Establishing Organic Blackcurrants in Atlantic Canada

by

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The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled "Establishing Organic Blackcurrants in Atlantic Canada" by David W. Hobson in partial fulfilment of the requirements for the degree of Master of Science.

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Abstract

A study on Prince Edward Island was initiated to assess the impact of organic fertility amendment rate and timing treatments and deflowering on the growth, yield, and berry size and soluble solids, and plant and soil available nutrients of blackcurrants (Ribes nigrum L cv. Titania.). Plants at the site with lower leaf P and K showed lower growth and yield (492-2540 kg ha-1) than the other site (3935-5016 kg ha-1No significant differences were found in final size or 2011 yield at the site with larger bushes, while at the other site the medium spring fertility treatment gave the greatest growth and yield, followed by the high spring fertility treatment. Deflowering increased yield but not growth at the site with recommended ranges of leaf P and K; at the site with P and K deficiencies, growth increased in 2010 and 2011. There was no interaction between deflowering and amendment timing.

List of Abbreviations and Symbols Used

–FLWR	deflowered
+FLWR	non-deflowered
AE	agronomic efficiency
ANOVA	analysis of variance
B	boron
C	carbon
^{o}C	degrees Celsius
Ca	calcium
CEC	cation exchange capacity
C/N	carbon to nitrogen ratio
Cu	copper
cv.	cultivar
dm	decimeter
DM	dry matter
EAN	estimated available nitrogen
Fe	iron
FT	Farmington, PEI
ha	hectare
HBW	hundred berry weight
HR	Hunter River, PEI
K	potassium

kg	kilogram
kg ha^{-1}	kilogram per hectare
L	low
LSD	least significant difference
LSMeans	least square means
M	medium
m	meter
Meq	milliequivalent of hydrogen
Mg	magnesium
Mn	manganese
MT	mega tonne
N	nitrogen
NB	New Brunswick
n/a	not applicable
NH_4^+-N	ammonium-nitrogen
NO_3^--N	nitrate-nitrogen
NSR	nutrient supply rate
NZ	New Zealand
P	phosphorus
p	probability > F
ppm	parts per million
PEI	Prince Edward Island

PRS™	Plant Root Simulator™
PUFA	poly-unsaturated fatty acid
r	correlation coefficient
SAS	statistical analysis system
SE	standard error
SK	Saskatchewan
SPL	split application
SPR	spring application
SUM	summer application
t	tonne
WPBR	white pine blister rust
Zn	zinc

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Chapter 1. Introduction

1.1 Project Goal

To determine the most suitable fertility rate and timing for establishing organic blackcurrants, with the aim of increasing vegetative growth and maximizing the first commercial harvest.

1.2 Objectives

1. To determine the effect of fertility rate and timing on bush growth, yield and berry size and soluble solids in the first three years of growth.
2. To determine the effect of fertility rate and timing on soil nutrient supply rate (PRS™ probes) and leaf tissue nutrient concentration.
3. To determine whether soil nutrient supply rate and tissue nutrient status are correlated with plant growth, bush yield, berry size and soluble solids.
4. To determine the effect of deflowering on bush growth, yield and berry size and soluble solids in the year of, and the year following, deflowering.

Together, these objectives will elucidate the effects of the organic fertility amendments on soil fertility, plant fertility and performance, giving recommendations as to which of the treatments work the best maximizing growth and yield for establishing organic blackcurrants.

Chapter 2 will address objective 1, Chapter 3 objectives 2 and 3, and Chapter 4 objective 4.

1.3 Introduction

Canadian fruit production was worth $687 million in 2009, with $424 million from small fruit crops, and $57 million from Atlantic Canada. Despite Canada's potential for fruit production, a huge trade deficit exists, with more than $6.54 billion of imported fruits in 2009, versus only $737 million exported. The highest production of fruit in Canada is in apples, followed by blueberries, cranberries, grapes, peaches, strawberries, cherries and raspberries; blackcurrant production is too low to be listed.

1.4 Organic Farming

The organic industry is booming. In 2009, certified organic small fruit and berry acreage was 1136 ha in Canada and 53 ha in Atlantic Canada (Macey, 2010).

The rise of organic agriculture is partly a consumer response to degenerative effects of industrial farming that has led to soil erosion, nutrient-leaching into ponds, rivers, lakes and oceans, loss of biodiversity, reduction of soil organic matter, pesticide-induced evolution of weeds, insects and diseases, agriculture worker health issues, wildlife loss and high pesticide residues. Nitrate levels, a growing concern for people due to their cancer-links, have been shown to be lower in organic foods (Lairon, 2011). An expert panel called for incentives and political support for sustainable farming practices to address these issues and "inform landscape management practices to be used by farmers and ranchers for sustaining food and ecosystem security" (Reganold et al., 2011). While increasing soil fertility has led to important increases in crop yields, the current reliance on synthetic fertilizers is unsustainable (Fageria, 2007; Bacon, 1995)

Organic farming systems have been suggested to be good for human health, conserve biodiversity, increase economic activity, slow climate change, benefit wildlife, reduce runoff into soil and water and increase soil quality (Dimitri et al., 2011). Organic farming systems support microbial and faunal decomposers over the long term, helping to propagate aboveground predators which increase biological control (Birkhofer et al., 2008).

Organic farming methods have been found to affect the proteomes of vegetables (Nawrocki et al., 2011). In a meta-analytical study, organic foods have been found to be higher in Vitamin C, iron, magnesium and phosphorus, with significantly less nitrates compared to conventionally farmed crops (Worthington, 2001). Another meta-analysis found organic foods had higher levels of micronutrients than conventional foods (Hunter et al., 2011). Organic foods have lower levels of pesticide residues, nitrates, artificial additives which may be harmful to the health (Matt et al., 2011). In a comprehensive study, organically farmed strawberries were found to have better flavour and a higher antioxidant activity, as well as soils having greater microbial biomass and activity, with higher concentrations of micronutrients (Reganold et al., 2010). Polyphenols were higher in organically farmed strawberry and marionberry (Asami et al., 2003).

1.5 Phytonutrients in Blackcurrants

Functional foods and nutraceuticals are a $15 billion industry in Canada (Wolfe, 2007). Antioxidants are one of the most sought-after chemicals in nutraceuticals, given their ability to scavenge for free-radicals, believed to be responsible for aging and cancer development (Valko et al., 2007). Anthocyanins, pigments that give fruits their dark red or blue colours, are strongly in demand as powerful antioxidants, after studies have found that they play a role in reducing risks to cancer, cardio-vascular disease and other degenerative diseases like alzheimers (He and Giusti, 2010; Wallace, 2011; de Pascual-Teresa et al., 2010). A whole industry has emerged to extract antioxidants from fruits to be inserted into cosmetics, food supplements and fortified foods (Castañeda-Ovando et al., 2009). Blackcurrant berries contain 15 different anthocyanin structures, with the 3-O-glucosides and 3-O-rutinosides of delphinidin and cyanidin making up more than 97% of the total anthocyanin content (Slimestad and Solheim, 2002). Consumption of blackcurrant juice has been found to strongly increase in-vivo antioxidant levels (Rosenblat et al., 2010). Blackcurrants have some of the highest levels of anthocyanins of any fruit (Häkkinen et al., 1999; Benvenuti et al., 2004). Buds and leaves also have high levels of anthocyanins (Tabart et al., 2012). Blackcurrant seeds, a byproduct of the juicing industry, are high in antioxidants as well as poly-unsaturated fatty acids (PUFAs), with contents up to 80% (Bakowska-Barczak et al., 2009). Blackcurrants are also very high in ascorbic acid (vitamin C), which also has strong antioxidant activity (Lister et al., 2002).

Modern food science has replaced many of the traditional uses of berries, extracting flavours, nutrients, colours or healthful chemicals to create a culinary chimera. Instead of juice, jams, jellies, concentrates, purees, syrups, pie fillings and sauces, berries are being converted into powders for dry-mix beverages, nutritional supplements and confectionary products: products like nutritional bars, cereals and bakery products, colouring and flavouring agents, concentrated extracts that deliver specific levels of proanthocyanins, these are the destinations for berries grown for commercial processing (Patterson, 2008). For growers then, creating a distinctive product can be difficult, as the final use of the food hides whatever unique features it may have. Some possible attributes to promote berries could be high anthocyanin contents, the approach taken by New Zealand in their marketing campaign for Japanese export, or organic production (NZ Berryfruit Group Japan Ltd, n.d.). Seeing as organic production of berries, and blackcurrants in particular, is quite low on the global scale, Canadian farmers could establish a competitive edge, as many berries are native to our climate and therefore have ideal growing conditions.

1.6 Blackcurrants Around the World

Currants are grown primarily in Russia (327, 000 MT), Poland (190, 782 MT) and other European countries (FAOSTAT, 2012). Blackcurrants are grown primarily for juice, jams and wines. Winter chilling requirements limit their growth to Northern areas where winters are cold enough and summers are not too hot, as they do not tolerate temperatures above 30^{o}C (Barney and Hummer, 2005).

Black currants, have gained in popularity in North America over the last few years, with developing export markets in Japan. New Zealand has capitalized on the growing demand for "superfoods," foods like blackcurrants that have high antioxidant levels, with a $3.6 million export market of processed blackcurrants to Japan in 2006 (Hansen, 2007). New Zealand, however, benefits from over 15 years of government- and industry-funded research into breeding cultivars that are optimal to the NZ climate and high in anthocyanins, researching health benefits and creating a strong marketing campaign that has been extremely successful at almost exclusively winning the Japanese market in blackcurrants (NZ Berryfruit Group Japan Ltd, n.d.). Organic growers are diversifying their production, and blackcurrants promise a value-added fruit product with little management required compared to other fruits. To date there are 30 small farms in PEI with young, experimental plantings seeking new knowledge on how to grow this crop. Prince Edward Island farmers are looking to expand operations from the current total of 16 hectares (40 acres) of young plants. Japan is looking for significant quantities of blackcurrant fruit from PEI, which will be processed either here in Canada or sent frozen to Japan (Raymond Loo, personal communication). Processing includes sugar infusion, a process whereby berries are frozen, then soaked in a sugar solution, then removed and dried. This product keeps for up to 18 months. Other processed foods include: jams, jellies and liqueurs.

1.7 History of Blackcurrants in Canada

Plants of the Ribes genera were banned from commercial production in the United States from 1909 to 1966, as they were believed to be spreading the White Pine Blister Rust (WPBR) that was obliterating white pines (Baldelli, 2003). *Cronartium ribicola* J.C. Fisch*,* a fungus of Asiatic origin, spread throughout Europe and was introduced to North America after 1900, where the effect on native pine trees was so devastating, that the systematic removal of all Ribes plants from white pine forests was deemed the most "practicable and profitable" way to prevent the devastation of the trees (Martin, 1922). The fungus uses *Ribes* species as an alternate host. Basidiospores from *Ribes* spp. leaves are wind-blown to pine needles, the initial site of infection, where it then grows in the sapwood and along the twig over a period of about 12 months. It then causes a canker to form in the tree branch, and this girdling prevents the movement of water and nutrients along the trunk or branch. Pyncnidia, the fruiting structures of the fungus on the tree, are produced about 2-4 years after infection, and aeciospores, which infect Ribes plants, are only released about 3-6 years after the initial infection of the pine tree (Gilman, 1999). These aeciospores then land on Ribes plants, where they reproduce asexually with teleospores, and the fungus causes moderate damage to leaves, leading to premature defoliation and therefore reducing photosynthetic potential in the plants, and finally basidiospores are produced in the late summer and fall to infect the pines (Geils et al., 2010). The cultivar Titania is supposedly resistant to WPBR, with reports of resistance in Alberta and Quebec (Rousseau and Roy, 2002; Neeser, 2008). In North America, the largest producer of blackcurrants is located in Connecticut, with 100 acres of blackcurrants in production primarily for juice from frozen berry concentrate (Hibma, 2008).

1.8 Blackcurrant Production

Blackcurrants are a woody perennial shrub in the Grossulariaceae family, which includes gooseberry and many species of wild currants, many of which are native to North America. Site establishment and the crop previously grown on the site are important factors for establishing blackcurrants (Łabanowska-Bury et al., 2005). Other site considerations include: soils that are not too sandy, but well drained; north-facing slopes to delay bloom and prevent early frost damage; a climate with between 800 and 1600 hours between 0 and 7^{o}C in the winter for chilling requirements and summer temperatures not exceeding 30^{o}C; shelter from strong winds; a frost-free growing period between 120 and 150 days; and access to irrigation water in dry areas (Barney and Hummer, 2005).

New shoots, or canes, grow from the base of the plant, growing up to 1 m in a growing season (Barney and Hummer, 2005). Bushes reach maturity after about three years, at which point they reach heights of 1.5 to 2 meters, and produce yields between 6 and 10 t ha^{-1} (Opstad et al., 2007). However, larger bushes do not necessarily lead to greater yields and extra vegetation can interfere with harvesting, while denser plantings of 30 cm between plants and 3 m rows have been found to yield the highest in New Zealand (Thiele, 1979). Pull-type mechanical harvesters drive alongside the row pulled by a tractor, requiring wider row-spacing, but self-propelled over-the-row harvesters require much narrower row spacing. Established bushes are pruned yearly, leaving half one-year-old and half-two-year-old canes, as fruits grow mostly on one to three-year-old canes (Barney and Hummer, 2005). Blackcurrant fruits grow on short racemes, and flower bud development typically takes place on long, late-summer days (Barney and Hummer, 2005).

The most pressing need for blackcurrant growers in Atlantic Canada is the early establishments of plants to allow for mechanical harvesting. To help achieve this, this study was established in 2009 to determine the effects of organic fertility amendments on growth, yield and berry characteristics of new plants at two sites on PEI. Deflowering was also trialed to test the effects of this technique on plant growth and yield along with the organic amendments.

Producing blackcurrants organically is a new endeavor, however, and there is still much to be learned in this area. Studies conducted at the Organic Agriculture Centre of Canada (OACC) in Truro, Nova Scotia, began in 2009. Two 2009 plantings of two-year bare-root blackcurrants cultivar Titania were planted in PEI on two sites. To date, Titania has shown fair resistance to WPBR at these sites. These were accompanied by two 2008 plantings of Ben Hope variety, which proved to be highly susceptible to WPBR. The trials have focused on nutrient management to achieve maximum vegetative growth, bringing the bushes to harvestable yields as soon as possible. However, bushes have taken longer to grow than expected, due to low fertility, poor understanding of management techniques and lack of effective weed control. This study, therefore, seeks to find new techniques to increase vegetative growth to establish the blackcurrants in a cost-effective manner. These methods include flower removal, fertility timing and application trials and several weed management strategies.

Chapter 2. Fertility Rate and Timing Effects on *Ribes nigrum* L. Growth and Yield During Establishment

2.1 Introduction

In order to bring blackcurrant (*Ribes nigrum* L.) bushes to a harvestable yield in the shortest time possible, the fertility management strategy for establishing bushes must focus on maximizing vegetative growth in the first three years, as mechanical harvesters have a minimum height threshold of about 40 cm, where berries below this point cannot be collected. First-year growth also plays a crucial role in determining future bush yields (Rhodes, 1986). Management practices that increase shoot number and length at the first harvest can increase future productivity (McCarthy and Stoker, 1988). Blackcurrant vegetative growth is most affected by fertility in the first few years of establishment, thereafter fertility only slightly increases yields (Opstad et al., 2007). However, in organic systems, synthetic fertilizers are not used, and their organic fertility amendments substitutes behave very differently. Plant- and animal-based amendments must first become mineralized by the soil biota before the majority of the nutrients are available to the plants, so the rate of mineralization is highly influenced by soil type, soil moisture and temperature and other variables (Hammermeister et al., 2006). Minerals are released gradually into the soil solution, and therefore the plant may not be able to uptake all the applied nutrients until later in the growing season (Sharifi et al., 2009). While the slow-release of organic amendments may improve nitrogen utilization rate, giving recommendations for the optimal fertility rate and timing of organic amendments to perennial plants can be difficult (Liu et al., 2010). In conventional systems, rates of 100 to 150 kg N ha^{-1} have been recommended for blackcurrants to maximize growth and yield for producing plants (Barney and Hummer, 2005; Langford and Craighead, 2008). However, other studies have shown little effect of N fertility on bush yield (Opstad et al., 2007).

Woody plants translocate nutrients from root, stem and bud tissues in the spring to accommodate a flush in vegetative growth, while after fruiting, plants reallocate nutrients and energy back into these storage tissues for use the following year (Coleman, 2004). Generally, N applied in the spring promotes vegetative growth, while fertilization in the summer promotes vegetative and reproductive growth the following year (Christensen et al., 1994). Increased vegetative growth will increase potential for a greater number of buds (Ostermann and Hansen, 1988). Splitting spring and summer fertility could increase N use efficiency, maximizing growth and yield (Hanson and Retamales, 1992). Splitting fertilization or using slow-release fertilizers have been recommended for blackcurrants, particularly to maximize soluble solids in berries (Hoppula and Salo, 2005). A summer amendment could encourage bud formation, but if too high a rate, fertilization could lead to unwanted vegetative growth which would delay the onset of winter dormancy (Childers, 1978). The objectives of this experiment were to find the optimal fertility rate and timing to maximize bush growth, yield, berry size and soluble sugars in their first three years. Newly planted bushes were given one of seven different fertility treatments for three years to determine their effects of plant performance (growth, yield, berry sugars and size) at two sites on Prince Edward Island.

2.2 Methods

2.2.1 Experimental Design

The experiment was a randomized block design, consisting of one factor (fertility rate coupled with timing of application) with seven treatments replicated three times set-up in a randomized block design at two sites (Farmington (FT) and Hunter River (HR)) on Prince Edward Island (PEI). The experimental unit was one plot with five plants. Bush and berry means were taken from the three middle plants in the plot. Plots were separated by two untreated buffer plants.

2.2.2 Site and Climate

Soils at both sites were well-drained sandy loam (classified as an Orthic Humo-Feric Podzol). Hunter River was a gently North-sloping field that buttressed the woods. The previous management was under hay. Farmington was gently West-sloping and was also previously a hay field. Both were renovated by tillage, where Hunter River was only tilled along the planted rows. No other soil amendments were applied before planting, but Hunter River previously had compost applied, and Farmington previously had manure applied. Baseline soil characteristics taken from aggregate core samples (15 cm) taken in 2009 before planting and analyzed at the PEI soil and feed testing laboratory (Mehlich III extraction) are shown in Table 2.1. Hunter River had higher soil pH, organic matter, K, Ca and Mg levels than Farmington, but was slightly lower in P, Cu, S and Fe (Table 2.1). Using PEI soil recommendations for raspberry, Cu was low at Hunter River and Ca and B were low at Farmington, but P, K and Mg were medium to high at both sites in 2009. At Hunter River, rows were tilled (2 m wide) between a white-clover/sod alleyway before planting, and in Farmington the whole plot area was tilled before planting, and alley crop of white clover was seeded. Planting stock was 2-year-old bare-root of cv. Titania (McGuiness Berry Crops, Courtenay, BC) planted in May 2009. Plants were spaced 0.76 m apart with rows 4m apart, giving 3,289 plants ha-1 (2,500 m row ha^{-1}). Immediately after planting, plots were covered with a landscape fabric (Quest Plastic Ltd., Brampton, ON). In 2010, the fabric was breaking down and was replaced with a tree-grade black plastic mulch (Dubois Agrinovations, Quebec). Climate data was recorded from the nearest available weather stations from 2009 to 2011.

2.2.3 Treatments and Amendments

Each of the seven fertility treatments was a blend of two amendments: crabmeal (powdered waste from crab processing, W.E. Acres, NB) and granulated poultry manure (Nutriwave™, Envirem Organics Inc., NB). Using the total N from the amendment analysis (Table 2.2), and an estimated N availability of 75 % for the crab meal and 40 % for the poultry manure, a blend was formulated with half of the available N being provided by each amendment. Rates of 50, 100 and 150 kg estimated available N ha^{-1} were described as low, medium and high respectively. These application rates also supplied 31, 62 and 93 kg ha^{-1} P and 28, 55 and 82 kg ha^{-1} K for low, medium and high respectively. There were seven treatments: a control (Control), low, medium and high spring treatments (SPR-Low, SPR-Med, SPR-High), a summer treatment (SUM-High) and two treatments with applications split across the spring and summer either with a low spring, medium summer (SPL-L/M), or medium spring, low summer rate (SPL-M/L) (Table 2.3). Amendments were applied in a 50 cm wide band along the row and lightly incorporated into the soil (about 3 cm) by hand. Spring amendments were applied at the end of April and summer amendments in the third week of August from 2009 to 2011 on the same plots, thus treatments were cumulative.

2.2.4 Bush Volume, Berry Yield and Soluble Solids

Bush volume was recorded as the cylindrical volume (3.142 * height * width * 0.5 * breadth * 0.5, modified from (Erb et al., 1993)) taken in the spring of 2009 and 2010 and summer and fall of 2009-2011 with a tape measure . There was no pruning performed over the three years of the trial. Mean yearly growth was calculated from spring to fall (2009) or fall to fall (2010-2011).

In 2010, the first year of berry production, bushes were harvested on August 8 (FT) and 10 (HR). In 2011, berries were splitting and dropping, so harvest was done before complete berry ripening on August 9 (FT) and 10 (HR). Berries were picked by hand, weighed immediately, and a 300 g sample randomly taken from each 3-plant harvest. Berry samples were placed into a cooler (4^{o}C), and analyzed within 3 days. Berry size was determined by counting 100 random berries from the sample and weighing them, giving a 100-berry-weight (HBW). The average of three samples was reported. Berry soluble solids were measured with a portable refractometer (Atago, Bellevue, WA, calibrated with distilled water at 23^{o}C) by taking a random sample of 50 g and squeezing it in cheesecloth until no more juice could be removed. After mixing the juice, one drop was placed on the refractometer after zeroing with a drop of distilled water. The average of three samples was reported in degrees Brix.

2.2.5 Statistical Analysis

A separate analysis of variance (ANOVA) was used to test effects of fertility treatments on blackcurrant growth, yield, etc. for each site-year. Analysis were done using PROC GLM in SAS (9.2, SAS Institute, Cary, NC) at $\alpha=0.05$, except where noted. Residual values of all analyses were checked for normality using a normal probability plot. Non-normal data were transformed to satisfy ANOVA assumptions, and back-transformed means are reported. Treatment means were compared using Fisher's protected least significant difference (LSD) test.

2.3 Results

Hunter River had greater precipitation and slightly higher temperatures than Farmington in all three years of the trial (Table 2.4). Cooling degree days (the number of ^{o}C where the temperature was greater than 18^{o}C) were less than four during May, and June was much warmer in 2009. Precipitation was below normal for April and May in 2010 and 2011, but above normal in June and July 2010.

2.3.1 Growth

Three years of fertility treatments had no significant effect on bush growth at Farmington ($p=0.61$), while differences were significant at Hunter River ($p<0.01$). At Hunter River, SPR-Med and SPR-High showed the greatest overall growth, followed by SPL-M/L (Figure 2.1). SUM-High, SPL-L/M and SPR-Low showed no significant increase in growth from the Control.

Similarly, SPR-High and SPL-M/L had the highest growth at Farmington, but differences were not significant. However, the bushes were much larger than at Hunter River, and tended to sag, skewing the volume measurement. Low significance was observed because of high within treatment variability across plots. At both sites, there was a large variation in size for SPR-High. SPR-Med, SUM-High and SPR-Low also had large size variation, although not as extreme. Overall, plants at Farmington had about double the growth on average as Hunter River for most of the treatments, including the unfertilized Control. Growth of SPR-Low treated plants was greater at Farmington than Hunter River, but SPR-Med treated plants performed better at Hunter River. Growth of the two split treatments showed a similar pattern at both sites, with SPL-M/L plants having the greatest growth, but SPL-L/M plants having poor growth compared with the other high treatments.

At Farmington, there were no significant differences in yearly growth (2009 p=0.216, 2010 p=0.530, 2011 p=0.872), but at Hunter River, plant growth rates were significantly different for each of the three years (2009 p=0.001, 2010 p=0.029, 2011 p=0.031) (Figure 2.2). At Hunter River, plants in the SPR-High treatment had the highest growth rate for 2009 and 2010, but in 2011 SPR-Med treated plants showed the highest growth. Growth in the Control treatment at Farmington (0.647 and 0.532 m^3) had nearly double the growth than the Control at Hunter River (0.245 and 0.231 m^3) in both 2010 and 2011.

For both sites, growth rates were not consistent across site-years. In 2010 at Hunter River, for example, a more vigorous growth was observed for SPR-High, where in 2011 the same treatment had much lower growth rates. This was not the case at Farmington, where in 2011 plants were more vigorous in the same treated plants compared to 2010. Similar observations were made for SPL-L/M and SPL-M/L treated plants in 2010 and 2011 at Farmington. It is likely that plants with these two treatments converted more energy to yield, as they had the two highest site yields, but the lowest growth rates of the high treatments for 2011. This does not explain why growth rates were low in 2011 plants treated with SPR-High while yields were also low compared with other treatments.

2.3.2 Yield

Yields were significantly different at both sites in 2010. Yield at Farmington in 2010 was greatest for the SPL-M/L and SPR-Low treated plants, but all fertilized plants had greater yields than the Control (Table 2.5). At Hunter River, yield was greatest for the SPR-Med treatment, SPR-High, SPL-M/L, SUM-High and SPL-L/M treated plants. The SPR-Low treatment showed the lowest growth after the Control (p=0.01). At Farmington, the yield was more than double that of Hunter River in 2010 (1650 vs. 626 kg ha^{-1}). Differences across treatments at Farmington were not significant in 2011 (p=0.836). At Hunter River, however, SPR-Med, SUM-High, SPL-L/M and SPL-M/L had the greatest yields (p=0.003). The SPR-High treatment had a much lower yield at Hunter River than in 2010 relative to the other treatments. A greater yield was found at Farmington in 2011 as well. Total yield (2010-2011) was not significantly different across treatments at Farmington (p=0.409).

2.3.3 Berry Size and Soluble Solids

Significant variation between berry size and soluble sugars was found in 2010 and 2011 due to a necessary premature harvest in 2011. In 2010, there were no significant differences in berry size or soluble solids at either Farmington or Hunter River (Table 2.6). In 2011, however, at Farmington there were differences in berry size and soluble solids. The largest berries were found in SPL-M/L treated plants, however plants in all treatments increased berry size beyond the Control except for SPR-Low. Soluble solids were highest in the unfertilized plants, but only significantly higher than SPR-Med and SPL-M/L. At Hunter River in 2011, there were significant differences only in soluble solids, with the two split treatments having the lowest levels.

2.4 Discussion

2.4.1 Overall Effects of Rate and Timing

Increasing fertility was expected to increase bush growth and yield, while also leading to superior berry size and soluble sugar content. Bould (1969), testing synthetic fertilizers individually in a factorial pot-trial, found that N had no influence on shoot length or berry weight, but increased yield when P was also high. Higher P levels had highly significant increases in shoot length, yield (only when paired with high N) and berry weight. Increasing K levels also increased shoot length, berry weight and had a highly significant effect on yield. Bould’s study therefore suggests that increasing the fertility levels of the plants has great potential to increase growth, yield and berry size and sugars.

Limited response to fertility treatments at Farmington may have been due to adequate fertility of the site prior to applying the treatments, difficulty in measuring crop responses due to the high variability of the crop, or the inherent nature of blackcurrant’s low response to N fertility

(Opstad et al., 2007). In soils with adequate N, high N applications may not lead to increased growth or fertility. Red raspberry growth and yield showed little response to poultry manures of 100 and 200 kg ha^{-1} total N added to soils with high N fertility (150 kg N ha^{-1}) (Dean et al., 2000).

Increasing spring rates of soil amendments did not produce a consistent response. While a linear increase in yield was expected, SPR-Med treated plants outyielded SPR-High treated plants at Hunter River, and had a much higher growth rate in 2011, where SPR-High treated plants grew much less in this site-year. It is not clear why the SPR-High treatment slowed their growth in 2011, as this did not happen at Farmington. SPR-High treated plants had almost the highest growth of all the treatments at both sites in 2010, so this should have led to an increase in yield in the following year, as has been reported in several studies (Goode and Hyrycz, 1970; Kongsrud and Nes 1999). All plants at Hunter River greatly underperformed compared with Farmington, suggesting that the low levels of soil P found before the study at this site may be responsible, and leaf nutrient concentrations showed P deficiencies in both 2010 and 2011(data not shown). The highest rate of treatments in this study supplied 62 kg ha^{-1} total P and 55 kg ha^{-1} total K, while blackcurrant removal rates of three-year-old plants were on average about 15 kg ha^{-1} P and 50 kg ha^{-1} K (Langford and Craighead, 2008). Mineralization rates of P and K are unknown in these amendments, but estimated K levels supplied are lower in K than crop removals.

There was a linear increase in yield with increased bush volume at Hunter River, but not at Farmington (Figure 2.1). This suggests that bushes at Hunter River had greater yields when bush volume was greater, as has been found in many other studies (Rhodes, 1986; McCarthy and Stoker, 1988; Ostermann and Hansen, 1988). The Farmington site had much more variability in yields, which may have been why there was no such relationship.

At Farmington in 2010, for the spring rates, yield was inversely proportional to rate increase, while growth followed a somewhat proportional increase. In 2011, both yield and growth increased proportionally with rate increases, although growth much more sharply. However, the differences in yield across treatments at Farmington were small in 2011, whereas the differences in growth were much larger (Table 2.5 and Figure 2.1). Low cropping rates in blackcurrants have been correlated with increased growth rates (Hansen, 1985)

While yields are highly dependent on seasonal conditions, 2011 yield at both sites was below typical third year Titania yields obtained in Europe of about 6-9 tonnes ha^{-1} (Opstad et al., 2007; Siksnianas et al., 2006)). Opstad et al (2007) found no significant increase in yield with increased fertility; however, the differences in rates were small and confounded with different fertilization strategies. Craighead et al. (2007) found no increase in yield with synthetic N (urea and ammonium nitrate) applications of 50 kg N ha^{-1} in a 2-year field trial, but calculated that bushes remove 55-65 kg N ha^{-1}, and therefore recommend fertilizer applications of 80-100 kg N ha^{-1}. Nes and Hageberg (2002) found no significant effects on yields across synthetic fertility treatments applied in spring or fall within a single harvest, but medium-rate (100 kg N ha^{-1}) treatments broadcast in the fall only yielded on average 1 tonne ha^{-1} more and with larger berries than those broadcast in the spring only.

Fertilizer amendments added in the spring were hypothesized to increase bush growth, while fertilization in the fall was hypothesized to increase yield the following season. Additional fertilization in the fall has been found to increase blackcurrant yield over spring-only amendments (Kongsrud and Nes, 1999). To explore the effect of fertility and timing, the SPR-High, SUM-High, SPL-L/M and SPL-M/L treatments can be compared, as they all received the same total amount of amendment. The SUM-High and the split applications SPL-L/M had lower growth compared with SPR-High and SPL-M/L. Considering the total amount of amendment was the same for all four treatments, it appears that fertility added in the spring only increased vegetative bush growth over the summer-only applications, as hypothesized. Meanwhile, SPL-M/L had greater vegetative growth than SPL-L/M at both sites, also suggesting that spring-applied fertility leads to greater vegetative growth than summer applied fertility, while growth for SUM-High was the lowest.

Blackcurrant bushes mobilize nutrients for reproductive growth in the late summer and early fall, and much less vegetative growth takes place compared with the spring (Barney and Hummer, 2005). This explains why higher summer fertility treatments do not increase fall vegetative growth. However, there may be residual N in the soil or plant storage tissues that could be used for spring growth. The black plastic mulch which covered the soil could prevent volatilization and leaching from rainfall, increasing plant N recovery (Strik et al., 2006). While high summer fertility lead to slight increases in growth when compared with the Control, it appears that very little of this N is translating to spring growth, but is instead going into yield, as SUM-High had the second greatest cumulative yield at Hunter River, supporting the second half of the hypothesis.

The split treated plants both showed higher yields than SPR-High, and SPL-M/L showed the best overall yield at Farmington. Yield is highly influenced by the vegetative growth the bush achieved in the previous season (Kongsrud, 1969; Dencker and Hansen, 1995). This trend was observed at both sites in 2011 (except for SPR-High at HR), and less so at Hunter River in 2010, but not at Farmington in 2010. Medium-Low split treatments like SPL-M/L have been found in blackcurrants to provide a higher yield than spring-only fertilization of the same overall amount, but highest yield was from the highest fertility in the spring (Kongsrud, Skog and Nes 1999). The nutrients applied in the summer could have been used to increase reproductive growth, leading to the higher yields found in the SUM-High, SPL-L/M and SPL-M/L at Hunter River in both 2010 and 2011. Split N treatments also led to the highest growth in raspberries (Rempel et al., 2004).

Berry size was larger than found by Denisow (2003), but others have shown that berry size increases with increasing fertility levels, while soluble solids are greatest with the lowest fertility rate (Opstad et al., 2007). However, berry sugars were inversely correlated with yield, suggesting that bushes cannot commit as many nutrients for soluble solids when their numbers are greater. Berries with abundant N may not accumulate as many sugars, as is found in grapes (Okamoto et al., 2003; Amiri and Fallahi, 2007) .

N from poultry manure was found to become mostly available within the first 10 days of application with incorporation into the soil (Sharifi et al., 2009). At Farmington the overall split yields were greater than the SPR-High yield. However, as these organic fertility amendments have not been deeply incorporated into the soil, and protected from precipitation, all the nutrients will not be immediately available upon application and therefore spring applications will gradually become available throughout the season. Similar split chemical fertilizer treatments had no significant effect on bush growth or yield in a four-year trial of blackberry (Naraguma and Clark, 1997).

Plants at Farmington were covered in rust by September 2010 and 2011, and leaves defoliated before leaves at Hunter River. Hunter River had little or no occurrence of the rust. There was no evidence that the rust had any detrimental effect on plants at Farmington, despite early defoliation. The cultivar Titania is supposedly resistant to this disease, and bushes of other varieties in the area did not survive after several years of repeated infection. Therefore this cultivar appears to be resistant to the rust, despite showing signs of the rust growing on the leaves of plants at Farmington.

2.4.2 Site Effects

At Hunter River, increasing growth led to an increase in yield across all the treatments except for SPR-High treated plants, which while they had the highest overall growth, did not have the highest yield (Table 2.5). At Farmington, however, there were no significant differences in growth or 2011 yield. The high rates all contributed to good cumulative yield at Farmington compared with Hunter River (except for SUM-High at Farmington, which had poorer yield compared to the other high rates). SPR-High had the highest overall growth at Farmington, and one of the highest yields, while at Hunter River, SPR-High showed low growth and yield in 2011 compared with other treatments. It appears that at Farmington, bushes reached their maximum growth, and were putting most of their energy into reproduction by 2011.

2.5 Conclusion

Site strongly influenced growth and yield. The site with higher background soil P had more vigorous growth, higher yields, and to a lesser extent larger berries than the site with lower background soil P. However, amendment treatments affected only yield (2010), HBW (2010-2011) and soluble solids (2010-2011) at the higher fertility site. At the site with K and P deficiency, fertility treatments significantly increased growth (2009-2011), yield (2010-2011), but decreased soluble solids (2011). While bush size generally increased with increasing spring rates, yield responses were not as clear. Timing of amendment application followed expectations found in other field trials, where spring treatments supported more vegetative growth, but a split treatment of medium spring amendment and low summer amendment produced the highest overall yields and reasonable bush growth for the three years of the trial.

Table 2.1 Initial soil characteristics (0-15 cm) of two PEI sites taken May 2009.

Site		Farmington	Hunter River
OM	%	2.2	2.6
pH		5.6	6.3
CEC	Meq 100g^{-1}	10.0	9.0
P_20_5	ppm	279.0	209.0
K_20	ppm	67.0	120.0
Ca	ppm	448.0	614.0
Mg	ppm	43.0	85.0
B	ppm	0.4	0.5
Cu	ppm	1.5	0.5
Zn	ppm	1.4	1.5
S	ppm	23.0	16.0
Mn	ppm	57.0	58.0
Fe	ppm	234.0	154.0
Al	ppm	1431.0	1523.0

Table 2.2 Total nutrient analysis of the organic amendments on a dry weight basis and amounts of total nutrient applied at each rate.

		Poultry	Crab	Low	Medium	High
					kg ha^{-1}	
Dry matter	%	93.4	92.2			
C:N ratio		12.80	5.36			
C	%	40.4	12.8			
N_{total}	mg kg^{-1}	31,600	69,500	126	248	374
NH_4^+-N	mg kg^{-1}	3,700	n/a			
P	mg kg^{-1}	15,400	12,900	29	57	86
K	mg kg^{-1}	16,400	4,000	16	31	47
Ca	mg kg^{-1}	25,200	85,200	146	289	435
Mg	mg kg^{-1}	4,000	5,200	10	20	31
Cu	ppm	175.38	51.97			
Zn	ppm	284.51	80.60			
B	ppm	n/a	15.77			
I	ppm	n/a	505.33			
Mn	ppm	n/a	61.47			
pH		n/a	8.2			

Table 2.3 Fertility treatments showing yearly application rates and timings of soil amendments. SPR=Spring, SUM=Summer and SPL=Split.

		Spring		Summer		Year Total	
		Crab	Poultry	Crab	Poultry	Crab	Poultry
		kg ha^{-1}					
1	Control	0	0	0	0	0	0
2	SPR^{x}-Low	595	1,540	0	0	595	1540
3	SPR-Med	1,155	3,045	0	0	1155	3045
4	SPR-High	1,750	4,585	0	0	1750	4585
5	SUM-High	0	0	1,750	4,585	1750	4585
6	SPL-L/M	595	1,540	1,155	3,045	1750	4585
7	SPL-M/L	1,155	3,045	595	1,540	1750	4585

Table 2.4 Mean monthly temperature, cooling degree days and total monthly precipitation for the Farmington and Hunter River sites (Environment Canada, 2012).

Site	Month	2009	2010	2011	Normals[w]		2009	2010	2011
Farmington[x]									
Temperature (°C)	April	3.9	5.4	3.7	2.7	Cooling Degree Days[z]	0	0	0
	May	9.7	8.5	9.4	8.9		0	1.8	1.7
	June	15.0	13.9	12.1	14.4		14.9	2.5	0.8
	July	18.0	19.9	17.5	18.2		44.0	76.6	20.3
	August	19.5	18.5	18.0	17.8		69.9	38.4	25.6
	Sept	13.8	15.2	15.2	13.4		2.1	24.3	10.4
Precipitation (mm)	April	74.7	53.8	71.5	89.1				
	May	41.5	37.4	77.1	93.3				
	June	101.7	132.7	54.2	87.3				
	July	101.8	135.0	118.4	85.4				
	August	130.2	29.5	84.8	92.9				
	Sept	44.0	119.7	28.9	109.4				
Hunter River[y]									
Temperature (°C)	April	4.5	6.3	4.3	2.9	Cooling Degree Days	0	0	0
	May	10.2	10.0	10.0	9.1		0	2.3	3
	June	15.3	14.8	12.9	14.8		14.9	3.1	2.6
	July	18.9	20.4	18.8	18.8		52.5	88.8	40.7
	August	20.1	18.7	19.0	18.3		84.8	47.8	45.4
	Sept	13.8	15.6	15.7	13.8		2.8	30.5	16.7
Precipitation (mm)	April	89.7	72.8	93.2	89.1				
	May	109.4	42.5	82.0	92.1				
	June	113.1	165.4	100.8	90.3				
	July	167.0	118.7	86.3	86.4				
	August	127.3	53.4	140.0	83.4				
	Sept	82.0	137.5	26.7	83.2				

[w] Normals for the period of 1971-2000; Farmington normals from Bangor, PEI

[x] Data from St. Peters, PEI weather station

[y] Data from New Glasgow, PEI weather station

Table 2.5 Blackcurrant yield at the two sites for 2010 and 2011 and total cumulative yield over the two years.

Site	Treatment	2010	2011	Total
			ANOVA p-values	
FT[x]		0.023	0.836	0.410
HR		0.013	0.003	<0.001
			LS Means kg ha^{-1}	
FT	Control	977 c[y]	3935	4912
	SPR[z]-Low	1895 ab	4516	6411
	SPR-Med	1714 b	4636	6350
	SPR-High	1457 b	4858	6315
	SUM-High	1742 b	4445	6188
	SPL-L/M	1607 b	5016	6623
	SPL-M/L	2155 a	4978	7134
	SE	95	195	63
HR	Control	276 b	492 d	768 d
	SPR-Low	313 b	1205 cd	1518 bc
	SPR-Med	840 a	2540 a	3380 a
	SPR-High	789 a	1430 bcd	2219 c
	SUM-High	717 a	2264 a	2981 ab
	SPL-L/M	678 a	2087 ab	2765 abc
	SPL-M/L	765 a	1903 abc	2668 ab
	SE	65	174	70

[x] FT=Farmington and HR=Hunter River sites

[y] Means followed by the same letter within each site year are not significantly different ($p<0.05$).

[z] SPR=Spring, SUM=Summer and SPL=Split

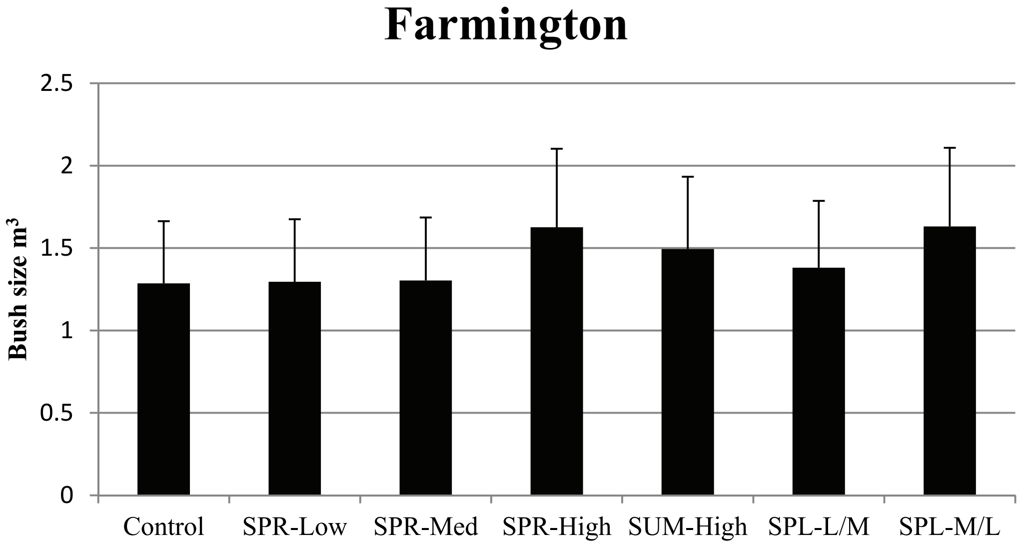
Table 2.6 Hundred-berry-weight and soluble sugars for 2010 and 2011

Site		2010		2011	
		HBW[x]	Sugars	HBW	Sugars
			ANOVA p-values		
FT[y]		0.285	0.83	0.052	0.082
HR		0.192	0.18	0.211	0.018
			LS Means		
		g	*°Brix*	*g*	*°Brix*
FT	Control	119.3[z]	17.5	83.6c	14.7a
	SPR-Low	118.3	17.3	88.5bc	14.3ab
	SPR-Med	107.3	17.3	94.6ab	14.1b
	SPR-High	116.6	17.5	91.5bc	14.3ab
	SUM-High	116.8	17.4	96.4ab	14.3ab
	SPL-L/M	111.5	17.7	96.5ab	14.4ab
	SPL-M/L	120.3	17.1	103.1a	13.9b
	SE	1.59	0.098	1.73	0.111
HR	Control	86.5	19.1	70.2	15.1a
	SPR-Low	84.5	19.2	86.0	14.9ab
	SPR-Med	102.8	18.5	86.4	13.8ab
	SPR-High	104.2	18.2	77.1	14.4ab
	SUM-High	100.8	18.9	85.7	14.6b
	SPL-L/M	101.6	18.5	88.4	14.5bc
	SPL-M/L	88.8	19.1	84.1	14.5c
	SE	2.76	0.124	2.14	0.075

[x] HBW= Hundred-berry weight

[y] FT=Farmington and HR=Hunter River sites

[z] Means followed by the same letter are not significantly different within each site-year ($p<0.05$)



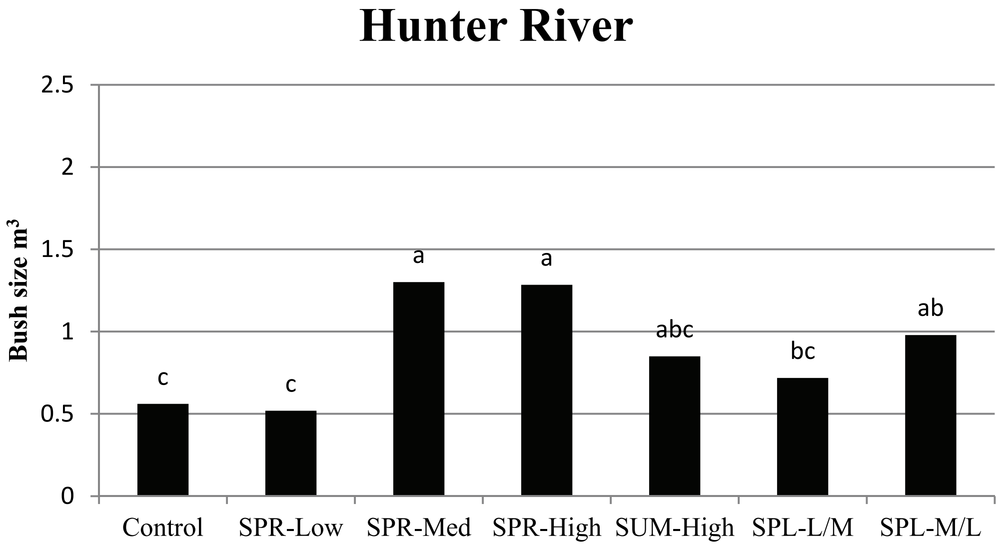


Figure 2.1 Blackcurrant bush volume at the end of 2011 for Farmington (above) and Hunter River (below). Means followed by the same letter are not significantly different within each site ($p<0.05$). Error bars represent back-transformed confidence intervals. SPR=Spring, SUM=Summer and SPL=Split.

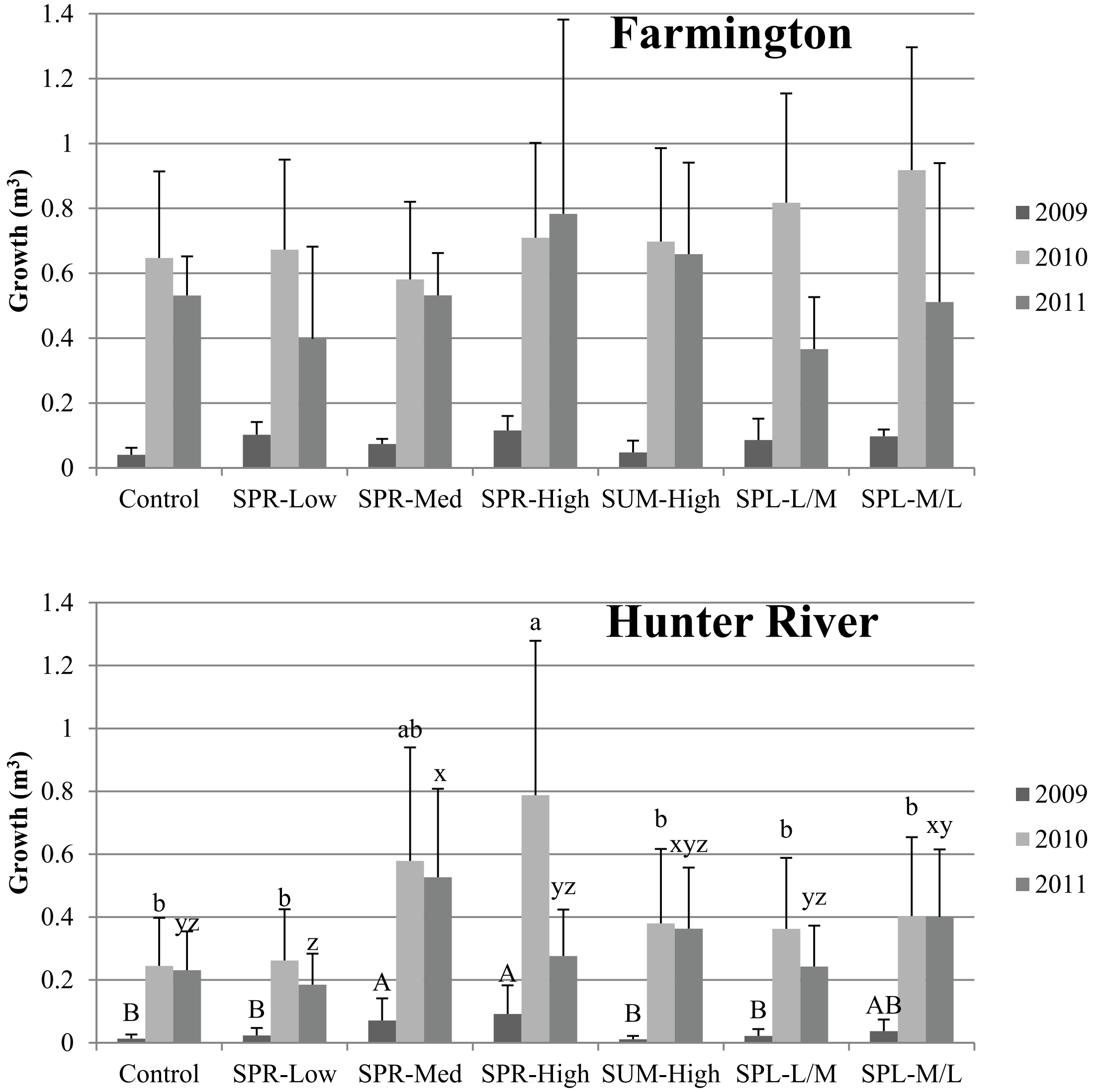


Figure 2.2 Yearly blackcurrant bush growth from 2009 to 2011 at Farmington (above) and Hunter River (below) Means with the same letter are not significantly different within each site-year ($p<0.05$). No significant differences were found at Farmington for all three years. Error bars represent standard error of the mean (FT 2009 and 2011) or confidence intervals if back-transformed (FT 2010 and HR all years). SPR=Spring, SUM=Summer and SPL=Split.

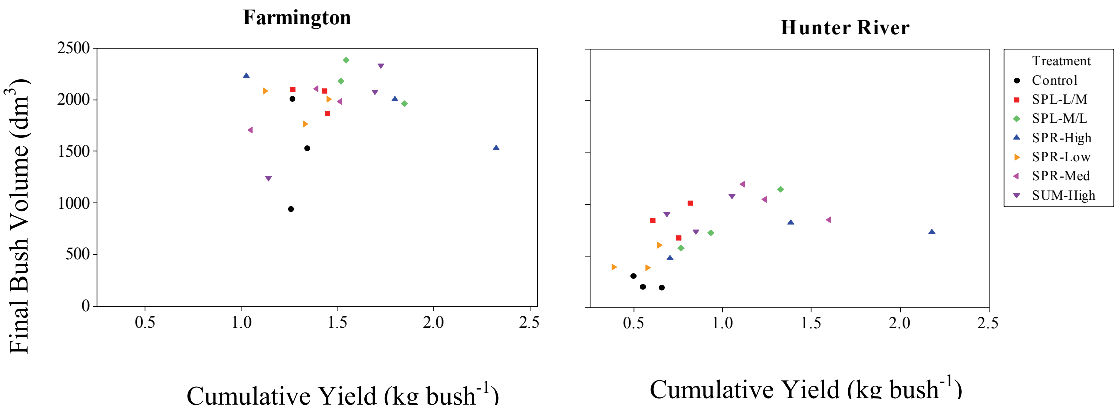


Figure 2.3 Overall bush size vs. cumulative yield at Farmington (left) and Hunter River (right). Only Hunter River shows a linear relationship with bush size and yield (R^2=23.6, p=0.015). FT (R^2=0, p=0.659).

Chapter 3. The Relationship of Plant-Available Soil (PRS™ Probes) and Leaf Tissue Nutrients with Bush and Berry Production

3.1 Introduction

Nitrogen (N) applications increase growth and yield of berry crops, but optimal rate and timing can be crucial, as excessive N is not only environmentally damaging, but expensive, and can kill young plants, or lead to fruit quality problems like post-harvest rot, or delayed fruit ripening (Bryla and Machado, 2011; Davenport, 1996; Kowalenko, 1981a). Rates of 100 to 150 kg N ha^{-1} have been recommended for blackcurrants to maximize growth and yield (Barney and Hummer, 2005; Langford and Craighead 2008). In order to bring blackcurrant (*Ribes nigrum* L.) bushes to a harvestable yield in the shortest time possible, the fertility management strategy for establishing bushes must focus on maximizing vegetative growth in the first three years, as mechanical harvesters have a minimum height threshold of about 40 cm, where berries below this point cannot be collected. Blackcurrant vegetative growth is affected by fertility only in the first few years of establishment, thereafter fertilizers only slightly increase yields (Opstad et al., 2007). On establishing plants in a pot trial, Bould (1969) found little effect of N on blackcurrant vegetative growth, but a strong yield effect, while P and K both had strong effects on growth.

Plant and fruit growth in perennial plants relies on minerals available in the soil throughout the season, but there is also a large supply of nutrients stored in the plant from the previous year. Throop and Hanson (1997) found that high-bush blueberries tended to absorb N based on demand more than the available supply, especially between late-bloom and fruit maturity. Birkhold and Darnell (1993) found that total N derived from storage pools for vegetative growth in blueberries was 65 % four weeks after floral budbreak but only 20 % by fruit maturity. Because of this large storage reservoir, blackcurrants could also benefit from late summer applications for growth and development the following year (Righetti, 1997). While much of this storage goes towards new growth, reproductive growth draws the majority of required N from storage in roots and stems (Birkhold and Darnell, 1993). Compost-amended apples can draw sufficient N from perennial tissues to meet spring N demands, reducing N uptake from fertilizer amendments (TerAvest et al., 2010). This suggests that N applied in the summer could benefit spring growth and yield. New growth of establishing fruit trees benefit from both fertilizer N and reserve N (Bi et al., 2003). Nitrogen fertilizer (urea) increased blueberry bush growth, yield and leaf N levels, but splitting N applications into early and late spring increased yields by 10% (Hanson and Retamales, 1992).

As opposed to synthetic fertilizers, organic fertility amendments are mineralized only gradually, and there may still be some residual, unmineralized product left in the soil by the following year. These complications make estimating the best fertility amendment rate and timing for establishing blackcurrants challenging. Animal residues produce a significant increase in available N for plants through the increase in soil microbial biomass (Cayuela et al. 2009). Nutrients in dried poultry manure (ex. Nutriwave™) are about 30-40% plant available during the growing season, with most of the readily mineralizable N released within the first 10 days after application (Sharifi et al., 2009). Crab shell powder increased N, P, Ca, Mg, Fe, Cu and Mn while decreasing leaf tissue K in maize (Adiloglu and Adiloglu, 2008). Organic N sources, due to their slow-release of nutrients, can be less damaging to establishing plants when applied in a single application; applications of 150 kg ha^{-1} of ammonium sulfate killed up to 50% of young highbush blueberry plants (Bryla and Machado, 2011).

Recommendations for evaluating soil fertility generally rely on sampling with soil cores and extraction with a dilute salt. However, used alone, soil analysis is not a satisfactory means of determining fertility of perennial crops such as berry bushes. Leaf tissue sampling is also used to determine the nutrient status of the plant, and together the two measures can be used to plan a nutrient management plan for perennial cropping systems. Niskanen (2001), for example, found a close correlation between leaf tissue and soil nutrients. However, in organic systems, nutrients from fertility amendments become available to the plants gradually, making it much more difficult to evaluate the efficacy of the amendments from soil sampling alone (Hammermeister et al., 2006). A better indicator of soil fertility in organically-amended soils would show the nutrients available to the plants over a period of time. Plant Root Simulators (PRS™) utilize ion exchange membranes to measure the supply rate of nutrients from the soil. This method allows in situ comparisons of fertility treatments over time rather than standard soil sampling, which gives only a snapshot of the available nutrients in the soil at the time of sampling (Qian et al., 1996). The results are highly influenced by the length of burial, soil type, and soil moisture and temperature, which affect mineralization rates. Nutrient levels in leaf tissue are the most common means of determining the fertility status of the plant. Leaf tissue sampling can be used in conjunction with PRS^{TM} probes to evaluate nutrient release from the soil, thus enabling the efficacy of the organic amendment to be scrutinized.

The objectives of this experiment were to determine 1. the effect of fertility rate and timing when applied to second and third-year blackcurrant bushes on nutrient supply rate (PRS^{TM}

probes) and leaf tissue nutrient concentration; 2. the relationship between can be found with nutrient supply rate and leaf nutrient status and bush growth, yield, fruit size and soluble sugars.

3.2 Methods

3.2.1 Experimental Design

The experiment was a randomized block design, consisting of one factor (fertility rate coupled with timing of application) with seven treatments replicated three times set-up in a randomized block design at two sites (Farmington (FT) and Hunter River (HR)) on Prince Edward Island (PEI). The experimental unit was one plot with five plants. Bush and berry means were taken from the three middle plants in the plot. Plots were separated by two untreated buffer plants.

3.2.2 Site and Climate

Site and climate was described in Chapter 2.

3.2.3 Treatments and Amendments

Treatments were as described in Chapter 2.

3.2.4 Soil Sampling

Initial soil fertility status was determined from soil samples collected in May 2009 by taking a composite sample of 25 soil cores (0-15 cm) at random points along the rows (HR) and by a transect through the field (FT) after soil was tilled and immediately prior to planting. The samples were analyzed at the Soil Feed Testing Laboratory in PEI. Mineral nutrient concentrations were determined by Mehlich III extraction (Mehlich, 1984).

3.2.5 PRS^{TM} Probe Analysis

In 2010, three anion and three cation probes were used per plot, and in 2011 four of each were used. Burial, removal, cleaning and shipment followed the procedure outlined in the PRS™ Operations Manual provided by Western Ag Innovations (Saskatoon, SK, Canada). The probes were buried 10 cm deep, between the plants in the middle of the row, for a two-week period in the last two weeks of June. The black plastic mulch covered the probes at the seam where two sheets of plastic overlapped. Probes were removed and cleaned with distilled water and a clean brush to remove all soil particles, cooled during transport, and immediately sent to the Western Ag Innovations Inc. laboratory for analysis of total N, P and K. The probes for each plot were pooled into one sample.

3.2.6 Leaf Tissue Analysis

Leaf tissue samples were selected randomly, taking about 40 (including the petiole) leaves per plot from the top third of the plant, in the third week of July in 2009, 2010 and 2011. After drying and grinding to 1 mm, leaf samples were sent to the Prince Edward Island provincial analytical laboratory for elemental determination by inductively-coupled plasma spectrometer (ICP, Thermo Fisher Scientific Inc., Waltham, MA).

3.2.7 Bush Volume, Berry Yield and Soluble Solids

Sampling and analysis for bush volume, yield and soluble solids were described in Chapter 2.

3.2.8 Agronomical Efficiency

Agronomical efficiency was calculated using the formula (adapted from Baligar et al. 2001)

$$\sum_{i=2009}^{2011} \frac{\text{GrowthF} - \text{GrowthC}}{\text{Quantity of nutrient applied}}$$

Where GrowthF is the growth (m^3) of the fertilized treatment for the given year, GrowthC is the growth of the Control for the given year and Quantity of nutrient applied is the estimated available N applied for the given year. Yield was measured in the same way, using the total 2010 and 2011 harvests, with the yield of each treatment subtracted from the Control.

3.2.9 Statistical Analysis

A separate analysis of variance (ANOVA) was used to test effects of fertility treatments on blackcurrant growth, yield, etc. for each site-year. Analysis were done using PROC GLM in SAS (9.2, SAS Institute, Cary, NC) at $\alpha=0.05$, except where noted. Residual values of all analyses were checked for normality using a normal probability plot. Non-normal data were transformed to satisfy ANOVA assumptions, and back-transformed means are reported; error bars are not presented on back-transformed means. Treatment means were compared using Fisher's protected least significant difference (LSD) test.

3.3 Results

3.3.1 Weather

Weather data is described in detail in Chapter 2.

3.3.2 Bush Growth, Yield, Berry Size and Soluble Solids

Bush growth, berry yield, size and soluble solids results in response to fertility treatments are shown in Chapter 2. Here only the relationship between soil fertility status and leaf tissue nutrient concentration as a correlation with bush growth and yield variables is presented.

3.3.3 Nutrient Supply Rate

A two-week PRS™ probe burial from mid-June to the beginning of July was used to test the differences in fertility treatments. In 2010, N supply rate was greatest in SPR-High treated plots at Farmington, and SPR-Med was greatest at Hunter River, but N differences were not significant at this site (Table 3.1). At both site, SUM-High treated plots, which had not yet received applications of treatments in each current year, had the lowest N supply rates in 2010.

Supply rate of P was significantly greater at Farmington than Hunter River in 2010 and a significant rate was observed at Farmington, with SPL-L/M having the highest P supply rate. Spring P supply rates increased in a rate-dependent manner.

At Farmington in 2011, N supply rate was significantly higher only for SPR-High and SPL-L/M, with K rate higher only for SPL-L/M.

At Hunter River in 2011, nutrient supply rates were significantly higher in the amended plots than the Control for N with the notable exception of SUM-High, which was closer to the Control. Other nutrients that had amended plots higher than the Control were Ca and Mg (except SPR-Low, SUM-High and SPL-L/M). For Fe, only SPR-Low was significantly higher than the Control, and SUM-High showed the lowest level.

Linear increases were expected from the Control across the three spring rates, and were found for most of the N, P and K supply rates in both years, with the exception of the SPR-Low treatment (N, both years) and the SPR-High treatment at Hunter River (K, 2011), and the SPR-High treatment at Farmington (P, 2011). In all of these cases, however, spring amendments were greater than the Control. The Control treatment had a high level of K in 2010 compared with the other treatments, but was the lowest in 2011.

3.3.4 Leaf Tissue Nutrient Status

At Farmington in 2011, only K was within recommended ranges (1.0-1.5 % K) for most treatments, and while N and P were slightly below recommended ranges (2.7-2.9 % N, 0.26-0.3 % P), micronutrients Cu, Zn and B were below recommended ranges (1.0% Ca and 15-15 ppm Zn), and Ca and Mg were above the ranges (1.0-1.5 % Ca and 0.10-0.15 % Mg) suggested by Barney and Hummer (2005). At Hunter River, all nutrients were below recommended ranges except Ca and Mg which were above (Table 3.2). Mean N levels at both sites were similar at each site, but compared with Farmington, Hunter River had significantly lower levels of P (39% lower in 2011) and K (64% lower in 2010 and 78% lower in 2011).

In 2011, there were significant differences across treatments for leaf N concentrations at both sites but not for P or K. In 2011, the three spring-only applied treatments showed a linear increase in tissue N at Farmington from SPR-Low to SPR-High, but the summer and split treatment plants had lower N than SPR-Med. At Hunter River, all the amended plots had significantly higher leaf N than the Control, but differences were not significant. Each site had declining levels of N since a 2009 high of 3.15 at Farmington and 2.62 at Hunter River.

Leaf N, P and K concentrations decreased with each year at each site, except P at Farmington from 2009 to 2010, which increased. Both sites had declining leaf P levels which showed deficient levels in 2011, although Hunter River rates declined more than Farmington in this year.

3.3.5 Correlations of Nutrient Supply Rate and Leaf Tissue Nutrients with Bush and Berry Production

Leaf nutrients in 2010 had few correlations with plant growth, yield, berry size or soluble sugars (Table 3.3). At Farmington, only growth had significant correlations ($p<0.05$) with leaf N, and yield was negatively correlated with Zn. At Hunter River, yield correlated negatively with P, and berry size had a negative correlation with Cu. In 2011, at Farmington there was a positive correlation with leaf K and growth, and negative correlations with Mg and yield and berry size. At Hunter River, there were positive correlations with leaf N and yield and berry size and K with yield.

Nutrient supply rate had no correlations with growth or yield parameters at Farmington in 2010. At Hunter River, however, there were correlations between growth and P, Cu, Zn and S, between yield and P, Cu and Zn, and negative correlations between berry soluble solids and P, Cu and Zn.

A correlation was found at Hunter River with bush growth and P supply rate in 2010 and 2011, but this correlation was not found in leaf tissue P. At Hunter River in 2010, yield was correlated with P supply rate, but strongly negatively correlated with leaf P.

More significant correlations were observed in 2011 than 2010. There were positive correlations between yield at Farmington and N, Ca and Cu. There were also positive correlations between berry size and Zn, while berry sugars were negatively correlated with Cu and Zn. At Hunter River, growth was positively correlated with P, and Cu, while berry size was positively correlated with K.

3.3.6 Agronomical Efficiency

From the agronomical efficiency (AE) of yield, there were no differences at either site (FT p=0.774; HR p=0.139) (Figure 3.1). There was no significance at Farmington because of high variability, most likely attributed to the highly variable yields in the Control and SPR-Low treated plants. The SPR-High treated plants tended to be the most inefficient for yield at both sites, while SPR-Low plants were had more efficient yields at Farmington, while SPR-Med treated plants at Hunter River were the most efficient for yield.

Significant difference was found not found at Farmington (p=0.047) but was found at Hunter River (p=0.012). SPR-Med and SPR-High treated plants had the greatest growth efficiency at Hunter River. SPR-Med and SPR-High had higher growth efficiency at Hunter River than Farmington, but the summer and split treated plants had similar patterns in growth efficiency.

3.4 Discussion

3.4.1 Nutrient Supply Rate

Supply rates of N, Ca and Cu had correlations with yield at Farmington for 2011, which is particularly interesting considering yield did not respond to amendment treatments at this site. The supply rate of N was very low for the Control and SUM-High compared with the other treatments at both sites in this year, which is not surprising considering that the only N SUM-High plants received was from the previous season.

The linear increases found for the spring treatments in most of the N, P and K supply rates suggest that the PRS™ probes, despite large variability within treatments, were providing accurate results. The biggest exception was N at Hunter River, where SPR-Low had higher N than the other spring treatments in 2010. A possible source of error may have been due to the placement of the probes between the seam of the overlapped black plastic fabric in the middle of the plant row. While efforts were made to ensure the uniformity in the placement of the probes and closure of the overlapping plastic, it is possible that there may have been variability in how much moisture infiltrated the plastic through the seams, affecting moisture content in the soil, and hence mineralization rates. PRS™ probes were buried 10 cm under the soil surface, which encompasses the range of highest blackcurrant root density (Coker, 1958).

Mineralized N may have been lower at Farmington in 2011 due to a much lower precipitation rate than Hunter River during the burial period, as mineralization rates of N are very sensitive to soil moisture. However, rates were lower at Farmington in 2010 as well, when precipitation was not as variable between sites. The black plastic, non-permeable mulch used in this trial prevents soil desiccation by preventing evaporation (Chalker-Scott, 2007). This could prevent the reduction in mineralization rates with drier periods. However, after prolonged drying periods, recharge is limited under black plastic mulches, and greater levels of moisture are required to resupply depleted soil moisture (Bowersox and Ward, 1970). As there were no prolonged dry periods during the length of this trial, it is unlikely that the soil desiccated to the point that mineralization rates steeply declined.

At Hunter River in 2011, Ca supply rate was lower for the Control than the other treatments, but the SUM-High and SPL-L/M showed a lower Ca supply rate. While this did not affect leaf nutrient Ca for SUM-High, SPL-L/M had leaf Ca even lower than the Control. A similar pattern occurred at Farmington, where SPL-L/M but also SPR-High had the lowest leaf Ca levels.

3.4.2 Leaf Tissue Nutrients

Significant differences in leaf N contents from the Control were found at both sites in 2011 only. Leaf tissue nutrient requirements were not met for the majority of the nutrients tested. A Finland survey found that most commercial blackcurrant plants had leaf N, P, K, Mg, Ca and B concentrations within recommended ranges (Niskanen, 2001). In this study, there was a decline in leaf N, P and K from 2010 to 2011. Increased applications of N tended to decrease foliar Ca, K, Zn, Fe and Mn in raspberry (Spiers, 1993), but here leaf K increased with higher rates, while Ca decreased and Zn showed little change. Fertigation and broadcast synthetic fertilizer increased leaf N content in blackcurrants in one study (Kongsrud and Nes, 1999), but in another, no significant effects on leaf nutrients were observed over seven years, and were below recommended ranges (Opstad et al., 2007). A study using rates of up to 45 kg N ha^{-1} (urea) found no significant increase in leaf N (Aaltonen and Dalman, 1993). Decreased leaf nutrients may be due to disproportionate shoot growth that could have resulted from the high amendment N, as inadequate root growth can prohibit the plant's ability to uptake sufficient nutrients required for aboveground growth (Marschner, 1995). There may also have been a dilution effect of bush growth, decreasing leaf nutrient concentrations. Leaf P decreased with increased N rates and increased with increased moisture (Niskanen, 2001).

In an eight-year blackcurrant field trial, leaves had low leaf-N values for spring broadcasting treatments compared with late summer broadcast and spring + late summer treatments, but K values were higher (Nes and Hageberg 2002). The authors suggested that this may have been due to the higher yield in the late summer treated plants, which would remove more K than the lower yielding plants.

While N was significantly correlated with yield at Hunter River in 2011, this correlation was much weaker at Farmington. Interestingly, K showed positive correlations between growth at Farmington only but between yield at Hunter River only in 2011. As plants had higher levels of deficiency in K at Hunter River, these correlations suggest that where K was available to plants, it was used for reproductive instead of vegetative growth. SUM-High had the second highest yield in 2011 and the highest level of leaf K, while the Control had the lowest yield and lowest leaf K.

Leaf tissue sampling of raspberry was determined to be inadequate in determining N requirements, as fertility fluctuates throughout the growing season (Kowalenko, 1981b). Leaf nutrients are influenced by soil nutrient availability, as well as interactions, antagonism and synergism in uptake and plant age (Marschner, 1995).

3.4.3 Effects of Nutrients on Bush Growth and Yield

Effects of fertility amendment treatments on bush growth and yield are described in Chapter 2.

Leaf nutrients concentrations of P and K indicate deficiencies at both sites, but were more severe at Hunter River, suggesting that these may be the limiting nutrients, and not N. Blackcurrant harvest can remove 55-65 kg N ha^{-1} and 10-12 kg P ha^{-1} (Craighead et al. 2007). As the fertility amendments were high in N, but much lower in P and K (7-1-1 for the crab meal and 4-1-1 for the poultry manure), a site that was deficient in P or K may not respond strongly to the treatments. This likely explains why the two sites behave so differently: Farmington had sufficient levels of essential nutrients, and therefore did not respond strongly to the treatments, while Hunter River did respond to the treatments, but did poorly overall because it was still deficient in P and K. Using this hypothesis, Farmington showed how the bush growth responded to the different treatments (high in N, but containing other nutrients as well) in a soil with well-balanced fertility. The higher N treatments slightly increased growth and yield at Farmington, but not significantly. Hunter River likely did not show the effects of nitrogen stimulation, as P and K were limiting. Recommendations for blackcurrant fertilization call for K applications about equal to N levels (Langford, 1996; Barney and Hummer 2005). However, as 70-80 % of K is removed with the fruit, K demands increase with increased crop loads, so levels should be lower in the establishing years and increase over time (Craighead et al. 2007).

There was high variability in P and K supply rates. This could have been due to the limited timing of the PRS^{TM} probe placement, failing to capture the mineralization of these nutrients from the organic amendments. The shallow depth of amendment incorporation also may have negatively influenced the capture of these nutrients from the probes 15 cm burial.

In a greenhouse pot study, Bould (1969) found that N levels did not significantly affect vegetative growth, but increased flower number and yield, while increasing leaf tissue N; Phosphorus, however, did increase shoot length, and leaf tissue P levels below 0.20% severely restricted growth, whereas 0.25% P was associated with optimum growth, and 0.30% showed maximum yield. Also, K was associated with increased growth, with severely reduced growth below 1.00% K. Increased rates of K fertilizer increased blackcurrant yields and shoot length (Scibisz and Mucha, 1990). In grapes, P increased yields in a P-deficient soil (Skinner et al. 1988).

Total plant K removal in fruit and leaves is estimated to be between 6.6 and 21.3 kg ha^{-1} , or between a third to a half of N removal (Craighead et al. 2007). High Ca levels can inhibit K uptake by creating a cation imbalance. Antagonism in K and Ca uptake was found in another blackcurrant study (Ljones, 1963). A negative correlation was found between soil and leaf K in a study surveying commercial red currants fields, possibly due to Ca inhibition (Niskanen, 2002). High Ca and low P and K has been found previously in currants (Aaltonen and Dalman, 1993). The crab meal used in this study contained high levels of Ca, and the blend was adding 265 kg Ca ha^{-1} at the highest treatment rates, so this may have caused excessive Ca levels in the high treatments. All plants at both sites showed high levels of leaf tissue Ca, but only Hunter River showed K deficiencies.

Other ways that K uptake can be limited is by soil compaction and poor aeration; however, there is no evidence that these conditions were present at Hunter River. Before the trial began, Hunter River had higher levels of soil Ca than Farmington (614 vs. 448 ppm), and Hunter River also had a higher pH than Farmington, but mean leaf tissue Ca was about the same at both sites in 2011. Levels of leaf Ca increased in all treated plants at Farmington from 2010 to 2011, and this was correlated to a decrease in K for all treatments, although most leaf nutrients showed decline. At Hunter River, however, while there was also a decrease in K from 2010 to 2011, there was a decrease in leaf Ca for most treatment plants. Other sources suggest that good yields are obtained with leaf Ca levels well above those found at either site, with soil Ca ranging from 500-4100 ppm; however, these fields were conventional, not organic, where high levels of NPK fertilizer were being applied, therefore supplying much higher levels of K, averaging 1.7% in the late summer (Niskanen, 2002).

While Craighead et al. (2007) found N strongly affected blackcurrant shoot length and yield in a pot trial, they found no correlations with soil N levels and bush yield. Where N was most likely the limiting factor to yield, 95-100 kg N ha^{-1} were suggested to produce a 10-12 t ha^{-1} crop. Increased N rates increased raspberry bush growth and berry size, but did not increase yield (Chaplin and Martin 1980). Increased vegetative growth increase bush's capacity to store N in the fall for the subsequent growing season, but also increases the pool of available N from new leaf growth which increases N relocation to reserves prior to leaf senescence (TerAvest et al., 2010). According to this theory, increased vegetative growth can lead to increased growth and yield in the following year. SPR-Med, which showed the next highest growth in 2010 at Hunter River, had the highest growth and yield in 2011, supporting this theory. At the same site, however, SPR-High had almost double the growth of the other high treatments in 2010, but in 2011 growth and yield was greatly reduced in this treatment, thus contradicting the theory. However, judging from the treatment effects on shoot growth alone neglects to take into account the growth of roots. Root biomass is greater than shoot biomass in blackcurrant's second year, but becomes less than half that of shoot biomass by their third year (Craighead et al. 2007). Root growth increases under low N conditions at the expense of shoot growth (Grechi et al., 2007; Beck, 1996). As these treated plants were low in P, and most plants were P deficient, it is possible that higher N treatments resulted in lower root growth, reducing plants capacity to remove sufficient amounts of soil P.

Berry size was larger than found by Denisow (2003), but larger berries can be expected on younger bushes as yields are smaller (Kahu et al., 2009). Bould (1969) found that black currant berries increased in size with increased K fertility, while increased N had no effect. In grapes, K has been shown to have the strongest influence on berry size (Amiri and Fallahi, 2007). Smaller berries at Hunter River may be due to the lower levels of K in plant tissues compared with Farmington. This is supported by the correlation found at Hunter River with leaf K and HBW in 2011, which was not seen at Farmington. However, leaf N at Hunter River in 2011 was strongly correlated with HBW. Leaf Cu concentrations in 2010 at Hunter River and Mg in 2011 at Farmington were negatively correlated with berry size. Berry size has previously been found to increase with increasing fertility levels (Kahu et al., 2009; Opstad et al., 2007). Summer-amended plots tended to have higher yields and larger berries, as outlined in Chapter 2. Plants prioritize stored nutrients for reproductive growth, so a post-harvest fertility amendment could be giving nutrients to the following year's crop (Rempel et al. 2004).

Soluble solids showed significant differences across treatments only in 2011, but were much lower than in 2010, likely due to a necessitated early harvest which may have prevented complete maturation. Berries in the Control treatment showed the highest soluble solid content at both sites in both years. Higher Brix levels in berries of lower fertility treatments was also found in other blackcurrant studies (Opstad et al., 2007), and fertilization did not affect soluble solids in blackberries (Alleyne and Clark, 1997). However, berry sugars were inversely correlated with yield, suggesting that bushes do not commit as many nutrients to soluble solids when their numbers are greater. Larger berries also tended to have lower soluble solids. Berries with abundant N may not accumulate as many sugars, as has been shown in other fruits (Okamoto et al. 2003). Amino acid and protein formation comes at the expense of non-structural carbohydrates, which are required for their carbon skeletons, which could reduce fruit sugars (Cheng et al., 2004).

Soluble solids were greater at Hunter River than at Farmington. This may have been due to the greater light penetration at Hunter River as a result of reduced bush development, reflected in the decreased bush growth of plants at this site, as greater light intensity results in higher levels of soluble sugars (Knee, 2002).

Plants treated with SPR-Med showed the greatest N efficiency for growth at Hunter River, followed by SPR-High. However, at Farmington while SPR-High treated plants showed the greatest growth efficiency, the differences were not significant. This suggests that higher spring rates increase vegetative growth as discussed above, but are only high rates are only efficient when nutrients are limiting.

No significant differences were found in N efficiency for yield at either site. At both sites, the SPR-High treated plants tended have the lowest efficiency in terms of yield than other treatments. This agrees with the hypothesis that high spring rates increase vegetative growth, but not necessarily yield. However, summer and split treatments were expected to have higher yield efficiencies than what was found, which does not support the hypothesis that higher yields come from summer or split applications.

Growth efficiency was significantly different across treatments at Hunter River, but not Farmington. SPR-Low growth efficiency was low at both sites, suggesting there was not an adequate amount of N for bush growth promotion from this treatment; bushes with the SPR-Med treatment, however, responded very well in terms of growth at Hunter River, and SPR-High treated bushes responded well at this site, but were less efficient in their N use. The N efficiency of the summer and split treatments tended to be poor in terms of growth when compared with the spring treatments at Hunter River.

While soil moisture and temperature were not directly measured, the plastic likely increased temperatures and prevented some soil evaporation, as well as preventing some leaching of nutrients due to the non-permeable nature of the material (Percival et al., 1998). Higher soil temperatures and moisture under black plastic mulch increases soil mineralization rates and increase plant uptake of N (Strik et al., 2006). Increased soil moisture has been shown to increase blackcurrant yield dramatically (Ostermann and Hansen, 1988). Heavy precipitation in June and July could have led to some fruit drop, as blackcurrants are susceptible to losing fruit to heavy rains during bloom (Opstad et al., 2007).

Growth and yield of the black currants were affected more strongly by the balance of background soil fertility than amendment application. Although more difficult with organic amendments, consideration should be given to nutrient balance of the amendments even in the establishing years when vegetative growth is being promoted at the expense of yield. In this case, background soil P levels were found to be deficient, and the amendments did not specifically address the issue. However, deficiencies in leaf P and K were not clear until plants were growing and leaf tissue samples could be collected.

3.5 Conclusion

While most of the treatments showed leaf N, P and K below recommended levels in 2011 ranges, leaf P and K were found to be much lower at Hunter River than at the Farmington site. Maximum bush growth was achieved with high spring fertility, and strong correlations were found with P supply rate and growth at one site. Leaf N and K concentrations had correlations with N and growth in one site-year, but with yield in another. However, the rate of K but also P in the amendments used is not sufficient, and should be increased, particularly by the second or third year when crop yields are removing higher amounts of K. Summer treatments did not increase bush growth. High N rates may not be necessary to increase growth and yield if soils have a sufficient N level prior to planting. Maximum yields were found when a summer fertility application was made, although good yields were also found from spring-only treatments. The SPL-M/L provided a good yield at the site that had higher leaf P and K concentrations, while the spring only fertility at a medium rate provided the best yield at the. Higher levels of K are recommended for fruit-bearing plants, as blackcurrant fruits are high in K. Generally, high spring rates are recommended to maximize growth, but adding an additional summer rate is recommended for increased yield.

Table 3.1 Nutrient supply rate supply of N ($NO_3^- + NH_4^+$), P and K for two week burials in 2010 and 2011. Means within a column followed by the same letter are not significantly different within a site-year (p<0.05).

Site	Treatment	N		P		K	
		2010	2011	2010	2011	2010	2011
				LS means			
				(μg 10 cm^{-2} 14 d^{-1})			
FT[x]	Control	22.1 c	38.2 b	3.4 c	3.3	113.8	80.8 b
	SPR[y]-Low	35.6 bc	157.2 ab	4.5 bc	9.0	66.1	109.2 ab
	SPR-Med	72.6 abc	177.6 ab	6.2 abc	9.6	97.3	164.4 ab
	SPR-High	167.3 a	218.6 a	7.2 abc	8.7	177.3	184.1 ab
	SUM-High	29.6 bc	99.1 ab	8.9 ab	13.0	103.9	153.0 ab
	SPL-L/M	123.1 ab	231.0 a	11.0 a	11.0	125.6	196.6 a
	SPL-M/L	53.9 abc	146.4 ab	6.2 abc	1.2	89.5	96.1 ab
HR	Control	159.2	62.0 c	2.1	4.9	76.9	67.5
	SPR-Low	528.0	441.3 a	5.1	6.6	83.7	151.7
	SPR-Med	210.5	394.1 ab	9.5	8.5	101.8	163.8
	SPR-High	283.0	639.9 a	9.8	11.1	154.9	141.5
	SUM-High	139.2	89.4 bc	5.2	6.6	185.5	135.2
	SPL-L/M	420.2	291.4 ab	3.9	8.1	136.7	146.2
	SPL-M/L	267.9	375.6 ab	6.1	10.3	122.7	189.0
Source				*ANOVA p-values*			
FT		0.08	0.02	0.08	0.17	0.65	0.02
HR		0.37	<0.01	0.23	0.36	0.49	0.14
Rate		0.04	<0.01	0.05	0.05	0.34	<0.01
Site		<0.01	<0.01	0.04	0.46	0.41	0.86
Site*Rate		0.37	0.40	0.50	0.62	0.86	0.23

[x] FT=Farmington and HR= Hunter River sites

[y] SPR=Spring, SUM=Summer and SPL=Split

Table 3.2 Leaf nutrients for N, P and K (2009-2011) and Ca, Mg, Cu, Zn and B (2011 only). Means followed by the same letter are not significantly different within a site-year ($p<0.05$). Recommended ratings from Barney and Hummer (2005).

		N			P			K			Ca	Mg	Cu	Zn	B
Source		2009	2010	2011	2009	2010	2011	2009	2010	2011	2011	2011	2011	2011	2011
								ANOVA p-values							
FT[x]			0.78	0.06		0.17	0.45		0.94	0.44	0.07	0.83	0.87	0.21	0.44
HR			0.81	0.01		0.21	0.86		0.11	0.17	0.36	0.86	0.72	0.46	0.04
Site	Treatment							*LSMeans*							
							%						ppm	ppm	ppm
FT	Control	2.85	2.46	2.06 c	0.23	0.37	0.28	1.72	1.31	0.96	1.96	0.29	3.52	16.9	8.4
	SPR-Low	3.05	2.49	2.16 bc	0.24	0.32	0.23	1.74	1.28	0.89	1.69	0.29	3.32	13.9	8.4
	SPR-Med	3.3	2.48	2.28 ab	0.27	0.3	0.24	1.81	1.26	1.01	1.91	0.27	3.46	16.2	8.9
	SPR-High	3.39	2.47	2.32 a	0.29	0.31	0.23	1.83	1.31	1.16	1.64	0.26	3.39	15.2	7.7
	SUM-High	n/a	2.5	2.22 ab	n/a	0.35	0.25	n/a	1.35	1.09	1.73	0.26	3.58	15.6	9.8
	SPL-L/M	n/a	2.49	2.2 abc	n/a	0.36	0.26	n/a	1.33	1.06	1.65	0.26	3.54	13.8	8.6
	SPL-M/L	n/a	2.76	2.19 abc	n/a	0.33	0.25	n/a	1.26	1.02	1.95	0.25	3.67	15.9	8.9
	Site mean	3.15	2.52	2.2	0.26	0.33	0.25	1.78	1.3	1.03	1.79	0.27	3.5	15.3	8.7
HR	Control	2.21	2.17	1.6 b	0.38	0.34	0.19	0.89	0.61	0.4	1.79	0.43	2.6	11.2	4.8
	SPR-Low	2.43	2.45	2.2 a	0.34	0.27	0.19	0.93	0.66	0.51	2.02	0.45	2.46	9.7	6.6 c
	SPR-Med	2.77	2.48	2.16 a	0.33	0.29	0.18	1.07	0.83	0.6	1.78	0.44	3	10.6	7.6 ac
	SPR-High	3.07	2.6	2.14 a	0.32	0.3	0.16	1.18	0.94	0.56	1.68	0.47	2.47	9.1	5.9 ab
	SUM-High	n/a	2.39	2.22 a	n/a	0.28	0.2	n/a	0.81	0.79	1.82	0.4	3.03	12.5	10.3 b
	SPL-L/M	n/a	2.62	2.35 a	n/a	0.3	0.15	n/a	1	0.59	1.36	0.35	2.34	9.6	6.2 a
	SPL-M/L	n/a	2.37	2.17 a	n/a	0.22	0.18	n/a	0.68	0.62	1.78	0.43	2.75	11.3	7.4 abc
	Site mean	2.62	2.58	2.12	0.34	0.29	0.18	1.02	0.79	0.58	1.75	0.42	2.67	10.6	7 abc
<u>Rating</u>															
Deficient			2.6			0.25			1		-	0.1	5	15	20
Recommended			2.7-2.9			0.26-0.3			1.0-1.5		1.0-1.5	0.1-0.15	5-20	15-50	20-40
Excessive			3			0.3			-		-	0.15	-	-	40

[x] FT=Farmington and HR=Hunter River sites, SPR=Spring, SUM=Summer and SPL=Split

Table 3.3 Pearson's correlations coefficients with yearly growth, yield, hundred berry weight (HBW) and soluble solids (Brix) for 2010 and 2011 nutrient supply rate (NSR) and leaf nutrients (leaf). Only significant values are shown at p<0.1 within a site-year.

		Farmington				Hunter River			
NSR		Growth	Yield	HBW	Brix	Growth	Yield	HBW	Brix
N	2010								
	2011		0.87						
P	2010					0.94	0.7		
	2011					0.77			
K	2010								
	2011							0.76	
Ca	2010								
	2011		0.71						
Mg	2010								
	2011								
Cu	2010					0.85	0.71		-0.74
	2011		0.91		-0.83	0.75			
Zn	2010					0.76	0.75		-0.76
	2011			0.82	-0.89				
Fe	2010								
	2011								
S	2010					0.69			
	2011								
Leaf									
N	2010	0.76							
	2011						0.76	0.90	
P	2010						-0.96		0.73
	2011								
K	2010								
	2011	0.72					0.81		
Ca	2010								
	2011								
Mg	2010								
	2011		-0.80	-0.95					
Cu	2010							-0.84	
	2011					0.80			
Zn	2010		-0.75						
	2011								
B	2010								
	2011						0.71		

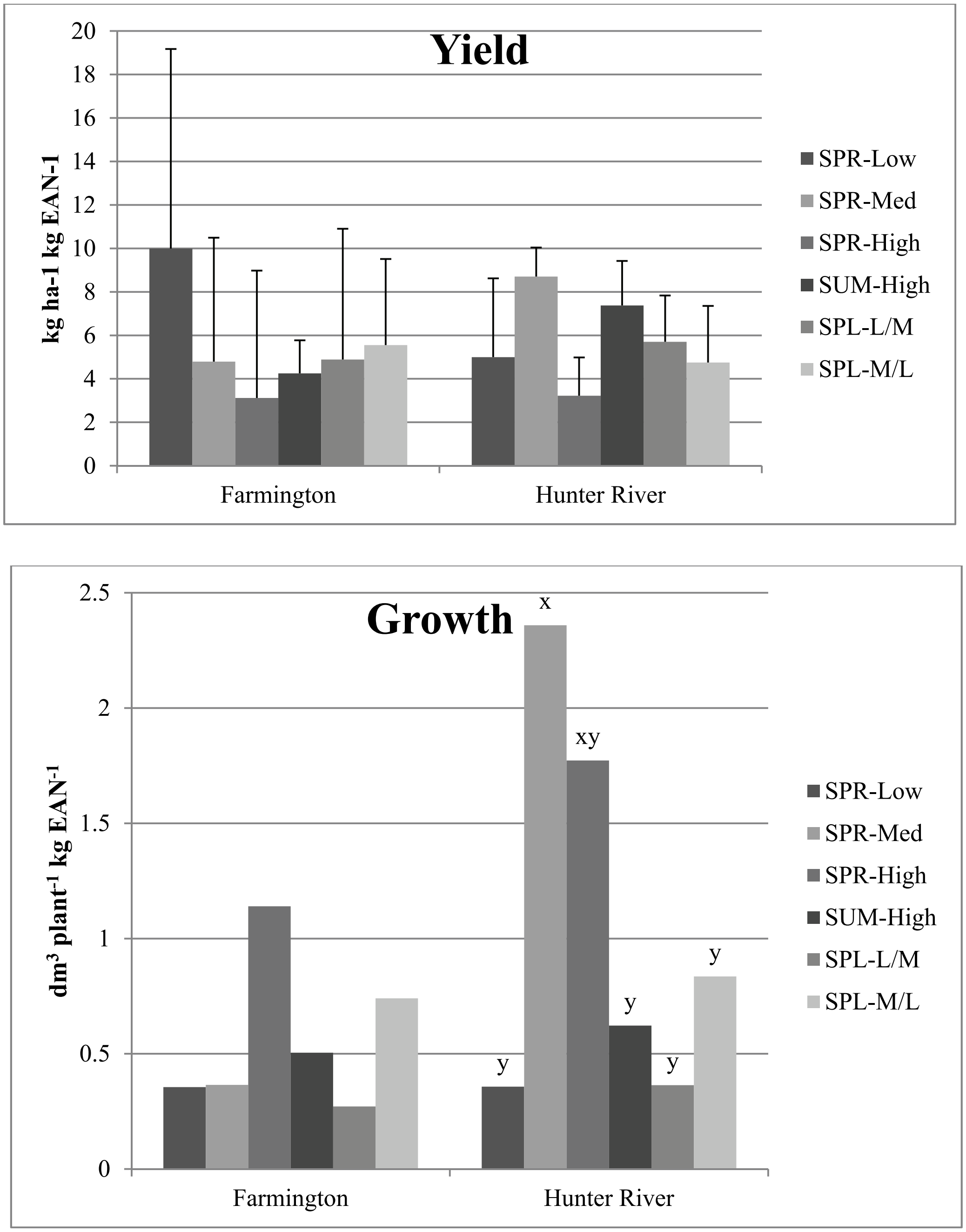


Figure 3.1 Agronomical efficiency of yield (above) and growth (below) over three years based on estimated available nitrogen applied to each treatment. Within a site (Farmington or Hunter River) columns with the same letter are not significantly different ($p<0.05$). Error bars represent standard error of the means.

Chapter 4. Deflowering and Fertility Timing Affect Growth and Yield in Establishing Organic Blackcurrants

4.1 Introduction

Mechanical harvesting of blackcurrants (*Ribes nigrum* L.) requires a minimum height of about 40 cm above the ground, making bush growth crucial during establishing years. Blackcurrant growth during establishment years has a strong influence on future harvests (Rhodes, 1986). As blackcurrant bushes have not yet reached a height acceptable for mechanical harvesting and furthermore do not produce a substantial yield in the second year of establishment, fruit produced during this period can be considered an impediment to vegetative growth. Fruiting structures are the dominant sinks during the peak of fruit growth, strongly competing with vegetative growth (Forney, 1984). Reproductive structures can drain resources from the whole branch (Reekie and Bazzaz, 1987).

Flower thinning is a common practice in fruit production, helping to promote larger fruit and prevent biennial bearing, as in apples, or increase vegetative growth and yield, as in strawberries (Williams and Edgerton, 1981; Hawes, 1996; O'Carroll and Hennerty, 1976). Fornery (1984) found that strawberry plants that had their flowers removed had 62 and 44 % more dry matter in the roots and leaves respectively than plants allowed to fruit. Removal of flowers from blackberries increased carbon accumulation by 10 % and increased overall photosynthetic capacity by 36 % compared to fruiting canes (McDowell and Turner, 2002).

For perennial bushes like blackcurrants, the first year's yield is typically not significant enough to warrant harvesting (Thiele, 1979). When flowers are removed from establishing plants, energy could be diverted from reproductive to vegetative growth, helping to increase plant size, which could also lead to a larger harvest in the following year. Flower removal on establishing plants has the potential to reduce fertilizer costs, as plants are not allocating nutrients to fruit that will not be harvested. Blackcurrant growth increased in young plants with flowers removed, and the following year showed improved growth and yield compared with flowered plant growth (Hansen, 1985). The author suggested that in establishing deflowered plants, vegetative growth increases in the deflowering year, leading to an increase in yield the following year, as yield is closely tied to previous year's growth.

Combining fertility amendments with deflowering could further increase growth and yield. Fertility amendments are recommended for establishing plants at a rate of 100 kg N ha^{-1} (Craighead et al., 2007). Fertility applications split across different seasons have different effects on growth and reproduction, with spring amendments increasing growth and amendments applied post-harvest tending to have more effect on yield, as shown in Chapters 2 and 3. As flowers and developing fruit derive the majority of their nitrogen (N) from perennial tissues, N from spring amendments in the fruiting year will not be used for reproductive growth until fruits have started to develop (Munoz et al., 1993). Autumn applied N for peach was found to supply perennial storage N to improve spring growth and yield, and N supplied in the spring could not supplement this perennial N (Jordan et al., 2009). Similarly, blueberry plants utilized perennial N for new growth even when N was available in the soil (Birkhold and Darnell, 1993). This suggests that applying fertility in the spring only, in the summer only, or split across the spring and the summer, could have an interaction with flower removal on growth and yield. If deflowering can divert more resources to vegetative growth in the deflowering year, there will be a greater stem area for fruiting buds. Furthermore, if fertility amendments can increase nutrient levels in perennial tissues, then yield could benefit from the increased nutrients in the year following deflowering year, influencing yield, berry size and soluble sugars.

The objectives of this experiment were to test the effects of deflowering on growth, yield, and berry soluble solids, and to test whether an interaction effect exists with deflowering and the timing of fertility treatments applied in the spring, summer or split across the spring and summer.

4.2 Methods

4.2.1 Experimental Design

The experiment was a randomized block design, consisting of two factors: 1) Fertility rate coupled with timing of application (NoAmend, SPR-High, SUM-High or SPL-M/L) and 2) Flower presence (–FLWR or +FLWR) replicated three times at two sites (Farmington (FT) and Hunter River (HR)) on Prince Edward Island (PEI). The experimental unit was one plot with five plants. Bush and berry means were taken from the three middle plants in the plot. Plots were separated by two untreated buffer plants.

4.2.2 Site and Climate

Site and climate were described in detail in Chapters 2 and 3.

4.2.3 Treatments and Amendments

Two amendments and amendment rates were as described in Chapter 2, however only the three timings, were used with one rate, so the total amount of amendment applied to each of the three amended treatments was the same. Fertility treatments consisted of one spring-only application (SPR-High), one summer-only (SUM-High) and one application that was split between the spring and summer (SPL-M/L) as well as an unamended treatment (NoAmend). Amendments were applied in a 50 cm wide band along the row and lightly incorporated into the soil by hand. Spring amendments were applied at the end of April and summer amendments in the third week of August from 2009 to 2011 on the same plots, thus treatments were cumulative.

4.2.4 Flower Removal

Each of the four fertility treatments had a flowered and a deflowered treatment. Flowers were removed May 26 and 27 2010 by hand, by pulling the whole flower off of the stem, to achieve a minimum of 90% removal. Flowers were left on the ground, but as they landed on top of the black plastic, their nutritional value to the plants was considered negligible. In 2011, no flowers were removed, so as to study the effects of deflowering on both the deflowering year (2010) and the following year's growth and yield (2011).

4.2.5 Bush Volume, Growth, Berry Yield and Soluble Solids

Methods describing measurements and analysis of bush volume, growth and berry yield and soluble solids are detailed in Chapter 3, section 3.2.6. Briefly, bush volume was measured as the cylindrical volume of one height and two width measurements (3.142 * height * width * 0.5 * breadth * 0.5, modified from (Erb et al., 1993)) taken in the spring of 2009 and 2010 and summer and fall of 2009-2011. Mean yearly growth was calculated from the three data plants in each of the three plots, from spring to fall (2009) or fall to fall (2010-2011).

4.2.6 Statistical Analysis

A separate analysis of variance (ANOVA) was used to test effects of fertility and deflowering treatments on blackcurrant growth for each site-year, and for berry yield, HBW, soluble sugars and final size each site was analyzed individually. Analysis were done using PROC GLM in SAS (9.2, SAS Institute, Cary, NC) at $\alpha=0.05$, except where noted. Residual values of all analyses were checked for normality using a normal probability plot. Non-normal data were transformed to satisfy ANOVA assumptions, and back-transformed means are reported; error bars are not presented on back-transformed means. Treatment means were compared using Fisher's protected least significant difference (LSD) test.

4.3 Results

There were no significant interaction effects with deflowering and the amendments (Table 4.1). Yield only significantly increased at Farmington, but growth only increased at Hunter River from deflowering treatments. The –FLWR plants in both 2010 and 2011 showed increased growth over +FLWR plants at Hunter River (Figure 4.1). Final size was not significantly different at either site in either of the treatment effects (Table 4.2).

Differences in growth were greater in 2011 than in 2010, with a mean growth increase in –FLWR plants of 29 % in 2010, compared with 61 % in 2011 at Hunter River. Bush growth and yield were both greater at Farmington. Mean yield of –FLWR plants at Farmington was 19% greater than +FLWR plants.

Vegetative growth in the deflowering year was not closely correlated with yield the following year at Farmington, as deflowering decreased 2010 growth, but increased yields in 2011. At Hunter River, however, yield was much more closely tied to 2010 growth in the –FLWR plants ($p=0.11$, $r=0.49$).

No significant increase in berry weight was found from deflowering but berries tended to be larger in the –FLWR plants at Hunter River, while at Farmington the opposite was the case (Table 4.2).

Soluble solids were marginally significantly reduced at Farmington by 1.4% and significantly reduced in the –FLWR plants at Hunter River by 2.8%.

4.4 Discussion

Overall bush growth and yield were greater at Farmington than Hunter River, likely due to fertility issues discussed in detail in Chapter 3. These soil fertility issues interacted with fertility amendments differently at either site, discussed in Chapter 2, but here bushes in the deflowering treatment also showed strong differences between the two sites, while plants did not significantly respond to the interaction of deflowering and treatment timings at the two sites. Plants at Hunter River had significantly more growth from deflowering treatments, but increases in yield were not significant, whereas at Farmington plants had significantly greater yields but not growth. Fertility differences outlined in Chapter 3 suggest that Hunter River was more deficient in K and P than Farmington. In another trial at these sites, Hunter River plants had significantly different yields across fertility treatments, whereas Farmington plants did not in 2011, detailed in Chapter 2. As K is important in fruit development, and P amendments can increase blackcurrant yields (Bould, 1969), plants at Farmington, with higher levels of these nutrients, may have had the appropriate nutrients required to increase yield by using perennial reserves, while plants at Hunter River did not. Another possibility is that plants at Hunter River were less mature, so reserves were focused on vegetative growth and not yield, whereas at Farmington bushes were much more mature (larger) and therefore spent more resources on fruiting in 2011.

Deflowering significantly increased plant growth at Hunter River in the deflowering year, and yield tended to increase the following year, however differences were not significant. Similar results have been found in potted-plant trials: deflowering blackcurrant bushes to 25 % the yield of fruiting bushes increased bush growth by 40 %, significantly increased leaf growth in the deflowering year, and increased yields the following year (Hansen, 1985). In a study with apples, deflowered plants amended with synthetic fertilizer showed only slight increases in growth at low N levels, but at higher N levels, deflowered plants grew much more than fruiting plants (Hansen, 1973).

As shown in Chapter 3, plants at Hunter River had lower leaf P and K levels and reduced growth and yield at this site. Deflowering therefore seems to have more of an influence on plant growth than yield when there are deficiencies in P and K, as seen at in Hunter River. Adequate levels of these nutrients are found at Farmington, where deflowering increased yields but not growth.

Differences in growth from deflowering were greater in 2011 compared with 2010 at both sites, even though overall growth rates were lower in 2011. At Farmington this may have been due to the increased yield and therefore sink strength that the –FLWR plants experienced in the year following deflowering. Plants at Hunter River seem to have divided any incurred benefit from deflowering more evenly across vegetative and reproductive growth, showing increases in both in 2011, compared with +FLWR plants. However, differences were not always significant, possibly because the allocation of resources was split. Cooling degree days were also much lower in spring 2011 than 2010, particularly in June, which could have contributed to temperatures better suited to growth than yield.

There was a correlation with 2010 growth and 2011 yield only in plants in the –FLWR treatment at Hunter River. This was similar to findings by Hansen (1985). However, for plants Farmington and in the +FLWR plants at Hunter River, no such correlations were found.

The –FLWR bushes in the deflowering year produced from 5-24 % (14 % on average) of their fruit (compared with +FLWR plants of the same amendment treatments) due to flowers that were overlooked or flowers that emerged following the deflowering treatment. There was high variability in –FLWR yields, but not +FLWR yields at Hunter River, which reduced significance levels, but the NoAmend plants showed much lower variability. The +FLWR plants produced statistically similar amounts of fruit over the two years as –FLWR plants did in 2011 (data not shown). However, +FLWR bushes in 2010 produced a small yield compared with 2011, and as the heights of the bushes were not sufficient to allow for mechanical harvesting of a large portion of the fruit, this 2010 yield would not be typically harvested. Therefore it is reasonable to compare only the 2011 yields of the +FLWR vs. –FLWR plants.

It is not clear why growth was greater in the +FLWR treatment at Farmington, particularly in 2010, where differences were marginally significant ($p<0.1$). Blackcurrant bushes have shown growth increases of up to 40% with flowering removal, but fruiting blackcurrant plants had greater shoot growth the following year, as vegetative growth compensates for the lack of growth the previous year (Hansen, 1985). Hansen (1985) suggests that because root growth was not affected as much as shoot growth in the first year, the following year’s roots may contain growth promoting factors that encourage more shoot growth to compensate for the reduction in the previous year. Removal of blackcurrant shoots reduces the length of roots within a period of about two weeks (Atkinson, 1972). Plants attempt to balance root:shoot ratios when they are not in equilibrium (Wilson, 1988). It then follows that a reduced growth rate in a high-fruiting year which isn’t compensated for by a complementary root growth could lead to greater shoot growth the following year. While root growth was not studied in this trial, roots clearly play an important role in the regulation of shoot growth and fruiting.

Soluble solids were lower in the –FLWR treatment at both sites although the difference was only marginally significant at Farmington. Increased yields often reduce soluble solid content, as was found in another trial at these sites, discussed in Chapter 2. The increase in growth at Hunter River suggests that nutrients were allocated to growth instead of yield in the –FLWR treated plants, which may have compromised berry sugars. Berry size was not affected by the deflowering treatment. Other studies have found correlations between yield and berry size (Kongsrud and Nes, 1999).

While in this study flowers were removed by hand, this is not commercially feasible, as it is very labour intensive. Flower thinning is common in other fruit production systems, like apples, and these techniques may find use in blackcurrant production. However, the chemical thinning techniques used in apples, for example, can have toxic effects on the vegetative tissues if the dose is too high. Other mechanical means may be available, such as running the harvester through the bushes to brush off the flowers. New mechanical thinning machines are being developed in apples as chemical thinning agents are being phased out (Hehnen et al., 2012).

4.5 Conclusions

Response to deflowering depends on the background levels of soil fertility, particularly P and K. At the site with P and K deficiencies, deflowering resulted in higher growth rates, but at the site with adequate levels of these nutrients, yield was higher in the year following deflowering, without an increase in . The differences may have been due to the smaller size of the bushes with low P and K leaf concentrations, which diverted nutrients to greater growth instead of yield. Results from this trial therefore show that deflowering benefits plants either by increasing growth or yield, depending on plant size or fertility status. As manual flower removal is labour intensive, deflowering will only be economically viable if a method can be found to manually or chemically remove the flowers at a low cost.

Table 4.1 ANOVA p-values for 2010 and 2011 growth, final size, yield, hundred berry weight (HBW) and soluble solids from the 2011 harvest.

Source	Site	2010 Growth	2011 Growth	Final Size[1]	Yield	HBW	Soluble Solids
Flower	FT[2]	0.099	0.361	0.170	0.038	0.720	0.060
	HR	0.033	0.003	0.083	0.152	0.338	0.006
Flower*Amend[3]	FT	0.787	0.694	0.940	0.496	0.655	0.242
	HR	0.154	0.165	0.463	0.692	0.877	0.218

[1] Final Size= the bush volume at the end of the last growing season
[2] FT=Farmington and HR=Hunter River sites
[3] Amend= fertility amendment timing treatment

Table 4.2 Mean bush size (September), yield, hundred berry weight (HBW) and soluble solids for 2011. Means of the flower treatments at the same site followed by the same letters are not significantly different at the 90% level.

	Amendment	Farmington		Hunter River	
		Flower	Deflower	Flower	Deflower
Bush Size		m^3			
	NoAmend	1.29	1.17	0.56	0.92
	SPR-High	1.72	1.35	1.42	1.16
	SUM-High	1.52	1.42	0.86	1.19
	SPL-M/L	1.64	1.40	1.01	1.68
	Site mean	1.54	1.33	0.96 b	1.24 a
Yield		kg ha^{-1}			
	NoAmend	4133	5223	476	520
	SPR-High	4899	4941	1423	1601
	SUM-High	4613	6295	2250	2876
	SPL-M/L	4999	5720	1864	3085
	Site mean	4673 b	5568 a	1409	1849
HBW		g 100 $berries^{-1}$			
	NoAmend	83.6	88.0	70.2	69.7
	SPR-High	91.5	87.2	77.1	86.3
	SUM-High	96.4	97.5	85.7	88.6
	SPL-M/L	103.1	97.2	84.1	89.4
	Site mean	93.7	92.5	79.3	83.5
Soluble Solids		^{o}Brix			
	NoAmend	14.7	14.1	15.1	14.5
	SPR-High	14.3	14.1	14.4	14.5
	SUM-High	14.3	14.3	14.6	14.0
	SPL-M/L	13.9	13.9	14.5	13.7
	Site mean	14.3	14.1	14.6 a	14.2 b

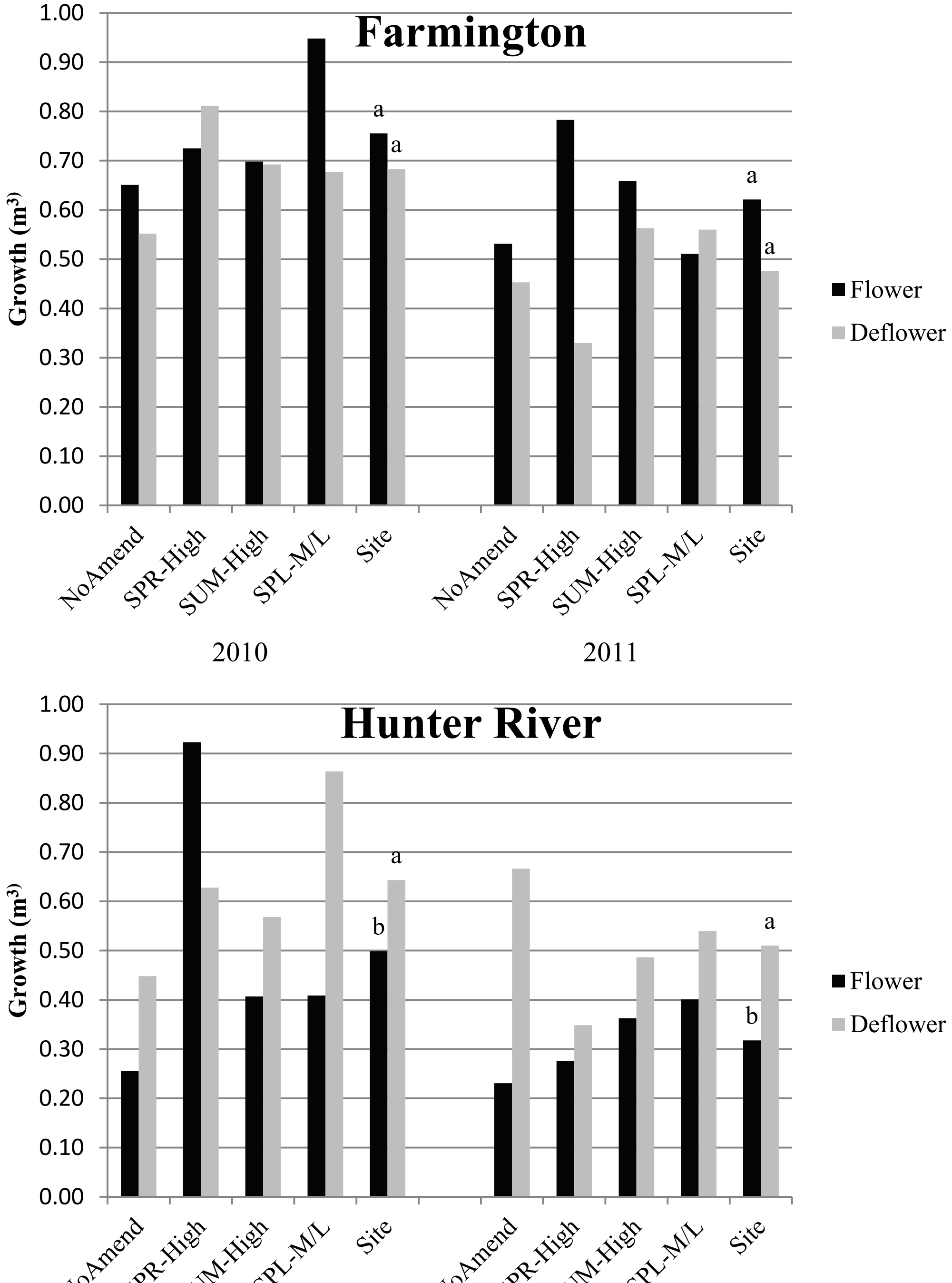


Figure 4.1 Flowered and deflowered plant growth for 2010 and 2011 at Farmington (above) and Hunter River (below). No significant interactions in bush growth (i.e. annual change in volume) between amendment treatment and deflowering treatment was found within any site-year, however, a significant effect of deflowering was observed as indicated for the columns labeled site.

Chapter 5. Conclusion

Commercial blackcurrant production is still nascent in North America, and best management practices for organic production are still being evaluated. However, if production is to be cost-effective, mechanical harvesting will be necessary, meaning that bushes will have to be of a minimum size. In conventional production, the use of synthetic fertilizers provides enough nutrients for rapid bush establishment, but for organic production, the best way to provide this fertility has not been determined.

While it is clear that weeds are strong competitors of establishing bushes, weed management can be effectively resolved with the use of black plastic mulch, which can remain intact for up to five years. However, if fertility amendments are to be added yearly or twice-yearly, this mulch may prove to be a nuisance to applying fertility amendments to the soil around plants. Granulated fertility amendments like the ones used in this trial used in conjunction with this weed management strategy require a better application method. However, as was seen at one of the sites (FT), a good level of initial fertility provided adequate growth and yield for the first three years, with no significant differences in three-year growth over even the highest fertility treatments. This suggests that if a good level of fertility is established prior to planting, over the course of three years fertility amendments may not be required. This would allow the mulch to stay in place for at least three years, thereafter amendments could be applied or the mulch could be removed if plants have reached maturity and weeds are no longer considered strong competitors to the established plants. By the time bushes have reached this stage of development, they are much less susceptible to weed competition. Roots are well-developed, and can spread into the plant row (Thiele, 1979). Plants become much bushier, and shade out weeds underneath them. It is clear, however, that each harvest removes a considerable amount of nutrients, particularly N and K, and these must be replenished for satisfactory yields in continued harvests.

Future research could also examine the effects of the black plastic mulch on root growth. Unimpeded blackcurrant roots grow well into the plant alleys by the time they reach adult stage (Thiele, 1979). Mulches that capture soil moisture significantly improve young blackcurrant root growth (Larsson et al., 1997). The black plastic used in these trials increased soil moisture in establishing blackcurrants grown in NS (data not presented). It was noted at Hunter River that the shallow roots of the plants would grow to the edge of the plastic where they met with the edge that was folded under the soil. As they could not puncture the plastic, the roots would grow perpendicularly, along the plastic edge. This could cause issues with nutrient and water uptake if the roots are not free to grow where they need to. The black plastic mulch is important for weed management, particularly for organic production where low-cost herbicides are not available, and more research needs to be conducted to test the effects of this product on the growth of perennial plants. There may be ways of using the plastic that allow for a shallower burial of the material that would allow the shallow roots to continue to grow into the alleys.

Black plastic mulch has also been criticized by organic growers for stifling biological activity by limiting organic matter in the soil it covers. This could be reduced by adding organic matter to the soil before covering it with plastic. This and other strategies are currently being tested in a blackcurrant trial at the OACC in NS. Compost, or other organic matter will slowly degrade under the plastic, which provides good soil moisture and temperature conditions for mineralization. Blackcurrant bushes, which reach maturity in about three years, would no longer require the weed-control effects of the plastic when they are full grown, and the plastic could be removed. At this point, other organic amendments could be added. At Farmington, the Control showed little significant differences from amended treatments, suggesting that for the first three years the soil fertility was adequate, and the effects of the black plastic on soil biology did not negatively impact bush growth or yield. When soil fertility is not optimal, however, as seen at Hunter River, plants without fertility amendments will suffer from reduced growth and yield. Finding the appropriate organic amendment that promotes biological activity in the soil as well as adequate nutrient to the plants for the period of mulching could be an interesting future project. If black plastic did somehow have a negative effect on the long-term soil biology, Control plants and soil under the plants used in these PEI trials could be analyzed in future years to examine the effects of three-years of black plastic mulching. The Control plants at Farmington would be of particular interest, as they showed growth and yield comparable with the high fertilized plants.

The fertility treatments used in this trial were much higher in N than P and K, and P and K deficiencies were noted at one of the sites, while the other was marginally sufficient. In order to meet the needs of the plants, it is suggested that an amendment with higher levels of P and K be used, particularly if the soil is deficient in these nutrients prior to planting. Following establishment, nutrients removed from the crop must be returned to the soil. This trial did not determine the effects of these amendments on plants the year after a full harvest, but fertility treatments did increase yields. However, tissue nutrient levels of P and K decreased each year, even with high levels of fertility amendments.

There is a concern that the fertility treatments used in this trial were high in Ca, particularly the crab meal. While it is not certain that high levels of Ca had a detrimental effect, there is a risk that if adequate K is not supplied to the plants, Ca could restrict the amount of K that the plant takes up. Because blackcurrant fruits are particularly high in K, this is cause for concern. Sufficient K should be added, particularly when bushes are yielding, from the second year on, but also if sites are deficient or low in K before planting. Kelp is abundant in Atlantic Canada, and a good source of organic potash, and may be an alternative or addition to these amendments to provide sufficient K. Future research could determine the effects of crab meal used at this volume on blackcurrant productivity and relationship with K uptake over the long term. Applications of K, perhaps in the form of kelp meal, could be tested to determine if K uptake is impeded by high Ca levels, or if the crab meal added in these amounts is not high enough to have an effect on K uptake.

Organic blackcurrants have good potential for growth in Atlantic Canada. However, there is still a major disease issue that has yet to be resolved: that of the White Pine Blister Rust. Bushes at Farmington were highly infected by late August, and completely defoliated by the end of September, but at Hunter River while the rust was noted, infection levels were very low and little or no defoliation occurred by this same date. Ironically, bushes showed better growth and yield at Farmington, despite high levels of WPBR infestation, which suggests that the rust may not be having a strong negative impact on the bushes at this stage of infection in the growing season. The rust, while clearly leading to premature defoliation, is much more destructive to its White Pine host than it is to blackcurrants, but it is not clear if these cv. Titania plants can tolerate this level of infection for more than three years while still maintaining good levels of growth and yield.

The PRS™-probe burial may have had some inconsistencies due to the placement of the probes between the overlap of the two sheets of black plastic mulch. This location was chosen as it was an even distance between two plants, and could be consistently placed for each burial. Also, it was easy to open and place the probes without having to disturb the plastic. However, this location likely had uneven moisture as any precipitation would not fall through the seams evenly across different plots, as the folds in the plastic were slightly different between each plant. As moisture is important for these probes, affecting mineralization and leaching rates, variability due to this placement likely resulted (Johnson et al., 2005). A better location would have been under the plastic, where the moisture levels would have been more controlled. However, reaching under the plastic to insert the probes may be difficult, and the plastic may need to be pulled up to some extent, causing extra hassle. It is important also that the probes get proper soil contact, and it is best not to compromise this contact.

The plots in this trial were not irrigated. Although there was substantial rainfall during the growing periods, many studies have shown the benefits of irrigation on blackcurrant yield (McCarthy and Stoker, 1988; Ostermann and Hansen, 1988; Hoppula and Salo, 2005). While Hunter River did have greater rainfall during most of the trial, much higher yields were found at Farmington, and it is more likely that lower yields at Hunter River were due to low bush growth. During the spring growing period, there were precipitation periods that should have provided ample water to the plants. However, it is not clear how the plastic affected moisture uptake. A trial in Nova Scotia found higher moisture levels under the black plastic than under bare soil or sod (unpublished). A trial with raspberries found that black plastic mulch increased shoot and root mass, and flower and berry numbers in the establishing year, but in subsequent years had little effect (Percival et al., 1998). By the second year of growth, the bushes should have root systems that extend beyond the mulch, allowing greater access to soil moisture beyond the mulch zone. However, PEI does have fairly sandy soils, and so even with high precipitation rates, the soil could dry fairly quickly. Drip irrigation under the plastic would not be a huge expense if greater yields could be achieved. However, nutrient leaching could be a concern with the irrigation, particularly in establishing years when N is needed to maximize plant growth (Percival et al., 1998).

While broadcasting amendments may be difficult with the black plastic mulch, fertigation could be used under the plastic. Fertigation has been found to give the best yields when combined with spring broadcast fertilizers (Nes et al., 2002). Future research could test organic fertilizers using fertigation under the plastic, possibly in combination with broadcasted amendments.

No significant interactions with deflowering and different fertility amendments were found. However, there were some trends noted that should be followed up with future research. In particular, the different effects on plant growth with the high spring amendment rate and deflowering compared with the other amendments were noted at one site. The effect on roots for this treatment would be particularly interesting to explore, as the relationship to shoot and root growth could be an important element in the lower shoot growths observed. Analyzing the plant fertility of these plants may give some clues as to the growth rates observed.

Trialing other types of mulches for weed control, in combination with irrigation or fertigation and their effects on soil and plant fertility would be useful. The optimal organic fertility amendments for blackcurrants also need to be studied to test plant performance and nutrient uptake for establishing plants. There are many opportunities to further explore the effects of fertility and deflowering on blackcurrants in Atlantic Canada.

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