 15% double cut red clover (TM) and iv) a tilled bare soil control treatment (BS). Seeding rates were based on cover crop guidelines in the *Maritime Guide to Cover Cropping* (Wallace and Scott, 2008).

The SA treatments included: i) synthetic fertilizer blend without N (NDEF), ii) synthetic fertilizer including N (FERT), iii) wood ash (WA) plus supplemental fertilizer, iv) municipal solid food waste (MSFW) plus supplemental fertilizer and v) mussel sediments (MS) plus supplemental fertilizer. The split of the SA sub-plots consisted of i) SA applied in 2011 (1YR) only and ii) SA applied in both 2011 and 2012 (2YR). This allowed the testing of residual and accumulative effects of the SA as they matured and broke down over time. It aimed to provide a better understanding of the long-term dynamics of mineralization and nutrient supply potential of the amendment. All treatments received the same estimated level of nutrients as the FERT treatment based on assumptions described below, with the exception that no N was applied in the NDEF treatment. Having the NDEF treatment allowed a determination of how much N cover crops and soil organic matter supplied to the grape vine. It also permitted observation of N deficiency issues with the grape vines.

Amendment application rates (Table 2-2) were determined according to nutrient application recommendations from 2011 baseline soil samples (Table 2-1) and from previous studies assessing the nutrient bioavailability of WA, MSFW and MS in a greenhouse setting over a twelve week period (Sharifi et al. 2010). Application rates were adjusted for moisture content. To ensure that an appropriate balance of N, K, Mg, S, and B (where appropriate) was provided with each SA treatment, the SA treatment was supplemented with synthetic fertilizer shown in Table 2-2 to meet the minimum nutrient requirements and to provide comparable levels of available plant nutrients (i.e. nutrient application rate was not intended to be a factor). Average composition of WA, MS and MSFW are shown in Table 2-3.

The WA treatment was applied at 6.3 Mg ha^{-1} on a dry weight basis. Using this application rate the estimated total supply of K was 83 kg ha^{-1}, with the assumption that 80% of the total WA potassium was available in the first year. Nitrogen and S were supplied by inorganic fertilizers in the WA treatment at 40 kg ha^{-1}.

For MS, a land application rate of 42,000 L ha^{-1} was used. Based on this application rate 99 kg ha^{-1} of N was estimated to be supplied with the assumption that 40% of the total N is available in the first year. The MS application was supplemented with K fertilizer at 83 kg ha^{-1} to accommodate inadequate levels in the MS (Table 2-2).

Municipal solid food waste was applied at 13.4 Mg ha^{-1} on a dry weight basis based on the assumption that 15% of the total N is available in the first year. To balance the nutrients in the MSFW, 30 kg ha^{-1} N and 83 kg ha^{-1} K was required.

Amendments were applied in a 1.3 m wide band between vine rows in May and lightly incorporated into the soil in 2011 with seedbed preparation. In 2012, the amendments were top dressed on the soil.

Rocks had been previously piled around the base of the vines by the vineyard owner in an attempt to harness heat during the day and keep the microclimate around the vines warmer at night. The land was prepared by tillage with a rototiller pulled by a small tractor. Oats and hairy vetch were broadcast, and then incorporated into the soil; the other cover crop seeds were broadcast on the soil surface without incorporation. After all CC treatments were prepared, the alleyways were packed with a roller. Due to the aesthetic condition that needs to be maintained by vineyards with wineries overlooking them, cover crops were mowed four times; once in mid-June, twice in July and once in early

August. In the second year of the study, the annual OPV cover crop was replanted using the same technique used in year one.

A unique local trellising system, sometimes called the LaHave River Valley trellis, is a low wire trellis that was developed to deal with the wind in the area and early autumn frosts (Naugler et al. 2004). The vineyard calendar begins in March with pruning of unwanted wood from the previous season growth. All vine prunings were left on the ground in the vine rows. In late April, the vine rows without a permanent cover crop were tilled to prepare a seedbed or to remove resident vegetation and incorporate it into the soil before weed seeds have germinated and roots translocate. Fungicide sprays began in mid-June when shoots were at appropriate lengths. Folpan® (folpet) and Nova® (myclobutanil) fungicides were sprayed on the foliage to combat grape cluster and vine disease. Disease control was monitored throughout the rest of the season and was sprayed accordingly. Ignite® (glufosinate ammonium) herbicide was used in all treatments to keep a 0.50 m weed free zone under the vines to minimize competition for nutrients and water. This was applied up to three times during the growing season depending on weed competition, weather and labour restraints. Mowing of weeds under vine rows was necessary when weed pressure was too great. Bird netting, raccoon fencing and deer fencing were used to deter animals from devastating the vines and fruit. Tucking shoots into trellis catch wires began after flowering in early July. The first shoot thinning occurred at this time as well. Hedging the canopy was done in August as vines became excessively vigorous for the low trellising. Cultivating between vine rows and mowing ceased after August as growth in vines does not want to be encouraged at a time they should be slowing down. Léon Millot typically reaches veraison in late August to early

September. A heavy pruning took place at this time to allow the grapes to have direct sunlight, build sugar, and turn dark red. The harvest occurred in mid-October. Previous management to the vineyard has seen no fertilizer or soil amendments applied to plots within the last three years. Only mowing and mulching of resident vegetation has occurred with a lawn tractor. All prunings were left on the vineyard floor.

2.3 Field, Laboratory and Analytical Methods

2.3.1 Soil Sampling

In the first year of the project, an initial soil sample was taken on May 9, 2011 before SA and CC treatments were applied to get a base measurement of soil fertility status. A representative sample of each plot was taken by mixing eight random samples per plot in a bucket and taking a subsample. Each random sample was taken from where the cover crop meets the weed free buffer zone under the vine on the measurable vine row. Soil samples from each plot were taken from a depth of 0-15 cm. Soil samples were taken two more times in 2011: bloom (July 6) and post-harvest (October 31) from the alleyways between vine rows. In the second year (2012) of sampling, a 7 cm diameter soil auger more suited for dealing with the soil conditions was used to collect 0-15 cm depth samples on April 28, July 6 and October 20. Soil samples were placed in a cooler with ice packs until they were placed in a refrigerator and stored at 4°C until analysis.

2.3.2 Soil Properties

2.3.2.1 KCl Extractable $N0_3^-$ - N and NH_4^+ - N

The NO_3^- - N and NH_4^+ - N were analyzed in all soil samples in 2011 and 2012. Fresh soil sieved at 2 mm was used for this analysis. The NO_3^- - N and NH_4^+ - N were extracted with a 2M KCl extraction (Maynard et al. 2007). A 5:1 volume ratio of KCl solution to soil sample was used. Extracts were frozen until concentrations of NO_3^- - N and NH_4^+ - N were measured colorimetrically using a Technicon Auto Analyzer II (Technicon Industrial Systems 1973; Technicon Industrial Systems 1978; Parent and Caron 2008).

2.3.2.2 Total Soil N and C

Percent total soil N (N_{tot}) was measured in May 2011 and April 2012 soil samples using the Dumas method (Rutherford et al. 2008). The sample was air dried and sieved at 2 mm then ground with a mortar and pedestal. Total soil N and C was measured using an Elementar Vario MAX CNS analyzer (Skjemstad and Baldock 2008; Elementar Analysis Systems 2013).

2.3.2.3 $NaHCO_3^-$ Extractable N

The $NaHCO_3^-$-extractable N was determined as described by Fox and Piekielek (1978) and Hong et al. (1990). $NaHCO_3^-$ extractable N was measured in July 2011 and July 2012 fresh soil sieved to 2 mm. $NaHCO_3^-$-extractable N is an index of soil mineralizable N and is sensitive to management practices that influence available N such as fertilizer and manure. $NaHCO_3^-$ was used to extract N from the soil to produce a filtered soil extract that was read on a microplate on a Thermo Scientific Evolution 60s UV-Visible Spectrophotometer (Thermo Scientific 2009). The UV absorbance of the extract was measured at 205 and 260 nm. Mineral N plus dissolved organic N (DON) was measured at an absorbance of 205 nm and DON was measured at an absorbance of 260 nm (Serna and Pomares 1992). Concentrated HCl was added to 205 nm absorbance samples to eliminate HCO_3^- interference. Each sample was done in duplicate. Samples were stored in a fridge at 4°C and analyzed within three days of $NaHCO_3^-$ extraction.

2.3.2.4 Particulate Organic Matter C and N

Particulate organic matter (POM) is a size fractionation of physically uncomplexed organic matter that is composed of particles of organic matter that are not bound to soil mineral particles and can be isolated from soil by size fractionation. A 25 g fresh soil sample sieved at 2 mm was used from July 2011 and 2012 sampling dates. The POM was recovered on a 53 µm sieve and is a quantifiable component of the whole soil organic matter ranging in size from 53 to 2000 µm in diameter (Gregorich and Beare 2007). The POM was recovered by washing the sand sized material and macro-organic matter, such as small roots and partially decomposed plant material, from the sieve into a pre-weighed drying tin using a wash bottle. It was left to evaporate overnight then oven dried at 60ºC. Samples were then taken and analyzed for C and N concentrations by dry combustion using an Elementar Vario MAX CNS analyzer (Skjemstad and Baldock 2008; Elementar Analysis Systems 2013). Masses of C and N per gram of air-dried soil were calculated as particulate organic matter carbon (POMC) and particulate organic matter nitrogen (POMN).

2.3.2.5 Microbial Biomass C

The chloroform fumigation extraction method was used as an index of soil microbial biomass C (MBC) (Voroney et al. 2007). Fresh soil was used from the July 2011 and 2012 sampling dates under the TM cover crop and all SA treatments. Samples were subject to chloroform fumigation for 24 hours followed by K_2SO_4 extraction. Samples were frozen until concentrations of dissolved organic C in the extract were measured using a Technicon Auto Analyzer II (Technicon Industrial Systems 1973; Technicon Industrial Systems 1978; Parent and Caron 2008).

2.3.2.6 Soil Physical Properties

Bulk density was measured in initial samples each season and sampled by adapting to the stony conditions at the vineyard as described by United States Department of Agriculture (USDA) (2001). A calculation to determine the bulk density was then completed and presented as grams of soil per cubic centimeter. Percent organic matter was determined by the loss on ignition method (Donald and Harnish 1993).

2.3.2.7 Phosphorous, Potassium and Micronutrients

Soil P, K and micronutrients were determined for May 2011 and April 2012 samples by Mehlich III extraction and was analysis of extract by inductively coupled plasma (ICP) emission spectrometer where complete ionization occurs to measure mineral concentrations (Ziadi and Sen Tran 2008).

2.3.2.8 Soil pH and Cation Exchange Capacity

Soil pH was determined using a 1:1 ratio of dry soil to deionized water as described by the USDA (2001). Cation exchange capacity (CEC) was determined by at Nova Scotia Agriculture Laboratory Services (NSALS) through calculation (NSALS, 2011). Soil pH and CEC were measured in May 2011 and April 2012.

2.3.3 Grapevine Characteristics

2.3.3.1 Trunk Diameter

Grapevine trunk diameter is considered an important indicator of grapevine growth characteristics. The vine growth was measured once in 2011 and at the three soil sampling dates in 2012 to give a full year of data. The diameter was calculated using geometry by taking the circumference of each measurable vine using a flexible measuring tape 15 cm above the ground. The trunk diameter was measured to see if it could be used as a covariate but it could not.

2.3.3.2 *Spring 2012 Dry Pruning Weight*

The growth of vines in 2011 after the last pruning was determined by measuring the biomass removed when the plants were pruned in early 2012. This initial pruning removed any vine shoots that would not be required for the 2012 growing season therefore showing the vigor of each plot's vines in the previous year (2011).

2.3.3.3 *Whole Leaf Nitrogen*

Whole leaf N was measured at flowering in the first week of July for both years. Whole leaf N status is a good indicator of plant N and is commonly used by vineyard managers as a way to budget N applications for the vineyard. In NS, the leaf and petiole opposite the first newest flower cluster on the terminal end of the shoot is used. Approximately 20 - 25 representative leaves and petioles from each plot were collected. These samples were dried in a crop dryer at 60°C for 48 hours then placed in a Thompson Wiley Mill and ground to 2mm. The samples were then analyzed using an Elementar VarioMAX CNS analyzer (Skjemstad and Baldock, 2008; Elementar Analysis Systems, 2013).

2.3.4 *Cover Crop Growth and Nitrogen Content*

Cover crop samples were collected from the field using one 0.50 m^2 quadrant per plot. All matter inside the quadrant was cut at 6 cm, which was the height it was being mowed. Samples were then stored on ice in coolers until their biomass was weighed. The samples were then dried at 60ºC for a minimum of 48 hours. After the samples were dried, they were separately ground to 2 mm on a Thomas-Wiley Mill and placed in a 7 mL vial until analysis. In 2011, only the grass from the triple mix (70% timothy) was analyzed as a representation of the N in TM grass. In 2012, biomass from all of the CC plots was sampled once in mid-June, twice in July and once in early August to coincide with mowing. This was weighed and recorded as a sum of fresh biomass growth over the season. In 2012, the cover crop total C and N was measured once by taking an aliquot from the grinded biomass sample, which encompassed a full season of growth. Total cover crop C and N was measured using an Elementar VarioMAX CNS analyzer (Elementar Analysis Systems 2013).

2.3.5 Statistical Analysis

Data on all the parameters and response variables were subjected to analysis of variance (ANOVA) using the GenStat statistical package (VSN International 2011). An ANOVA test was used to evaluate the 3-way treatment combination of CC x SA x application year (APP). Planned comparisons were used to compare specific treatments and determine if results were significant at a 0.05 or 0.01 probability level. Planned comparisons for the main effects were as follows. For CC, the comparisons analyzed were; a) BS vs. cover crops, b) legume based cover crops (OPV+ORC) vs. grass based cover crops (TM) c) ORC vs. OPV. These allowed a comparison of a soil with no cover to one with cover, the legume based cover crops to the grass based cover crops and finally to compare the two legume based cover crops of ORC and OPV. The planned comparisons used for the SA were; a) NDEF vs. FERT+MS+MSFW+WA, b) FERT+WA vs. MS+MSFW, c) MS vs. MSFW, d) FERT vs. MS. The first would allow analysis of N from cover crops on the NDEF treatment compared to others. The WA behaved more like an inorganic fertilizer in previous studies, with most of its nutrients in inorganic form, so it was grouped with FERT to assess how FERT and WA performed against MS and MSFW amendments, which were also similar products. The third comparison between MS and MSFW allowed an assessment of how these natural products would compare to one another. The final comparison of FERT and MS was done because little research has been done on MS and how comparable it would be to synthetic fertilizer to supply nutrients to vines. In previous greenhouse studies, it was noted that MS has more available N than other soil amendments being used (Sharifi et al. 2010). The APP was also a main effect used to assess whether cumulative or residual effects were significant. Interaction effects grouped these comparisons together between SA, CC and APP. A covariate of vine location was used in this project between blocks, which helped to account for spatial variation, as each measurable effect was done in triplicate over the area of the research block.

2.4 Results and Discussion

2.4.1 Soil Properties

2.4.1.1 Soil Mineral Nitrogen

Soil NH_4^+ - N averaged 0.92 kg ha^{-1} to 1.32 kg ha^{-1} over the 2011 season. There were significant differences in NH_4^+ - N observed among SA treatments in July 2011 (Table 2-4). The NDEF plots contained significantly less NH_4^+ - N than other soil amendments ($p = 0.045$). While WA plots showed the greatest NH_4^+ - N in the soil in July 2011 (1.41 kg ha^{-1}) there was no significant differences between WA and other soil amendment treatments.

In 2012, soil NH_4^+ - N averaged 1.19 to 8.69 kg ha^{-1} among sample dates. In April 2012, significant differences in NH_4^+ - N were observed among SA treatments (Table 2-4) with the FERT and WA plots containing significantly less NH_4^+ - N than MSFW and MS plots ($p = 0.002$). Other significant comparisons in 2012 were found in October soil samples where significant differences in NH_4^+ - N were observed among CC treatments (Table 2-4). The BS plots contained significantly less NH_4^+ - N than plots with a cover crop (p = 0.033) and the ORC plots contained significantly more NH_4^+ - N than OPV plots (p = 0.050).

Soil NO_3^- - N overall mean values in 2011 were 3.52 kg ha^{-1} in May, 38.49 kg ha^{-1} in July and 10.59 kg ha^{-1} in October. There were no significant treatment effects on soil NO_3^- - N in 2011. In July 2012 significant differences in NO_3^- - N were observed among SA treatments (Table 2-4). The NDEF plots contained significantly less NO_3^- - N (p=0.010) than other soil amendments and MS plots contained significantly less NO_3^- - N than MSFW plots (p=0.014). In the October 2012, main effects did not significantly affect soil NO_3^- - N; however, the interaction between CC and SA led to significant differences in soil NO_3^- - N (Table 2-4). The first significant comparison was that cover cropped plots amended with the MSFW treatment had higher soil NO_3^- - N than in the MS treatment (p = 0.010). The second significant comparison was that legume-based cover crop plots amended with the FERT treatment had higher soil NO_3^- - N than in the MS treatment (p = 0.011). The third significant comparison was that ORC plots amended with the FERT treatment had higher soil NO_3^- - N than in the MS treatment (p = 0.001).

The significant differences in soil NH_4^+ - N among SA treatments in July 2011 (Table 2-4) could have been due to NDEF plots receiving no N fertilization and that cover crops were not established enough to provide any benefit. The significant difference among SA in April 2012 could be from the residual nutrients remaining from MS and MSFW application in 2011. Although these differences are mathematically significant, their biological significance is limited. The October 2012 sampling occurred when most vegetation was dead which could have led to increased NH_4^+ - N values in the soil. The increase in NH_4^+ - N at this sampling date could be attributed to the decomposing vegetation that was in the soil at this time compared to 2011, from cooler autumn temperatures. The BS plots contained less NH_4^+ - N possibly because there was added N from legumes in cover crop plots that could not mineralize to NO_3^- - N due to the low temperatures. As described below, the OPV plots had much less vegetation than the ORC plots in October 2012 which could have led to the ORC plots having an increased soil NH_4^+ - N concentration this late in the season. The overall seasonal NH_4^+ - N trend was expected as the conversion to NO_3^- - N becomes inhibited at the end of the season producing more NH_4^+ - N as well as the added NH_4^+ - N from legume based cover crops were evident as also seen in Sawyer (2014). Stamatis et al. (1996) evaluated the soil NH_4^+ - N levels in organically and conventionally managed vineyards in Greece where NH_4^+ - N in both types of management were greater than what was observed in this study. Lower NH_4^+ - N levels were found in this study when compared with soils used for annual crops. (Sharifi et al. 2007; Sharifi et al. 2008a; Dessureault-Rompré et al. 2010; Sharifi et al. 2011c). Davenport (2012) also found very low NH_4^+ - N soil test values in an organically managed vineyard. This is expected, as vines require minimal N compared to other crops and due to lack of input into the soil in the past.

The lack of significant differences among treatments for the 2011 NO_3^- - N data shows that the experiment started with similar NO_3^- - N values between treatments and that there were no noticeable differences between treatments NO_3^- - N concentrations in the first year. In both 2011 and 2012 there was an increased concentration of NO_3^- - N in mid-season sampling dates due to soil organic matter mineralization from increased temperature but still low uptake by cover crops and vines. The large increase in NO_3^- - N that occurred in July 2011 was attributed to the release of N from the recently incorporated native vegetation of broadleaf weeds and clover before the cover crops were planted in their respective plots. The significant differences between SA treatments in July 2012 was expected because the only N input in NDEF plots was from cover crops while the MS may have contained a smaller amount of total organic N to mineralize than MSFW. The significant interaction between SA and CC in October 2012 resulted in combinations that had higher soil NO_3^- - N values than others. The first significant comparison where cover cropped plots amended with the MSFW treatment had higher soil NO_3^- - N than in the MS treatment was due to the cover crop interacting with the MSFW and stimulating an N release possibly because the biology of the soil. This created a greater availability of NO_3^- - N in MSFW than previous greenhouse trials predicted. The N in the MSFW also may have mineralized slower and later in the fall when the vine utilization was low whereas, the aqueous MS product penetrated into the soil earlier in the season and mineralized.

The second significant comparison was where the legume-based cover crop plots amended with the FERT treatment had higher soil NO_3^- - N than in the MS treatment where in grass-based cover cropped plots FERT and MS had similar results. This was significant because the available N in MS was lower than assumed from greenhouse trials where FERT treatments had N available upon application. Legume based cover crops performed better in FERT treatments and provided more N to the soil compared to TM. The MS was also top dressed in 2012, which may have smothered out cover crops, due to the crusting that occurred, preventing them from capturing N to later supply to the vine.

The third significant comparison was that ORC plots amended with the FERT treatment had higher soil NO_3^- - N than in the MS was significant because the FERT supplied the ORC with more available nutrients during the season which allowed the ORC to better establish and capture N. The MS being top dressed in 2012 probably also contributed to this difference, as ORC was the most established cover crop at the time of application.

Sharifi et al. (2011c) found that fertilizer history and crop rotation could potentially affect soil N mineralization. The July sampling of both years had an increase in NO_3^- - N values. Besides the incorporation of the native vegetation in June 2011, the other factor is that the soil is warmer at this time and most active with soil organisms breaking down organic matter. It is also the time of most rapid nutrient uptake for the vine. The mid-season soil samples were the first sampling after application of soil amendments. For wine grape production, this was a good balance of N in the soil because the most N was available to the vine when it was required and the least amount of NO_3^- - N over the sampling dates was in October when the vine wood needs to harden and not continue to grow. Stamatis et al. (1996) evaluated the soil NO_3^- - N levels in organically and conventionally managed vineyards in Greece where NO_3^- - N in both types of management were greater than what was observed in this study. Davenport (2012) observed NO_3^- - N levels in an organically managed vineyard with values higher then observed in this study. Lower NO_3^- - N levels were found in this study when compared with soils used for annual crops (Hong et al. 1990; Sharifi et al. 2008a; Sharifi et al. 2011c). This was expected in the rocky vineyard soil where N management had not been included in the management of the property but also because N is not required in large amounts by the vines in general.

2.4.1.2 Soil Total Nitrogen

In 2011, the interaction between CC and SA led to significant differences in N_{tot} as shown in Table 2-5. There were two significant interactions, both involving legume based cover crops. The first significant comparison was that in ORC plots amended with MS were higher in N_{tot} than if amended with MSFW (p = 0.022). The second significant comparison was that the OPV plots amended with MS were higher in N_{tot} than if amended with FERT (p = <0.001).

In 2012, N_{tot} was significantly different between SA (Table 2-5). The MSFW and MS treatments had significantly greater N_{tot} than FERT and WA treatments (p = 0.003) while the MSFW treatment contained a significantly greater N_{tot} than MS treatments (p = 0.003).

In 2011, under the SA main effect, MSFW was marginally greater than MS, but, in the CC and SA interaction due to the influence of ORC, the MS in combination with ORC had significantly greater N_{tot} than MSFW. The ORC cover had a greater percent biomass yield with a MS amendment than MSFW, discussed below, which most likely led to the increase of N_{tot}. This difference in cover crop growth (Table 2-11) could be due to the variability of available nutrients in the raw MS product as well. The second interaction can be explained by the MS raw product containing greater %N compared to FERT. Coulter et al. (2009) also found N_{tot} was influenced by cropping system. The higher N_{tot} can be attributed to greater residue from production of cover crop biomass and organic N in the amendments. The N_{tot} was significantly affected by amendments in this study, which does not support Havlin et al. (1990) research that concluded cover cropping had the greatest effect on N_{tot}. The significant differences of N_{tot} between SA in

2012 may have been due to MS and MSFW containing more N_{tot} than FERT as most of the MSFW and MS nitrogen was not in a plant available form at the time of application according to previous studies (Sharifi et al. 2010). The MSFW raw product containing significantly greater N_{tot} than the MS raw product can possibly explain the significant differences between MSFW and MS. Hargreaves et al. (2008b) found that MSFW treatments significantly increased total N compared to other amendments in the study. The N_{tot} was low compared to other studies that assessed this soil quality factor (Deng et al. 2000; Coulter et al. 2009). Although N_{tot} results were statistically significantly different, the biological significance is limited. The low N_{tot} at this site could be attributed to N losses, which occur mainly through leaching surface runoff, denitrification and the overall low quality and texture classification of the soil.

2.4.1.3 $NaHCO_3^-$ Extractable Nitrogen

In 2011, $NaHCO_3^-$ extractable N was significantly different between CC treatments at 205 nm (Table 2-5) where the ORC was significantly greater than OPV ($p = 0.034$) and the BS plots were significantly less than the cover cropped treatments ($p = 0.038$). At the 260 nm reading the $NaHCO_3^-$ extractable N was different between SA treatments (Table 2-5) where the MSFW treatment was marginally higher than MS.

In 2012, SA and APP effects showed significant differences among treatments in the 205 nm extractable N samples indicating that treatments only affected extractable mineral N and not DON (Table 2-5). The SA had significant differences among treatments where NDEF plots had a significantly lower absorbance at 205nm than the average of N containing SA and the MS treatments had a significantly lower absorbance at 205 nm than MSFW treatments ($p=0.021$). The other significantly important result was that plots receiving an amendment application in 2011 and 2012 were significantly greater at the 205 nm absorbance than the plots that only received amendment in 2011 (p=0.001).

Measuring $NaHCO_3^-$ extractable N is an essential tool for estimating N mineralization and determining the rate of N fertilization application requirements to optimize vine yield and grape quality and to minimize adverse impacts of excessive N on the environment (Sharifi et al. 2007). Although most soil contains a large quantity of organic N, most of this is stabilized and resistant to microbial degradation, whereas a small portion is labile and a source of N for mineralization (Stanford and Smith 1972; Parton et al. 1987). The size of the mineral N pool is based on crop management, amendment history abiotic and biotic soil characteristics and various environmental factors (Griffin 2007).

In 2011, the significance between CC treatments was mainly caused by the added benefit of cover crops to the soil N that the BS plots did not have. The ORC had a greater biomass than OPV and therefore most likely contributed a greater amount of N to the soil causing the ORC 205 nm extractable N results to be significantly greater than OPV. In 2011, SA was significant between MSFW and MS at 260 nm, which could have been due to the MSFW containing a greater %N. The soil also may have been altered from previous management of these plots or because MSFW contained less available N than initially measured at application.

With the only significance between treatments occurring at 205 nm in the 2012 season, it can be stated that mineral N had a significant impact on this soil quality indicator and dissolved organic N was not as important. The significant effect of application years (APP) was expected because of the added application of SA in 2012 and the influence of legumes in cover crop biomass production. The significant effect of SA at 205 nm in 2012 was expected and attributed to NDEF plots not receiving the supplemental N that other plots did. The MSFW may have contained more available N than predicted in greenhouse studies making the MSFW 205 nm absorbance higher than MS treatments.

The $NaHCO_3^-$ extractable N measurement can be used as an early indicator of soil quality changes in N composition. Absorbance values at 205 nm were in the lower spectrum of literature values while 260 nm absorbance values were lower than values found by other research thus limiting mineralizable N from the soil in this study (Michrina and Fox 1982; Norman et al. 1985; Hong et al. 1990; Serna and Pomares 1992; Sharifi et al. 2007). Hong et al. (1990) found that UV absorbance at 200 nm was well correlated with soil NO_3^- - N and that 260 nm was well correlated with total soil N and organic matter content of the soil. Hong et al. (1990) further went on to describe that 200 nm absorbance would be a good index of N supply capability. Sharifi et al. (2007) determined that dissolved organic N and mineralizable N were highly correlated to UV absorbance at 205 nm while 260 nm was highly correlated with potentially mineralizable N. Although most soil contains a large quantity of organic N, most of this is stabilized and resistant to microbial degradation, whereas a small portion is labile and a source of N for mineralization (Stanford and Smith 1972; Parton et al. 1987). Sharifi et al. (2008b) found UV absorbance at 205 nm and 260 nm to be a good predictor of soil N supply to crops.

2.4.1.4 Particulate Organic Matter

Cover crop treatments significantly affected POMN and POMC in 2011 (Table 2-6) where BS plots had significantly less POMN (p = 0.015) and POMC (p = 0.005) than plots with cover crops. The legume based cover crop treatments contained significantly less POMC than the TM treatments (p = 0.05) and POMC was marginally higher in the ORC than the OPV treatment (p = 0.06). A marginally significant interaction between CC and SA for POMC was observed in 2011 (p=0.07). No significant CC or SA effects were observed on POMC in 2012 while POMN was only marginally different among CC in 2012 where BS had less POMN than treatments with a cover crop (Table 2-6).

Changes in POMC represent early signs of soil management changes, which were implemented in 2011 at the vineyard. POMC and POMN were significantly different between cover crop treatments in 2011, which may have been due to the extra tillage disturbance in BS plots lowering POM in the soil as it is diluted into the soil where microbes can access it. The aggregates of soil are also broken up with tillage and organisms can more easily assess them to decompose the OM. The roots and plant residue from cover crops can be a direct source of POM. The grass based TM plots contained a higher POMC possibly because it has a higher percentage of grass, which has a higher C:N ratio than the legume-based cover crops. Wander and Bidart (2000) reported higher POMC and POMN in the top 5 cm of a cover-cropped soil than a soil that was tilled and left bare, which agrees with the results found in this research. This layer of soil organic matter benefits from the cover crop biomass decaying (Christensen, 1992). The POMN that was greater in cover cropped plots in 2012 was expected because of improved soil structure and added N from legumes. The POMN and POMC followed a similar pattern to each other over the two-year study. The values for POMC and POMN are low relative to previous research studying POM (Sharifi et al. 2007; Coulter et al. 2009). This further concludes that the soil in the vineyard research plot was not high in N or organic matter resulting in these low values.

Light fraction organic matter has been considered a good indicator of soil N changes (Curtin and Wen 1999). Short-term differences in soil organic matter resulting from cropping systems and N fertilization are most pronounced with the POM fraction of soil organic matter (Wander 2004). The quantity and quality of POM depends on soil (pH, mineralogy, aeration and nutrient status), plant (plant litter), and climatic conditions (temperature, moisture). Due to the relative availability of C in POM it may immobilize N in the early stages of decomposition. POM is especially important to N retention and availability in sandy soils. Coulter et al. (2009) also found that POMC was affected by the combination of fertilizer and cropping system. It was also noted that POM is more responsive to crop and soil management than total soil organic matter. This study found that the choice of cover crop had a larger influence on POMC and POMN than the choice of N fertilization.

2.4.1.5 Microbial Biomass

Microbial biomass carbon was determined for all SA treatments in only the TM and BS plots. In 2011, there were no significant differences in MBC between treatments. In 2012, there was a significant interaction effect between CC and SA for MBC in the plots (Table 2-7). The first significant comparison was that in BS plots amended with the MS treatment had a higher MBC than if the FERT treatment was used ($p = 0.034$). The second comparison was that TM plots amended with MSFW were marginally greater in MBC than the MS treatment (p = 0.074).

The soil fumigation makes some of the humic fractions of soil more available for degradation and it is the most widely applied technique for estimating MBC. It is possible that the added organic matter resulted in increased MBC in the MS plots. Carter and MacLeod (1987) also found that the effects of a soil amendment (semi-solid beef manure) application had greater positive effect on MBC than synthetic fertilizers. The results obtained from this study were low when compared to these other results, which was expected from this perennial semi-stable agricultural system with low inputs and disturbance (Sharifi et al. 2007; Sharifi, et al. 2008b; Sharifi et al. 2011c). Wander et al. (1995) and Shannon et al. (2002) observed significantly higher MBC in soils under organic compared to conventional management. The highly carbonaceous material in vine prunings could have served as an energy source for microbial growth. According to Ross (1987), crop residues can have a large effect on MBC, which in turn affect the ability of soil to supply nutrients to plants through SOM turnover.

The microbial biomass is an agent in the transformation of added and native organic matter and acts as a labile reservoir for plant- available N, P, S (Jenkinson and Ladd 1981). The activity of the soil MB is commonly used to characterize the microbiological status of soil (Nannipieri et al. 1990) and to determine the effects of field management. The fluctuations could be due to variations in the soil moisture and temperature and stage of plant growth (Campbell et al. 1999). Few differences were observed in this study, possibly due to inherent soil variability.

2.4.1.6 Soil Physical Properties and Nutrient Composition

The following properties were measured in July 2012;

There were no significant differences in organic matter between the treatments, which ranged from 2.97-3.27%. A regular supply of organic materials such as compost and mulches is necessary to raise the percent organic matter in the soil because exposed soils low in organic matter can experience a greater loss of C to the atmosphere as CO_2. Two of the best ways to increase organic matter content is to add compost and grow CC (Cantisano 1997).

The P_2O_5 soil test values were significantly different between SA treatments (Table 2-8). The MS plots had a significantly lower level of P_2O_5 than the MSFW treatment ($p = 0.001$).

No P fertilizer was applied to any plots because the research site had adequate to excessive soil P_2O_5 levels at the onset of this study (Table 2-1). Some SA did contain P as can be seen by test results on SA nutrient status (Table 2-3); there was a small amount of P in the MS and MSFW products with slightly higher amounts in MSFW than MS (Table 2-3).

The K_2O soil test values were significantly different among SA treatments (Table 2-8) where NDEF plots had lower K_2O values than the other soil amendment treatments ($p = 0.047$) and the MS treatment had lower K_2O than FERT treatments ($p = 0.006$). The WA and FERT treatments were marginally greater in K_2O than MSFW and WA treatments ($p = 0.070$).

The MS product could have possibly contained different %K than laboratory results showed due to the variability of the product (Table 2-3) resulting in less available K than FERT. Although the NDEF had significantly less K_2O than other soil amendments, it was not biologically significant as the level of K_2O in NDEF was still in optimal range. Potassium has shown to affect the availability of Ca, Mg and N (Cantisano 1997). Calcium can inhibit the uptake of K (Cantisano 1997). Much of the K is retained in the leaf after harvest and is composted into the soil over winter. The application of K has shown to increase vine growth, increasing pruning weights and trunk growth. Potassium has also shown to affect berry ripening and colour intensity (Cantisano 1997). All plots are within acceptable ranges of soil K for grape production (NSDAF 2004; NSALS 2012).

Sulfur (S) was significantly different between SA treatments (Table 2-8). The FERT and WA treatments had significantly greater amount of S than MSFW and MS treatments ($p = <0.001$). The FERT treatment had a significantly greater amount of S than the MS treatment ($p = 0.002$).

Plots receiving S from synthetic fertilizer had a greater level of available soil S than if S was applied using non-synthetic sources. The result is that MSFW and MS plots should have supplemental sulfur added or soil amendments that use no synthetic fertilizer S should be applied at a higher rate. Sulfur is used by some soil microbes for organic matter decay. Legumes require large amounts of available S. Nitrogen and S commonly enter the plant in unison to form plant proteins (Cantisano 1997). The average S levels in all plots are below literature values (GGNS 2004; NSALS 2012). A long-term study could be conducted to assess the effects of treatments on soil S.

Magnesium (Mg) values were significantly different among SA treatments (Table 2-8). Magnesium was significantly greater in NDEF plots than the other soil amendment treatments (p = 0.008). The MFSW treatment had a significantly greater amount of Mg than MS treatment (p = 0.028). There was marginally significant pattern that WA and FERT treatments were statistically greater in Mg than MSFW and MS treatments (p = 0.085).

Mehlich III extractable Mg content was significantly higher for the MSFW treatment than the MS treatment despite comparable levels of Mg in the product and overall higher application of Mg applied with the MS. This indicates that the Mg was more readily available in the MSFW. Majer (2004) showed higher levels of Mg increased harvested yield. Wolf et al. (1983) found that plots with increased N levels have lower Mg, which would explain why NDEF has higher levels than other treatments. Most Mg uptake during the season is stored in the vine material (Cantisano 1997). Wen et al. (1999) and Hargreaves et al. (2008b) suggested that soils with high levels of Ca, from application of Ca rich material, might depress the amount of extractable soil Mg. This may have been the case as Table 2-3 shows where the MS had more Ca present in its raw product than MSFW did.

Calcium (Ca) was significantly different among SA treatments (Table 2-8). The NDEF plots contained significantly less Ca than the other soil amendment treatments (p = 0.005). The FERT and WA treatments had significantly less Ca in the soil than MSFW and MS treatments (p = <0.001). The MS treatment had a significantly greater concentration of Ca than FERT treatment (p = <0.001).

The MS and MSFW amendments contained Ca in their raw product, which could have led to greater concentrations in the soil compared to WA and FERT treatments (Table 2-3). Low Ca can cause poor fruit set and plant growth. Wolf et al. (1983) found that with increasing soil K concentrations, Ca will also be increased which agrees with results in this study. Hargreaves et al. (2008a) indicated that increased soil Ca occurred when MSFW was applied although (Hargreaves et al. (2008b) saw no effect on Ca from MSFW application.

Soil copper (Cu) concentrations were marginally different among CC treatments (Table 2-9). The ORC treatment had a greater concentration of Cu than the OPV treatment.

Although not statistically significant, it should be noted that Cu concentration in WA was double that in MSFW and 25 times higher than that in MS (Table 2-3). Copper deficiency in the vineyard is rare. It is known to be involved in the hardening of canes and shoots at the end of the growing season. Excessive Cu in the soil can be considered toxic to plants and soil fungi. The higher Cu levels in this vineyard soil could be attributed to late season Cu sprays in the past.

The concentration of extractable iron (Fe) in soil was significantly different among SA treatments (Table 2-9). The FERT treatment was significantly lower in Fe than MS treatments ($p = 0.004$) while there was a marginally higher extractable Fe in the MSFW treatment than the MS treatment ($p = 0.095$).

This significance can be explained because MS and MSFW contained Fe in their raw product where the FERT treatment did not receive supplemental Fe. Table 2-3 shows that on average MS raw product did contain more Fe than MSFW, which does not agree with the result. Chlorophyll concentrations could be measured to determine if the Fe concentration is in an acceptable range, for the vines (Bertamini and Nandunchezhain 2005). Deficiency symptoms usually occur in cool wet weather when Fe movement in the soil is very slow. Deficiency symptoms usually seen in soils that have relatively high Ca content (Pearson and Goheen 1988). Iron deficiency can also lead to fruit drop, affecting yield (Bertamini and Nandunchezhain 2005). Iron is an important factor in legume N-fixing crops. The Fe levels in the vineyard soil are within an acceptable range for wine grape production in NS (NSALS 2011). The differences within treatments are more than likely due to lab or soil sampling variability.

Manganese (Mn) soil concentrations were significantly different among SA treatments (Table 2-9). The NDEF treatment was significantly lower in Mn than other soil amendment treatments ($p = <0.001$). The FERT and WA treatments contained significantly higher levels of Mn than MS and MSFW ($p = <0.001$). The MSFW treatment contained higher levels of Mn than MS treatment ($p = 0.025$). The interaction of SA and CC led to marginal differences in soil Mn ($p = 0.089$).

This significant interaction can be attributed mainly to the WA where it is evident that WA contained a high level of Mn (Table 2-3). Manganese deficiency can affect the growth of berries and shoots and may delay veraison (Pearson and Goheen 1988). Manganese levels in all treatments were in the optimal range for vine nutrition (NSALS 2011).

Zinc (Zn) soil concentrations were significantly different between SA treatments (Table 2-9). The NDEF plots contained significantly less Zn than other soil amendment treatments (p = <0.001). The MSFW treatment contained significantly more Zn than the MS treatment (p = <0.001). The FERT treatment contained significantly more Zn than MS treatment (p = <0.001).

These significant results could be the result of traces of Zn in WA, MS and MSFW amendments (Table 2-3). Zinc may become deficient in sandy soils, soils with a high pH, soils with high P content and soil where the topsoil has been removed (Pearson and Goheen 1988). Low levels of Zn have been shown to affect fruit set (Holzapfel et al. n.d.). All plots had Zn concentrations in optimal range for vine growth (NSALS 2011).

Boron (B) was the final element that was analyzed in the soil at the vineyard. Boron was significantly different among SA treatments (Table 2-9). The NDEF plots contained significantly less B than other soil amendment treatments (p = <0.001). The average of FERT and WA treatments contained less B than the average of the MS and MSFW treatments (p = 0.002) although the WA contained more B than all other soil amendments. The MS treatment had significantly greater concentration of B than FERT treatment (p = <0.001).

The results show that MSFW and MS treatments may have contained a greater percentage of B than was applied with synthetic fertilizer treatments. The reason the WA and FERT was significantly less than MS and MSFW in soil B comes mainly from the FERT treatments. The WA treatment contained the greatest concentration of B from the soil samples and should be tested to ensure that the application of WA does not cause toxic B levels in the soil. The WA also contained the most B in the raw product (Table 2-3). The B in all test plots fell within the optimal range for wine grape production (NSALS 2011). From the 2011 sampling to 2012 sampling an average increase of 0.26 ppm B was reported which was a benefit because in the 2011samples B was deficient in some plots (B<0.5ppm). High rainfall can result in B leaching out of the soil profile in sandy soils (Pearson and Goheen 1988). Christensen (1986) suggested that small amounts of a ground application should be used over a foliar spray and every season rather than every couple of years. Hargreaves et al. (2008b) found that soil B concentrations were significantly greater in MSFW than other amendment treatments. Wojcik (2005) and Hargreaves et al. (2008b) found B additions to soil deficient in B increased yield.

2.4.1.7 Soil pH

In 2011, there were no significant differences of soil pH between treatments. In 2012, pH was significantly different among SA treatments (Table 2-10). The NDEF plots had a significantly lower pH than the average of other SA treatments ($p = <0.001$). The FERT treatment had a significantly lower pH than the MS treatment ($p = <0.001$). It should also be noted that although not significantly different MSFW, WA and MS increased soil pH to 7.3 whereas FERT and NDEF plots pH level was near 7.0 concluding that WA, MSFW and MS have liming properties.

No significant differences in July 2011 samples were expected as SA were applied only one month prior and pH adjustments take time after amendment application. Although an increase in pH is sometimes good, when the soil pH approaches 7.4 elements such as Cu, Fe, Mn, Zn and B become less available. The soil pH will need to continue to be monitored to ensure that the pH stay in an optimal range for the soil nutrients to be in an available form to the plant.

2.4.2 Grapevine Characteristics

2.4.2.1 Spring 2012 Dry Pruning Weight

The spring pruning weight in 2012 was significantly different between CC treatments planted in 2011 ($p = 0.011$) (Table 2-10). The BS plot had significantly lower pruning weight than the average of treatments with cover crops ($p = 0.020$). Vines in the ORC treatment had significantly less pruning weight than vines in the OPV treatment ($p = 0.036$). The vines in the TM treatment had a significantly greater pruning weight than OPV and ORC treatments ($p = 0.013$).

The covariate of vine location was significant in initial dry pruning weight ($p = 0.017$). This result means that the canopy of Leon Millot was influenced by its location in the research plot. Vines within the OPV treatments may have had a greater spring pruning weight than ORC because OPV is an annual cover crop and possibly provided more N to the vine as the red clover did not establish a dense floor cover until 2012. Costello (2010) found no differences in pruning weights between cover crop treatments. This vineyard is in remediation and vines are being trained back to a vertically shoot positioned trellis system meaning dry pruning weights are exclusive to this study and will not compare to that of a mature, properly trained vineyard.

2.4.2.2 Whole Leaf and Petiole Nitrogen

In 2011, there were no significant differences between treatments in whole leaf and petiole N. In 2012, whole leaf and petiole N was significantly different among SA treatments ($p = 0.031$) (Table 2-10). The NDEF plot vines contained significantly lower %N in whole leaf and petiole samples than the average of other soil amendment treatments ($p = 0.05$). The MSFW treatment vines were marginally higher in whole leaf and petiole N than the MS treatment vines.

The NDEF contained a lower whole leaf and petiole N in comparison to the average of other soil amendment treatments probably because no N was added as fertilizer to the NDEF plots. From the results, it was determined that WA had a small amount of N in its raw product (Table 2-3) and added to the synthetic N that was applied to these plots at 40 kg ha^{-1}. This N could be from an incomplete combustion of the WA in processing. The MSFW may have provided more available N to the vine than previous greenhouse trials concluded. A small difference between treatments caused significant differences within %N in the leaf and petiole tests. Values were in the 2.8% N range that is optimal for French Hybrid wine grapes (Mills and Jones 1997). Although some researchers (Lewis 2009) have found that French hybrids have higher whole leaf and petiole N levels in cooler climates.

2.4.3 Cover Crop Biomass and Nitrogen Content.

In 2011, only TM was analyzed for differences in cover crop N content between SA treatments to gain an understanding of possible N differences from amendment N supply. No significant differences were found in the TM nitrogen content between SA treatments indicating that comparable levels of N were applied to all plots with the exception of NDEF. Cover crop biomass was not assessed in 2011 as the treatments were mowed prior to sampling and a representative sample of cumulative growth could not be assessed.

In 2012, main effects or 1st order interactions did not significantly affect cover crop N content; however the interaction between CC, SA and APP led to significant differences in the cover crop N content (Table 2-11). The significant comparison was that the 1YR OPV plots amended with MS or MSFW contained a significantly greater %N than when WA or FERT was used ($p = 0.021$).

In 2012, cover crop biomass was also significantly affected by the three-way interaction of CC, SA and APP (Table 2-11). The first significant comparison was that 2YR ORC plots amended with NDEF produced a significantly lower biomass than when other soil amendment treatments were used ($p=0.011$). The second significant comparison was that the 2YR ORC plots amended with MS produced a significantly greater cover crop biomass than when FERT was used ($p=<0.001$).

The %N in biomass was significantly higher in OPV relative to other cover crops, while the weight of cover crop biomass was significant higher with ORC relative to other cover crops, meaning the significance of biomass and N content did not correlate. The OPV is an annual cover crop and therefore requires available nutrients to establish and to grow each season. The residual nutrients of MSFW and MS may have become available with tillage in 2012 when the OPV seedbed was prepared which, along with the MS and MSFW other soil improving benefits allowed the OPV to have a higher %N than if WA or FERT was used. Overall, legumes tend to have higher tissue N than grasses.

The possible reason for significant differences in cover crop biomass in 2YR treatments may be due to slow establishment of red clover in 2011. In 2012, red clover was much denser and more nutrients were available, specifically N. Studies have shown that half the N fixed by a legume will mineralize during the season after planting and be available to that seasons crop (Patrick 2004). The MS possibly containing more available N than predicted from previous greenhouse trials along with residual N from 2011 helped to create a denser red clover cover. The NDEF produced significantly less ORC biomass in 2YR treatments because the red clover had no supplemental N to create a dense cover. It should be noted when cover crops are mowed and left on the soil surface mineralization takes place much more slowly and significantly less N is available for plant uptake. Incorporation nearly doubles soil available N content compared to no-till green manure systems (Hirschfelt 1998). The OPV was incorporated in the spring of 2012 and the ORC biomass was left on surface.

2.5 Conclusion

Despite efforts to equalize N supply between SA, aside from NDEF, mineral N in the MS treatment was found to be lower than other N fertilized treatments indicating that the N supply rate may have been overestimated in the MS. The NDEF treatment contained the least amount of mineral N. Application of N containing SA to the soil was seen as a beneficial practice as the observed soil quality indicators (N_{tot}, $NaHCO_3^-$ extractable N, POMC, POMN and MBC) had higher values in treatments receiving N. The MSFW treatment was equivalent to or outperformed the FERT treatment in these soil quality variables, demonstrating the added benefit of organic matter contributions to the soil. Higher soil N was found in treatments with cover crops compared with BS, suggesting that there is a benefit to having cover crops between vine rows. The ORC outperformed or was equivalent to other cover crops in all soil quality variables. Soil MBC was higher in TM indicating cover cropping is beneficial for hosting organisms that are decomposing organic matter and cycling nutrients in the soil. Soil nutrient content in

2012 was influenced by SA where, K was increased most with WA; soil S was highest in the FERT treatment, but overall still low across treatments. The MS should be supplemented with S fertilizer to address deficiencies at this site. The magnesium was highest in NDEF plots although other plots were still in a sufficient range. The application of soil amendments affected soil B concentrations where an average increase across all treatments of 0.26 ppm occurred between 2011 and 2012. Soil B was greatest in the WA treatment and soil B was higher in the MS and MSFW than FERT and NDEF, which there was no difference.

The ORC combined with N-containing soil amendments produced the greatest amount of cover crop biomass when the soil amendment was applied both years. Whole leaf and petiole N status was highest in WA, which is most likely explained by the N contained in the WA raw product that was applied in addition to the synthetic N.

The MS, MSFW, and WA needs to be researched further to assess the influence they have on the nutrient dynamics of the vineyard in combination with cover cropping. The WA could be used as a source of B in addition to providing P, K and acting as a liming agent in vineyards. Future research could look at the effects soil amendment application in combination with cover cropping have on a full season of vine canopy pruning weight and also all essential nutrients in whole leaf and petiole results and the allocation of N in the vine. Other research could also look into soil porosity and erosion susceptibility measurements of the soil to see if SA or CC had an effect on soil physical properties.

Table 2-1 Initial soil characteristics (0 - 15 cm) at Petite Riviere Vineyards (2011).

Measurement	Unit	2011 Sample Value	GGNS Sudy [1]	Recommended Range	Reference
OM	%	2.43	2.9-7.1	3.5-5.0	NS Soil Test Lab, 2012
pH		7.327	5.3-6.9	6.0-7.0	Naugler et al, 2006
CEC	Meq 100 g^{-1}	11.23	7.0-17.5	11.0-50.0	NS Soil Test Lab, 2012
P_2O_5	kg ha^{-1}	436	189-876	274-360	NSDAF, 2004
K_20	kg ha^{-1}	171	178-700	156-236	NSDAF, 2004
Ca	kg ha^{-1}	3070	524-4418	2500+	NS Soil Test Lab, 2012
Mg	kg ha^{-1}	294	125-628	225+	NS Soil Test Lab, 2012
S	kg ha^{-1}	23	39-66	40+	NS Soil Test Lab, 2012
B	ppm	0.54	0.37-1.61	0.50-2.0	NS Soil Test Lab, 2012
Cu	ppm	3.82	0.99-5.39	0.6-3.0	NS Soil Test Lab, 2012
Zn	ppm	3.9	1.4-5.0	2	NS Soil Test Lab, 2012
Mn	ppm	28	11.1-60	40-60	NS Soil Test Lab, 2012
Fe	ppm	89	82-283	50-100	NS Soil Test Lab, 2012

[1] The Grape Growers of Nova Scotia conducted a study in 2002, which gave a range of soil test values over six NS vineyards.

Table 2-2 Fertilizer and soil amendment application rates based on soil test results.

Source	Amendment Application Rate	Nutrient (kg ha^{-1})				
		N[1]	*K*[2]	*Mg*[3]	*S*[4]	*B*[5]
N-Deficient Fertilizer	-	-	83	24	40	2.4
Inorganic Fertilizer	-	40	83	24	40	2.4
Woodash	6.3 Mg ha^{-1} [6]	40	-	-	40	-
Mussel Sediment	42000 L [7]	-	83	-	-	-
Municipal Solid Food Waste	13.4 Mg ha^{-1} [6]	30	83	-	-	-

[1] Nitrogen was supplied to the soil at 40kg ha^{-1} using **NH_4NO_3 (34-0-0).**

[2] Potassium was supplied to the soil at 83 kg ha^{-1} using **KCl (0-0-62).**

[3] Magnesium was added to the soil at 24 kg ha-^{1} using **$MgSO_4^{2-}$-7H_20 (0-0-0-9.8Mg-14S).**

[4] Sulfur was added to the soil at 40 kg ha-^{1} by first utilizing the S from **$MgSO_4^{2-}$-7H_20 (0-0-0-9.8Mg-14S)** in plots that received synthetic magnesium fertilizer. Elemental **sulfur (0-0-0-90S)** fertilizer was then used to ensure each plot received 40 kg ha-^{1} of sulfur. Elemental sulfur **(0-0-0-90S)** was used in plots receiving only sulfur and not magnesium fertilizer.

[5] Boron was added to the soil at 2.4 kg ha-^{1} using $Na_2B_4O_7$ **(0-0-0-15B).**

[6] Application on a dry weight basis.

[7] Application on a liquid slurry basis.

Table 2-3 Soil amendment average initial nutrient composition (n = 3).

Variable	*Unit*	Amendment		
		WA[1]	MSFW[2]	MS[3]
pH		12.95	7.84	7.35
DM[4]	%	89.12	63.25	26.43
N	%	0.06	1.99	0.58
C	%	1.97	25.72	7.81
P	%	0.36	0.67	0.07
K	%	1.64	0.32	0.12
S	%	0.37	0.42	0.27
Mg	%	0.69	0.27	0.30
Ca	%	6.33	4.60	6.01
Cu	*ppm*	105	49.38	3.53
Fe	*ppm*	12100	5923	8620
Mn	*ppm*	5583	378	217
Zn	*ppm*	541	159	21.55
B	*ppm*	91.57	21.52	19.71

[1] WA = wood ash.

[2] MSFW = municipal solid food waste.

[3] MS = mussel sediment.

[4] DM = dry matter.

Table 2-4. Selected values of (0 – 15 cm) soil NH_4^+ - N (kg ha^{-1}) and NO_3^- - N (kg ha^{-1}) at specific sampling dates in relation to cover crops and soil amendments.

	Cover Crop	NO_3^- - N		NH_4^+ - N		
		2012		2011	2012	
Soil Amendment *(n=30)* [1]	*(n=24)* [2]	**July**	**October**	**July**	**April**	**October**
NDEF	TM	6.81	4.04	0.71	1.26	12.41
FERT	TM	13.72	5.06	1.05	0.82	9.16
MSFW	TM	16.57	5.45	1.53	1.87	10.67
WA	TM	11.44	3.73	1.63	1.63	10.04
MS	TM	9.95	3.49	1.05	1.25	9.96
NDEF	ORC	12.68	4.08	0.83	1.62	15.71
FERT	ORC	18.91	8.04	0.86	0.68	10.13
MSFW	ORC	22.92	5.58	0.62	1.85	10.87
WA	ORC	21.03	8.42	1.76	1.46	16.30
MS	ORC	16.18	3.75	1.00	2.44	14.35
NDEF	OPV	17.34	6.89	0.35	0.90	5.33
FERT	OPV	20.93	4.11	0.15	0.27	6.66
MSFW	OPV	20.97	9.98	0.42	1.05	5.61
WA	OPV	23.65	13.63	1.33	0.64	10.02
MS	OPV	16.87	4.41	0.58	0.44	6.28
NDEF	BS	14.64	3.30	0.58	0.50	4.14
FERT	BS	12.30	4.01	1.12	0.58	3.26
MSFW	BS	12.62	4.72	1.31	1.50	4.66
WA	BS	18.39	3.67	0.94	0.79	3.54
MS	BS	11.36	7.60	0.59	2.26	4.52
Grand Mean		*15.96*	*5.70*	*0.92*	*1.19*	*8.68*
SEM		*3.28*	*1.67*	*0.34*	*0.54*	*2.52*

		Analysis of Variance (Prob>F)				
Source of Variation	d.f.					
Soil Amendment (SA)	4	0.008	0.029	0.030	0.021	n.s.[3]
NDEF vs FERT, WA, MSFW, MS		*0.010*	-	*0.045*	-	-
FERT, WA vs MSFW, MS		-	-	-	*0.002*	-
MSFW vs MS		*0.014*	-			
Cover Crop (CC)	3	n.s.	n.s.	n.s.	n.s.	0.050
BS vs CC		-	-	-	-	*0.033*
OPV vs ORC		-	-	-	-	*0.050*
SA x CC[4]	12	n.s.	0.002	n.s.	n.s.	n.s.
BS vs CC.MS vs MSFW		-	*0.010*	-	-	-
ORC,OPV vs TM.FERT vs MS		-	*0.011*	-	-	-
ORC vs OPV.FERT vs MS		-	*0.001*	-	-	-

[1] NDEF = synthetic fertilizer with no nitrogen, FERT = synthetic fertilizer, MSFW = municipal solid food waste, WA = wood ash, MS = mussel sediments.

[2] TM = triple mix, ORC = oats underseeded with red clover, OPV = oats, field pea and hairy vetch mix, BS = tilled bare soil.

[3] n.s. = not significant at 0.10 probability level.

[4] This represents the interaction of soil amendments with cover crops. If this interaction was significant, the planned comparisons are shown that were significant under this effect. For example, the comparison (*BS vs CC . FERT vs* MS) represents the comparison between bare soil or cover cropped plots with applications of FERT or MS. The period in-between main effects represents the interaction. The following values are an example if the above interaction was significant ($p < 0.05$). a) First find the mean of BS when FERT was used = 4.01 b) Next calculate the mean of CC (add up the means of all plots with a cover crop) when FERT was used = 5.73 c) Then find the mean of BS when MS was used = 7.60 d) Finally get the mean of CC (add up the means of all plots with a cover crop) when MS was used = 3.88. Using this information, you find the interaction with the greatest difference between data groups and that is the significant interaction. In this example, it would be the BS plot amended with MS is significantly greater than if FERT was used. The CC plots amended with MS or FERT were not significantly different from one another.

Table 2-5. Mean values for percent soil total N (n = 3) and $NaHCO_3^-$ extractable N (n = 2) in response to cover crops and soil amendments.

		% Total N		205 nm Absorbance		260 nm Absorbance	
Treatment		**2011**	**2012**	**2011**	**2012**	**2011**	**2012**
Cover Crop (*n=24*)[1]							
TM		0.133	0.169	1.177	0.342	0.091	0.181
ORC		0.137	0.166	1.149	0.429	0.091	0.157
OPV		0.116	0.148	1.058	0.401	0.097	0.140
BS		0.118	0.141	1.061	0.321	0.092	0.111
Grand Mean		*0.126*	*0.156*	*1.111*	*0.373*	*0.093*	*0.147*
SEM		*0.008*	*0.007*	*0.021*	*0.026*	*0.004*	*0.021*
Amendment (*n=30*)[2]							
NDEF		0.125	0.154	1.060	0.345	0.098	0.135
FERT		0.117	0.141	1.113	0.356	0.089	0.139
MSFW		0.127	0.184	1.134	0.421	0.106	0.152
WA		0.138	0.149	1.131	0.389	0.089	0.152
MS		0.122	0.153	1.116	0.356	0.082	0.157
Grand Mean		*0.126*	*0.156*	*1.111*	*0.373*	*0.093*	*0.147*
SEM		*0.006*	*0.007*	*0.030*	*0.019*	*0.006*	*0.008*
Application Year[3]							
1YR		-	-	-	0.357	-	0.144
2YR		-	-	-	0.389	-	0.150
Grand Mean		-	-	-	0.373	-	0.147
SEM		-	-	-	0.007	-	0.004
		Analysis of Variance (Prob > F)					
Source of Variation	d.f.						
Cover Crop (CC)	3	n.s.[4]	0.097	0.033	0.097	n.s.	n.s.
BS vs ORC, OPV, TM		-	-	*0.038*	-	-	-
ORC vs OPV		-	-	*0.034*	-	-	-
Amendment (SA)	4	n.s.	0.002	n.s.	0.046	0.074	n.s.
FERT, WA vs MSFW, MS		-	*0.003*	-		-	-
MSFW vs MS		-	*0.003*	-	*0.021*	-	-
Application Year (APP)	1	-	n.s.	n.s.	0.001	n.s.	n.s.
SA x CC[5]	12	0.045	n.s.	n.s.	n.s.	n.s.	n.s.
ORC vs OPV . MS vs MSFW		0.022	-	-	-	-	-
ORC vs OPV . FERT vs MS		<0.001	-	-	-	-	-

[1] TM = triple mix, ORC = oats underseeded with red clover, OPV = oats, field pea and hairy vetch mix, BS = tilled bare soil.

[2] NDEF = synthetic fertilizer with no nitrogen, FERT = synthetic fertilizer, MSFW = municipal solid food waste, WA = wood ash, MS = mussel sediments.

[3] 1YR = amendments only applied in 2011, 2YR = amendments applied in 2011 and 2012.

[4] n.s. = not significant at 0.10 probability level.

[5] This represents the interaction of soil amendments with cover crops. If this interaction was significant, the planned comparisons are shown that were significant under this effect. For example, the comparison (BS vs CC . FERT vs MS) represents the comparison between bare soil or cover cropped plots with applications of FERT or MS. The period in-between main effects represents the interaction. The following values are an example if the above interaction was significant ($p < 0.05$). a) First find the mean of BS when FERT was used = 4.01 b) Next calculate the mean of CC (add up the means of all plots with a cover crop) when FERT was used = 5.73 c) Then find the mean of BS when MS was used = 7.60 d) Finally get the mean of CC (add up the means of all plots with a cover crop) when MS was used = 3.88. Using this information, you find the interaction with the greatest difference between data groups and that is the significant interaction. In this example, it would be the BS plot amended with MS is significantly greater than if FERT was used. The CC plots amended with MS or FERT were not significantly different from one another.

Table 2-6 Mean values for soil POM - C and POM - N in response to cover crops and soil amendments.

		POMN g kg^{-1}		POMC g kg^{-1}	
Treatment		**2011**	**2012**	**2011**	**2012**
Cover Crop (*n=24*)[1]					
TM		0.44	0.25	6.51	4.97
ORC		0.41	0.23	5.99	4.48
OPV		0.33	0.25	5.10	3.91
BS		0.28	0.14	4.62	3.76
Grand Mean		*0.36*	*0.21*	*5.56*	*4.28*
SEM		*0.03*	*0.03*	*0.24*	*0.37*
Amendment (*n=30*)[2]					
NDEF		0.38	0.18	6.00	4.30
FERT		0.31	0.17	4.70	4.26
MSFW		0.44	0.26	6.39	4.45
WA		0.36	0.21	5.73	3.77
MS		0.34	0.24	4.96	4.60
Grand Mean		*0.36*	*0.21*	*5.56*	*4.23*
SEM		*0.05*	*0.05*	*0.54*	*0.55*
		Analysis of Variance (Prob > F)			
Source of Variation	d.f.				
Cover Crop(CC)	3	0.043	0.074	0.019	n.s.[3]
BS vs ORC, OPV, TM		*0.015*	-	*0.005*	-
ORC,OPV vs TM		-	-	*0.050*	-
Amendment(SA)	4	n.s.	n.s.	n.s.	n.s.
SA x CC[4]	12	n.s.	n.s.	0.077	n.s.

[1] TM = triple mix, ORC = oats underseeded with red clover, OPV = oats, field pea and hairy vetch mix, BS = tilled bare soil.

[2] NDEF = synthetic fertilizer with no nitrogen, FERT = synthetic fertilizer, MSFW = municipal solid food waste, WA = wood ash, MS = mussel sediments.

[3] n.s. = not significant at 0.10 probability level.

[4] This represents the interaction of soil amendments with cover crops. If this interaction was significant, the planned comparisons are shown that were significant under this effect. For example, the comparison (BS vs CC . FERT vs MS) represents the comparison between bare soil or cover cropped plots with applications of FERT or MS. The period in-between main effects represents the interaction. The following values are an example if the above interaction was significant ($p < 0.05$). a) First find the mean of BS

when FERT was used = 4.01 b) Next calculate the mean of CC (add up the means of all plots with a cover crop) when FERT was used = 5.73 c) Then find the mean of BS when MS was used = 7.60 d) Finally get the mean of CC (add up the means of all plots with a cover crop) when MS was used = 3.88. Using this information, you find the interaction with the greatest difference between data groups and that is the significant interaction. In this example, it would be the BS plot amended with MS is significantly greater than if FERT was used. The CC plots amended with MS or FERT were not significantly different from one another.

Table 2-7 Mean values of microbial biomass C in response to specific cover crops and soil amendments.

		MBC (g C g soil^{-1})	
Treatment		**2011**	**2012**
Cover Crop (*n=6*)[1]			
TM		334	105
BS		228	98
Grand Mean		*281*	*101*
Amendment (*n=15*)[2]			
NDEF		350	72
FERT		199	77
MSFW		280	148
WA		337	112
MS		237	97
Grand Mean		*281*	*101*
		Analysis of Variance (Prob > F)	
Source of Variation	d.f.		
Cover Crop(CC)	1	n.s.[3]	n.s.
Amendment(SA)	4	n.s.	n.s.
SA x CC[4]	4	n.s.	0.033
BS vs CC . FERT vs MS			*0.034*

[1] TM = triple mix, BS = tilled bare soil.

[2] NDEF = synthetic fertilizer with no nitrogen, FERT = synthetic fertilizer, MSFW = municipal solid food waste, WA = wood ash, MS = mussel sediments.

[3] n.s. = not significant at 0.10 probability level.

[4] This represents the interaction of soil amendments with cover crops. If this interaction was significant, the planned comparisons are shown that were significant under this effect. For example, the comparison (BS vs CC . FERT vs MS) represents the comparison between bare soil or cover cropped plots with applications of FERT or MS. The period in-between main effects represents the interaction. The following values are an example if the above interaction was significant ($p < 0.05$). a) First find the mean of BS when FERT was used = 4.01 b) Next calculate the mean of CC (add up the means of all plots with a cover crop) when FERT was used = 5.73 c) Then find the mean of BS when MS was used = 7.60 d) Finally get the mean of CC (add up the means of all plots with a cover crop) when MS was used = 3.88. Using this information, you find the interaction with the greatest difference between data groups and that is the significant interaction. In

this example, it would be the BS plot amended with MS is significantly greater than if FERT was used. The CC plots amended with MS or FERT were not significantly different from one another.

Table 2-8. Soil Mehlich III extractable macronutrients content in July 2012.

	kg ha^{-1}				
Treatment	**P_20_5**	**K_20**	**S**	**Mg**	**Ca**
Cover Crop (*n=24*)[1]					
TM	463.2	199.3	23.3	352.4	3615
ORC	461.8	212.9	26.9	332.8	3559
OPV	466.5	230.6	26.3	314.3	3585
BS	461.4	208.8	23.2	301.3	3290
Grand Mean	*463.2*	*212.9*	*24.9*	*325.2*	*3512*
SEM	*73.2*	*6.4*	*2.5*	*37.6*	*416*
Amendment (*n=30*)[2]					
NDEF	384.4	192.0	25.4	387.2	2919
FERT	418.4	204.8	24.7	344.7	2562
MSFW	642.2	216.4	23.3	328.7	4159
WA	457.8	257.1	30.3	317.3	3894
MS	413.4	194.2	20.8	248.1	4027
Grand Mean	*463.2*	*212.9*	*24.9*	*325.2*	*3512*
SEM	*47.9*	*12.4*	*1.3*	*25.2*	*225*

		Analysis of Variance (Prob > F)				
Source of Variation	d.f.					
Amendment (SA)	4	0.002	0.005	<0.001	0.007	<0.001
NDEF vs FERT, WA, MSFW, MS[3]		-	*0.047*	-	*0.008*	*0.005*
FERT, WA vs MSFW, MS		-	*0.070*	*<0.001*	*0.085*	*<0.001*
MSFW vs MS		*0.001*	-	-	*0.028*	-
FERT vs MS		-	*0.006*	*0.002*	-	*<0.001*

[1] TM = triple mix, ORC = oats underseeded with red clover, OPV = oats, field pea and hairy vetch mix, BS = tilled bare soil.

[2] NDEF = synthetic fertilizer with no nitrogen, FERT = synthetic fertilizer, MSFW = municipal solid food waste, WA = wood ash, MS = mussel sediments.

[3] This represents the interaction of soil amendments with cover crops. If this interaction was significant, the planned comparisons are shown that were significant under this effect. For example, the comparison (BS vs CC . FERT vs MS) represents the comparison between bare soil or cover cropped plots with applications of FERT or MS. The period in-between main effects represents the interaction. The following values are an example if the above interaction was significant ($p <0.05$). a) First find the mean of BS when FERT was used = 4.01 b) Next calculate the mean of CC (add up the means of all plots with a cover crop) when FERT was used = 5.73 c) Then find the mean of BS when MS was used = 7.60 d) Finally get the mean of CC (add up the means of all plots with a

cover crop) when MS was used = 3.88. Using this information, you find the interaction with the greatest difference between data groups and that is the significant interaction. In this example, it would be the BS plot amended with MS is significantly greater than if FERT was used. The CC plots amended with MS or FERT were not significantly different from one another.

Table 2-9. Soil Mehlich III extractable micronutrient content in July 2012.

	ppm				
Treatment	**Cu**	**Fe**	**Mn**	**Zn**	**B**
Cover Crop (*n=24*)[1]					
TM	6.05	94.77	38.69	6.05	0.84
ORC	7.16	96.06	38.16	6.01	0.83
OPV	2.54	92.44	39.39	5.14	0.78
BS	7.01	92.94	33.69	4.99	0.76
Grand Mean	*5.69*	*94.05*	*37.48*	*5.55*	*0.80*
SEM	*1.00*	*4.18*	*4.91*	*1.01*	*0.09*
Amendment (*n=30*)[2]					
NDEF	5.55	91.75	26.38	4.37	0.62
FERT	5.80	85.29	28.28	4.25	0.67
MSFW	6.04	100.90	36.60	6.74	0.76
WA	5.88	98.98	66.90	8.22	1.17
MS	5.18	93.30	29.26	4.15	0.79
Grand Mean	*5.69*	*94.05*	*37.48*	*5.55*	*0.80*
SEM	*0.35*	*3.22*	*2.37*	*0.36*	*0.04*

		Analysis of Variance (Prob > F)				
Source of Variation	d.f.					
Amendment (SA)	4	n.s.[3]	0.011	<0.001	<0.001	<0.001
NDEF vs FERT, WA, MSFW, MS		-	-	*<0.001*	*<0.001*	*<0.001*
FERT WA vs MSFW, MS		-	-	*<0.001*	-	*0.002*
MSFW vs MS		-	*0.095*	*0.025*	*<0.001*	-
FERT vs MS		-	*0.004*	-	*<0.001*	*<0.001*
Cover Crop (CC)	3	0.076	n.s.	n.s.	n.s.	n.s.
SA X CC[4]	12	n.s.	n.s.	0.089	n.s.	n.s.

[1] TM = triple mix, ORC = oats underseeded with red clover, OPV = oats, field pea and hairy vetch mix, BS = tilled bare soil.

[2] NDEF = synthetic fertilizer with no nitrogen, FERT = synthetic fertilizer, MSFW = municipal solid food waste, WA = wood ash, MS = mussel sediments.

[3] n.s. = not significant at 0.10 probability level.

[4] This represents the interaction of soil amendments with cover crops. If this interaction was significant, the planned comparisons are shown that were significant under this effect. For example, the comparison (BS vs CC . FERT vs MS) represents the comparison between bare soil or cover cropped plots with applications of FERT or MS. The period in-between main effects represents the interaction. The following values are

an example if the above interaction was significant ($p < 0.05$). a) First find the mean of BS when FERT was used = 4.01 b) Next calculate the mean of CC (add up the means of all plots with a cover crop) when FERT was used = 5.73 c) Then find the mean of BS when MS was used = 7.60 d) Finally get the mean of CC (add up the means of all plots with a cover crop) when MS was used = 3.88. Using this information, you find the interaction with the greatest difference between data groups and that is the significant interaction. In this example, it would be the BS plot amended with MS is significantly greater than if FERT was used. The CC plots amended with MS or FERT were not significantly different from one another.

Table 2-10. Soil pH values, spring dry pruning weight and % whole leaf petiole nitrogen in relation to cover crops and soil amendments in 2012.

Treatment		Soil pH	Dry Pruning Weight (g per vine)	Whole leaf and Petiole %N
Cover Crop (*n=24*)[1]				
TM		7.19	81.42	2.76
ORC		7.17	65.56	2.87
OPV		7.18	74.33	2.88
BS		7.26	65.49	3.05
Grand Mean		*7.20*	*71.70*	*2.89*
SEM		*0.13*	*2.36*	*0.11*
Amendment (*n=30*)[2]				
NDEF		7.03	73.03	2.80
FERT		6.99	71.86	2.89
MSFW		7.31	71.55	2.93
WA		7.35	69.16	3.01
MS		7.32	72.91	2.81
Grand Mean		*7.20*	*71.70*	*2.89*
SEM		*0.04*	*4.58*	*0.05*
		Analysis of Variance (Prob > F)		
Source of Variation	d.f.			
Cover Crop(CC)	3	n.s.[3]	0.011	n.s.
BS vs ORC, OPV, TM		-	*0.020*	-
ORC vs OPV		-	*0.036*	-
ORC, OPV vs TM		-	*0.013*	-
Soil Amendment(SA)	4	<0.001	n.s.	0.031
NDEF vs FERT, WA, MSFW, MS		-	-	*0.050*

[1] TM = triple mix, ORC = oats underseeded with red clover, OPV = oats, field pea and hairy vetch mix, BS = tilled bare soil.

[2] NDEF = synthetic fertilizer with no nitrogen, FERT = synthetic fertilizer, MSFW = municipal solid food waste, WA = wood ash, MS = mussel sediments.

[3] n.s. = not significant at 0.10 probability level.

Table 2-11 Cumulative biomass and C and N content of cover crops in response to soil amendment and cover crop treatments in the 2012 growing season.

Amendment[1]	Cover Crop[2]	Application[3]	Cover Crop %N[4]	Cover Crop %C[4]	Cover Crop Biomass (kg ha^{-1})[5]
NDEF	TM	1YR	2.72	44.18	14682
NDEF	TM	2YR	2.75	44.03	13756
FERT	TM	1YR	2.87	43.97	16168
FERT	TM	2YR	2.80	44.14	14902
MSFW	TM	1YR	2.75	44.24	15642
MSFW	TM	2YR	2.57	44.08	14768
WA	TM	1YR	2.76	44.37	13982
WA	TM	2YR	2.68	43.43	13554
MS	TM	1YR	2.48	43.97	11808
MS	TM	2YR	2.50	43.47	13764
NDEF	ORC	1YR	3.69	43.47	19978
NDEF	ORC	2YR	3.62	43.03	16130
FERT	ORC	1YR	3.73	42.56	17700
FERT	ORC	2YR	3.47	40.90	17262
MSFW	ORC	1YR	3.10	42.18	13770
MSFW	ORC	2YR	3.64	42.26	19234
WA	ORC	1YR	3.63	42.49	16610
WA	ORC	2YR	3.46	42.17	27580
MS	ORC	1YR	3.32	42.60	19488
MS	ORC	2YR	3.67	41.74	21000
NDEF	OPV	1YR	2.62	42.97	9600
NDEF	OPV	2YR	3.24	42.37	10726
FERT	OPV	1YR	2.54	38.68	13274
FERT	OPV	2YR	2.67	42.30	15390
MSFW	OPV	1YR	2.80	42.42	11730
MSFW	OPV	2YR	3.13	42.79	13878
WA	OPV	1YR	2.56	42.48	14482
WA	OPV	2YR	3.33	42.46	13318
MS	OPV	1YR	2.61	42.17	9500
MS	OPV	2YR	2.63	42.94	11892
Grand Mean			*2.26*	*32.14*	*11418*
Standard Error			*0.20*	*0.49*	*1838*

Source of Variation	d.f.	*Analysis of Variance (Prob > F)*		
CC x SA x APP[6]	12	0.032	0.001	0.011
ORC vs OPV . NDEF vs FERT, WA, MSFW, MS . APP		-	-	*0.011*
ORC vs OPV . FERT vs MS . APP		-	-	*<0.001*
ORC vs OPV . FERT, WA vs MSFW, MS . APP		*<0.001*	*0.021*	-

[1] NDEF = synthetic fertilizer with no nitrogen, FERT = synthetic fertilizer, MSFW = municipal solid food waste, WA = wood ash, MS = mussel sediments.

[2] TM = triple mix, ORC = oats underseeded with red clover, OPV = oats, field pea and hairy vetch mix, BS = tilled bare soil.

[3] 1YR = amendments only applied in 2011, 2YR = amendments applied in 2011 and 2012.

[4] %N and %C results were from a bulk sample which combined samples collected over an entire season not an individual sampling date.

[5] Cover crop biomass results was a sum of the entire 2012 season growth (4 cuts).

[6] This represents the interaction of soil amendments with cover crops. If this interaction was significant, the planned comparisons are shown that were significant under this effect. For example, the comparison (BS vs CC . FERT vs MS) represents the comparison between bare soil or cover cropped plots with applications of FERT or MS. The period in-between main effects represents the interaction. The following values are an example if the above interaction was significant ($p < 0.05$). a) First find the mean of BS when FERT was used = 4.01 b) Next calculate the mean of CC (add up the means of all plots with a cover crop) when FERT was used = 5.73 c) Then find the mean of BS when MS was used = 7.60 d) Finally get the mean of CC (add up the means of all plots with a cover crop) when MS was used = 3.88. Using this information, you find the interaction with the greatest difference between data groups and that is the significant interaction. In this example, it would be the BS plot amended with MS is significantly greater than if FERT was used. The CC plots amended with MS or FERT were not significantly different from one another.

Chapter 3.0 The Response of Wine Grape Yield and Yield Quality Parameters in Relation to Selected Amendments and Cover Crops

3.1 Introduction

Nova Scotia is becoming recognized for its high quality wines made from locally grown grapes. With a rapidly growing industry, being just over 30 years old now is the time to explore the effects of sustainable management practices on grape yield and quality. It is important to maintain optimal yields without sacrificing quality (Jackson and Lombard 1993). Providing optimal vine nutrition is one of the most important determinants of wine grape yield and quality (Naugler and Wright 2006).

Growers can significantly influence grape yield and quality through various management practices, but climate can play an important role as well. Buds or even entire vines can be killed by cold winter temperatures and late spring frosts affecting yield substantially (Lewis 2008). Sunlight and temperature influences bud burst and fruit set. Veraison and harvest may be delayed if climactic conditions are unfavorable affecting °Brix and other quality factors. In a cool climate with a shortened growing season, the attainment of a certain maturity level is limited by the environment (Lewis 2008). Management practices that hasten ripening become paramount for achieving a certain flavor, colour or aroma of the wine (Wrinkler 1974). The amount of growing degree days are also very important from veraison to harvest as quality factors are most vulnerable to change during this time (Naugler and Wright 2006). During veraison there is a change in skin colour, berries soften, sugars increase, acidity declines and volume increases. Temperature has a distinctive influence on the development of colour with warm days and cool nights allowing the grape to become riper and skin to become darker (Wrinkler 1974; Delrot et al. 2010).

Nutrients are required by the vine and berry for optimal yields providing high quality berries for winemaking. Without optimal levels of essential nutrients, the vine can experience reduced yield, uneven ripening and lower disease resistance, all of which affect quality. Nitrogen is most required by the grape from veraison to harvest where it helps to develop and ripen the fruit. Excessive N during ripening tends to divert the sugar produced by the leaves to continued shoot growth rather than to the fruit (Wrinkler 1974). Phosphorus promotes maturation of fruit. Phosphorus plays an important role in energy transfer of the vine, as it is necessary for photosynthesis and transforming starch to sugars (Wrinkler, 1974; Spectrum Analytic (B), 2011 Chien n.d.). Potassium is required by grapevines in a relatively high amount primarily for transport, production and storage of carbohydrates and sugars (Wrinkler 1974; Spectrum Analytic (C) 2011; Chien n.d.). It also affects the acid balance in grape juice and the pH and colour of wine (Spectrum Analytic (C), 2011). During ripening K content of the grape increases which leads to the formation of potassium bitartrate, which reduces the juice acidity (Dharmadhikari 2010).

In vineyards that would benefit from devigouration and yield reduction a permanent cover crop can improve soil physical properties and juice quality (Morlat and Jacquet 2003). Cover crops effect on juice quality arises through competition for water and nutrients, which reduces vigour and enhances fruit exposure to the sun (David et al. 2001; Maigre and Aerny 2001).

Laboratory analysis of grapes can provide an understanding of the quality of wine that will be produced, as grapes are the most important quality factor of wine. An optimal balance between yield and quality must be achieved as a high yield can delay maturity. The quality indicators in this project were assessed on harvested grapes before they were subject to the winemaking process. It should be noted that quality indicators other than chemical analysis include tasting wine for quality, which is done by seasoned and talented sommeliers.

With the industry only blossoming, sustainable management practices have not been evaluated in NS vineyards. Soil nutrient management recommendations for grape production are not well developed. Further study is required on soil management in relation to the performance of wine grape yield and quality especially in the context of alleyway cover cropping and soil fertility management. Non-synthetic SA of interest have not been assessed for their performance on grape quality, productivity, and fruit quality in NS vineyards. Although the effect of cover crops with legumes and grasses has been studied, the effect of cover crops combined with soil amendments has not been studied in NS vineyards.

In contrast with most fruit crops, high yields are usually not desired in premium wine grape production. High crop yields can delay sugar accumulation, possibly resulting in grapes not reaching target degree Brix (°Brix) before the end of the growing season (Jackson and Lombard, 1993). Since phenolics and antioxidants accumulate most in the skin, it is assumed wine made from smaller grapes with higher skin to pulp ratio will have better colour, aging and flavor potential (Matthews and Nuzzo 2007). However, researchers have found that wine quality parameters can remain unaffected by increasing yields and in some cases improve with increasing yields (Bravdo et al. 1985). Yield is also vulnerable as unprotected grapes become attractive to pests such as birds and raccoons as they ripen.

The number of clusters are determined in the dormant pruning of vines by how many bud nodes were left on the vine canes for shoots to grow from. These shoots will produce clusters depending on vine nutrient status, climate and cultivar. Dormant pruning is the primary means of controlling the crop growth. If left unpruned, all nodes will produce shoots and will have a negative effect on vine vigor, vine hardening, °Brix levels and reduced pigmentation in the fruit. With Leon Millot, cluster thinning is not typically done so dormant pruning is the only type of cluster regulation for the entire season. Shoots produce leaves; pruning determines the vine's leaf area and therefore the vine's ability to produce sugar, which is important in wine grape quality. If a vine is over cropped it stresses the vine causing weak growth and incomplete ripening.

In grapes, a large portion of the soluble solid is sugar. All sugars are considered total soluble solids and are expressed as °Brix (Dharmadhikari 1994). The unit °Brix represents grams of sugar per 100 mL of juice (Dharmadhikari 1994). Close to maturity, the level of soluble solids are within 1% of the actual sugar content (glucose and fructose) of the berry (Dharmadhikari 1994). Soluble solids accumulate most rapidly with daytime temperatures from 18 to 33°C and are delayed by cool and hot daytime temperatures, high winds, high crop load, fruit zone shading, high soil moisture and high soil N (Jackson and Lombard 1993; Christensen et al. 1994; Spayd et al. 1995; Hilbert et al. 2003). Glucose and fructose are present in equal amounts at maturity. The sugar levels indicate the potential alcohol yield after fermentation and the likelihood of residual sugars remaining (Jackson 2008). During fermentation, yeast converts these sugars to alcohol and CO_2. As the grape matures, soluble solids increase to the level, which can indicate an appropriate level of ripeness to harvest. °Brix is a useful indicator of ripeness and quality in short season climates (Lewis 2008). Prices are usually adjusted to the °Brix present in the harvested grapes (Jackson and Lombard 1993). The increase of sugar in the grape comes from the storage of carbohydrates in the roots and trunk of the grapevines as well as through the process of photosynthesis where the sucrose produced from photosynthesis is transferred from the leaves to the berries as it is broken down into glucose and fructose molecules. The rate of this build up will depend on several factors including the climate (such as a string of cloudy weather which prohibits sunlight from reaching the vine) as well as the potential yield size of grape clusters and young vine shoot tips which compete for the resources from the mother vine. As the concentration of sugars build, the concentration of the acids decrease in the berry (Jackson and Lombard 1993).

Following sugars and acids, phenolic compounds are the most abundant in grapes (Dharmadhikari 1994). They play a vital role in determining the wines colour and flavor (Dharmadhikari 1994).They are mainly found in the skin and seeds of the berry and very little is found in the juice (3-5%) (Dharmadhikari 1994). Phenolics, which are extracted from the skin, seeds and juice during crushing, pressing and the fermentation of wine are the tannic component of wine, which imparts bitterness and astringency (LaGatta et al. 2007). It has been found that wine, one of the most consumed beverages in the world, has considerable antioxidant properties. Red wine phenolics contain 10 to 30x more phenolics than white wine (Dharmadhikari 1994). The total phenolic content of grapes is therefore an important parameter of their antioxidant property (Martin 2012). Phenolics are organic compounds metabolized by plants as a means of defending themselves against environmental stress. The range of phenolics present and their concentration are important determinants of flavor. The two main substances in this group are anthocynanis and tannins (Dharmadhikari 1994). Anthocynanis are the pigments and responsible for the red and purple colour of the grapes (Dharmadhikari 1994). The accumulation of phenolic compounds depends on climate, soil, genetics and management practices (Delrot et al. 2010). The total berry phenolic concentration slowly increases during maturation until a maximum is reached one or two weeks before harvest. Before veraison, there is no significant increase of phenolic compounds in the berries. Accumulation of phenolic compounds depends on soil type and fertility, inherent soil water holding capacity, and the annual amount and distribution of the rainfall in a specific terroir (Lutz et al. 2011). The phenolics extracted from grapes during crushing pressing and fermentation are the tannic component of the wine, which imparts bitterness and astringency. The range of phenolics present are important determinants of flavor (Jackson and Lombard 1993).

Phenolic compounds can give red wines their unique characteristics and accumulate in the skin (Jackson and Lombard 1993). The concentration of phenolic compounds, are mainly dependent upon genetic factors, while agronomic practices and environmental factors also have an influence (Haslegrove et al. 2000; Tsao et al. 2006). Some N is required for phenolic synthesis but excess N can reduce can reduce wine quality by decreasing phenolics and developing less desirable flavor compounds (Martin, 2012).

There is an increasing interest in the use and measurement of antioxidant capacity as a wine grape quality indicator (Huang et al. 2005). Phenolic compounds in wines, especially red wines possess a strong antioxidant activity (Dharmadhikari 1994). Oxygen radicals are chemicals that form naturally inside the body through the process of oxidation. Activities humans perform everyday such as physical motion and digestion produces oxygen radicals. Exposure to rancid food, polluted air, the sun and electricity also contribute to oxygen radicals. An antioxidant is a chemical substance that can inhibit the oxidation of other molecules (ORAC Database 2013). Oxidation reactions can produce free radicals, which can start chain reactions in cells where it can cause damage or death to the cell (ORAC Database 2013). Antioxidants terminate these chain reactions by removing free radical intermediates and inhibiting other oxidation reactions (ORAC Database 2013). Common antioxidants in food include vitamin A, C and E, melatonin, polyphenolic compounds such as flavanoids and phenolic acids (ORAC Database 2013). Since no universal assay accurately reflects all of the antioxidants in a complex system, it is convenient to use at least two complimentary methods to evaluate the antioxidant capacity invitro (Lutz et al. 2011). It is difficult to quantify individual antioxidant compounds so ORAC is a method that provides a sum of the antioxidant components in Léon Millot wine grapes. ORAC uses peroxy radicals and provides a measure of the antioxidant capacity primarily of a group of compounds called flavanoids (ORAC Database 2013). Foods or supplements with high ORAC score may be able to protect cells from this oxidative damage (ORAC Database 2013). The ORAC score covers all the antioxidants in foods that cannot be easily measured separately. The ORAC assay measures the degree of inhibition of peroxy-radical-induced oxidation by the compounds of interest in a chemical solution. It measures the value as Trolox equivalents.

The purpose of this project was to identify optimal sustainable soil management practices in Nova Scotia's viticulture industry using soil amendments and cover crops. The effect of soil amendments and cover crops on wine grape yield and quality was studied. Treatments of interest in this project include mussel sediments (MS), municipal solid food waste compost (MSFW), wood ash (WA), and the use of alleyway cover cropping between vine rows, which will be discussed in more details below.

The specific objectives related to this chapter are:

1. To evaluate the response of wine grape yield and quality in relation to:

A) CC- oat/pea/hairy vetch mixture (OPV), oat underseeded with red clover (ORC), triple mix (TM), and tilled bare soil (BS).

B) SA- MS, MSFW, WA, inorganic fertilizer (FERT) and inorganic fertilizer without nitrogen (NDEF).

Ho: There will be no significant differences in yield components and/or quality of wine grapes due to CC, SA and/or SA x CC combinations.

2. To investigate the residual effects of SA on grape yield and quality parameters in the year after application.

Ho: There will be no significant residual effects of SA on grape yield and quality parameters.

3.2 Experimental Design

The research took place in Crousetown, NS in the LaHave River Valley area of Lunenburg County (Naugler et al. 2004). This study, initiated in 2011, was conducted in a slightly concave section of a 3.24 ha^{-1} field planted with cv. Léon Millot in 1999 at a 1.8 m row spacing. Although the vineyard is located relatively close to the ocean, it lies above the fog line and grapes ripen here at about the same time as areas of the region with more growing degree-days during the growing season (Naugler et al. 2004; Environment Canada 2014). Spring frosts are rarely a problem but heat unit accumulation in the area varies widely within a short distance (Naugler and Wright 2006). In the LaHave River Valley the moderating effect from the Atlantic Ocean in the winter months is a benefit to vineyards.

The most prominent geological feature of the research site is the south facing glacial drumlin composed of slate till consisting of a large gravel component which contributes to the unique terroir of the wines produced from the grapes (Cann and Hilchey 1958; Naugler and Wright 2006). The till is thin and consists of yellowish brown sandy loam or gravelly sandy loam (Cann and Hilchey 1958). The soil type is a Bridgewater loam-drumlin phase soil (Cann and Hilchey 1958). Baseline soil characteristics were taken from composite core samples (0 - 15 cm) in 2011 before the project began and analyzed at the NS Department of Agriculture Analytical Laboratory (Table 2-1). These soil test results are compared to a study done by the Grape Growers of Nova Scotia in 2002, which gave a range of soil test values over six NS vineyards and literature values for adequate levels for each soil nutrient (Table 2-1).

The selected section of the vineyard for this study was planted in Léon Millot. This section was chosen because it was one of the most vigorous and productive sections in the vineyard and contained a single variety that was consistent over the entire research plot. Léon Millot is a hardy red variety of French hybrid grape used for winemaking (Smiley 2010; Lewis n.d). It ripens mid-season with a nice sugar content and moderate acid making it a popular grape among wine producers (Lewis n.d.). It is a sister to the Marechal Foch grape with the differences being Millot ripens a week earlier on average and has a higher vigour, but smaller grape bunch size (Lewis n.d.). Léon Millot is grown on its own rootstock like most hybrid vines. The grape variety was created in 1911 by the French viticulturist Eugene Kuhlmann (Waterkeyn n.d.). It was created from crossing the hybrid grape Millardet et Grasset 101-14 O.P. (*Vitis riparia x Vitis rupestris*) with Goldriesling (*Vitis vinifera*) (Smiley 2010; Waterkeyn n.d.).

The experiment was conducted in 2011 and 2012 as a nested design with four cover crops (CC) as main factors done in triplicate with five soil amendment (SA) treatments. In order to evaluate residual effects, each SA subplot had a split for application year (i.e. first year treatment only versus first and second year) giving 120 experimental units. Each experimental unit contained three vines in production. Each sub-plot size was slightly different due to factors such as dead or unhealthy vines. To eliminate variability, three productive vines were chosen for measurable vine characteristics. Vine rows were 1.8 m apart and spacing within the row was 1.0 m between plants. Cover crop and SA treatments were applied to each side of the measurable vine row in the alleyway with a guard row separating each main effect. Within the measurable vine row, each treatment was separated by single guard vine.

The four CC treatments included: i) an oats, pea and hairy vetch mixture (OPV), ii) oats underseeded with double cut red-clover (ORC), iii) a triple mix of forages which consists of 70% timothy, 15% alsike clover and 15% double cut red clover (TM) and iv) a tilled bare soil control treatment (BS). Seeding rates were based on cover crop guidelines in the *Maritime Guide to Cover Cropping* (Wallace and Scott 2008).

The SA treatments included: i) synthetic fertilizer blend without N (NDEF), ii) synthetic fertilizer including N (FERT), iii) wood ash (WA) plus supplemental fertilizer, iv) municipal solid food waste (MSFW) plus supplemental fertilizer and v) mussel sediments (MS) plus supplemental fertilizer. The split of the SA sub-plots consisted of i) SA applied in 2011 only (1YR) and ii) SA applied in both 2011 and 2012 (2YR). This allowed the testing of residual and accumulative effects of the SA as they broke down over time. It aimed to provide a better understanding of the long-term dynamics of mineralization and nutrient supply potential of the amendment. All treatments received the same estimated level of nutrients as the FERT treatment based on assumptions described below, with the exception that no N was applied in the NDEF treatment. Having the NDEF treatment allowed a determination of how much N cover crops and soil organic matter supplied to the grape vine. It also permitted observation of N deficiency issues with the grape vines.

Amendment application rates (Table 2-2) were determined according to nutrient application recommendations from 2011 baseline soil samples (Table 2-1, NS Department of Agriculture and Fisheries (2004)), and from previous studies assessing the nutrient bioavailability of WA, MSFW and MS in a greenhouse setting over a twelve week period (Sharifi, 2011b). Application rates were adjusted for moisture content. To ensure that an appropriate balance of N, K, Mg, S, and B (where appropriate) was provided with each SA, the SA treatment was supplemented with synthetic fertilizer shown in Table 2-2 to meet the minimum nutrient requirements and to provide comparable levels of available plant nutrients (i.e. nutrient application rate was not intended to be a factor). Average composition of WA, MS and MSFW are shown in Table 2-3.

The WA treatment was applied at 6.3 Mg ha^{-1} on a dry weight basis. Using this application rate the estimated total supply of K was 83 kg ha^{-1}, with the assumption that 80% of the total WA potassium was available in the first year (Sharifi et al. 2013). Nitrogen and S were supplied by inorganic fertilizers in the WA treatment at 40 kg ha^{-1}. For MS, a land application rate of 42,000 L ha^{-1} was used. Based on this application rate 99 kg ha^{-1} of N was estimated to be supplied with the assumption that 40% of the total N is available in the first year. The MS application was supplemented with potassium fertilizer at 83 kg ha^{-1} K to accommodate inadequate levels in the MS (Table 2-2). Municipal solid food waste was applied at 13.4 Mg ha^{-1} on a dry weight basis based on the assumption that 15% of the total N is available in the first year. To balance the nutrients in the MSFW, 30 kg ha^{-1} N and 83 kg ha^{-1} K was required. Amendments were applied in a 1.3 m wide band between vine rows and lightly incorporated into the soil in 2011 with seedbed preparation. In 2012, SA were top dressed aside from in the OPV treatment where SA were lightly incorporated into the soil with annual seedbed preparation. The SA were also lightly incorporated into the soil in BS treatments where tillage occurred throughout the season. Previous management to the vineyard has seen no fertilizer or soil amendments applied to plots within the last three years.

Rocks had been previously piled around the base of the vines by the vineyard owner in an attempt to harness heat during the day and keep the microclimate around the vines warmer at night. The land was prepared by tillage with a rototiller pulled by a small tractor. Cover crops were seeded in early June where oats, peas and hairy vetch were broadcast with a seeder, and then incorporated into the soil with a rototiller; the other cover crop seeds were broadcast on the soil surface without incorporation. After all cover crops were seeded, the alleyways were packed with a roller. Due to the aesthetic condition that needs to be maintained by vineyards with wineries overlooking them, cover crops were mowed four times; once in mid-June, twice in July and once in early August. In the second year of the study, the annual OPV crop was replanted using the same technique used in year one.

A unique local trellising system, sometimes called the LaHave River Valley trellis, is a low wire trellis that was developed to deal with the wind in the area and early autumn frosts (Naugler et al. 2004). The vineyard calendar begins in March with pruning of unwanted wood from the previous season growth. All vine prunings were left on the ground in the vine rows. In late April, the vine rows without a permanent cover crop were tilled to prepare a seedbed or to remove resident vegetation and incorporate it into the soil before weed seeds have germinated and roots translocate. Fungicide sprays began in mid-June when shoots were at appropriate lengths. Folpan® (folpet) and Nova® (myclobutanil) fungicides were sprayed on the foliage to combat grape cluster and vine disease. Disease control was monitored throughout the rest of the season and was sprayed accordingly. Ignite® (glufosinate ammonium) herbicide was used in all treatments to keep a 0.50 m weed free zone under the vines to minimize competition for nutrients and water. This was applied up to three times during the growing season depending on weed competition, weather and labour restraints. Mowing of weeds under vine rows was necessary when weed pressure was too great. Bird netting, raccoon fencing and deer fencing were used to deter animals from devastating the vines and fruit. Tucking shoots into trellis catch wires began after flowering in early July. The first shoot thinning occurred at this time as well. Hedging the canopy was done in August as vines became excessively vigorous for the low trellising. Cultivating between vine rows and mowing ceased after August as growth in vines does not want to be encouraged at a time they should be slowing down. Léon Millot typically reaches veraison in late August to early September. A heavy pruning took place at this time to allow the grapes to have direct sunlight, build sugar, and turn dark red. The harvest occurred in mid-October. Only mowing and mulching of resident vegetation has occurred with a lawn tractor. All prunings were left on the vineyard floor.

3.3 Field, Laboratory and Analytical Methods

3.3.1 Grape Yield Parameters

The harvest date of the research plot was based on when the vineyard manager of Petite Riviere and the winemaker agreed the grapes were at a satisfactory stage for harvest, when the weather was dry for at least a 24-hour period before harvest and that the day was a relatively sunny and warm in mid to late October. The harvest in 2011 occurred on October 15th and 20th. The first day of harvest was stopped due to weather but grapes were harvested in the first two blocks. In 2012 harvest occurred on October 21st. Harvesting each cluster was done with a set of harvesting pruners. Harvested clusters were counted per sub-plot and then placed in a 20 L pail that was weighed to determine the weight of the clusters per sub plot. Samples for grape quality indicators were taken randomly from each plot. Approximately 100 individual berries were taken from each sampling plot to measure each quality indicator. This weight was included in the total weight of grapes per sub-plot. Berry sampling is an accurate technique used to gauge grape quality. However, the following variables can affect the integrity of the sample: i) the composition of berries can differ with their position on the rachis, ii) the variability in microclimate and soil in a large research plot, iii) the location of the cluster on the vine, iv) the degree of sun exposure (variation in leaf cover) and v) the natural tendency to select samples based on eye appeal (Napa Valley Vinters Association 2007). Berries were picked as complete as possible in order not to lose their juice.

The number of clusters per vine were counted at harvest as they were pruned from the vine. The cluster was pruned from the vine and placed into a 20 L pail. Results were recorded on a data sheet. After grape clusters were harvested from the vine into 20 L pails, each vines grape yield was weighed with a digital hanging scale. Average cluster weight was calculated.

3.3.2 Total Soluble Solids (Degree Brix)

A representative sample of 100 berries from each plot was used. The °Brix was measured with a handheld refractometer. Grapes were collected in a Ziploc bag and frozen until analysis. The samples were allowed to thaw then mashed, filtered and centrifuged in the lab to remove the pulp. The handheld refractometers prism box was opened and cleaned, and then several drops of the sample was placed on the glass surface, ensuring the entire surface was covered. The prism box was closed and through the eyepiece, the °Brix level was recorded (Vasquez and Mueller n.d.).

3.3.3 Antioxidant Capacity Assays

3.3.3.1 Total Phenolic Compounds

Total phenolic compounds were measured for all SA treatments only under the TM cover crop to give an indication of SA effects only. Total phenolics were extracted and analyzed based on the method of Singleton and Rossi (1965) and Folin, and

Ciocalteau (1927) with some modifications. Powdered freeze dried samples for each plot were taken from a -80°C freezer. Then 0.125 g of powder was weighed out into a 50 mL centrifuge tube. Added then was 10 mL of extraction solution (40% acetone, 40% methanol, 20% Milli-Q water and 0.1% formic acid) which was vortexed and then sonicated at #15 for 30 seconds with the tube remaining on ice. The sample was then left under dim light for 30 minutes. The sample was then centrifuged at 10,000 xg for 15 minutes and the resulting supernatant was transferred to a clean 50 mL centrifuge tube and kept in fridge until use. A second extraction was done similarly and the supernatant was added together to have a 20 mL sample volume. Then 25 µL of standard or sample extract was placed into four wells each on a 96 well microplate. Samples were measured for assay activity at 750 nm on a multiscan Spectrum microplate reader (Thermo-Fischer Scientific, Verta Finland) using 250 uL Milli-Q water, 50 µL Folin-Ciocalteau reagent and 12.5 µL saturated Na_2CO_3. After assay, data from reader was placed on a spreadsheet and transferred to excel. A regression line was generated from the standard absorbance's and used to quantitate the samples absorbance to obtain mg GE/g DW (mg Gallic Acid Equivalent g^{-1} dry weight) values using the following formula;

$$\text{sample mg/L x extraction volume(L)/tissue weight (g)= mg GE } g^{-1} \text{ DW}$$

3.3.3.2 Oxygen Radical Absorbance Capacity (ORAC)

Sample preparation consisted of freezing 100 berries after harvest in liquid N and storing at -80°C until analysis. Total extraction (without separation into lipo/hydro fractions) was carried out under dim light. Approximately 0.050 g of finely ground lyophilized grape tissue was weighed into 50 mL centrifuge tubes ad placed on ice. Then 10 mL 70% acetone, 29.5% Milli-Q water and 0.5% acetic acid (AWA) was added to each sample and sonicated at #15 for 1 minute with the tube remaining on ice. It was then centrifuged at 2000 rcf for 15 minutes and the supernatant was transferred to a 25 mL volumetric. 10 mL of AWA was added to the remaining sample then the extraction was repeated and the resultant supernatant was transferred to the same volumetric. After the extraction, volume was brought to 25 mL using AWA and kept on ice. For whole red grape analysis 500 µL of supernatant was removed in an appendorf and placed in a 10 mL tube. Then 4500 uL of AWA (room temperature) was added to the tube (10x) dilution and vortexed. A 500 µL aliquot from the 10x dilution was then taken and placed into a centrifuge tube. 1000 µL of AWA (room temperature) was added to the tube creating a 30x dilution from the original sample. This dilution was seen as the best option from preliminary work. Samples were kept in the dark in a fridge until analysis. The samples were analyzed on a fluoroskan ascent FL 96-well microplate reader (Thermo-Fischer Scientific, Verta Finland 2009) using AAPH 2,2'-azobis (2-amidinopropane) dihydrochloride as a peroxyl generator and 6-hydroxy-2-5-7-8 tetramethylchroman-2-carboxylic acid (Trolox) as a standard according to the method of Prior et al. (2003). As the reaction progresses, fluorescein is consumed and FL intensity decreases. In the presence of antioxidant, the FL decay is inhibited ORAC was determined by plotting results in a standard curve obtained by the addition Trolox by regression by relating Trolox concentrations and the net area under the fluorescein decay curve. The antioxidant capacity was expressed as TE g^{-1} DW.

3.3.4 Statistical Analysis

Data on all the parameters and response variables were subjected to analysis of variance (ANOVA) using the GenStat statistical package (VSN International 2011). An ANOVA test was used to evaluate the 3-way treatment combination of CC x SA x application year (APP). Planned comparisons were used to compare specific treatments and determine if results were significant at a 0.05 or 0.01 probability level. Planned comparisons for the main effects were as follows. For CC, the comparisons analyzed were; a) BS vs. cover crops, b) legume-based cover crops (OPV+ORC) vs. grass-based cover crops (TM) c) ORC vs. OPV. These allowed a comparison of a soil with no cover to one with cover, the legume based cover crops to the grass based cover crops and finally to compare the two legume based cover crops of ORC and OPV. The planned comparisons used for the SA were; a) NDEF vs. FERT+MS+MSFW+WA, b) FERT+WA vs. MS+MSFW, c) MS vs. MSFW, d) FERT vs. MS. The first would allow analysis of N from cover crops on the NDEF treatment compared to others. The WA behaved more like an inorganic fertilizer in previous studies, with most of its nutrients in inorganic form, so it was grouped with FERT to assess how FERT and WA performed against MS and MSFW amendments, which were also similar products. The third comparison between MS and MSFW allowed an assessment of how these natural products would compare to one another. The final comparison of FERT and MS was done because little research has been done on MS and how comparable it would be to synthetic fertilizer to supply nutrients to vines. In previous greenhouse studies, it was noted that MS has more available N than other soil amendments being used (Sharifi et al. 2010). The APP was also a main effect used to assess whether cumulative or residual effects were significant. Interaction effects grouped these comparisons together between SA, CC and APP. A covariate of vine location was used in this project between blocks, which helped to account for spatial variation, as each measurable effect was done in triplicate over the area of the research block.

3.4 Results and Discussion

3.4.1 Yield Parameters

In 2011, no significant interactions between CC and SA were observed, however significant differences in the number of clusters per vine were observed between SA treatments while yield per vine and average cluster weight were significantly different between CC plots (Table 3-1). The NDEF plots contained fewer clusters than other soil amendments ($p = 0.058$). The MS treatment produced more clusters per vine than FERT ($p = 0.042$). The BS treatment had significantly lower fresh weight yield and average cluster weight per vine than other cover crop treatments ($p = 0.013$ and $p = 0.003$, respectively). The covariate of spatial variation was significant in determining fresh weight yield per vine in 2011 ($p = 0.023$).

In 2012, main effects or first order interactions did not significantly affect yield components; however, the interaction between SA, CC and APP led to significant differences in the number of clusters per vine and average of cluster weight per vine (Table 3-2). The first significant comparison was that 2YR BS plots amended with MS or MSFW produced a greater number of clusters per vine than if WA or FERT was used ($p = 0.047$). The second significant comparison was that 1YR BS plots amended with MS produced a greater number of clusters per vine than if MSFW was used ($p = 0.019$). The third significant comparison was that 1YR TM plots amended with FERT had significantly fewer clusters per vine than MS plots ($p = 0.026$). The covariate of spatial variation was significant in determining the average clusters per vine in 2012 ($p = 0.010$). The pattern of spatial variation (covariate) was key in several productivity variables identified in the vineyard research block. The blocks were characterized by both changes in aspect and elevation. Different degrees of shade, moisture and soil structure can have an impact on grape parameters. The 2YR plots seeded with a legume based cover crop and amended with NDEF contained significantly lower average clusters weights than 1YR plots ($p = 0.009$). The second significant comparison was that 2YR TM plots amended with FERT or WA produced a significantly greater average cluster weights than 1YR plots of the same treatment ($p = 0.032$). The final significant comparison was that 1YR TM plots amended with MSFW produced greater average cluster weights than 2YR plots ($p = 0.001$).

The number of clusters per vine ranged from 19-24 in 2011 and 39-52 in 2012 as shown in Table 3-1 and Table 3-2. In 2011, the treatments may not have had as much of an effect on the number of clusters per vine since cane bud development was determined in the pruning prior to experiment implementation. Although primary bud development could not be altered, secondary and tertiary cluster development may have been effected more from the treatment, which is a possible reason why there was significant differences between SA treatments in 2011. In some cases clusters per vine decreased and average berry weights increased because the vine was compensating for the reduced number of clusters. Weather conditions, including frost events after bud break or extreme temperature fluctuation, precipitation or wind during bloom can cause sustainable yield losses reducing the number and size of clusters.

The increase in yield per vine and average cluster weight in 2011 in plots seeded with a cover crop could have been due to the increased supply of mineral N and added benefits provided to the soil by the cover crop early in the season. The BS average yield per vine and average cluster weight could have been less than cover cropped plots due to tillage in this treatment continuing to mineralize N, which promotes shoot growth instead of berry development. Singh (2006) found that an increase in average cluster weight came with an increased spring N level because N increased fruit set in spring. Palliotti et al. (2007) showed that cover crops reduced yield compared to BS up to 2.3 Mg ha^{-1}. Guerra and Steenworth (2012) showed cover crops decreased grapevine yield but that fertilization practices could overcome the cover crop impact. Hostetler et al. (2007) suggested that excessive weed competition could reduce yield and fruit quality. Hostetler et al. (2007) also reported no differences between bare soil and mulches. Tesic et al. (2007) found that yield per vine was significantly affected by cover crop treatments, where bare soil rows had greater yield than cover crop rows, which contradicts findings in this study. Fourie et al. (2006) found that N-fixing cover crops had a positive impact on yield, especially in young grapevines. Hanna et al. (1995) found that cover crops did not have an effect on overall yield but represented a tradeoff for fertilizer and pesticide use in vineyards. Although Hanna et al. (1995) did not find cover crops affected yield, however, they reported greater berry weights in clusters as a result of cover crop use.

In 2012, vines were more reactive to the treatments imposed on them in this study. Clusters per vine and average cluster weight were affected by significant comparisons involving all three variables. The 2YR BS treatments amended with MSFW or MS possibly had more available B at the time of bloom compared to WA and FERT treatments. Boron aids in the length of pollen tubes during flowering and can greatly influence yield. Hargreaves et al. (2008b) attributed variation in year - to - year fruit yield to N and B deficiencies. The 1YR BS plots amended with MS produced more clusters than MSFW possibly because the MSFW was supplying too much N to the vine creating more vigor and less time for mature cluster formation. This was seen in the greater whole leaf and petiole %N in MSFW (Table 2-10). The 1YR TM plots amended with FERT produced fewer clusters than MS plots possibly because the FERT was supplying too much N to the vine creating more vigor and less time for mature cluster formation. The FERT treatments in the TM cover crop also contained more Mg and S in the soil, which helps legumes capture atmospheric N. Sandler et al. (2009), found that crustacean waste increased yield components compared to other treatments in the study. Abassi et al. (2004) found that nutrients in fish waste had similar effects on yield as synthetic fertilizer when equal amounts of nutrients were applied. In 2012, the dry pruning weight was greater in MS plots (Table 2-10) which could be an indicator of a healthier canopy for the following production year, resulting in a greater number of clusters. This was also a possible reason 2YR plots seeded with legume based CC and amended with FERT produced fewer clusters than if MS was used. Palliotti et al. (2007) found fewer clusters on vines in cover cropped plots than in bare soil plots in dry years, and grass cover crops significantly reduced the clusters per vine compared to other covers used. Guerra and Steenworth (2012) found that in cover crop plots there were less clusters per vine than in bare soil plots. Reeve et al. (2005) found no differences in number of clusters per vine between organic and biodynamic plots. Mercado-Martin (2006) found that the number of clusters per vine significantly affected yield and °Brix. Tesic et al. (2007) found that the number of clusters per vine was significantly affected by cover crop treatments, where bare soil rows had more clusters than cover crop rows. Other possibilities for reduced cluster numbers per vine are frost damage, pruning techniques and vine disease.

In 2012, 1YR plots seeded with legume-based cover crop and amended with NDEF had a higher average cluster weight than in the 2YR plots of the same treatment possibly due to legumes in 2YR plots providing more nutrients to the vine. This greater nutrient availability can create a larger canopy with multiple clusters on one shoot with secondary and tertiary clusters being smaller reducing the average cluster weight. Higher average cluster weight in 2YR TM plots amended with WA or FERT compared to 1YR plots of the same treatment, was probably the result of 2YR treatments supplying more nutrients than 1YR treatments. The nutrients in the TM were not as available to the vine due to the efficiency of grass in taking up soil N as discussed in chapter two and seen in Table 2-11. It was also observed that 1YR plots amended with WA produced more shot berries than other plots, which would have decreased average cluster weight. Greater average cluster weights in 1YR TM plots amended with MSFW compared to 2YR plots of the same treatment could have been the result of an established grass cover crop tying up nutrients longer in 2YR plots and reducing the amount of mineral N in the soil available to the vine. Neilson et al. (2010) found that applications of 80 kg ha^{-1} N resulted in lower Merlot fruit yields compared with 40 kg ha^{-1} N indicating that excess N could decrease fruit yields. It should be noted that smaller berries make better wine due to a higher sugar: volume ratio (Matthews and Nuzzo 2007). Hargreaves et al. (2008b) found that yield was not affected by applications of MSFW or other amendment treatments involved in the study. Guerra and Steenworth (2012) found that vines in bare soil plots had heavier clusters than plots with a cover crop. These results contradict Sweet and Schreiner (2010), where no effect on cluster weight was found with cover crops, but an effect of year on cluster weight was significant. Tesic et al. (2007) recorded that cluster weight decreased with the use of cover crops. In NS, precipitation can vary from year to year and Palliotti et al. (2007) found that in years with high precipitation a lower average cluster weight was recorded in cover cropped plots than bare soil treatments.

Although there were only marginal differences ($0.10 > p > 0.05$) between treatments for yield in 2012 it is important to measure in vineyards. Planting a cover crop in the vineyard led to higher yield than having a bare tilled soil. Table 3-2 shows that there was an increase in yield of approximately 0.5 kg per vine in cover cropped soil compared to the tilled bare soil treatment. There were still marginal differences between APP treatments where 2012 produced a greater yield per vine than 2011. This result can possibly be attributed to climactic differences between growing seasons but could also be the result of variations in canopy management, despite attempts to maintain consistent conditions (Guerra and Steenworth 2012). An average increase of approximately 200 g per vine was seen between 2011 and 2012 growing seasons. Christensen et al. (1994) found that plots fertilized with N had significantly greater yield than other plots without N fertilization in year two of the study. Christensen et al. (1994) also observed that soil amendments increased yield in general. Neilson et al. (2010) found that altering timing of N over seasons could influence yield, with inadequate amounts at bloom reducing overall yield. Walser et al. (2007) found no significant differences in yield over amendment treatments or year. Spayd et al. (1993) found that each year vines received N, they grew fuller clusters resulting in a heavier crop load to previous years. Spayd et al. (1993) found that petiole N was inversely correlated with fruit yield, but adding N fertilizer to vineyards with low petiole N increased yield; Nielson et al. (2010) also found an increase in Marechal Foch yield, which is similar to Leon Millot, with increased N fertilization.

Spayd et al. (1993) found that a possible rapid response of yield to N was due to the initial low N status of the soil. Increasing N fertilization rates has been found to substantially improve fruit yield components if a preexisting N deficiency is evident (Spayd et al. 1993; Keller et al. 1998). Nitrogen fertilization of grapes has been reported to increase fruit yields (Spayd et al. 1993; Keller et al. 1998; Wolf and Pool 1998; Neilson et al. 2010) while in other studies N treatment reduced fruit yields (Hilber et al. 2003; Neilson et al. 2010). Higher yield can mean lower quality wine as flavor compounds get diluted (Matthew and Nuzzo 2007). Jackson and Lombard (1993) found that high yields delayed the maturity of grapes affecting sugar accumulation but other studies found no consistent results. Other possibilities for yield differences per vine are frost damage, pruning differences, bird injury, berry drop prior to harvest and weather. High rainfall in the previous winter can increase the availability of soil moisture during early vegetative growth leading to higher cluster weights at fruit set (Bravdo et al. 1985). It should also be remembered that yield can be adjusted by pruning, cluster thinning, irrigation and shading. The high yield - low quality paradigm may be applicable in our climate where sugar accumulation is a limiting factor because reducing crop generally increases the rate of sugar concentration in the remaining clusters (Matthews and Nuzzo 2007).

3.4.2 Degree Brix

Treatments did not affect °Brix in 2011 or 2012 as seen in Table 3-1 and Table 3-2. The overall results of °Brix was low compared to what a red wine grape at this stage of growth should have been. The sample preparation and length of storage, which was five months, may have lowered the soluble solids in the grape samples and reduced the accuracy of °Brix measurements. Chiralt et al. (2001) found that during the freezing and storage process, physical and chemical changes occurred in the fruit including loss of water and soluble solids although Spayd et al. (1987) found freezing did not have an impact on wine quality. Mulywanti et al. (2010) found that the total soluble solids of sliced mango decreased after three months storage. The integrity of the sample could have been also been a factor and affected by the following variables: i) the composition of berries with their position on the rachis, ii) the location of the cluster on the vine and iii) the degree of sun exposure (variation in leaf cover) (Napa Valley Vinters Association 2007).

Temperature is also an important factor when measuring °Brix as refractive index is influenced dramatically by temperature (Hanson 2003). The samples were kept in a fridge before analysis, which may have affected the result. The refractive index expressed on a °Brix scale may also be influenced by suspended particles but in this project, the suspended solids did not increase °Brix levels. These may have been factors that contributed to low and insignificant variations in the °Brix measured from the grape samples in this study.

Wang et al. (2008) explored the effects of tillage to a permanent cover on blueberries and found that sugar content was higher on berries under permanent cover than those in conventionally tilled blocks. Palliotti et al. (2007) showed that a cover crop had no effect on °Brix although soil management influenced sugar content. It should also be noted that after veraison, the metabolism of the berry changes drastically from acid accumulation to sugar accumulation making harvest the time where the most sugar will be present in the berry (Lizana et al. 2007). Matthews and Nuzzo (2007) found that fruit harvested in the afternoon would contain less solvent water than fruit harvested at dawn therefore increasing °Brix. ETS Laboratories (2013) found that °Brix was greatly affected by grape water content. The grapes in this project were harvested over a period of time when weather and moisture conditions were consistent. Matthews and Nuzzo (2007) reported that sugar content was proportional to berry size and that °Brix was dependent on crop yield.

Conradie and Saayman (1989) found no effect of N treatments on °Brix. In a study by Ratnasooriya et al. (2010), °Brix was significantly greater in Léon Millot than reported in this study. The accumulation of TSS is often delayed by excessive N application. Hilbert (2003) found that the greater the application of N the lower the °Brix level was in the grapes. No significant N effects on °Brix were observed in other studies in wine grapes (Bell et al. 1979; Conradie and Saayman 1989; Neilson et al. 2010).

3.4.3 Antioxidant Capacity Assays

No significant differences in total phenolic compounds were found between SA treatments in TM plots over the course of this project (Table 3-3). In 2011, fresh samples were used with mean values ranging from 3.28 - 4.21 mg GAE L^{-1}. In 2012, freeze-dried samples were used with mean values ranging from 9.75 - 11.46 mg GAE g^{-1}. Lutz et al. (2011) found that total phenolics in juice of table grapes grown in Chile ranged from 283-564 mg GAE L^{-1} and from 63-125 mg GAE g^{-1} in the solid fractions. Ratnasooriya et al. (2010) found that total phenolic compounds in Nova Scotian grown Léon Millot wine grapes were 7.73 mg GAE L^{-1} while other grapes assessed ranged from 7.56-23.4 mg GAE L^{-1} which were greater than reported values in this study.

Wang et al. (2008) explored the effects of tillage over a permanent cover and found that total phenolics in permanent cover organic blocks were higher than conventionally tilled blocks. Palliotti et al. (2007) found that phenolics in a dry growing season were increased along with berry colour in cover-cropped plots. Guerra and Steenworth (2012) discovered that permanent cover crops increased total phenolic compounds over temporary covers.

No significant differences in ORAC antioxidant capacity was found between SA treatments in 2012 (Table 3-3). The mean values of results obtained in this study ranged from 287.6 – 328.0 umol TE g^{-1} on a dry weight basis. The mean values found from other studies were (17.59 umol TE g^{-1}) for red vinifera grape juice and 18.37 umol TE g^{-1} for red table grape juice (min 9.85 umol TE g^{-1}, max 26.05 umol TE g^{-1}) (ORAC Database, 2013). Ou et al. (2001) found red wine to contain 6492 TE g^{-1} and grape seed extract to contain 11889 TE g^{-1} concluding that most antioxidants may be contained in other parts of the grape aside from the juice. Higher phenolics and antioxidants are found in grape skins (Lutz et al. 2011). Lutz et al. (2011) research ranged in ORAC scores of 9300 - 32700 umol TE L^{-1} in juice and 8800 - 15800 umol TE g^{-1} in the skin. Ratnasooriya et al. (2010) had ORAC scores of 4.48 g TE L^{-1} for Léon Millot while the range went from 1.40-12.2g TE L^{-1} for other grape varieties used in the study. Results in this study were lower than other research most likely because seed, skin and juice were not analyzed separately.

Wang et al. (2008) explored the effects of tillage over a permanent cover and found that ORAC in permanent cover organic blocks were higher than conventionally tilled blocks. The composition of phenolics in grapes varies according to the cultivar, grape fractions, growing conditions, agronomic practices, rainfall, temperature and storage conditions (Diharmadhikari 1994; Rodriguez et al. 2006; Ratnasooriya et al. 2010). Ratnasooriya et al. (2010) found that ORAC antioxidant score was higher in wine grapes than table grapes and a high positive correlation was observed between total phenolic concentrations and ORAC antioxidant capacity. Hargreaves et al. (2008b) found that total antioxidant capacity was not affected by MSFW or other amendment treatments in the study. It was speculated that the increase in antioxidant activity from the compost applications occurred in the strawberries from improved physical and chemical soil characteristics and increased soil microbial activity.

3.5 Conclusion

There are a wide range of external factors causing changes in grape yield and quality such as climate, soil, geography and management practices. It is why the resultant wines reflect the terroir their grapes were grown in. Due to the high acreage of Léon Millot planted in NS, the variety was an excellent red hybrid grape to test the effects of various nutrient sources on yield and quality parameters of the grape.

From the results of this research, we can speculate that cover cropped vineyards receiving N containing soil amendments yearly may produce significantly larger yields over time. The number of clusters were significantly affected by soil amendment type for the 2011 harvest where MSFW and MS plots were comparable to FERT and higher than NDEF and WA. In both years of the study, the actual weight of clusters and yield per vine was influenced by CC treatments where treatments with a cover crop had a greater yield per vine than BS plots possibly due to the cover crops ability to balance out canopy and crop ratio by taking up excess nutrients. The percent increase in yield as a result of establishing a cover crop was 27% in 2011, while in 2012 increases in yield of 34% in residual treatments and 26% in cumulative treatments were observed. In 2012, along with APP having significant implications on yield parameters, the establishment of cover crops and continued application and residual effect from soil amendments had an important significance on yield factors. In general, a greater number of clusters does not represent a greater yield. This vineyard had low overall yields and the goal was to increase yield with treatments. The sustainable soil management practices implemented in this project produced yield comparable to synthetic fertilizer. Extra boron from MS, MSFW and WA may have led to a heavier fruit set in spring causing overall yield to be increased.

Treatments had no effect on °Brix, total phenolics and ORAC in this project. Other studies have reported differences in quality factors as mentioned. The °Brix should have been analyzed directly after harvest at room temperature to eliminate possible experimental error. The other quality factors should have been done on all treatments to see if the cover crop affected these factors. The ORAC should have been done for 2011 and 2012 to see if there were changes between growing seasons. Although there were no differences between treatments, results were comparable to other antioxidant assay studies done on grapes.

The results may have been improved with greater control over the number of buds per cane that were left at pruning. The MS, MSFW and WA treatments should be continued to assess their long-term effects on grape yield and the complex relationships between cover crops and soil amendments. Future research could look at a long-term study to assess quality factors to evaluate response over more than two growing seasons and preferably at more than one site. Future research could also look at the impact that treatments have on wine quality by fermenting and producing wine from the separate treatments to determine differences.

Table 3-1 Mean values of grape yield parameters and °Brix in response to cover crops and soil amendments (2011).

Treatment		**Number of Clusters per Vine**	**Yield Fresh Weight per Vine (Kg)**	**Average Cluster Weight (Kg)**	**Average Brix (°)**
Cover Crop (*n=24*)[1]					
TM		19.18	1.31	0.067	15.66
ORC		23.56	1.46	0.061	13.69
OPV		19.69	1.18	0.057	14.07
BS		18.61	0.96	0.048	13.38
Grand Mean		*20.26*	*1.23*	*0.059*	*14.20*
SEM		*1.41*	*0.09*	*0.002*	*0.74*
Amendment (*n=30*)[2]					
NDEF		18.22	1.05	0.057	14.45
FERT		21.48	1.25	0.057	14.51
MSFW		21.01	1.27	0.055	13.76
WA		18.07	1.15	0.061	14.13
MS		22.50	1.42	0.062	14.14
Grand Mean		*20.26*	*1.23*	*0.059*	*14.20*
SEM		*1.16*	*0.10*	*0.003*	*0.21*
			Analysis of Variance (Prob > F)		
Source of Variation	d.f.				
Cover Crop(CC)	3	n.s.[3]	0.035	0.011	n.s.
BS vs ORC, OPV, TM[4]		-	*0.013*	*0.003*	-
ORC, OPV vs TM		-	-	*0.071*	-
ORC vs OPV		-	*0.066*	-	-
Soil Amendment(SA)	4	0.032	n.s.	n.s.	n.s.
NDEF vs FERT, WA, MSFW, MS		*0.058*	-	-	-
FERT, WA vs MSFW, MS		*0.094*	-	-	-
MSFW vs MS		-	-	-	-
FERT vs MS		*0.042*	-	-	-

[1] NDEF = synthetic fertilizer with no nitrogen, FERT = synthetic fertilizer, MSFW = municipal solid food waste, WA = wood ash, MS = mussel sediments

[2] TM = triple mix, ORC = oats underseeded with red clover, OPV = oats, field pea and hairy vetch mix, BS = tilled bare soil.

[3] n.s. = not significant at 0.10 probability level.

[4] This represents the interaction of soil amendments with cover crops. If this interaction was significant, the planned comparisons are shown that were significant under this effect. For example, the comparison (BS vs CC . FERT vs MS) represents the comparison between bare soil or cover cropped plots with applications of FERT or MS. The period in-between main effects represents the interaction. The following values are an example if the above interaction was significant ($p < 0.05$). a) First find the mean of BS when FERT was used = 4.01 b) Next calculate the mean of CC (add up the means of all plots with a cover crop) when FERT was used = 5.73 c) Then find the mean of BS when MS was used = 7.60 d) Finally get the mean of CC (add up the means of all plots with a cover crop) when MS was used = 3.88. Using this information, you find the interaction with the greatest difference between data groups and that is the significant interaction. In this example, it would be the BS plot amended with MS is significantly greater than if FERT was used. The CC plots amended with MS or FERT were not significantly different from one another.

Table 3-2 Mean values of grape yield parameters and °Brix in response to cover crops and soil amendments (2012).

Treatment		Number of Clusters per Vine	Yield Fresh Weight per Vine (Kg)	Average Cluster Weight (Kg)	Average Brix (°)
Cover Crop (*n=24*)[1]					
TM		51.84	2.56	0.052	13.48
ORC		46.15	2.28	0.050	13.16
OPV		43.76	2.12	0.047	13.30
BS		39.12	1.62	0.043	13.04
Grand Mean		*45.22*	*2.14*	*0.048*	*13.24*
SEM		*1.86*	*0.23*	*0.005*	*0.30*
Amendment (*n=30*)[2]					
NDEF		45.44	1.99	0.048	13.05
FERT		44.19	2.22	0.049	13.24
MSFW		44.35	2.02	0.045	13.53
WA		42.99	2.19	0.050	13.38
MS		49.12	2.29	0.048	13.02
Grand Mean		*45.22*	*2.14*	*0.048*	*13.24*
SEM		*1.54*	*0.16*	*0.003*	*0.22*
Application Year[3]					
1YR		44.37	2.05	0.047	13.25
2YR		46.07	2.24	0.049	13.23
Grand Mean		*45.22*	*2.14*	*0.048*	*13.24*
SEM		*1.02*	*0.07*	*0.001*	*0.12*
Source of Variation	d.f.				
APP[4]	1	n.s.	0.059	n.s.	n.s.
APP × CC	3	n.s.	0.086	0.000	n.s.
APP × CC × SA	12	0.004	0.078	0.005	n.s.
BS vs ORC, OPV, TM . FERT, WA vs MSFW, MS . APP[5]	-	*0.047*	-	-	-
BS vs ORC, OPV, TM . MSFW vs MS . APP	-	*0.019*	-	-	-
ORC, OPV vs TM . FERT vs MS . APP	-	*0.026*	-	-	-
ORC, OPV vs TM . NDEF vs FERT, WA, MSFW, MS . APP	-	-	-	*0.009*	-
ORC vs OPV . NDEF vs FERT, WA, MSFW, MS . APP	-	-	-	*0.059*	-
ORC, OPV vs TM . FERT, WA vs MSFW, MS . APP	-	-	-	*0.032*	-
ORC, OPV vs TM . MSFW vs MS . APP	-	-	-	*0.001*	-

[1] NDEF = synthetic fertilizer with no nitrogen, FERT = synthetic fertilizer, MSFW = municipal solid food waste, WA = wood ash, MS = mussel sediments

[2] TM = triple mix, ORC = oats underseeded with red clover, OPV = oats, field pea and hairy vetch mix, BS = tilled bare soil.

[3] n.s. = not significant at 0.10 probability level.

[4] This represents the interaction of soil amendments with cover crops. If this interaction was significant, the planned comparisons are shown that were significant under this

effect. For example, the comparison (BS vs CC . FERT vs MS) represents the comparison between bare soil or cover cropped plots with applications of FERT or MS. The period in-between main effects represents the interaction. The following values are an example if the above interaction was significant ($p < 0.05$). a) First find the mean of BS when FERT was used = 4.01 b) Next calculate the mean of CC (add up the means of all plots with a cover crop) when FERT was used = 5.73 c) Then find the mean of BS when MS was used = 7.60 d) Finally get the mean of CC (add up the means of all plots with a cover crop) when MS was used = 3.88. Using this information, you find the interaction with the greatest difference between data groups and that is the significant interaction. In this example, it would be the BS plot amended with MS is significantly greater than if FERT was used. The CC plots amended with MS or FERT were not significantly different from one another.

Table 3-3. Mean values of grape quality parameters in response to soil amendments.

Treatment		**2011** **Total Phenolics (mg GAE L^{-1})**	**2012** **Antioxidant Trolox Eq. (TE g^{-1} DW)**	**2012** **Total Phenolics (mg GAE g^{-1})**
Amendment (*n=15*)[1]				
NDEF		4.21	287.6	9.75
FERT		3.63	296.0	11.70
MSFW		3.85	328.5	10.27
WA		3.95	306.5	11.44
MS		3.28	302.3	11.46
Grand Mean		*3.79*	*304.2*	*10.92*
SEM		*0.34*	*20.1*	*0.63*
		Analysis of Variance (Prob > F)		
Source of Variation	d.f.			
Soil Amendment(SA)	4	0.430	0.683	0.203

[1] NDEF = synthetic fertilizer with no nitrogen, FERT = synthetic fertilizer, MSFW = municipal solid food waste, WA = wood ash, MS = mussel sediments.

Chapter 4.0 Summary, Conclusions and Recommendations

4.1 Effect of Soil Quality on Crop Production

This study has taken an in depth approach on sustainable nutrient management practices for the NS wine grape industry from assessing soil management changes and the effect the treatments had on grape yield and quality with a focus on soil fertility. There are numerous benefits in creating and maintaining a healthy soil. The vines are a reflection of the conditions within the soil. When all soil factors are in an optimal range, vine growth and production are optimized. The purpose of this project was to identify optimal sustainable soil management practices for the NS viticulture industry.

Nutrition is a key component of vineyard management and plays a significant role in wine production that includes fruit set, fruit quality and quality of wine produced from the grapes (Singh 2006). Although some differences among treatments were observed with the use of amendments, fertilizer and cover crops, it may take longer than the time vines were under observation in this study to see factors altered and improved by these sustainable management practices. Cover cropping has been a well-documented practice allowing a viticulturist to control vine vigor, yield and to enhance grape composition (Ingels et al. 2005; Olmstead 2006: Tesic et al. 2007). Cover cropping has also been well documented at improving physical and chemical soil characteristics while reducing soil erosion (Palliotti et al. 2007). Vineyard floor management has multiple goals that encompass weed suppression, soil conservation, vine vigor control, and influencing an optimal crop load for superior wine. Different cover crops are chosen for different reasons and can depend on the geography of where grapes are being grown. In Nova Scotia, either a perennial or annual cover crop is used, but in Northern and Eastern

Ontario where vines are hilled with soil each fall to protect them from the extreme cold temperatures, an annual cover crop would have to be used.

In cool climate viticulture, management practices used to control yield and hasten ripening may be more important than high yield or cluster weights in determining the quality of resulting grapes or wine due to the climatic limitations on ripening a crop (Matthews and Nuzzo 2007). Grape yield and composition, vine characteristics, the soil environment and canopy microclimate can change over a small geographical area. In this study we attempted to minimize variation and error in the field trial as much as possible. It is important to recognize that even small variations in grape composition are significant as they can have large impacts on wine quality (Oke et al. 2007). Although the results of this study did not analyze the complex relationships between yield and quality, it gave some insight on what effects the treatment combinations had on tested parameters.

The study demonstrated that WA, MSFW and MS have the potential to provide adequate nutrients to the vine when supplemented with required fertilizer to meet soil test recommendations. Using waste by-products, such as MSFW, have shown the added benefits of adding soil organic matter and promoting soil biology. The benefits of these amendments may not be seen for several years of repeated applications. The use of WA should be closely monitored to ensure there is no over accumulation of P and some micronutrients such as B and Cu or heavy metals. Amongst yield parameters, the use of cover crops proved more beneficial than the BS treatment.

4.2 Marketability of Sustainable Nutrient Management

As the wine industry continues growing with market demand still outweighing supply, the future holds plenty of opportunity to expand production in NS. The NS Wine

Industry Investment Initiative fund was established to provide incentives to increase grape production to 1000 acres by 2020. This will create economic benefits such as increased production, increased sales in vineyard equipment and supplies and more jobs including vineyard laborers and agronomic specialists for the industry.

Increasing fertilizer costs along with its transportation has prompted increased use of local waste products and utilizing cover crops to reduce purchased nutritional inputs. Sustainable soil nutrient management practices including the use of MS, MSFW and WA along with cover cropping provide a possible alternative to conventional fertilizer programs lowering costs and yearly inputs to the soil. The use of slow release N fertilization from compost can stimulate early canopy development and this can lead to increased yields and canopy density in subsequent seasons. This leads to an economic benefit to growers as long as fruit quality is not reduced at the expense of quantity. In NS, the added cost saving benefit of applying WA, MS and MSFW is increased, as the liming effect recorded from their application is substantial. As most soils in the province are acidic, most agricultural practices use lime in order to obtain optimal yields.

In 2013, 107,500 t of organic waste was diverted through municipal composting facilities (Resource Recovery Fund Board (RRFB) 2013). Over 75% of our waste is staying out of landfills and a large portion of that is due to the green bin program in place in NS (RRFB 2013). This MSFW product has shown many benefits when used in combination with cover cropping. With a continual push to compost and recycle in the province over 250 t of organic waste produced daily is an excellent source of nutrients to agricultural land. The same is true for other bio-waste products used in this project that would otherwise be sent to landfill or left unused. A test analysis should always be conducted on the amendments to determine the nutrients they contain due to their variability in nutrient concentrations in the products used to produce them. Fertilization with synthetic fertilizers is generally more expensive and although there is a known concentration of nutrients readily available, the added soil benefits provided by MS, MSFW and WA found in this project make these products more valuable to soil.

Wine grape production is still a small percentage of the NS agricultural sector and faces several challenges. In the LaHave growing region, the growing season is short, which creates problems for varieties needing longer ripening periods, the soils have low pH and soil organic matter and are light textured with a high gravel content that can create leaching problems. This study attempted to assess and mitigate these issues using sustainable practices where opportunities lie with ease of access to organic and industrial wastes and alternative cover crops that thrive in and improve these soil conditions while also providing benefits to the vine.

4.3 Recommendations for Future Research

Contrary to other sectors of agricultural, the grape and wine industry are economically healthy and expanding at this time. This aspect combined with the inherent need of vineyards for the production of wine; make viticulture an excellent industry for research in sustainable nutrient management practices.

Nutrient management is one component of a comprehensive vineyard management program. The issues here concern adequacy of vine nutrition, cost of fertilizer and fertilizer application, effects of nutrients on crop yield, fruit quality and other aspects of vine performance. Along with recommendations made in other chapters, future research could look at response of different varieties response to cover crops and soil amendment applications as the hybrid grapevine is primarily grown in the Maritimes and Quebec where the rest of Canada's wine grape industry is primarily *vinifera* grape varieties. As wine grape production increases across NS, it is important to implement the beneficial soil management practices assessed and further study the long-term effects of applying biowastes and other industrial by-products to the soil as nutrient supplements. Future studies such as this should mark out plots in a previous growing season to eliminate variability of vine health, as some vines are more mature than others are and some canopies may be denser. A mechanical applicator that was modified for vineyard application should be used in the future when applying MSFW and WA. The MS should have an agitator to allow the product to maintain the same viscosity throughout the product. Overall, with the experimental conditions, this project took place within; variability was limited as much as possible to ensure representative results.

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