The effect of municipal solid food waste compost amendment and fertigation adjustment on yield and fruit quality in strawberry plasticulture

Ben W. Thomas[1]

Final Report RRFB Nova Scotia

[1]School for Resource and Environmental Studies, Dalhousie University

December 23, 2011

Abstract

Municipal solid food waste (MSFW) compost is becoming increasingly available throughout Nova Scotia. However, little is understood about how to incorporate MSFW compost into food production systems. The objective of this experiment was to identify how MSFW compost amendment rate and fertigation adjustment affected yield and fruit quality parameters in a strawberry plasticulture. A strip plot randomized experimental design with three replications for each combination of treatment factors was used to measure the affect of MSFW compost amendment (0, 2.5, 5.0 and 10 Mg Fresh Weight [FW] ha^{-1}; Dry Matter [DM]: 48.3%) and fertigation rate (25, 50, 75 and 100% of the recommended rate). There were no statistically significant interactions between MSFW compost and fertigation rate on strawberry yield parameters. MSFW compost application led to a significant linear response in late season marketable yield (lin $P < 0.05$). Marketable yield had a significant linear response to fertigation rate in the late season (lin $P < 0.05$). Sugar content and berry mass were not significantly affected by any treatment factors. Total antioxidant capacity was significantly affected by an interaction between MSFW compost amendment and the low fertigation rate (lin $P < 0.01$). It is recommended that MSFW compost amendment is applied at 10 Mg FW ha^{-1}. Fertigation should be 25% of the recommended rate until September 1st or the fifth fruit harvest then increased to 100% of the recommended rate for the remainder of the season based on first season results. It is important to note, the 100% recommended rate is already reduced by 82% compared with rates used by other growers in the region. The new adjusted rate reduces the fertigation rate in the first year of production 47% compared with the 100% recommended rate of fertigation. Providing a net fertigation reduction of almost 90% compared with fertigation recommendations for no MSFW compost amendment in the first year of production.

Introduction

Currently the practice of incorporating MSFW compost into strawberry plasticulture in Nova Scotia occurs without knowledge of how the amendment interacts with fertigation rate. MSFW compost alone does not provide sufficient nutrient levels to maximize yield, so synthetic water-soluble fertilizer must be used to supplement the MSFW compost. Currently, 25 Mg FW ha^{-1} MSFW compost is applied, in combination with a rate of fertigation recommended by a Horticulturalist. However, little is understood about how MSFW compost affects soil quality and fertility. This may be leading to increased losses of nitrogen (N) to the environment, and decreased profitability for the producer. The purpose of this research was to help the producer identify how MSFW compost and fertigation rate affected yield and fruit quality parameters in the first year of a day-neutral strawberry plasticulture.

Strawberry production

Strawberry (*Fragaria* x *ananassa* Duch.) is a commonly consumed berry and is an important source of nutrition in the human diet (Tulipana *et al.*, 2008; Reganold *et al*., 2010). Strawberry is cultivated in every State in the United States and every Province of Canada (Small, 2009). The most important factors that influence strawberry production are yield and fruit quality that are most significantly affected by genotype, environment and argonomic practices (Wang *et al*., 2010). In Nova Scotia there are approximately 400 hectares in strawberry production with a farm gate value of $3.6 million (Statistics Canada, 2010; Statistics Canada, 2011). Although most producers in Nova Scotia grow June-bearing varieties, about 10% of production now involves day-neutral strawberry varieties (John Lewis, Personal Communication, 2011).

Day-neutral strawberry plants are insensitive to photoperiod which enables season-long flower bud initiation while temperatures remain suitable (Pritts & Handley, 1998). In northern areas day-neutrals can produce marketable fruit from June until October in the year of planting, compared to June-bearing varieties that produce from early-June to late-July in the second year after planting (Pritts & Handley, 1998; Khanizadeh *et al.*, 2006). Therefore, the nutrient demand of the day-neutral varieties differs from the typical June-bearing varieties because the duration of fruit production is extended. Although there are no day-neutral cultivars developed specifically for the North (Wang *et al*., 2010), in this experiment the day-neutral cultivar Albion was used. Albion was developed by the University of California strawberry breeding program, and was released to the market in 2004 (Shaw & Larson, 2008).

Plasticulture production

The plasticulture method of strawberry production has been shown to improve fruit yield, average fruit size, and plant growth compared to conventional matted-row production systems (Karhu *et al*., 2006; Kumar & Dey, 2011; Fan *et al.*, 2011). Hargreaves *et al*. (2008) studied the effects of MSFW compost tea, and MSFW compost on strawberry yield and fruit quality in a conventional matted-row strawberry production system and Fan *et al.*, (2011) evaluated the effect of plastic mulch and plastic mulch with row covers versus the conventional matted-row system on selected postharvest quality parameters in the June-bearing Orleans cultivar. However, no work has been completed in Nova Scotia on the effect of MSFW compost amendment and fertigation adjustment on yield and fruit quality parameters in a day-neutral strawberry plasticulture production system.

The plasticulture production system utilizes black polyethylene mulch and drip irrigation compared to the conventional matted-row system that uses straw mulch and surface irrigation. The polyethylene mulch conserves water, controls weeds, prevents nutrient leaching, advances crop maturity, increases yield, reduces insect and disease damages, and helps to keep the fruit clean (Karhu *et al*., 2006). Kumar and Dey (2011) found black polyethylene mulch significantly improved root growth and facilitated higher nutrient uptake, which led to enhanced plant growth and development in strawberry. Fan *et al.* (2011) found that strawberry fruit were significantly larger when grown with plastic mulch compared to the traditional matted-row system. Drip irrigation used in combination with black polyethylene mulch has been shown to increase yield 19%, reduce water-use efficiency by 51% compared to conventional surface irrigation (Kumar & Dey, 2011).

Municipal solid food waste compost

Nova Scotia has become a world leader in recycling and composting (Nova Scotia Environment, 2011). However, the legislation that mandated the composting of organic waste has led to an abundance of MSFW compost in the Province (Warman *et al*., 2011) In 2010, over 100,000 tonnes of organic waste was diverted from landfills and destined to composting facilities in Nova Scotia (Nova Scotia Environment, 2011). As more communities produce MSFW compost there is increased pressure to apply MSFW compost to agricultural land (Warman *et al*., 2009). The utilization of MSFW compost has been shown to have positive benefits, for the soil, the surrounding environment, and profitability of the producer (Hargreaves *et al*., 2008a). The application of MSFW compost is an important recycling opportunity for many communities (Hargreaves *et al*., 2009). However, more needs to be understood about how to integrate Nova Scotia MSFW compost into food production systems, because little is known about how it impacts soil fertility, quality and losses of excess nutrients to the environment (Radin &Warman, 2010).

Municipal solid waste compost is accepted as a soil amendment in crop production by the National Organic Standards Board in the United States, the Canadian Growers Standards Board in Canada (Radin &Warman, 2010) and is a permitted amendment by the Canadian Organic Standards (Warman *et al*., 2011). It has been found that a ratio of 50% soil and 50% compost combined with a 50% synthetic fertilizer rate produced statistically equivalent yields to 100% synthetic fertilizer in strawberry production systems (Wang & Lin, 2002). This is an important development because synthetic fertilizer costs have significantly increased since 2004 (Agriculture Statistic Service of the United States Department of Agriculture [AGSS USDA], 2011).

The use of less synthetic fertilizer with more reliance on MSFW compost has potential to improve the profitability and sustainability of strawberry production systems in Nova Scotia. Currently soils under intensive strawberry production may have reduced soil organic matter, and low biological activity because of fumigation practices required to disinfect the soil prior to planting (Mehdi Sharifi, Personal Communication, 2011). In addition to supplying plant-available nutrients (Whalen *et al*., 2008), MSFW compost increases soil organic matter, improves water retention, enhances soil structure, recovers cation-exchange capacity, improves pH, and ultimately improves the sustainability of the foundation of the food production system – the soil (Hargreaves *et al*., 2008a).

Nitrous oxide emissions from the use of synthetic N fertilizer contribute to agricultures 30-35% share of global greenhouse gas emissions (Foley *et al*., 2011). Furthermore, synthetic N production is fossil fuel intensive. The Haber–Bosch process of N synthesis requires temperatures of 500 ˚ C, pressure of 300 atmospheres, and is highly reliant on fossil fuel for a supply of hydrogen (Berg *et al*., 2007). This process is energy intensive, and accounts for one-third of the global energy budget for agriculture (Martin, 2011). By utilizing compost, N can be recycled, reducing unnecessary N synthesis, which can help reduce the energy demand of strawberry production systems in Nova Scotia.

Nova Scotia agriculture has unique soil and climate challenges

In Nova Scotia, the humid environment, rolling topography, and the shallow, light textured soils of the region significantly increase the risk of nutrient loss to the environment when synthetic fertilizers are used (Sharifi *et al.*, 2010). It is estimated that only 30-50% of applied synthetic N (Smil, 1999; Cassman *et al*., 2002) and 15-30% of synthetic phosphorous (P) is taken up by crops (Cordell *et al*., 2009). Nitrogen is usually lost by leaching into watercourses as nitrate (NO_3^-), and volatilization into the atmosphere as ammonia (NH_3) and nitrous oxide (NO_2) (Hansen *et al.* , 2001; Tilman *et al*., 2002; Velthof *et al.*, 2009); whereas, P has the tendency to accumulate in soils in unavailable forms (Schmit & Knoblauch, 1995; Zhang *et al*, 1995; Beegle *et al*., 2000).

Compost is less likely to lose nutrients to the environment compared with synthetic fertilizer (Reganold *et al*., 1990). Hargreaves *et al.* (2008a) report that MSWF compost supplies adequate P for food production systems. This is important because phosphate rock prices increased 700% between 2007 and 2008 (Elser & Bennett, 2011), and there is a looming phosphorous shortage (Cordell *et al*., 2009; Vaccari, 2009). With phosphate rock reserves approaching peril, and synthetic N requiring significant fossil fuel input (Berg *et al*., 2007; Cordell *et al*., 2009; Vaccari, 2009), the recycling of nutrients is important to maintain input costs, improve soil quality parameters, and reduce dependence on fossil fuel.

Nutrient recycling has been identified as one strategy to restore the quality and productivity of degraded soils and ecosystems in food production systems. Other strategies include: (i) enhancing soil organic matter, (ii) improving soil structure, (iii) conserving water in the root zone, (iv) creating positive C and nutrient budgets, and (v) improving soil biology (Lal, 2009). MSFW compost has been shown to positively contribute to all of the above strategies to restore soil quality and the environment in agriculture (Hargreaves *et al*., 2008a).

Fruit quality

Strawberry fruit is a good source of antioxidants (Khanizadeh *et al.*, 2006; Tulipani *et al*., 2008; Fan *et al.*, 2011). According to Szeto *et al*. (2002), strawberries have higher antioxidant capacity than many other fruit, such as green apples, red apples, pears, kiwis, oranges and mangoes. It is thought genotype and environmental conditions most affect antioxidant capacity in strawberry

(Khanizadeh *et al.*, 2006). Currently, there are conflicting studies in regards to the effect of organic practices on antioxidant capacity in strawberries.

A greenhouse study conducted by Wang and Lin (2002) reported increased fruit quality parameters with the use of compost, but a later field study in Nova Scotia by Hargreaves *et al*. (2008b) found that compost amendment did not significantly increase antioxidant capacity or sugar content compared to conventional production practices. Although a more recent study in California found organically produced strawberries had significantly higher total antioxidant activity than conventional berries (Reganold *et al*., 2010). There is no strong evidence to suggest organic foods are more nutritious (Reganold *et al*., 2010). Winter and Davis, (2006), as cited in, Hargreaves *et al.* (2008b) report a hypothesis to explain why organically grown food may have higher antioxidant activity than conventionally grown food. They propose that a reduction in pesticide application results in plants that are subject to more attacks from insects, weeds and plant pathogens. This triggers the plant's defence metabolism which increases the concentration of secondary plant metabolites such as antioxidants in the plant tissues. However, in subsequent research conducted by Hargreaves *et al*. (2008b) with Nova Scotia's MSFW compost and compost tea no significant difference was found between the antioxidant capacity in conventionally grown and organically grown strawberry fruit using a ferric reducing antioxidant power (FRAP) assay. Other research conducted by Olsson *et al*. (2006) found that strawberries grown organically had increased antioxidant capacity compared to conventionally grown strawberries. Wang *et al*. (2007) speculate that compost induces physical and chemical changes in soil that increase beneficial microbial activity, enhance nutrient availability, and nutrient uptake leading to high levels of antioxidant activity. Soils with high soil organic matter (SOM) are expected to have larger microbial populations and activity (St. Luce *et al.,* 2011) which has been linked to higher rates of N-mineralization (Sharifi *et al*., 2008).

The FRAP assay is a method that is currently used to measure total antioxidant capacity by measuring the potential of antioxidants in a sample to reduce ferric iron (Fe (III)) to ferrous iron (Fe (II)) (Benzie & Strain, 1996; Ou *et al*., 2002). Measuring the total antioxidant capacity versus single compounds known to have antioxidant activity, such as vitamin C, is important because antioxidants are thought to act synergistically. Therefore, measuring total antioxidant capacity may be more representative of the nutritional benefit of strawberries (Kahkonen *et al*., 2001).

Sugar content analysis is also used as a fruit quality parameter in strawberry (Wang & Lin, 2002; Hargreaves *et al*., 2008). Hargreaves *et al*. (2008) reported that MSFW compost and compost tea did not affect sugar content of strawberry fruit compared to synthetic fertilizer application. According to Haynes & Goh (1987) and Nestby (1998), sugar content was found to increase with N application and was correlated with increased leaf N. Hargreaves *et al*. (2008a) did not find a correlation between leaf N and sugar content. Weather conditions may have the greatest impact on fruit quality. As found by Daugaard (2001), the sugar to organic acid ratio in strawberry fruit that developed during overcast conditions was lower than in fruit that developed in sunny conditions.

Nitrogen dynamics in strawberry production

Although MSFW compost has been shown to positively affect soil quality parameters little is understood about how MSFW compost affects soil fertility (Radin & Warman, 2010). According to St. Luce *et al.* (2011), understanding crop-N availability is an important factor for improving fertilizer-use efficiency, and minimizing adverse impacts of N losses to the environment. Currently, it is accepted that the application of MSFW compost does not provide sufficient N to meet the demand of most crops. Therefore, to maximize yield, MSFW compost amendment must be combined with synthetic fertilizer application to meet crop-N demand (Hargreaves *et al*., 2009), as N is the most important nutrient taken up by strawberry plants (Taghavi *et al.*, 2004).

The combination of MSFW compost and fertilizer may lead to over-fertilization. The application of excessive N can lead to fruit softening and excessive vegetative growth (Dale & Pritts, 1998) and contribute to an adverse cascade of environmental impacts (Canfield *et al*., 2010). The timing of N fertilization to meet crop demand is a fundamental component of improving N-use efficiency (Sharifi *et al.*, 2007). Lieten and Misotten (1993) found that NO_3-N uptake increased from planting to fruit harvest, with rates of uptake notably high between the start of harvest and the end of harvest. Knowledge of crop nutrient demand is critical to ensure precise application of nutrients, especially in fertigation systems (Tagliavini *et al*., 2005).

There are conflicting in-field studies on the effects of increasing N application rates on strawberry fruit yield (Darnell & Stutte, 2001). Lamarre and Saxena (1994) found that there was no increase in yield as rates of N increased from 0 kg ha^{-1} to 180 kg ha^{-1}, whereas Albregts and Howard (1986) found significant increases in yield in that range.

Objectives

The first objective of this study is to investigate how rate of MSFW compost amendment and fertigation affect fruit yield parameters (marketable, unmarketable and biological - marketable + unmarketable), in a strawberry plasticulture production system. The second objective is to investigate how MSFW compost amendment and fertigation adjustment affect fruit quality parameters – average marketable fruit mass, sugar content and total antioxidant capacity. The third objective is to evaluate how MSFW compost amendment and fertigation adjustment affect soil mineral N levels and leaf N values at the midseason compared with the pre-planting baseline.

Materials and Method

The experiment was established at Dykeview Farms located in Kingston, NS. The layout of the experiment was a Strip Plot Design with 2 treatment factors and three replications. Replications were separated into 3 blocks as shown in Figure 1 to reduce the impact of in-field variation. Treatments consisted of four rates of MSFW compost amendment (0, 2.5, 5.0 and 10 Mg ha^{-1} FW) and four rates of fertigation (25, 50, 75 and 100% of the recommended rate).

Figure 1. Field layout of the treatments.

Rep	Fertigate MSFW	100% eUnit	25% eUnit	75% eUnit	50% eUnit
1	2.5 Mg/ha	13	9	5	1
1	10Mg/ha	14	10	6	2
1	0 Mg/ha	15	11	7	3
1	5.0 Mg/ha	16	12	8	4
2	10Mg/ha	29	25	21	17
2	5.0 Mg/ha	30	26	22	18
2	2.5 Mg/ha	31	27	23	19
2	0 Mg/ha	32	28	24	20
3	0 Mg/ha	45	41	37	33
3	2.5 Mg/ha	46	42	38	34
3	5 Mg/ha	47	43	39	35
3	10 Mg/ha	48	44	40	36

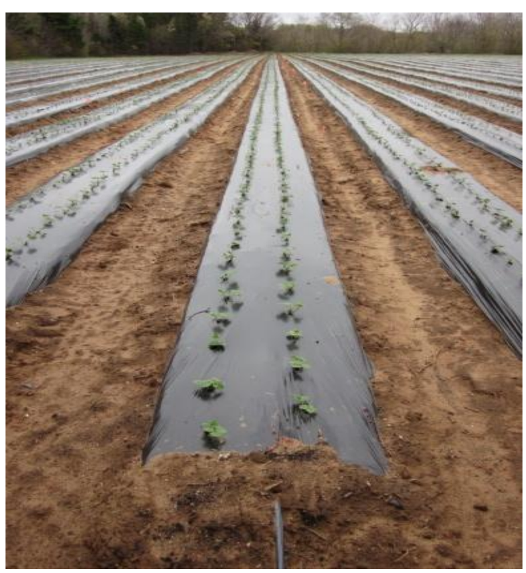
The 100% recommended rate of fertigation as shown in Table 1 was developed using soil test results and strawberry nutrient requirements based on a 25 Mg FW ha^{-1} compost amendment.

Table 1. Monthly fertigation based on 100%, 75%, 50% and 25%, and no compost rates with total monthly potassium nitrate (KNO_3) and total seasonal mineral N for each rate.

	100% rate ($kg\ ha^{-1}$)		**75% rate ($kg\ ha^{-1}$)**		**50% rate ($kg\ ha^{-1}$)**		**25% rate ($kg\ ha^{-1}$)**		**No compost ($kg\ ha^{-1}$)**
Month	Total KNO_3	Mineral N	Total KNO_3	Mineral N	Total KNO_3	Mineral N	Total KNO_3	Mineral N	Mineral N
April	6.1	0.8	4.5	0.6	3.0	0.4	1.5	0.2	6.3
May	30.3	4.2	22.7	3.1	15.2	2.1	7.6	1.0	15.7
June	30.1	4.1	22.6	3.1	15.0	2.1	7.5	1.0	15.7
July	52.8	7.3	39.6	5.4	26.4	3.6	13.2	1.8	22.0
August	52.8	7.3	39.6	5.4	26.4	3.6	13.2	1.8	31.4
September	52.8	7.3	39.6	5.4	26.4	3.6	13.2	1.8	22.0
October	18.2	2.5	13.6	1.9	9.1	1.3	4.5	0.6	18.9
Total	243.0	33.4	182.2	25.1	121.5	16.7	60.7	8.4	132.0

Plot dimensions were 4.0 m x 4.8 m. Each plot consisted of three flat hills (75cm wide and 10cm high) and there were two strawberry rows 30cm apart on each hill. The space between strawberry plants in the row was 28cm. Two guard rows were located on each side of the fertigation data rows as shown in Figure 2. Each plot had 24 strawberry plants used for data collection, with 8 strawberry plants acting as a buffer between each rate of compost amendment in each fertigation row.

Figure 2. A data collection row (center) with two guard rows on each side.



Municipal solid food waste compost was obtained from Northridge Farms in Aylesford, Nova Scotia. In early April 2011 compost was shallowly incorporated into the raised beds using a cultivator. Three fresh composite samples were collected from the MSFW compost and analyzed for dry matter, pH, carbon (C), and nutrient concentrations as shown in Table 2. The strawberry plants were transplanted April 15, 2011. The fertigation program started in April 2011 using water-soluble fertilizers through drip irrigation and continued throughout the summer until October 2011.

Table 2. Chemical composition of Northridge Farms MSFW compost.

Nutrient	Unit	MSFW
DM	%	43.8
pH	-	7.8
N	%	2.54
P	%	0.79
K	%	0.37
Ca	%	4.64
Mg	%	0.31
S	%	0.57
Cu	ppm	56.87
Fe	ppm	5130
Mn	ppm	349.16
Zn	ppm	186.74
B	ppm	26.85
C	%	26.4
C:N	-	10.4

Soil Sampling

Composite soil samples (eight auger samples with 2.5cm diameter; 0-30 cm depth) were collected from each plot before compost application on March 31, 2011 (Pre-planting), and were collected again July 4, 2011 (Midseason). Soil samples were divided into two equal parts. One sample was dried, and one remained fresh at 0 ˚C. The soil samples were analyzed for fertility parameters including pH, and mineral-N (NO_3^- and NH_4^+).

Mineral N was measured by extracting 5 g fresh weight soil with 50 mL 2 *M* potassium chloride (KCl) extractant in 100 mL French bottles. The soil-KCl mixture was then mechanically shaken for 30 minutes. Aliquots were made by filtering the KCl-soil mixture through #41 Whatman filter papers into 20 mL nalgene bottles. The samples were then sent to Nova Scotia Agricultural College for analysis using an Elementar VarioMAX CN analyzer made by Elementar Analysensysteme GmbH. For each plot's soil sample, a 5 g soil subsample was measured into a tin and placed in an oven for 48 hrs at 105 ˚C for % moisture calculation.

The bulk density for each plot was calculated by block and compost amendment rate (1 bulk density sample for each compost treatment rate in each block) using a slide hammer sampler (5cm diameter). The bulk density data was used for conversion of C and N concentration units from mg L^{-1} to kg ha^{-1}. Bulk density soil samples were laid to dry, and sieved using a 2 mm screen. The mass of stones greater than 2 mm diameter was measured and so was the mass of the dry soil passing through the 2 mm sieve for the bulk density calculation and correction.

Leaf Sampling

Twenty-five daughter (new) strawberry leaves from each plot were sampled July 4, 2011. The leaves were dried for 48 hrs at 65°C and ground using a Wiley Mill with a 1mm sieve. The ground leaves were then mixed well and 20 mL composite samples were made and analysed for C and N % using a CN analyzer.

Fruit Sampling

At each harvest, ripe fruits were collected from the 24 strawberry plants of each plot according to commercial standards described by the producer. Fruit harvest began July 29, 2011, and continued until October 12, 2011 – a period of approximately 11 weeks. During peak season, harvests were conducted twice weekly, and for the remainder of the season harvests were conducted weekly. For each plot, the fruit were separated into marketable and unmarketable fractions based on the marketability recommendations of the producer. The marketable and unmarketable fruit masses were measured for each plot, and converted from g/24 plants to kg ha^{-1} based on the current planting practice of 38, 400 strawberry plants ha^{-1}. The number of marketable fruit was counted during each harvest for each plot so that average marketable fruit mass could be calculated.

Hargreaves *et al*. (2008b) found that antioxidant capacity was not affected by compost amendment in strawberry. Consequently, for preliminary investigation, antioxidant analysis was conducted on all 0 Mg FW ha^{-1} and 10 Mg FW ha^{-1} MSFW compost treatments (24 plots). For antioxidant analysis 24 - 200 g fresh weight composite fruit samples were created using 2 – 100 g samples per plot from two harvests. The fruit were frozen at - 80°C until analysis. Total antioxidant activity was measured using FRAP assays. A 50 g composite fruit sample was blended in 150 mL methanol for 45 seconds, and the aliquot was topped to 250 mL using the methanol to rinse residual in the blender. The solution was filtered into a volumetric flask through 6 layers of cheese cloth. 50 mL aliquots were prepared, and centrifuged at 6000 RPM for 10 minutes, then 25 mL aliquots were collected from the supernatant for 3 replications $plot^{-1}$ of FRAP analysis.

The sugar content of the fruit was determined by selecting 10 consistent fruit from each plot during a peak season harvest. The fruit were sliced in half and a small amount of juice was squeezed uniformly onto the lens of a refractometer, and the Brix value (% sugar) was recorded.

Composite samples of fruit for C and N analysis were made using 4 - 100 g fresh weight fruit samples collected over 4 harvests. The fruit were sliced, and dried at 65°C for 48 hrs for further analysis.

Statistical Analysis

A strip plot design was used with fertigation crossed with 3 blocks of MSFW compost. The fertigation was randomized to the strips that ran north south while the MSFW compost was randomized within the blocks that ran east west in rows. The treatment factors were defined as four fertigation rates (25, 50, 75, and 100%) and four MSFW compost amendment rates (0, 2.5, 5.0, and 10 Mg FW ha^{-1}). An ANOVA was used to analyze differences between the treatments while differences within a treatment were evaluated using orthogonal polynomials (linear and quadratic responses). Harvesting occurred over a number of dates so a repeated measures analysis was completed for yield and weight parameters for early, mid and late season. The harvest seasons were defined as early (Jul 29 – Aug 18), mid (Aug 9 – Sep 9) and late (Sep 10 – Oct 12). Large residuals were removed to follow limits of ANOVA for normal distribution and significant was accepted at a < 0.1 probability level. The 50% fertigation row was compromised during the experiment, which resulted in the elimination of the treatment factor from the data set.

Results and Discussion

Soil

The March 31, 2011 soil test indicated the 25% fertigation row started the experiment with a statistically significant lower mineral-N mostly as NH_4-N compared with the 75% and 100% fertigation rows. There was no significant difference between the 75% and 100% fertigation rows. Also there was a statistically significant higher concentration of NH_4-N compared with NO_3-N in the soil of all treatments March 31, 2011 (Grand Means NH_4-N 19.49 kg ha^{-1} vs NO_3-N 2.355 kg ha^{-1}). This result was to be expected as much of the NO_3-N that remained in the soil over the winter would have leached due to high susceptibility of NO_3-N to over-winter leaching (St. Luce *et al*., 2011). Whereas NH_4-N is more resistant to leaching (St. Luce *et al*., 2011), and remained bound on the soils exchange sites.

The July 4, 2011 soil test indicated that the 25% fertigation row continued to have significantly less total mineral-N compared to the 75 and 100% fertigation, but no significant difference was detected between the 75 and 100 % fertigation treatments. In all treatments the most dominate form of mineral-N changed from NH_4-N to NO_3-N from preplant to midseason. Under humid temperate conditions, NH_4-N remaining in the soil would be quickly converted to NO_3-N through nitrification by chemoautotrophic microorganisms (Whalen & Sampedro, 2010). This may partially explain, the reversal in the mineral N composition, along with plant-uptake of NH_4-N (Taghavi, 2004), and the fertigation with KNO_3.

Plant

The July 4, 2011 leaf sampling indicated that all treatments were in the sufficiency range for N% for the beginning of the flowering cycle. The sufficiency range for leaf N is 2.0-2.8% in strawberries at midseason. Leaf N below 2.0% is considered to be deficient (Pritts & Handley, 1998; Hancock, 1999) but levels at 2.0% have been shown not to limit photosynthesis (Darnell & Stutte, 2001).

Fruit Yield

Biological yield

Total biological yield was not significantly affected by interaction between treatments as shown in Table 3, or by MSFW compost rate.

Table 3. MSFW compost rate and fertigation rate interaction affect on yield and total N uptake by strawberry fruit

Treatment		**Yield**			**Total N Uptake**
Compost (Mg ha^{-1})	**Fertigation (%)**	**Total Marketable (Mg ha^{-1})**	**Total Unmarketable (Mg ha^{-1})**	**Total Biological (Mg ha^{-1})**	**Fruit (kg ha^{-1})**
0	25	19.3	7.65	27.0	24
0	75	20.3	9.50	29.8	27
0	100	20.5	10.2	30.8	27
2.5	25	19.3	9.03	28.3	25
2.5	75	19.8	9.08	28.8	26
2.5	100	19.0	10.1	29.2	26
5	25	19.5	8.68	28.2	25
5	75	20.1	9.68	29.8	27
5	100	21.4	10.3	31.7	28
10	25	18.5	8.87	27.4	24
10	75	20.3	10.0	30.3	27
10	100	19.9	10.2	30.1	27
P Value		> 0.1	> 0.1	> 0.1	> 0.1

* N uptake based on an average of 8 N uptake % in strawberry fruit found by Wang and Lin (2002). Average N uptake = 0.89% Dry Matter. Adjusted for moisture content of 90%.

The fruit N uptake accounts for significantly more N than was applied through synthetic fertilizer. At the 25% rate of fertigation, only 8.4 kg ha^{-1} N was added to the soil. This indicates that the 25% with 0 Mg ha^{-1} MSFW compost treatment provided almost three times more N than was made available by fertigation for plant uptake. It is important to note that that these numbers do not account for total N uptake by other plant organs. So it is quite likely, the soil provided more mineral N than what is accounted for in the fruit. This highlights the importance of understanding N sources found in soil, as recommended by St Luce *et al*., (2011) and Sharifi *et al*., (2007).

Fertigation rate had a significant linear effect (*P* Value < 0.01) on total biological yield. The 100% fertigation rate had a biological yield 9.7 and 2.4% higher than the 25 and 75% fertigation rates respectively as shown in Table 4. The increase in biological yield is largely the result of significant differences in total unmarketable yield and as fertigation rate increased because there was no significant difference in total marketable yield caused by fertigation rate.

Table 4. Marketable, unmarketable and biological (marketable + unmarketable) mean yields (Mg ha^{-1}) of 25%, 75% and 100% fertigation rates.

	Yield (Mg ha^{-1})		
Treatment	**Marketable**	**Unmarketable**	**Biological**
25%	19.144	8.558	27.702
75%	20.109	9.576	29.686
100%	20.213	10.205	30.417
P Value	> 0.1	0.011	0.010
lin - *P* Value	> 0.1	0.004	0.004

Marketable yield

There was no significant interaction between treatments. As shown in Table 4 the 5.0 Mg FW ha^{-1} MSFW compost amendment with 100% fertigation had the highest numerical marketable yield of 21.4 ton ha^{-1} but the result was not statistically significant. Fertigation rate did not affect total marketable yield, but did significantly affect late season marketable yield (*P* Value < 0.1) which was attributed to a statistically significant linear response to fertigation rate (lin *P* Value < 0.05). This suggests that in October when fertigation rates were reduced by 34% (Table 1), yield decreased more in response to the 25% than the 75 and 100% fertigation rates as shown in Table 5. The 100% fertigation rate had late season marketable yields that were 23% larger than the average of 25 and 75% fertigation rates. The 5.0 Mg FW ha^{-1} MSFW compost rate had the highest total season marketable yields compared to the other compost amendments, but the differences between compost amendment rates were not significant. However, late season marketable yield was significantly affected by compost treatment rate as shown in Table 6. The 10 Mg FW ha^{-1} MSFW compost rate had 10% higher yields in the late season compared with the other MSFW rates.

Table 5. Seasonal marketable mean yields (Mg ha^{-1}) for 25, 75 and 100% fertigation rates.

	Seasonal Marketable Yield (Mg ha^{-1})			Total Marketable
Treatment	**Early**	**Mid**	**Late**	**(Mg ha^{-1})**
25%	6.27	8.60	4.28	19.1
75%	6.09	9.48	4.55	20.1
100%	5.98	8.79	5.44	20.2
P Value	> 0.1	> 0.1	0.055	> 0.1
lin - *P* Value	> 0.1	> 0.1	0.034	> 0.1

Table 6. Seasonal marketable mean yields (Mg ha^{-1}) for 0, 2.5, 5.0 and 10 Mg FW ha^{-1} MSFW compost amendment rates.

	Seasonal Marketable Yield (Mg ha^{-1})			Total Marketable
Treatment (Mg ha^{-1})	**Early**	**Mid**	**Late**	**(Mg ha^{-1})**
0	6.45	9.11	4.50	20.1
2.5	5.94	8.64	4.79	19.4
5	6.38	9.31	4.63	20.3
10	5.67	8.77	5.11	19.5
P Value	> 0.1	> 0.1	0.007	> 0.1
lin - *P* Value	> 0.1	> 0.1	0.002	> 0.1

The late season marketable yield response to MSFW compost amendment rate is difficult to conclusively rationalize based on parameters measured in this experiment. One explanation for the yield response to compost amendment rate may be that the calcium (Ca) levels in the compost influenced the strength of the fruit cell walls. The chemical analysis of the MSFW compost indicated 4.64 % Ca FW. Pritts and Handley (1998) report Ca has been shown to be an important element in the stability of cell walls, and Singh *et al*. (2007) found Ca application resulted in higher fruit firmness and decreased incidence of grey mould in strawberry fruit. There is potential that the MSFW compost is providing a non-nutrient effect in the late season, and more study is needed to verify this.

Unmarketable yield

Unmarketable yields increased from early to late season, but there was no significant interaction between treatments, or the compost amendment rate. Unmarketable yield was significantly affected by fertigation rate as shown in Table 7. As fertigation increased, so did unmarketable yield. The unmarketable fractions of fruit yield for the 75% and 100% fertigation rates were 10.6% and 16.1% greater than the 25% fertigation rate with a statistically significant linear relationship (*P* Value < 0.01).

Table 7. Seasonal unmarketable mean yields (Mg ha^{-1}) for 25%, 75% and 100% fertigation rates.

	Seasonal Unmarketable Yield (Mg ha^{-1})			Total Unmarketable
Treatment	**Early**	**Mid**	**Late**	**(Mgha^{-1})**
25%	0.96	1.67	5.93	8.56
75%	0.88	1.88	6.81	9.58
100%	0.94	1.91	7.36	10.2
P Value	> 0.1	> 0.1	0.020	0.011
lin - *P* Value	> 0.1	> 0.1	0.008	0.004

A contributing factor to increased unmarketable yields in high fertigation rates may relate to excessive N causing fruit softness as reported by Dale and Pritts (1989), which could be leading to greater fruit damage during rain and wind events. Excessive N may not fully account for the significant difference in unmarketable fruit mass as fertigation rate increases. The producer may be able to harvest a greater fraction of the experimental unmarketable yield as marketable yield by having greater control over harvest timing. In some cases, an extreme weather event such as a hurricane can render 90% of fruit unmarketable (Rolf Meier, Personal Communication, 2011). By timing the harvest before such an event, the producer may achieve a greater proportion of marketable fruit. If the unmarketable fractions of yield reported are representative of what the producer would harvest, it should be of concern because unnecessary labour is spent harvesting unmarketable fruit. It is likely that late in the season, marketable yields decrease as environmental conditions become less conducive to plant vigour. This may coincide with when cv. Albion produces the majority of its biological yield, resulting in significant increases of the unmarketable yield fraction.

Fruit Quality

Average berry mass and sugar content

There was no significant difference in berry size between treatments nor was there an interaction between treatments. The Brix values (sugar content) ranged from 7.0 to 7.7%. There was no significant effect caused by treatment or interaction between treatments. Hargreaves *et al.* (2008) reported similar findings with Brix values ranging from 5.8 to 8.8% over two years of study that found MSFW compost and MSFW compost tea did not affect sugar content in strawberry.

Total antioxidant capacity

Total antioxidant capacity results showed that compost amendment rate significantly interacted with fertigation rate (*P* Value < 0.01). The significant linear interaction (*P* Value <0.01) is most apparent in the 25% fertigation rate between the 0 Mg FW ha^{-1} and 10 Mg FW ha^{-1} MSFW compost amendment as seen in Table 6.

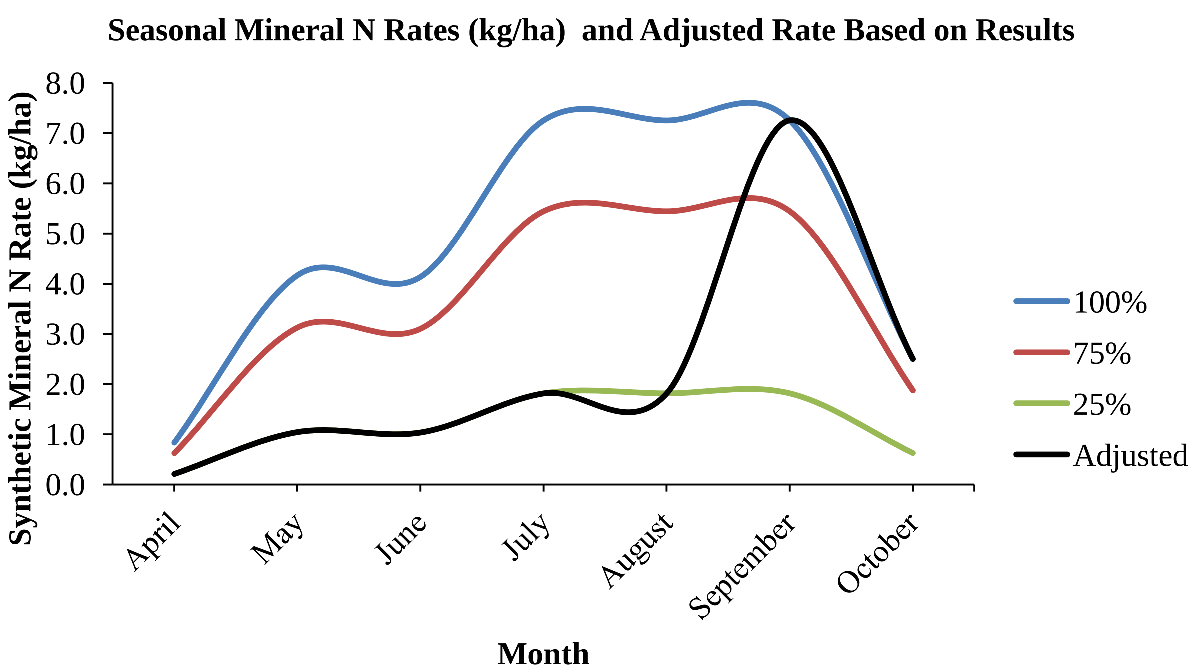
Table 6. Total antioxidant capacity (TAC) measured using the FRAP assay, and expressed as Trolox equivalents per gram of fresh weight of strawberries. Treatments included are the 25%, 75% and 100% rates of fertigation with 0 and 10 Mg FW ha^{-1} MSFW compost amendments.

Treatment		
Compost (Mg ha^{-1})	**Fertigation (%)**	**TAC (µ mole TE/g FW)**
0	25	9.60
0	75	10.8
0	100	11.2
10	25	10.9
10	75	10.9
10	100	10.6
P Value		0.007819
lin - *P* Value		0.003036

The increase in antioxidant activity at the low fertigation rate suggests that total antioxidant capacity was affected by nutrient supply as proposed by Wang *et al*. (2007). Our results are in the high end of the ranges found by Khanizadeh *et al*. (2006) who found day-neutral total antioxidant capacity to range from 0.3 to13.2 µmol TE g^{-1} FW.

Based on the results it is suggested that the fertigation rate is reduced to 25% until September 1, or the fifth week of fruit harvest, whichever occurs first - as shown in Figure 3. This will allow approximately two-weeks for the strawberry plants to adjust to the increased 100% fertigation rate that occurs at this time. The 100% fertigation rate should be continued for the rest of the season at regularly scheduled intervals because the 100% fertigation rate led to a 23% increase in marketable yield compared to the 25% and 75% fertigation rate in the late season (Sept. 10 – Oct. 12). Sharifi *et al*., (2007) emphasized the importance of matching nutrient supply to crop demand. Based on our results, the fertigation rates can be adjusted to more effectively match crop demand so that less N is lost to the environment, which also results in reduced input costs for the producer.

Figure 3. Seasonal mineral N rates (kg/ha) based on 25, 75, 100% fertigation rates and an adjusted fertigation rate based on first year results.



Municipal solid food waste compost is currently applied at a rate of 25 Mg FW ha^{-1}. This study has indicated that at high rates of compost amendment there lacks a total marketable yield response. Therefore, it is not efficacious to apply more compost than required. Until the second year of this study is complete, an accurate recommendation for changes to the compost amendment rate cannot be conclusively made. However, it appears the current practice of applying 25 Mg FW ha^{-1} MSFW compost is too high, and it can be reduced to 10 Mg FW ha^{-1} MSFW compost based on first year findings. However, the effects of MSFW compost on soil quality parameters have not been conducted yet, and yield will be measured in the second year of production to identify which compost rate is most suitable for the entire life cycle of the production system.

Although preliminary results have shown that compost amendment most significantly affects total antioxidant capacity at low fertigation rates, this was less evident as fertigation rate increased. Therefore, it should be expected that reducing fertigation rates in the early part of the season should not significantly impact antioxidant content in strawberries as long as compost amendment is applied to supplement nutrient supply.

Conclusion

It is recommended based on first year results of yield and fruit quality parameters that fertigation rates be reduced to 25% of the recommended rate until September 1, or the fifth week of fruit harvest, whichever occurs first. The 25% fertigation rate should be used until September 1 because there was no statistical difference between fertigation rates until late in the season. Thereafter, fertigation should be increased to the 100% rate, because in the late season (Sept. 10 – Oct. 12) marketable yield significantly increased 23% compared to the average of 25 and 75% fertigation rates. Although compost recommendation cannot be conclusively recommended until the second year of the study is complete. The compost amendment rate should be 10 Mg FW ha^{-1} based on first year results because it led to a significant 10% increase in late season marketable yield compared to the average of lower rates of compost amendment. It may be probable that low rates of compost amendment do not supply sufficient nutrient and non-nutrient effects in the second year of growth, as indicated by the late season trend between marketable yield and MSFW compost amendment rate. Total antioxidant capacity was significantly affected at 25% fertigation and no compost treatment. However, as compost amendment is recommended to be applied at the high experimental rate TAC should not be significantly affected by a reduction of fertigation in the early and mid season. As the 10 Mg FW ha^{-1} and 25% fertigation rate produced statistically equivalent TAC compared to the 75 and 100% fertigation rates at 10 Mg FW ha^{-1} MSFW compost amendment rate.

Acknowledgment

I would like to thank RRFB Nova Scotia for the funding and enabling this project to realize its full potential. I would also like to thank Dr. Mehdi Sharifi for providing me the opportunity to complete this project. I am thankful for the technical support provided by Kristie Mahoney, Ravinder Pannu, John Thomson, Alex Taul, Drucie Janes, Carolyn Marshal, Sherry Fillmore, Bradley Walker, and Kyle Gallant. The FRAP assay was performed in Dr. Vasantha Rupasinghe's Fruit Quality Laboratory. I appreciate Dr. Vasantha Rupasinghe's support. Funding for this research was provided by RRFB student grant and Technology Development Program 2000 of NSDA.

References

Albergts, E.E., & Howard, C.M. (1986). Response of strawberries to soil and foliar fertilizer rates. *HortScience*, 21, 1140-1142.

Beegle, D.B., Carton, O.T., & Bailey, J.S. (2000). Nutrient management planning: Justification, theory, practice. *Journal of Environmental Quality*, *29*, 72-79.

Benzie, I.F.F., & Strain, J.J. (1996). The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": The FRAP assay. *Analytical Biochemistry*, 239, 70-76.

Berg, J.M., Stryer, L., & Tymoczko, J.L. (2007). *Biochemistry* (6th ed.). New York: W.H. Freeman.

Canfield, D.E., Glazer, A.N. & Falkowski, P.G. (2010). The evolution and future of Earth's nitrogen cycle. *Science, 331*, 192-196. doi:10.1126/science.1186120.

Cassman, K. G., Dobermann, A. & Walters, D. (2002). Agroecosystems, nitrogen-use efficiency, and nitrogen management. *AMBIO, 2*, 132-140.

Cordell, D., Drangert, J., & White, S. (2009). The story of phosphorus: Global food security and food for thought. *Global Environmental Change*, *19*(2), 292-305. doi:10.1016/j.gloenvcha.2008.10.009

Dale, A. & Pritts, M. (1989). *Dayneutral strawberries*. Ontario Ministry of Agriculture. Retrieved May 10, 2011, from http://www.omafra.gov.on.ca/english/crops/facts/89-099.htm

Darnell, R.L., & Stutte, G.W. (2001). Nitrate concentration effects on NO3-N uptake and reduction, growth and fruit yield in strawberry. *Journal of the American Scoeity for the Horticultural Sciences*, 125(5), 560-563.

Daugaard, H. (2001). Nutritional status of strawberry cultivars in organic production. *Journal of Plant Nutrition*, 24, 1337-1346.

Elser, J. & Bennet, E. (2011). A broken biogeochemical cycle. *Nature*, 478, 29-31.

Fan L., Yu, C., Fang, C., Zhang, M., Ranien, M., Dube, C. & Khanizadeh, S. (2011). The effect of three production systems on the postharvest quality and phytochemical composition of Orleans strawberry. *Canadian Journal of Plant Science*, 91, 403-409.

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M. ... Zaks, D.P.M. (2011). Solutions for a cultivated planet. *Nature*, 000, 1-6. doi:10:1038/nature10452.

Hancock, J.F. (1999). *Strawberries*. Cambridge: CABI Publishing.

Hansen, B., Alroe, H.F. & Kristensen, E.S. (2001). Approaches to assess the environmental impact of organic farming with particular regard to Denmark. *Agriculture, Ecosystems & Environment*, 83, 11-26.

Hargreaves, J.C, Adl, M.S., Warman, P.R., & Rupasinghe, H.P.V. (2008b). The effects of organic and conventional nutrient amendments on strawberry cultivation: Fruit yield and quality. *Journal of the Science of Food and Agriculture*, 88, 2669-2675.

Hargreaves, J.C., Adl, M.S., & Warman P.R. (2008a). A review of the use of composted municipal solid waste in agriculture. *Agriculture, Ecosystems and Environment*, *123*, 1-14.

Hargreaves, J.C., Adl, M.S., & Warman, P.R. (2009). The effects of municipal solid waste compost and compost tea on mineral element uptake and fruit quality of strawberries. *Compost Science and Utilization, 17*, 85-94.

Haynes, R.J. & Goh, K.M. (1987). Effects of nitrogen and potassium applications on strawberry growth, yield and quality. *Communications in Soil Science and Plant Analysis*, 18, 457-471.

Kahkonen, M.P., Hopia, A.I., & Heinonen, M. (2001). Berry phenolics and their antioxidant activity. *Journal of Agricultural and Food Chemistry*, 49, 4076-4082.

Karhu, S.T., Puranen, R. & Aflatuni, A. (2006). White mulch and south facing position favour strawberry growth and quality in high latitude tunnel cultivation. *Canadian Journal of Plant Science*, 87, 317-325.

Khanizadeh, S., Ehsani-Moghaddam, B., & Levasseur, A. (2006). Antioxidant capacity in June-bearing and day-neutral strawberry. *Canadian Journal of Plant Science*, 86, 1387-1390.

Kumar, S. & Dey, P. (2011). Effects of different mulches and irrigation methods on root growth, nutrient uptake, water-use efficiency and yield of strawberry. *Scientia Horticulturae*, 127, 318-324.

Lal, R. (2009). Soils and world food security. *Soil & Tillage Research, 102,* 1-4. doi:10.1016/j.still.2008.08.001

Lamarre, M., & Lareau, M.J. (1994). Influence of nitrogen, potassium and magnesium fertilization on day-neutral strawberries in Quebec. *HortScience*, 29(4), 251.

Lieten, F.E., & Misotten, C. (1993). Nutrient uptake of strawberry plants (Cv. Elsanta) grown on substrate. *Acta Horticulturae*, 348, 299-306.

National Agricultural Statistics Service, USDA. (2011). *Agriculture prices*. Retrieved from: http://www.ers.usda.gov/data/fertilizeruse/

Nestby, R. (1998). Effect of N-fertigation on fruit yield, leaf N and sugar content in fruits of two strawberry cultivars. *Journal of Horticultural Science and Biotechnology*, 73: 563-568

Nova Scotia Environment. (2011). *Our path forward: Building on the success of Nova Scotia's solid waste resource strategy*. Halifax, NS.

Olsson, M.E., Anderson, C.S., Oreddson, S., Berglund, R.H. & Gustavsson, K. (2006). Antioxidant levels and inhibition of cancer cell proliferation *in vitro* from organically and conventionally cultivated strawberries. *Journal of Agriculture and Food Chemistry*, 54, 1248-1255.

Ou, B., Huang, D., Hampsch-Woodill, M., Flanagan, J.A., & Deemer, E.K. (2002). Analysis of antioxidant activities of common vegetables employing oxygen radical absorbance capacity (ORAC) and ferric reducing antioxidant power (FRAP) assays: a comparative study. *Journal of Agricultural and Food Chemistry*, 50, 3122-3128.

Pritts, M. & Handley, D. (1998). Strawberry production guide for the Northeast, Midwest and Eastern Canada. NRAES: Ithaca, NY.

Radin, A.M., & Warman, P.R. (2010). Assessment of productivity and plant nutrition of Brussels sprouts using municipal solid waste compost and compost tea as fertility amendments. *International Journal of Vegetable Science*, *16*, 374-391. doi:10.1080/19315260.2010.493549

Reganold, J. P., Papendick, R. I., & Parr, J.F. (1990). Sustainable Agriculture. *Scientific American*, June, 112-120.

Reganold, J.P., Andrews, P.K., Reeve, J.R. ... Zhou, J. (2010) Fruit and soil quality of organic and conventional strawberry agroecosystems. *PLoS ONE*, 5(9), 1-14. doi:10.1371/journal.pone.0012346

Sharifi, M., Zebarth, B., Burton, D., ...Arsenault, W. (2007). Evaluation of laboratory-based measures of soil mineral nitrogen and potentially mineralizable nitrogen as predictors of field-based indices of soil nitrogen supply in potato production. *Plant and Soil*, 301, 203-214.

Sharifi, M., Zebarth, B.J., Burton, D.L., Grant, C.A., & Porter, G.A. (2008). Organic amendment history and crop rotation effects on soil nitrogen mineralization potential and soil nitrogen supply in a potato cropping system. Agronomy Journal, 100, 1562-1572.

Sharifi, M., Zebarth, B.J., Burton, D.L., Rodd, V., & Grant, C.A. (2010). Long-term Effects of Semi-Solid Beef Manure Application to Forage Grass on Soil Mineralizable Nitrogen. *Soil Science Society of America Journal*, 75, 649-658.

Shaw, D.V. & Larson, K.D. (2008). Performance of early-generation and modern strawberry cultivars from the University of California breeding programme in growing systems simulating traditional and modern horticulture. *Journal of Horticultural Science and Biotechnology*, 83(5), 648-652.

Singh, R., Sharma, R.R., & Tyagi, S.K. (2007). Pre-harvest foliar application of calcium and boron influences physiological disorders, fruit yield, and quality of strawberry (*Fragaria* x *ananassa* Duch.). *Scientia Horticulturae*, 112, 215-220.

Small, E. (2009). Top 100 food plants: the World's most important culinary crops. NRC Press: Ottawa, ON.

Smil, V. (1999). Nitrogen in crop production: an account of global flows. *Global Biogeochemical Cycles 13*, 647–662

St. Luce, M., Whalen, J.K., Ziadi, N., & Zebarth, B.J. (2011). Nitrogen dynamics and indices to predict soil nitrogen supply in humid temperate soils. *Advances in Agronomy*, 112, 55-101.

Szeto, Y.T., Tomlinson, B., & Benzie, I.F.F. (2002). Total antioxidant and ascorbic acid content of fresh fruits and vegetables: implications for dietary planning and food preservation. *British Journal of Nutrition*, 87, 55-59.doi: 10.1079/BJN2001483

Taghavi, T.S., Babalar, M., Ebadi, A., Ebrahimzadeh, H., & Asgari, M.I. (2004). Effects of nitrate to ammonium ratio on yield and nitrogen metabolism of strawberry (*Fragaria x Ananassa* cv. Selva). *International Journal of Agriculture & Biology*, 6(6),994-997.

Tagliavini M., Baldi, E., Lucchi, P., Antonelli, M., Sorrenti, G., Baruzzi, G., & Faedi, W. (2005). Dynamics of nutrients uptake by strawberry plants (*Fragaria* x *Ananassa* Dutch.) grown in soil and soilless culture. *European Journal of Agronomy*, 23, 15-25.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R. & Polasky, S. (2002) Agriculture sustainability and intensive production practices. *Nature, 418*, 671-677

Tulipani, S., Mezzetti, B., Capocasa, F. ... Battino, M. (2008). Antioxidants, phenolic compounds, and nutritional quality of different strawberry genotypes. *Journal of Agricultural and Food Chemistry*, 56, 696-704.

Vaccari, D. A. (2009). Phosphorus: A looming crisis. *Scientific American, June 2009*, 42-47.

Velthof, G.L., Oudendag, D., Witzke, H.P., Asman, W.A.H., Klimont, Z. & Oenema, O. (2009). Integrated assessment of nitrogen losses from agriculture in EU-27 using MITERRA-EUROPE. *Journal of Environmental Quality*, 38, 402-417.

Wang, Q., Tury, E., Rekika, D., Charles, M.T. … Khanizadeh, S. (2010). Agronomic characteristics and chemical composition of newly developed day-neutral strawberry lines by Agriculture and Agri-Food Canada. *International Journal of Food Properties*, 13, 1234-1243. doi:10.1080/10942910903013415

Wang, S.Y., & Lin S. (2002). Composts as soil supplement enhanced plant growth and fruit quality of strawberry. *Journal of Plant Nutrition*, *25*, 2243-2259.

Warman, P.R., Burnham, J.C., & Eaton, L.J. (2009). Effects of repeated applications of municipal solid waste compost and fertilizers to three lowbush blueberry fields. *Scientia Horticulturae*, *122*, 393-398. doi:10.1016/j.scienta.2009.05.024

Warman, P.R., Rodd, A.V., & Hicklenton, P. (2009). The effect of MSW compost and fertilizer on extractable soil elements and the growth of winter squash in Nova Scotia. *Agriculture, Ecosystems and Environment*, *113*, 98-102. doi:10.1016/j.agee.2009.05.010

Warman, P.R., Rodd, A.V., & Hicklenton. (2011). The effect of MSW compost and fertilizer on extractable soil elements, tuber yield, and elemental concentrations in the plant tissue of potato. *Potato Research*, *54*, 1-11. doi:10.1007/s11540-010-9167-9

Whalen J.K., Benslim, H., Jiao, Y. & Sey, B.K. (2008). Soil organic carbon and nitrogen pools as affected by compost application to a sandy-loam soil in Quebec. (2008). *Canadian Journal of Soil Science*, 88, 443-450.

Whalen, J.K. and Sampedro, L. (2010). Soil Ecology and Management. Cambridge, UK: Cambridge University Press.

Zhang, T.Q., MacKenzie, A.F. & Liang, B.C. (1995). Long-term changes in Mehlich-3 extractable P and K in a sandy loam soil under continuous corn (*Zea mays* L.). *Canadian Journal of Soil Science*, 75, 361-367.

Zheljazkov, V.D., & Warman, P.R. (2004). Source-separated municipal solid waste compost application to Swiss chard and basil. *Journal of Environmental Quality*, *33*, 542-552.