IMPACT OF VARIABLE RATE SPLIT FERTILIZATION ON CROP PRODUCTION AND ENVIRONMENTAL CONTAMINATION IN WILD BLUEBERRY

by

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DEDICATION

I dedicate this thesis to my family and teachers for instilling the importance of hard work and higher education. I could not have done this without their help. A special feeling of gratitude to my loving parents Muhammad Saleem and Hameeda Bano, who introduced me to the joy of reading from birth, enabling such a study to take place today. Both of you have been my best cheerleaders. My brothers Akbar Abbas, Amir Abbas, Kashif Abbas, Muhammad Muneeb, and my sisters have never left my side and are very special. Thanks you all of your support along the way.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The heavy rainfall, gentle to severe topography with high proportion of bare spots, and weed patches emphasize the need of variable rate split (VRS) fertilization in wild blueberry. Two commercial fields were selected in central Nova Scotia to evaluate the impact of VRS fertilization on ammonia volatilization, subsurface water quality, and crop productivity. Management zones were delineated based on slope variability, and different fertilizer rates were applied using global positioning system (GPS) guided prescription map. Ammonia huts were used to quantify the ammonia volatilization losses, while the lysimeters were installed in the fields to evaluate the impact of different fertilizer treatments on subsurface water quality. The VRS treatment significantly decreased the ammonia volatilization losses and nutrients leaching losses as compared to uniform treatment. Based on the results of this study, it can be concluded that VRS fertilization in wild blueberry fields could reduce environmental contamination and improve crop productivity.

LIST OF ABBREVIATIONS AND SYMBOLS USED

ANOVA – Analysis of variance
ATV – All-terrain vehicle
cm – Centimeter
DAP – Diammonium phosphate
DGPS – Differential global positioning system
EC – Electrical conductivity
g – Gram
ha – Hectare
GIS – Geographical information system
GPS – Global positioning system
K – Potassium
KCl – Potassium chloride
kg – Kilogram
kg NH_4^+-N ha^{-1} – Kilogram ammonium nitrogen per hectare
kg ha^{-1} – Kilogram per hectare
kPa – Kilopascal
L – Liter
LSD –Least significant difference
m – Meter
mg L^{-1} – Milligram per liter
mL – Milliliters
mm – Millimeter
ms^{-1}– Meter per second
MZ – Management zone
MMC – Multiple means comparison
N – Nitrogen
NH_4^+ -N – Ammonium nitrogen
NH_4^+ – Ammonium
NO_3^--N – Nitrate nitrogen
NO_3^- – Nitrate
P – Phosphorus
RM ANOVA – Repeated measure analysis of variance
RTK – Real time kinematics
s – Second
SMMS – Slope measurement and mapping system
SOM – Soil organic matter
UR – Uniform rate
URS – Uniform rate split
VR – Variable rate
VRS – Variable rate split
VRT – Variable rate technology
Z1 – Zone-1
Z2 – Zone-2
Z3 – Zone-3

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CHAPTER 1

INTRODUCTION

Wild blueberry (*Vaccinium angustifolium* Ait.) is an important horticultural crop indigenous to northeastern North America. Wild blueberry is naturally a perennial crop but it is forced from its perennial production system into a biennial production system by regular pruning during sprout year (Hall et al., 1979) followed by a year in which bloom, pollination, fruit growth and development occurs (Eaton, 1988). The majority of fields are situated in acidic soils (pH 4.5 to 5.5), which are low in mineral nutrients, having poor water holding capacities, significant weed/bare patches, and gentle to severe topography (Trevett, 1962; Zaman et al., 2008a). The newly established fields may have substantial proportion of bare spots; in some cases up to 50% of the total field area (Zaman et al., 2010). Wild blueberry canopy expands by an underground rhizome system that is 70% to 85% of the total weight of the plant (Jeliazkova and Percival, 2003). Wild blueberry has a narrow optimal range for nutrients; therefore, excess nitrogen (N) may increase vegetative growth and reduce fruit yield (Percival and Sanderson, 2004). The unique feature of the wild blueberry cropping system emphasizes the need for precise and site-specific crop management to maximize profit and minimize negative environmental impacts.

Generally, fertilizer is applied uniformly in wild blueberry fields, without considering the substantial variation in soil and plant characteristics, topographic features, and fruit yield. Uniform fertilization can result in over- or under-application. Nutrients can be eroded from steeper slope positions to low lying areas of field during heavy rainfall causing surface runoff and soil erosion (Saleem, 2012). Unnecessary fertilization in low lying areas of the field can lead to deterioration of water quality (Zaman et al., 2010), increase ammonia volatilization losses, excessive weed growth, and increased cost of production (Thyssen and Percival, 2006). Under fertilization restricts yield and reduces berry quality (Zaman et al., 2010). Spatial variability within the fields can be managed by developing management zones (MZs), in which a field is divided into smaller areas with relatively homogeneous attributes, such as topography and soil conditions. These MZs can be used to apply variable rate (VR) fertilization (Ferguson et al., 2003) on as needed basis. Zaman et al. (2010) related slope variability with soil properties, leaf nutrients, and berry yield in wild blueberry fields and suggested slope maps could be used to develop MZs for VR fertilization to improve crop productivity and protect the environment. Farooque et al. (2012) used cluster analysis to develop MZs and suggested that MZs could provide a way to manage the spatial variability in soil properties and fruit yield within wild blueberry fields. Saleem et al. (2013) applied fertilizer on a site-specific basis with VR granular fertilizer spreader in different MZs based on slope variation in wild blueberry fields. Several researchers have found that VR fertilization was superior to the uniform applications in terms of economic and environmental benefits in different cropping systems (Schnitkey et al., 1996; English et al., 1999; Zaman et al., 2005 and 2006; Zaman et al., 2010).

The annual precipitation in Nova Scotia, Canada ranges from 1250-1500 mm (Environment Canada, 2012). Single uniform application of fertilizers can result in down slope nutrient movement with surface runoff due to heavy rainfall, which can decrease the available nutrients for optimum plant growth (Saleem et al., 2013). This problem can be addressed by split fertilization in wild blueberry cropping system. The total fertilizer amount can be divided into equal quantities using VRS fertilization, and VR fertilizer spreader can be used to apply fertilizer at different times during the growing season. The VRS fertilization has the potential to increase fertilizer use efficiency and reduce the nitrogen losses through reduction in volatilization and nutrient leaching losses (López-Bellidoa et al., 2012). The VRS fertilization has proven to be one of the most effective methods for achieving relatively high yields and fertilizer use efficiency for different crops (Wilson et al., 1989; Guertal, 2000; Zaman et al., 2005). Very limited attention has been paid to assess the benefits of the VRS fertilization in wild blueberry cropping system.

The central hypothesis of this study is that the VRS fertilization could improve crop production and reduce the environmental contamination, when compared with uniform rate (UR) and uniform rate split (URS) fertilization in wild blueberry fields. The VRS fertilization in different MZs based on slope variation can increase input use efficiency, improve crop growth and productivity, and reduce environmental threats.

1.1 Objectives

The objectives of this study are to:

i. Quantify the ammonia volatilization losses from variable rate split and uniform fertilizer applications,
ii. Compare the impact of different fertilizer treatments on subsurface water quality, and
iii. Examine the impact of different fertilizer treatments on plant growth and fruit yield.

CHAPTER 2

LITERATURE REVIEW

2.1 Wild Blueberry Cropping System

Wild blueberry is an important horticulture crop in Canada with over 60,000 ha under management, producing 98.57 million kg of fruit annually (Melanson, 2012). Wild blueberry production differs in many ways from the other fruit crops as they are not planted; rather they are managed on native existing wild blueberry stands. Wild blueberry fields are developed from the abandoned farmlands or forest areas which have pre-existing coverage of blueberries (Trevett, 1962). Wild blueberry grows generally in sandy loam and well-drained soil classified as Orthic Humo-Ferric Podzols (Webb et al., 1991). Infertile soils with pH ranging from 4.5 to 5.5 and well-developed organic horizons are the most favorable environment for low-bush blueberries (Trevett, 1962). Wild blueberry plants are about 10 cm tall having woody shrubs and a floral inflorescence that has only one vegetative flush and bears 4 to 5 petals white pedicellate flowers (Barker et al., 1964). A stem length of the plants varies from 10 to 30 cm. Wild blueberry roots are shallow and spread laterally (McMahon et al., 2002).

There are number of management practices and environmental conditions that seem to have influence on fruit yield in wild blueberry cropping systems. Management practices may include weed control, insect and disease control, fertilizer applications, and pruning (Hall et al., 1979). The differences in soil conditions (Trevett, 1972) and natural variation within stands (Hepler and Yarborough, 1991) can also have a significant impact on berry yield. Although the wild blueberry crop is resistant to low temperatures, the climatic factors like winter dormancy, droughts and severe frosts are uncontrollable environmental factors which can be harmful for fruit yield (Quamme et al., 1972).

Generally, half of the total wild blueberry fields are harvested every year to maintain an adequate supply of berries in market (Yarborough, 2007). Pruning is the first operation in the management cycle which forces wild blueberry from its natural perennial production system into a biennial production system to encourage strong and healthy growth (Hall et al., 1979) and helps the wild blueberry plant to remain dominant by controlling weeds (Trevett, 1962). Pruning can be accomplished either by burning or by flail mowing. During the first year (sprout) after pruning, the plant grows vegetatively and initiates flower buds formation for the crop year from August to October, which is followed by winter dormancy (Hall et al., 1979). In the second year (production), flower bud further develop during the spring (Eaton and Nams, 2006), and flowering occurs in May and June. The wild blueberry flowers are pollinated for fruit production by bee hives, which are managed properly for high level of pollination (Wood, 1961). Harvesting operations are carried out from early August to early September, when approximately 90% of the berries are ripe using hand raking or mechanical harvesting (Kinsman, 1993). Mechanical harvesters are more efficient as compare to hand raking as harvester can harvest over 1 hectare (approximately 4,600 kg of blueberries) per day. Excavators are used to level the wild blueberry fields to accommodate mechanical harvesting and mowing operations.

With respect to the management of nutrients and fertilizer, there are a number of management and environmental considerations in optimizing the fertilizer use efficiency. Wild blueberry has a narrow window of plant nutrients for optimum plant growth, and these nutrients help wild blueberry plants to have better growth and produce more berries (Sanderson and Eaton, 2004). Excessive nutrients may result in more vegetative growth and environmental pollution, while lower nutrients can negatively affect fruit quality (Percival and Sanderson, 2004).

In wild blueberry cropping systems, fertilizers are applied after pruning in vegetative year. Most of the fertilizers used contain only nitrogen and phosphorus (P), but recent fertilizers have also included potassium (K) in formulation such as 13-26-5, 14-18-10, or 18-46-0 (Eaton et al., 1997). Fertilizers can be used in various combinations of potassium, nitrogen, phosphorus, boron, and zinc magnesium. Results suggest that blueberry responds to fertilizer application by increased vegetative growth and yield potential (Eaton, 1988). With the passage of time, grasses and weeds become adaptive to fertilizers and their increased growth restricts the wild blueberry plant growth (Yarborough and Ismail, 1985). The numbers of shoots per plant and fruit yield are significantly affected by fertilization within wild blueberry fields, whereas fertilization has no significant effect on berry weight (Starast et al., 2007). Sanderson and Eaton (2004) reported that fertilization significantly increased stem length, number of buds per stem, total stems per blossom and fruit yield. Litten et al. (1997) proved that diammonium phosphate (DAP) increased yield components such as stem length, number of floral buds, and berry yield.

Over the past 20 years, wild blueberry industry is rapidly growing with over 7,700 ha of new field and fruit yield has increased by an average of 2.3 million kg each year (Yarborough, 2009). However, this substantial increase in yield is due to the better management within the fields. These management practices include weed management, fertility management, and pollination (Yarborough, 2007). Fertilizers can be applied in wild blueberry fields with other management practices, such as herbicide application, which will not only improve blueberry plant growth but also control the weeds (Hepler and Ismail, 1985; Yarborough et al., 1986). Previous studies on different physiological traits and yield components regarding the effects of N, P, and K fertilization in wild blueberry fields have provided conflicting results (Benoit et al., 1984; Warman, 1987; Jeliazkova and Percival, 2003; Percival and Sanderson, 2004). These conflicts are thought to be due to spatial variability in soil properties, topographic features, and type of nutrients inspected (Bourguignon, 2006). Townsend and Hall (1972) indicated that leaf nutrient concentrations were increased from July 22 to September 22 during sprout year, and decreased from July 22 to September 22 in crop year, suggesting that nutrients were translocated from the leaves to the fruit. Apart from fertilization, pollination is also one of the major factors that can affect the berry yield. To improve pollination of wild blueberries in Nova Scotia and in Maine, Karmo (1974) promoted the use of honeybees. The use of two to four hives per 0.4 ha is recommended by Ismail (1987).

Uniform application of fertilizer without considering the bare spots and weed patches in wild blueberry fields results in increased cost of production, excessive weeds, and may increase environmental risks (Zhang et al., 2010). The unique features of wild blueberry cropping system (variation in plant characteristics, soil properties, presence of bare spots, weed patches and topographic features) emphasize the need of spot application of fertilizer (Farooque et al., 2012). Bourguignon et al. (2006) found that nitrogen can increase the percentage of side branching; however fertilization should be site-specific due to variable nutrient levels in blueberry fields.

2.2 Ammonia Volatilization Losses

Nitrogen is one of the essential elements for plant growth and the main building block of many macromolecules such as proteins and nucleic acids, and usually applied in excess amount to enhance crop productivity (Bouwmeester et al., 1985). Excessive amount of applied N causes adverse impacts on the environment through volatilization (Jones and Jacobsen, 2005).

In the agricultural industry, application of the N-based fertilizer has increased the food production over the past century (Gruber and Galloway, 2008). Approximately, 78% of the earth's atmosphere is made up nitrogen gas (N_2) which is a major reservoir for N. Nitrogen in the atmosphere, or in the soil continually cycles in different forms, through many complex biological and chemical changes (Figure 2-1). The main forms of N include nitrate (NO_3^-), ammonium (NH_4^+), ammonia (NH_3), N_2, Nitrous oxide (N_2O), and organic N. The NO_3^- and NH_4^+ are the plant available forms of N. Crop yields and fertilizer use efficiency can be maximized by reducing the loss of available N to the air or water (Jones and Jacobsen, 2005). There are nine major processes in N cycling: mineralization, nitrification, denitrification, volatilization, N_2 fixation, leaching, exchange, plant uptake, and immobilization (Jones and Jacobsen, 2005). In agricultural fields, N can be lost to the environment by denitrification, plant uptake and removal in harvested portions of the crop, leaching, (downward movement of NO_3^- out of the root zone), and NH_3 volatilization (Jones et al., 2007). The immobilization (biological conversion of minerals N (NO_3^- or NH_4^+) to soil organic N) and exchange (binding to soil particles) are also considered temporary losses of N because it remains in the soil, and most of N finally may become available to plants (Jones et al., 2007).

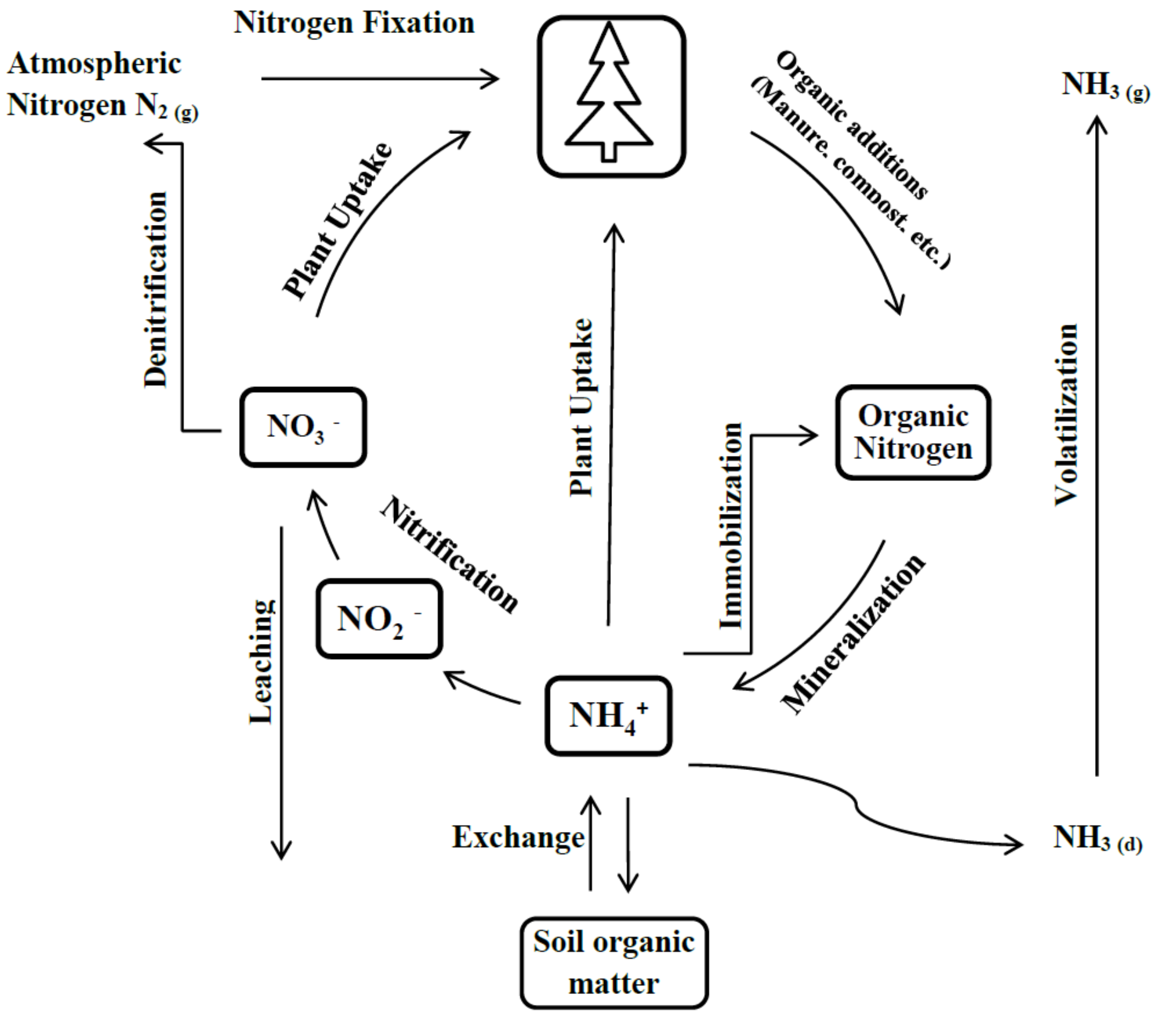

Figure 2-1. The Nitrogen Cycle.
$NH_{3(g)}$ = ammonia gas ; $NH_{3(d)}$ = dissolved ammonia

Ammonia volatilization refers to the emission of ammonia in a gaseous form (conversion from dissolved ammonia in soil to ammonia gas) into the atmosphere and it is a physiochemical process. Ammonia gas is often volatilized into the atmosphere following the surface application of fertilizers containing N (Hoff et al., 1981; Black et al., 1985 and 1989; Schimel et al., 1986; Brunke et al., 1988). In agricultural fields, both ammonia volatilization and denitrification cause the loss of considerable amount of plant available N (Jones et al., 2007). All ammonia based fertilizers have the potential to volatilize ammonia.

Highest volatilization occurs in first week after fertilization, following a decreasing trend, because the ammonia concentration in the soil decreases due to the absorption of NH_4^+ by the soil colloids (Black et al., 1985; Fenn and Hossner, 1985; Stevens et al., 1989). Ammonia volatilization depends on the hydrolysis and increase in hydrolysis can enhance ammonia volatilization (Jones et al., 2007) (Figure 2-2). Ammonia volatilization is also affected by rainfall (Bouwmeester et al., 1985), soil pH, moisture (Oenema and Velthof, 1993), temperature (Vitosh, 1990), and several soil properties. Ammonia volatilization can be influenced by organic matter content, and the enzyme urease (Fenn and Hossner, 1985). Increase in ammonia volatilization was reported with increase in the soil temperature, soil organic matter, and soil pH (Oenema and Velthof, 1993; Vitosh, 1990). Ernst and Massey (1960) reported an increase in loss of NH_4^+ to the atmosphere with an increase in the soil moisture content.

Thyssen and Percival (2006) found significant ammonia volatilization losses in fertilized wild blueberry fields, which can have an impact on the nutrient availability for plants. Concerns associated with the environmental contamination from agrochemicals have increased, and fertilizers are considered to be the major contributors to ammonia emissions (Bovis and Touchton, 1998). Excessive use of fertilizers in agriculture causes environmental pollution as well as the economic losses (Zaman et al., 2010). With the use of fertilizers, yield can be increased (Percival and Privé, 2002). However, the magnitude of environmental losses is not well identified. These losses can be reduced by using fertilizers more efficiently using alternative N, and by improving the basic understanding of the N cycle.

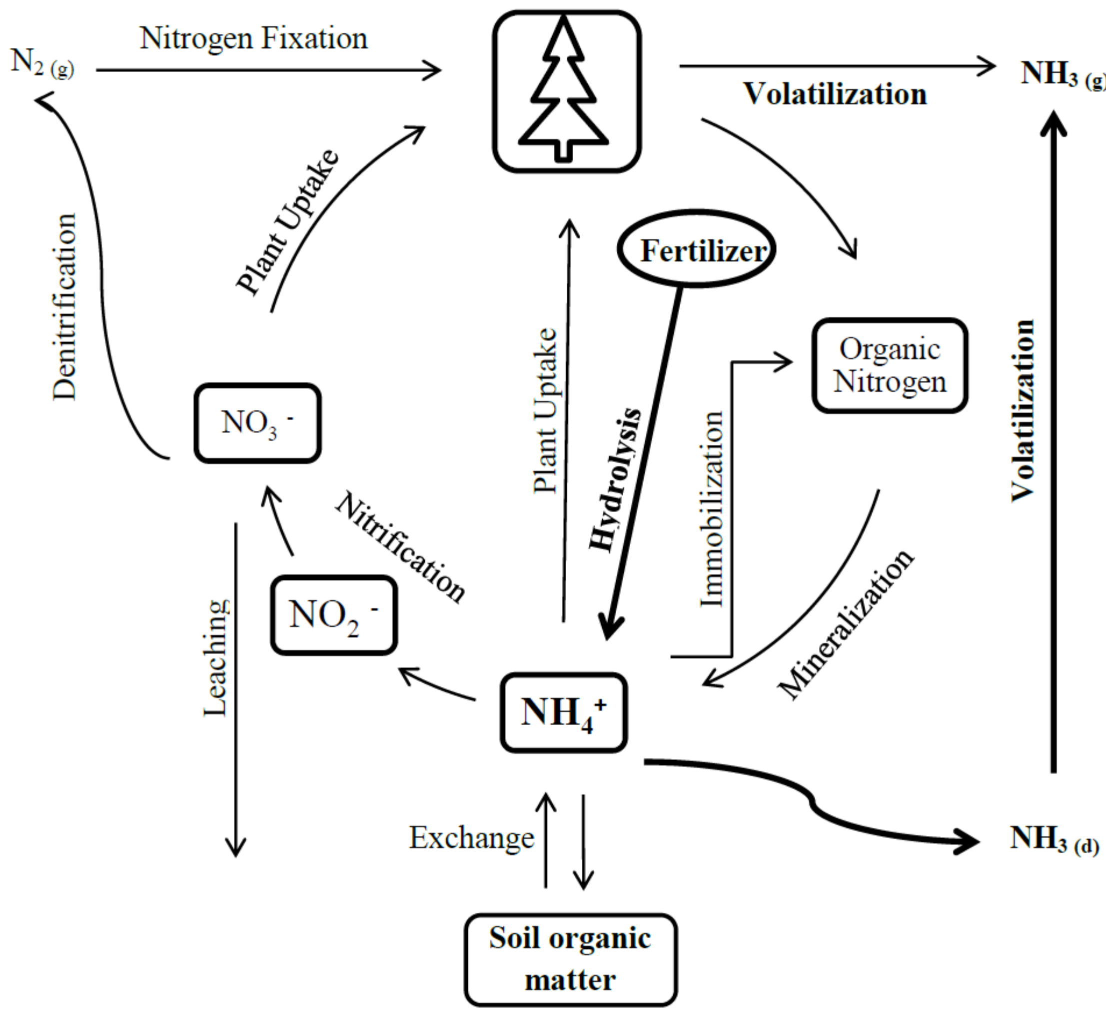

Figure 2-2. Process of ammonia volatilization.
$NH_{3(g)}$ = ammonia gas; $NH_{3(d)}$ = dissolved ammonia

2.3 Variable Rate Technology

Precision agriculture is a key tool for farm communities to increase crop production and reduce environmental impacts, by adjusting rates of fertilizers, seeds, and pesticides in a time and site-specific fashion, after proper characterization and quantification of spatial variability in soil properties, topographic features, and fruit yield

(Yang, 2001; Khosla et al., 2002; Schumann et al., 2006; Zaman et al., 2010). The variable rate technology (VRT) can reduce the amount of nutrients applied and is capable of varying the nutrients within field on as-need basis (Schumann et al., 2006). The VRT is classified as map-based (GPS and geographic information system (GIS)), on-the-go sensor-based, or a combination of map and sensors for site-specific applications (Miller et al., 2004; Schumann et al., 2006). The VRTs could be developed for seed, chemical fertilizers and pesticides, animal manure, and water applications (King et al., 1995; Schumann et al., 2006).

The VR fertilization based on the nutrient availability or fertility status of the soil is an important aspect of the VRT for site-specific applications (Lan et al., 2008). The VR fertilization offers an opportunity to improve fertilizer use efficiency and reduce nutrient losses to environment (Yang, 2001). The VR fertilization is a process of allocating inputs more efficiently by exploiting spatial variations in soil type, fertility levels, topographic features, and other field characteristics (Miller et al., 2004). The VR fertilization can reduce cost of production, N leaching, and potentially increase yields (Zaman et al., 2010). The VR fertilizer application, based on the variation in soil properties, has a potential to reduce under- and over-application of fertilizers, and subsequently improves crop yields and net farm profits (Fiez et al., 1994). Accurate estimation of field characteristics is very important for the precise allocation of fertilizer in a site-specific fashion. The VRT can control the variability of nutrients in fields and can also reduce the amount of nutrients applied within the field (Wittry and Mallarino, 2004; Schumann et al., 2006).

The VR fertilization has shown positive economic and environmental impacts in different cropping systems (Thrikawala et al., 1999; Intarapapong et al., 2002). Schumann et al. (2006) studied the performance of a VR spreader during fertilization of a commercial citrus orchard to improve profitability and reduce nitrate contamination of groundwater. Zaman et al. (2005) conducted VR fertilization on a single tree size basis for Florida citrus and saved 40% fertilizer as compared to uniform rate (UR) fertilization. Zaman et al. (2006) also reduced nitrate-nitrogen (NO_3^--N) concentration in soil solution from 28.5 and 14.0 mg L^{-1} to 1.5 and 4.5 mg L^{-1} under small and large size citrus trees, respectively, using VR fertilization when compared with UR fertilization. Yang et al. (2001) investigated the VRT by applying N and P fertilizer to sorghum, and showed that VR fertilization increased yield and economic returns. Wang et al. (2003) evaluated the VRT for the fertilizer application and quantified its effect on water quality in corn production. They reported that the VRT had less impact on deteriorating water quality as compared to UR application. Saleem et al. (2013) used VR fertilization in wild blueberry cropping system. They recommended the use of VRT in wild blueberry cropping system due to its unique features (variation in soil and plant characteristics, topographic features, and fruit yield). They showed that VR fertilization in wild blueberry fields can significantly decrease NO_3^--N and ammonium N (NH_4^+-N) loadings from leachates when compared with the UR fertilization.

Development and improvement of technologies for VR applications of crop inputs such as granular and liquid fertilizers, herbicides, pesticides, seed, and irrigation water have supported the cause of precise application (Robert, 2002). The VRT have provided many opportunities for researchers to evaluate the economic and environmental benefits of the developed VRTs. Bongiovanni and Lowenberg-Deboer (2004) concluded that VRTs protect environment and also maintain farm profitability when compared with uniform management ().

2.4 Split Fertilizer Application

Wild blueberry fields in Nova Scotia are often situated on sandy loam, infertile, acidic soils having gentle to severe topography (Zaman et al., 2010), and moderate annual precipitation (1250-1500 mm year^{-1}) (Environment Canada, 2012). The combination of moderate rainfall and gentle to severe topography may result in a high risk of environmental contamination through nutrient leaching, soil erosion, volatilization, and surface runoff (Trevett, 1962). Traditionally, fertilizers are applied only once at the start of the sprout year in wild blueberry fields without considering the variation in topographic features. The uniform application of fertilizer results in excessive leaf nutrients and vegetative growth by lowering the fruit yield in low lying areas of the field, as compared to steep slope areas (Zaman et al., 2009). It is very essential to determine most appropriate rate of fertilizer application for efficient utilization by the plants for better fruit yield. It is possible that a moderate rainfall event after fertilization can result in nutrient loss which will lead to less nutrient availability later in the growing season (crop year) for wild blueberry plants. Therefore, split fertilizer application could provide an adequate amount of nutrients throughout the growing season for optimum growth of plants. Split fertilizer application is the process of providing the N supply according to crop demand.

Agriculture is a major contributor to several environmental problems (Nurmakhanova, 2006) by volatilization, denitrification, nutrient leaching and runoff. Split application reduces the exposure of the N in saturated soils where the risks for losses (leaching and denitrification) are more. Split fertilizer applications can be an important part of a the best management practices and can help growers to decide right source, rate, time, and place of application. Finally, proper amount and placement of fertilizer may help to reduce NO_2 emissions, a very potent greenhouse gas.

Literature has reported the split fertilizer application studies for different cropping systems (Wilson et al., 1989; Huang et al., 1999; Nurmakhanova, 2006; Schumann et al., 2006). Patrick and Reddy (1976) studied the split applications of N fertilizer in rice crop and reported higher yield with split fertilizer applications. Santiago and Smagula (2012) used gypsum as a split application for wild blueberry cropping system, and observed that the leaf N and P concentrations were within the proposed standard set by Eaton et al. (2009). Santiago and Smagula (2012) also reported that the split application of gypsum is not better than the single application in affecting stem density, length, branches, and flower bud formation. Split application can increase N use efficiency by effectively relating nutrient supply with plant need. The efficient use of N to maintain the sustainability of the environment, the application of a suitable rate and splitting of N fertilizer is essential (López-Bellidoa et al., 2012). The effect of split application for inorganic fertilizer has not been tested in wild blueberry fields. The extensive use of fertilizer affects the soil and the environment through volatilization and nutrients leaching. Selection of the most appropriate rate of fertilizer is a major concern of economic viability of crop production and the impact of agriculture.

2.5 Nutrient Leaching

Nutrient leaching is the downward movement of agrochemicals caused by water flowing through the soil profile beyond the rooting zone, which deprives the soil of nutrients and other chemicals. Some researchers reported the leaching as a complete removal of nutrients from soil profile, while according to others leaching is the translocation of nutrients within soil profile (Owens et al., 2000). Saffigna and Phillips (2002) defined leaching as the downward translocation of nutrients with percolating water. Nitrate leaching is a significant source of acidification (Havlin et al., 1999). Application of fertilizers to mineral soils has resulted in an increased leaching of nutrients to surface water systems (Van et al., 1998; Willems and Boers, 2004) and groundwater (Fraters et al., 1998). Leaching of the N mostly occurs in the form of NO_3^- (Owens et al., 2000; Zhao et al., 2001) due to mobility of NO_3^- in the soils. Nutrients that are leached down below the root zone are unavailable for plant uptake. In most agricultural systems ammonium and nitrate are the main forms of inorganic N available to plants (Keeney and Walsh, 1972).

Nitrogen leaching and water contamination have become a major concern worldwide, due to the intensive use of N fertilizers in agricultural production for the past 50 years (Di and Cameron, 2002). The problems of N leaching and the contamination of groundwater are more severe in developed countries, due to the heavy use of N fertilizers (Spalding and Exner, 1993; Cameron et al., 1997). Recently, elevated of nutrients concentrations have also been identified in groundwater in some developing countries where agricultural production has improved with increasing use of fertilizers (Singh et al., 1995). The unavailable N for plant uptake present in the soil above the plant requirements can be major source of nutrient leaching. The potential of N leaching increases with over-application of fertilizers (Jaynes et al., 2001). Understanding the dynamics of the fertilizer use efficiency, rate, and timing of application are the important elements to solveing the N leaching problem. In sandy soils, N used for crop production requires careful management because of the high potential of nitrate leaching. In sandy soils most of the applied fertilizer (up to 54% of applied N) can leach down into subsurface soil profile (up to 0.5 m depth of soil), when N fertilizer application is followed by heavy rainfall (Jaynes et al., 2001).

Leaching of N from agricultural soils to groundwater is a potential risk to human health (Owens et al., 2000; Zhao et al., 2001), particularly for children less than 1 year of age (Van and Jarvis, 1997). High concentrations of NO_3^--N in drinking water can affect the circulation of oxygen in the blood, causing blue-baby syndrome (Golden and Leifert, 1999). Researchers have also investigated the possible links between the contaminated drinking water and stomach cancers in adults (Addiscott, 1993). High concentrations of NO_3^--N in drinking water are also harmful for livestock. In many countries, including Canada, reports linking nitrate concentrations in drinking water guidelines a maximum of 10 mg NO_3^--N L^{-1} is used (Health and Welfare Canada, 1996).

The actual amount of nutrient leaching from agricultural fields depend on a variety of factors including climatic condition, soil texture, soil structure, organic matter, management practices (Burt and Arkell, 1987), and types of fertilizers (Gordon et al., 2005). The quantities of NO_3^--N and NH_4^+-N leaching can be influenced by soil acidity. Literature suggested that nitrification process is very slow at low pH of the soil, therefore, NH_4^+-N may also be present in soil leachates (Alexander, 1977). Zhou et al. (2006) reported that approximately 16% of total applied ammonium fertilizer leached in sandy loam soils. Some studies have suggested that the nutrient losses through leaching can be reduced by site-specific application of fertilizers (Zaman et al., 2006). The NO_3^--N concentrations in drainage water were 31 to 63% lower in corn-soybean rotations compare to continuous corn systems (Kanwar et al., 1993). Saleem et al. (2013) found significant reduction of NO_3^--N and NH_4^+-N concentrations in the leachate samples collected from VR treatment in wild blueberry cropping system. Split fertilizer applications resulted in lower N leaching, in comparison with uniform application fertilization (Nakamuraa et al., 2004).

2.6 Global Positioning System

The location of a point within a field can be determined by the use of a GPS. A GPS is capable of determining 3-dimensional location data (longitude, latitude, and elevation) from a constellation of orbiting satellites and it is based on a radio navigation system. A GPS receiver determines the location of the point by using pseudo random signals from at least four satellites (more satellite signals gives higher accuracy) (Morgan and Ess, 1997). The differential global positioning system (DGPS) is used to reduce noise in the location, electronic noise in the receiver, and to compensate the data for timing errors (Saunders et al., 1996). A GPS provide precise guidance to farm operations such as spraying, planting, cultivation, irrigation, insect and disease infestations, and collection of data for mapping. The farmers and other agriculture services providers can record the data automatically rather manually for applying VR inputs to smaller areas within larger fields using GPS (Pfost et al., 1998).

The position information generated by real-time kinematics (RTK) GPS is not only be used for guidance but also for other applications such as seed mapping, traffic control, and tillage control (Li et al., 2009). Iqbal et al. (2005) used a GIS and RTK-GPS to derive and relate the topographic features with hydrologic attributes in a corn field. Saleem, (2012) used RTK-GPS and GIS to map topographic features in wild blueberry cropping system and related them with the surface runoff of the applied fertilizer using VRT.

2.7 Soil Sampling

The primary source of crop production is a soil, and soil classification is essential when making management decisions on field operations (Lark et al., 2003). A number of soil sampling techniques are used to collect the soil samples (grid sampling, directed sampling, random sampling, and MZs sampling). Grid sampling is usually performed when exact soil survey information (yield maps, past yield history, land use history, and remotely sensed images or other sources of spatial information) are not available, whereas if an accurate soil survey information is available direct sampling technique can be used as it is cheaper and more effective than grid sampling (Pocknee et al., 1996). In grid sampling, fields are divided into small areas and soil samples are collected at grid intersections (Chung et al., 1995). Grid sampling techniques include grid cell and grid point methods. In the grid cell method, soil samples are randomly collected throughout the cell for a composite sample, whereas in grid point method soil samples are collected from a geo-referenced point within a grid or at a grid intersection (Pocknee et al., 1996). Grid sampling is also used widely to describe soil variability (Brouder et al., 2005). Directed soil sampling is simply an extension of how soil samples were often collected in the past. The directed sampling technique is performed for sampling low and high yielding areas. The variation in soil nutrients data with the passage of time can be determined by collecting soil samples from same points in subsequent years, and these points should be geo-referenced with GPS (Logsdon et al., 2008). The collected soil samples can be used to determine the physical and chemical properties of soil.

Development of soil sampling strategy requires division of a field into either different zones or grids. Soil samples can be taken randomly at the intersection within those different zones or grids (Srinivasan, 2006). Zone sampling is preferred for a field that contains different soil properties and unique crop characteristics emphasizing the need to divide the selected field into MZs (Fleming et al., 2000). Spatial variability within wild blueberry fields can be managed using zone sampling that allows a field to be divided into different MZs. That is, a field is divided into smaller areas which have homogeneous attributes such as crop characteristics, topography, and soil properties. The shape, size, and number of zones are based on the degree of soil variability in zone sampling method; whereas, in grid sampling, a fixed design is used without considering soil variability (Mallarino and Wittry, 2004). Zone sampling can reduce the number of soil samples in comparison with grid or random sampling (Tan, 2005). To determine the nutrient variability within field grid and zone sampling are equally good (Mallarino and Wittry, 2004). However, the selection of the soil sampling is dependent upon the existence of the variability within selected sites, if soil variability is low, grid sampling is recommended; otherwise zone sampling is preferred (Fleming et al., 2000).

2.8 Management Zones

Agriculture inputs can be applied more efficiently by delineating a field into MZs to overcome spatial variability in soil properties and topographic features (Farooque et al., 2011). The MZs can be defined as a sub-region of a field with homogeneous yield potential (Schepers et al., 2004). The basic purpose of MZs is to identify of areas with similar productivity and yield potential, to describe soil variability (Khosla et al., 2002; Kitchen et al., 1995), and to optimize the crop production and environmental quality. Currently, management practices are performed uniformly without paying attention to substantial variation in soil/plant characteristics, fruit yield, and topographic features for wild blueberry cropping system. This may pollute surface water and groundwater systems and increase the cost of production (Zaman et al., 2008b). Management of agricultural inputs on a site-specific basis is becoming a popular approach for producers to manage field variability to increase farm profitability (Duffera et al., 2007).

Delineation of MZs depends on sources of spatial data that are stable or predictable with the passage of time and are related to crop yield (Doerge, 1999). Soil properties, aerial photographs, topography, soil survey maps, and yield maps have been used to develop management MZs (Schepers et al., 2004). Soil data that are temporally stable such as electrical conductivity and topography, can also be used to estimate soil variability and yield in delineated MZs (Fraisse et al., 2001). Elevation with electrical conductivity (Kitchen et al., 1995; Kravchenko and Bullock, 2000) and soil color with topography and electrical conductivity (Schepers et al., 2004) are recommended as combined approaches for delineating MZs.

The use of MZs within a field is the most popular approach to manage spatial variability (Ferguson et al., 2003). The MZs can be based on remotely sensed maps of yield estimates (Boydell and McBratney, 2002) and soil survey maps (Wibawa et al., 1993). The problems associated with soil variability and its impact on the application of agricultural inputs in site-specific manner can be solved by using MZs within a field. Many researchers have tried to quantify the spatial variation in soil properties, fruit yield, and leaf nutrients to delineate MZs for different crops (Wong and Asseng, 2006; McBratney and Pringle, 1999; Li et al., 2008; Mann, 2009).

2.9 Data Management

The spatial variation of soil properties, fruit yield, and topographic features can be characterized and quantified using geo-statistics and GIS. Blackmore (1994) defined GIS as: “A software application that is designed to process, manipulate and display the spatial data”. A GIS database used for agricultural purposes can consist of soil types, layers on field topography, surface and subsurface drainage, irrigation, rainfall intensity, fertilization, crop yield, and other chemical application rates. The information collected from the fields can be analyzed to understand relationships between different parameters having an impact on crop production (Ahmadi and Mollazade, 2009). Data used in GIS are in layers form, with each having its own features. Vector based (i.e. stored condition of boundaries) or raster based (i.e. stored as different cells) maps can be developed in GIS to represent spatial variation in selected parameters. The vector based map explains the position of points (x-y coordinates) by using a continuous coordinate system, thus allowing geo-referencing to be more accurate than raster based map (Morgan and Ess, 1997). The GPS guided prescription maps developed in GIS can be helpful for application of variable rate fertilization in different cropping systems.

The coefficient of variability is normally used to demonstrate the variability among different crop and soil parameters. However, it does not provide the information about spatial pattern of variability. Analysis of variance (ANOVA) can be used to compare the different treatments and to examine the variation in a response variable measured under conditions defined by discrete factors. Comparison of three or more than three treatments or sub-treatments suggest the use of ANOVA (Hopkins, 2000). The idea behind ANOVA is to partition the total variability in the system. According to Montgomery (2013) ANOVA specifies whether the difference in the response variable is due to the factor of interest or due the error terms. If the variability in the response variable due to the factor of interest is greater than the variability due to error terms, the effect due to factor of interest is considered to be significant (Montgomery, 2013). The rejection of null hypothesis suggests that at least one treatment mean is different from the others. Multiple means comparison (MMC) is performed to identify which means differ from the others. Orthogonal contrast or Scheffe's method can be used for MMC. Whereas, least significant difference (LSD), Duncan's, SNK, or Tukey's methods can be used to compare pair of means based on the magnitude of experimental error (Montgomery, 2013).

2.10 Summary

Spatial variations in soil properties and topography features vary from region to region, between fields, and within fields in wild blueberry fields. Wild blueberry fields have gentle to severe topography which influences nutrient availability and their relocation, root growth and nutrient supply to plants. The chances of nutrient erosion from steep slope and high elevations are more, which can influence the plant growth and berry yield. Wild blueberry producers are well aware of spatial variability in their fields. Currently, in wild blueberry cropping systems the fertilization is implemented uniformly without considering the substantial variation in soil/plant characteristics and topographic features. Precision agriculture practices can be used to overcome the spatial variability and to reduce the environmental contamination caused by agrochemical inputs.

Wild blueberry crops have a narrow optimum range of plant nutrients. Over application of fertilizer may increase the vegetative growth resulting in lower berry yield, and deteriorate groundwater quality through nutrient leaching and can also increase ammonia volatilization losses. On the other hand, under-fertilization can affect the fruit yield and quality. Therefore, proper management of fertilizer using VR application is necessary to overcome these problems, which may result in increased farm profitability and environmental protection.

Spatial variability within wild blueberry fields can be managed by developing MZs for VR fertilization. The successful delineation of MZs based on variation in topography can be useful in saving expensive fertilizer by improving crop productivity and reducing nutrient leaching in wild blueberry fields. Single application of fertilizer can result in nutrient erosion with surface runoff due to heavy rainfall by restricting the available nutrients for optimum plant growth. This problem can be addressed by VRS fertilization, which can enhance the fertilizer use efficiency and reduce the N losses through volatilization. Therefore, VRS fertilization in conjunction with precision agriculture technologies can be used for site-specific applications to provide necessary nutrients for plant uptake, which may increase crop yield and reduce environmental contamination.

CHAPTER 3

MATERIALS AND METHODS

3.1 Evaluation of Sites

In order to achieve the objectives of this research, two commercial wild blueberry fields were selected in central Nova Scotia. The impact of VRS, UR, and URS fertilization on crop productivity, ammonia volatilization, and subsurface leaching was investigated. The selected fields were the Cooper site (Area 5.01 ha; 45° 28′ N and 63° 34′ W) and the North River site (Area 5.9 ha; 45° 27' N and 63° 12' W). The Cooper site was in its sprout year in 2012 and crop year in 2013, while the North River site was in its sprout year in 2013 and crop year in 2014. Both fields were divided into three sections (i.e. VRS section, UR section, and URS section). A portable digital weather station was installed in each field during the experiment. Over the past decade, both fields had been under commercial management and received biennial pruning by mowing along with inorganic fertilizer, weed, and disease management practices. The soil at the both experimental sites is classified as well-drained sandy loam (Orthic Humo-Ferric Podzols), which is an infertile acidic soil (Webb et al., 1991).

3.2 Topographic Maps

Slope variability was measured and mapped with the slope measurement and mapping system (SMMS) at the onset of the experiment in the sprout year for both experimental fields. The system consists of a tilt sensor to determine the tilt of the vehicle in any orientation on the slope. A Trimble AgGPS-332 DGPS antenna (Trimble Navigation Limited, Sunnyvale, CA) was mounted on the all-terrain vehicle (ATV) to determine the location of the sampling point. A laptop computer with the SMMS software collects data from the tilt sensor and GPS, and calculated slope in real time

(Figure 3-1). Detailed procedure for measurement and mapping of slope is discussed in Zaman et al. (2010).

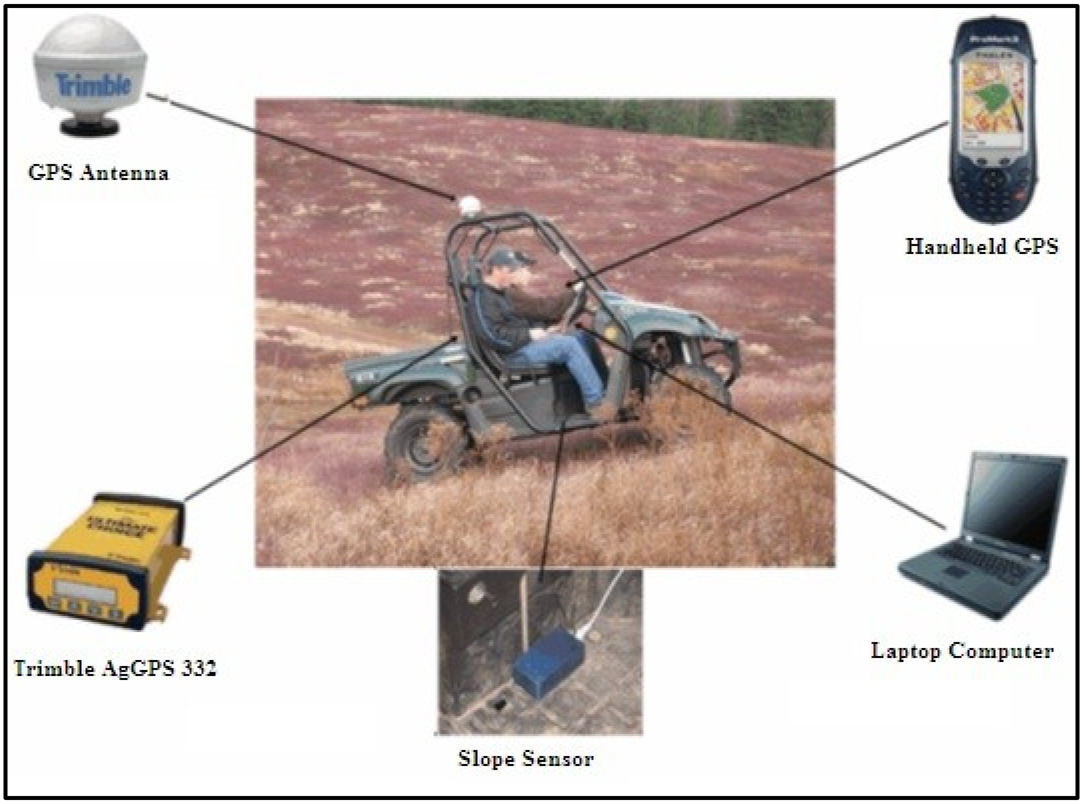

Figure 3-1. Slope Measurement and Mapping System (Zaman et al., 2010).

Slope maps of the fields were generated in ArcGIS 10 software (ESRI, Redland, CA, USA) using kriging interpolation technique and the slope of the fields were divided into three categories (steep, moderate, and low slope). Range, sill, and nugget were calculated by performing geo-statistical analysis using GS+ Geostatistics 9 software (Gamma Design Software, LLC, Plainwell, MI). Range, sill, and nugget are three parameters of a semivariogram. Range is the distance which causes the variogram to reach plateau; nugget semivariance is the variance at zero distance; sill is the lag distance between measurements at which one value of a variable does not affect the next values (Oliver, 1987). Kriged slope maps were generated by using semivariogram parameters.

The field boundaries, bare spots, weeds, and grass patches were mapped with RTK-GPS (Topcon HiPer Lite+ Operation Manual). Each section of both fields contained three slope zones. Slope maps for the Cooper field and North River field are shown in Figure 3-2.

A RTK-GPS receiver having a vertical accuracy of 1-2 cm was used to obtain the elevation from mean sea level for both fields. Prior to logging elevation data for each field, a reference base station was established. Data were logged using an FC-200 Field Computer (Topcon Positioning Systems, Inc., CA, USA). The rover antenna of the RTK-GPS was mounted on the top of the ATV which was driven with a constant speed of 2 m s^{-1}. A field computer recorded the elevation data and corresponding coordinates at 3 m intervals. The kriging interpolation technique was used to generate the elevation maps for both fields using ArcGIS 10 software. Elevation of both fields was divided into three categories (high, medium, and low elevation) (Figure 3-3).

3.3 Soil Sampling

Soil samples were collected from each field to evaluate the effect of VRS, UR, and URS treatments on soil nutrients, SOM, texture, EC, and pH. A zone sampling was established to collect equal number of soil samples from each MZs. Soil samples were collected in the sprout year prior to the first fertilization in 3rd week of May 2012 and after last fertilization 3rd week of July 2012 for Cooper field. Soil samples were collected from the North River field using the same scheme for year 2013. Eighty one soil samples were collected from each field for each sampling (Figure 3-4). Twenty seven soil samples were collected from each section, while nine soil samples from each MZ. Soil samples were collected from 0-15 cm below soil surface at each sampling point. Five cores were

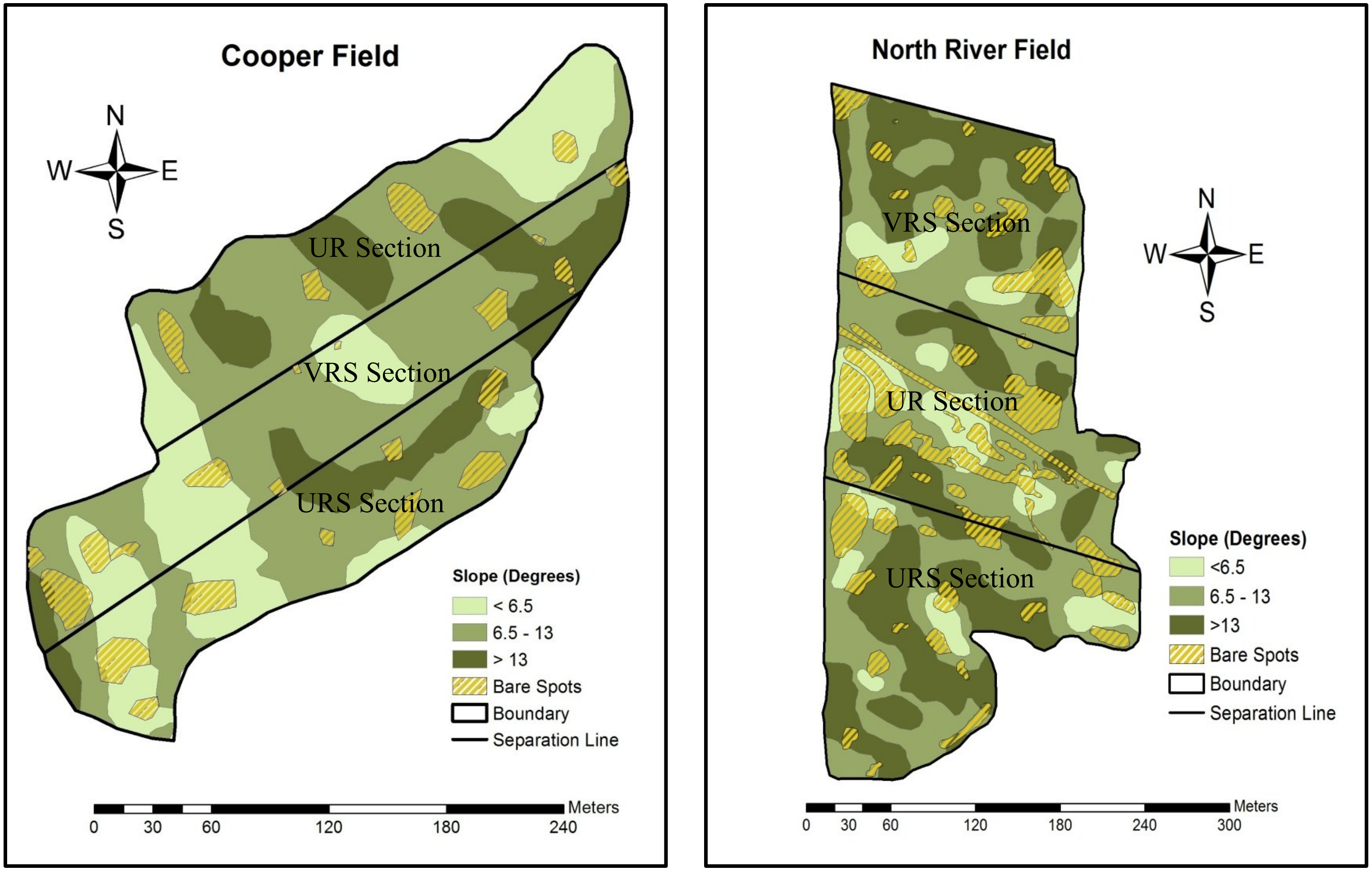

Figure 3-2. Slope maps of fields.

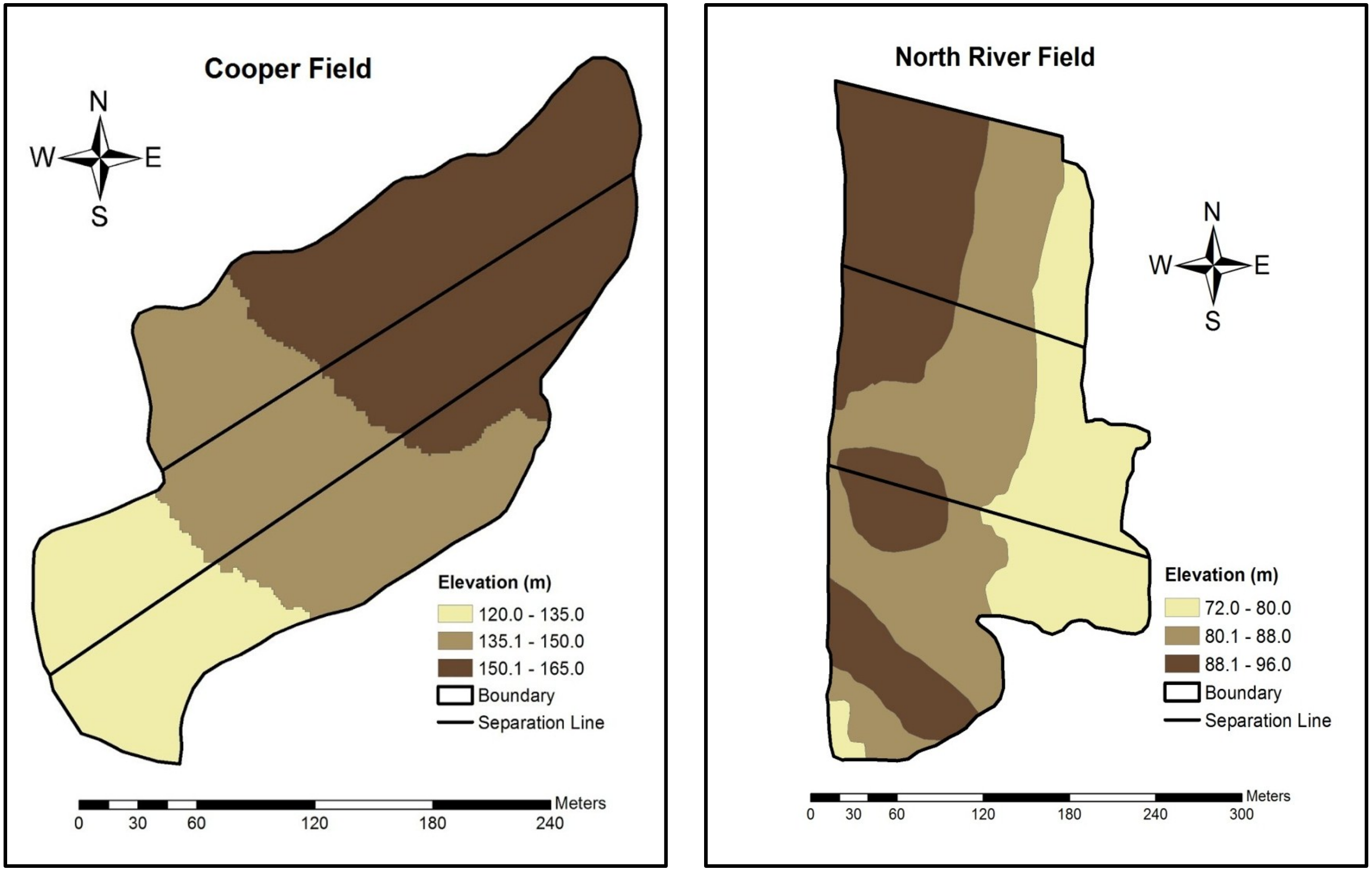

Figure 3-3. Elevation maps of fields.

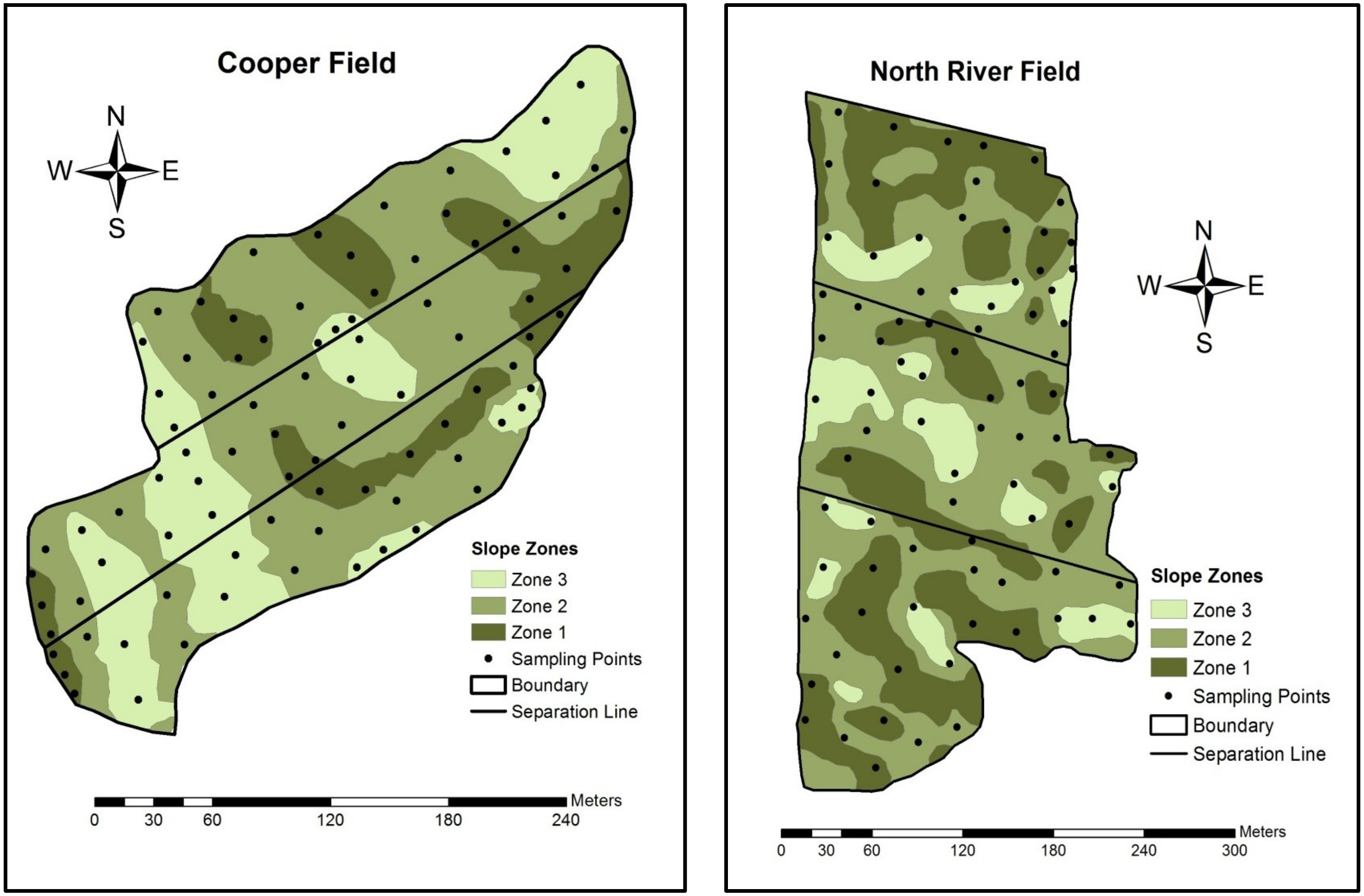

Figure 3-4. Sampling points within different slope zones for both fields.

collected from each sampling point to make a representative sample (Brouder et al., 2005). Each soil sample was divided into two sub-samples and saved in two properly labeled sampling bags. For all collected soil samples, one bag was immediately stored in the refrigerator at 4 °C for NH_4^+-N and NO_3^--N analysis, and the other bag was air dried for two weeks. The air dried soil samples were ground using a soil grinding machine (Nasco Farm and Ranch Co, WI, USA) and passed through a 2 mm sieve. These samples were analyzed for soil electrical conductivity (EC), soil organic matter (SOM), soil texture, and pH. The SOM and soil texture were measured once at the onset of experiment as these parameters are not expected to change during the duration of this research. Other parameters such as soil EC, pH, NH_4^+-N, and NO_3^--N were measured twice, before first fertilization and after last fertilization. The coordinates of each sampling point were recorded using RTK-GPS. The same sampling points were used to collect leaf and plant growth parameters along with fruit yield from both fields.

3.5 Soil Analysis

3.5.1 Electrical Conductivity and pH

A conventional EC meter, Accument 50 (Fisher Scientific, NH, USA) was used to determine the EC of the soil. The EC meter was calibrated using a 1:2 soil: water suspension (deionized water) (Mann, 2009). A mixture of soil and water were prepared in Dixie cups and these cups were placed on the shaker for 40 minutes on a medium speed. The pH meter Corning 450 (Corning, Incorporated, NY, USA) was calibrated to determining pH of the soil using a ratio of 1:2.5 soil: water suspension (deionized water) and were placed on the shaker for 40 minutes. The pH of the samples was measured by inserting the pH electrode in the soil water mixture (McLean, 1982).

3.5.2 Soil Organic Matter Content (SOM)

The SOM was determined using the loss-on-ignition method (Davies, 1974). Ten grams (g) of soil was placed in a ceramic crucible and it was kept in oven at 105 °C for overnight to evaporate the moisture present in the soil. Samples were weighed after keeping them in the oven for overnight. The samples were placed in a muffle furnace at 450 °C for 8 hours. The samples were re-weighed and % SOM was calculated by using the formula recommended by Davies, (1974).

3.5.3 Ammonium-N and Nitrate-N

The NH_4^+-N and NO_3^--N were determined from the soil extracts using a Technicon auto-flow analyzer (Technicon Instrument Corp., Tarrytown, NY) (Voroney et al., 1993). Soil extracts were prepared from the stored soil samples in the refrigerator at 4 ^{0}C with 2.0 M potassium chloride (KCl). The 2.0 M KCl solution was prepared by dissolving 150 g of KCl crystals in one liter distilled water. Twenty grams of soil was weighed into the square French bottles, and mixed with 100 mL 2.0 M KCl solution. The bottles were placed on a reciprocating shaker for one hour at low speed. After shaking, suspension was passed through Whatman No. 42 filter paper to get the extract for analysis. The filtrate was collected in 20 mL scintillation vials. When the vial was ¾ full of extract, the vial was capped and placed in the freezer for the further analysis (Voroney et al., 1993).

The NH_4^+-N in the extracted samples was determined by using Technicon auto-flow analyzer by following ammonium determination method (Technicon Industrial Systems, 1973). The ammonium ions were heated with reagents to produce blue color, which is proportional to the ammonium ion concentration in the solution. The amount of NH_4^+-N in the sample is determined colorimetrically. The NO_3^--N in the extracted samples was determined using Technicon auto-flow analyzer by following nitrate determination procedure (Technicon Industrial Systems, 1978). In this method, initially the entire nitrate concentration in the sample is reduced to nitrite, by utilizing a Coper/cadmium reduction column. The converted nitrate to nitrite with the original nitrite in the sample mixed with the reagents which result the reddish purple color. The concentration NO_3^--N in the sample was determined colorimetrically.

3.5.4 Soil Texture

A standard hydrometer (ASTM. No. 1-152H) was used to determine the soil texture (particle size distribution) of soil samples (Day, 1965). The hydrometer was calibrated by adding 100 g of Calgon© (sodium hexameta-phosphate diluted with water in 1: 20 ratio) in a cylinder and filled the cylinder up to one liter with distilled water. The hydrometer was placed into the solution and the calibration reading was recorded (Day, 1965).

Forty grams of oven dried soil sample was transferred into a 600 mL shaker jug. 100 mL of Calgon© solution and 300 mL of distilled water was added into the cylinder and left to stand overnight. This solution was then mixed in a shaker for 5-10 minutes to make a homogeneous mixture of soil and solution. After mixing, the solution was transferred into a graduated cylinder, and filled up to the marked line with distilled water. The Detailed procedures for soil texture can be adopted from Day (1965).

3.6 Fertilizer Application

Three MZs (zone-1 (Z1), steep slope; zone-2 (Z2), moderate slope; and zone-3 (Z3), low lying area) were delineated on the basis of slope variation within the selected fields (Figure 3-4). Different fertilizer rates were applied in each section of the experimental sites during the sprout years. Variable rate split fertilization was performed in the VRS sections, uniform rate split fertilization was performed in the URS sections, and the UR sections received uniform rate of fertilization. The fertilizer constituted of ammonium sulphate (21 – 0 – 0), di-ammonium phosphate (18 – 46 – 0) and muriate of potash (0 – 0 – 60).

3.6.1 Uniform Rate Fertilization

Conventional fertilizer rate (200 kg ha^{-1}) containing NPK (16.5-34.5-4.5) was applied in UR sections in all MZs including bare spots and weed patches. The UR sections were fertilized only once in 2nd week of May using 7.32 meters wide boom Valmar 1255 pull type granular applicator (Valmar Airflo Inc. MB, Canada).

3.6.2 Variable Rate Split Fertilization

Prescription maps were generated in ArcGIS 10 software for VRS fertilization in developed MZs (Figure 3-5). The VRS fertilization was performed using Farmworks Site Mate variable rate application software (Farmworks CTN Data Service, LLC, Hamilton, IN). Saleem (2012) used 200, 150, and 100 kg ha^{-1} for Z1, Z2, and Z3 respectively for fertilization. For the current study, the fertilizer rates applied in each MZ by Saleem, (2012) were divided into three equal amounts. The fertilizer rates of 66, 50, and 33 kg ha^{-1} were allocated to Z1, Z2, and Z3 respectively, based on the prescription map. Bare spots and weed patches were defined as a separate class in the developed MZs and zero rates were allocated to bare spots and weed patches. The VRS sections were fertilized three times during the sprout year (middle of May, June, and July) for the Cooper site during 2012 and for the North River field during 2013.

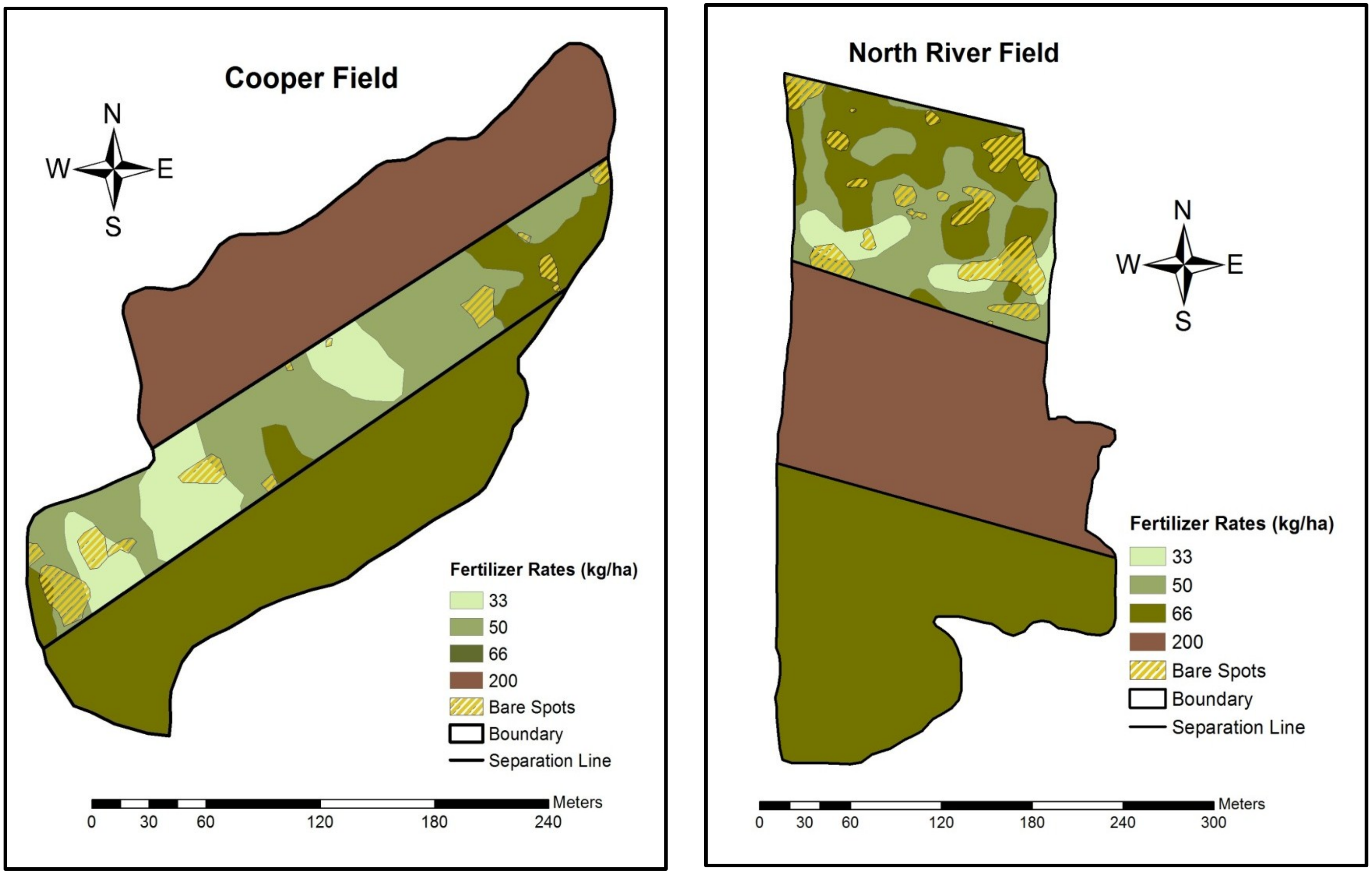

Figure 3-5. Prescription maps for both fields. The uniform rate of 200 kg ha^{-1} was a single application and all other rates were applied three times (split).

3.6.3 Uniform Rate Split Fertilization

Conventional fertilizer rate i.e. 200 kg ha^{-1} was divided into three equal amounts for URS fertilization. The fertilizer rate 66 kg ha^{-1} was used for fertilization in URS sections. The URS fertilization was performed three times during the sprout year (middle of May, June, July) for the Cooper site during 2012 and for the North River field during 2013 using same Valmar 1255 pull type granular fertilizer spreader.

3.7 Ammonia Volatilization

The ammonia huts were used to quantify the ammonia volatilization losses from VRS, URS, and UR fertilizer treatments (Figure 3-6). The impact of different fertilizer rates on ammonia volatilization was examined using the vented chamber method (Selles, 2005). Immediately following the first fertilization ammonia volatilization trials were

Figure 3-6. Ammonia hut used to quantify ammonia volatilization losses.

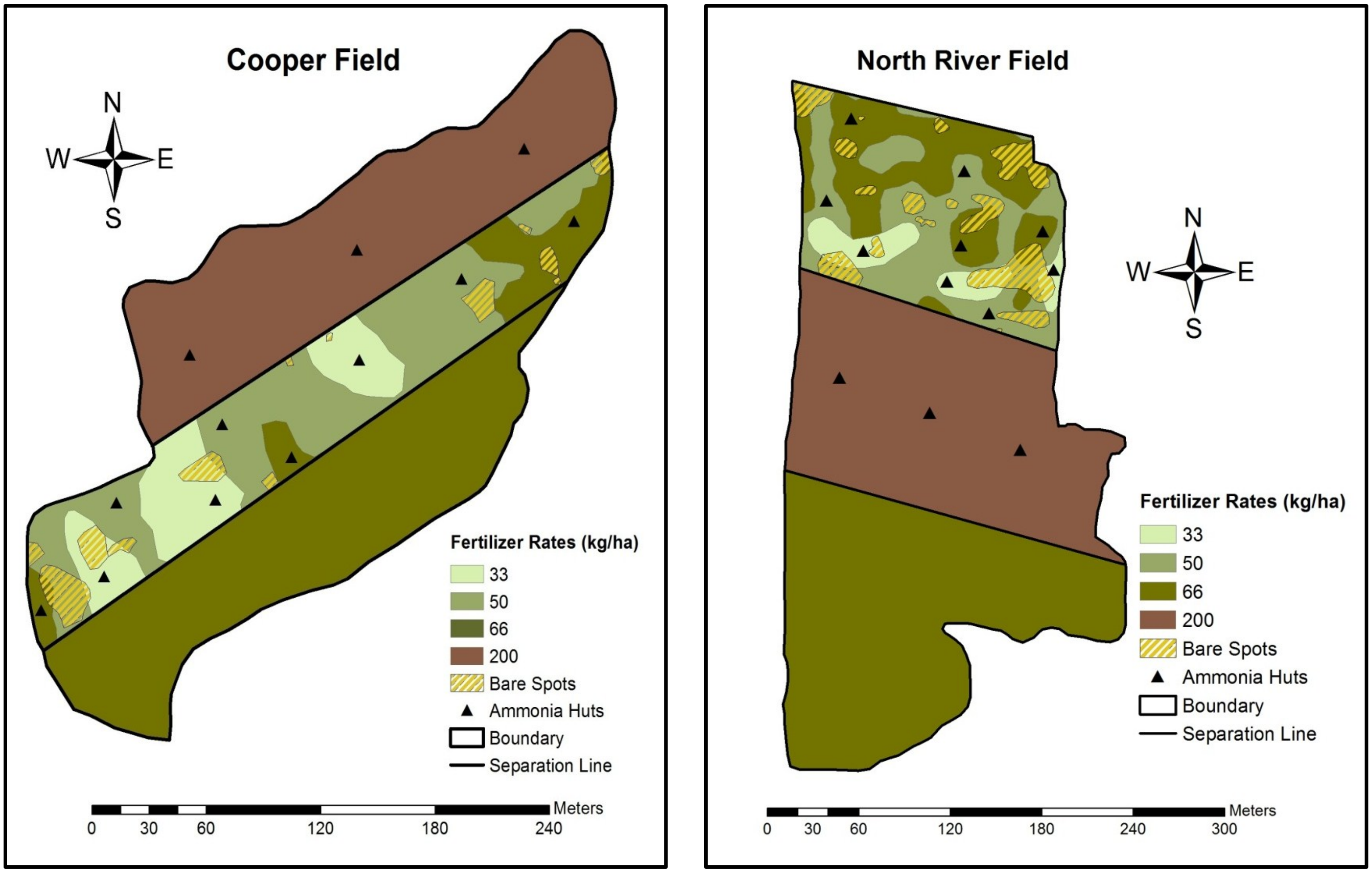

Figure 3-7. Ammonia huts position within both fields.

established. Twelve ammonia huts were installed in different fertilizer rates. Three huts were installed in each rate of fertilization (Figure 3-7). Same procedure was adopted in both experimental sites.

3.7.1 Ammonia Sponges Preparation

To collect ammonia volatilization samples from ammonia huts, polyfoam squares of 21 × 21cm were soaked in a standard solution of 200 mL of 5% phosphoric acid (11.8 mL of 85% phosphoric acid to 50 mL of deionized water and then the beaker was filled up to 200 mL using deionized water) and 200 mL of glycerol in 3600 mL of deionized water (Grant et al., 1996). Each sponge was soaked twice in the prepared solution and then the sponge was squeezed to remove excess solution from sponge. Soaked sponges were placed immediately in a Ziploc© bag to avoid possible contamination while being transported to the field.

3.7.2 Hut Installation and Sample Collection

Immediately following the first fertilization ammonia huts were installed in areas where different fertilizer rates were applied to determine the ammonia volatilization losses, making sure that there were no gaps between the ground and the huts. Two sponges were placed in each ammonia hut at specified locations. The bottom sponge was placed 15 cm from the ground. The top sponge was placed 15 cm above the bottom sponge to avoid any atmospheric contamination. The sponges were replaced on days 1, 2, 4, 7, 10, and 12 after first fertilization. The top sponge was removed and discarded. The lower sponge was removed and placed immediately in a labeled Ziploc© bag. Sponges were placed in a cooler place at 4 ºC until the ammonia was extracted by following a standard method (Selles, 2005). The soil temperature and soil moisture content were also measured from each huts on sampling day. The digital pocket thermometer (Rubbermaid® FGTHP302L, Suffern, NY) and time domain reflectometry (TDR-300) (Spectrum Technologies Inc., Plainfield, IL) were used to measure the soil temperature and soil moisture content respectively. Same procedure was repeated after second and third fertilization in the VRS sections.

3.7.3 Ammonia Sponge Extractions

Ammonium was extracted from the collected sponges using 2 M KCl solution. The sponges were washed three times with 2 M KCL solution to extract ammonia from the sponges. Extracted samples were analyzed for NH_4^+-N using Technicon auto-flow analyzer. The NH_4^+-N concentration (mg L^{-1}) of each sample obtained from Technicon auto-flow analyzer was converted into kg ha^{-1}.

3.8 Subsurface Water Collection

Fifty four lysimeters were installed in each field after the first fertilization to collect leachate samples (Figure 3-8). Eighteen lysimeters were installed in each section, and six lysimeters in each MZ (Figure 3-9). The lysimeter locations were recorded using RTK-GPS. The ceramic cup of each lysimeter was installed at a 40 cm depth, well below the rooting depth of wild blueberries. After a heavy rainfall event (>15 mm), leachate samples were extracted from each lysimeter using a vacuum pump. Leachate samples were placed in a cooler place at 4 °C until the analysis. The leachate samples were analyzed for NH_4^+-N and NO_3^--N using Technicon auto-flow analyzer.

3.9 Leaf Sample Collection and Analysis

The impact of VRS, UR, and URS fertilization on wild blueberry leaf nutrients was determined. Leaf samples were collected at tip-dieback stage (third week of July) in the sprout year from both experimental sites. The leaf samples were analyzed for N, P K, and other micronutrients. The purpose of this analysis was to determine the nutrient

Figure 3-8. Lysimeter used for leachates collection.

uptake by the leaves for crop growth and maturity. The leaf samples were collected at four to six locations (twenty randomly selected blueberry plants) from each sampling point (Figure 3-4). The leaves were removed from blueberry plants gently by holding the stem from its base and placed in the labeled paper bag. The leaves were dried in the greenhouse for seven to ten days and then placed in the oven at 65°C for 8-10 hours, to complete the drying process (Percival and Privé, 2002).

The ovendried leaf samples were ground using a Wiley Mill (Arthur H. Thomas Co, Philadelphia, PA) and passed through a 2mm sieve. Two grams of the ground leaf sample and 10 mL of concentrated nitric acid (HNO_3) were added in pre-conditioned digestion tube (250 mL). The digestion tube was twirled gently to ensure that the sample

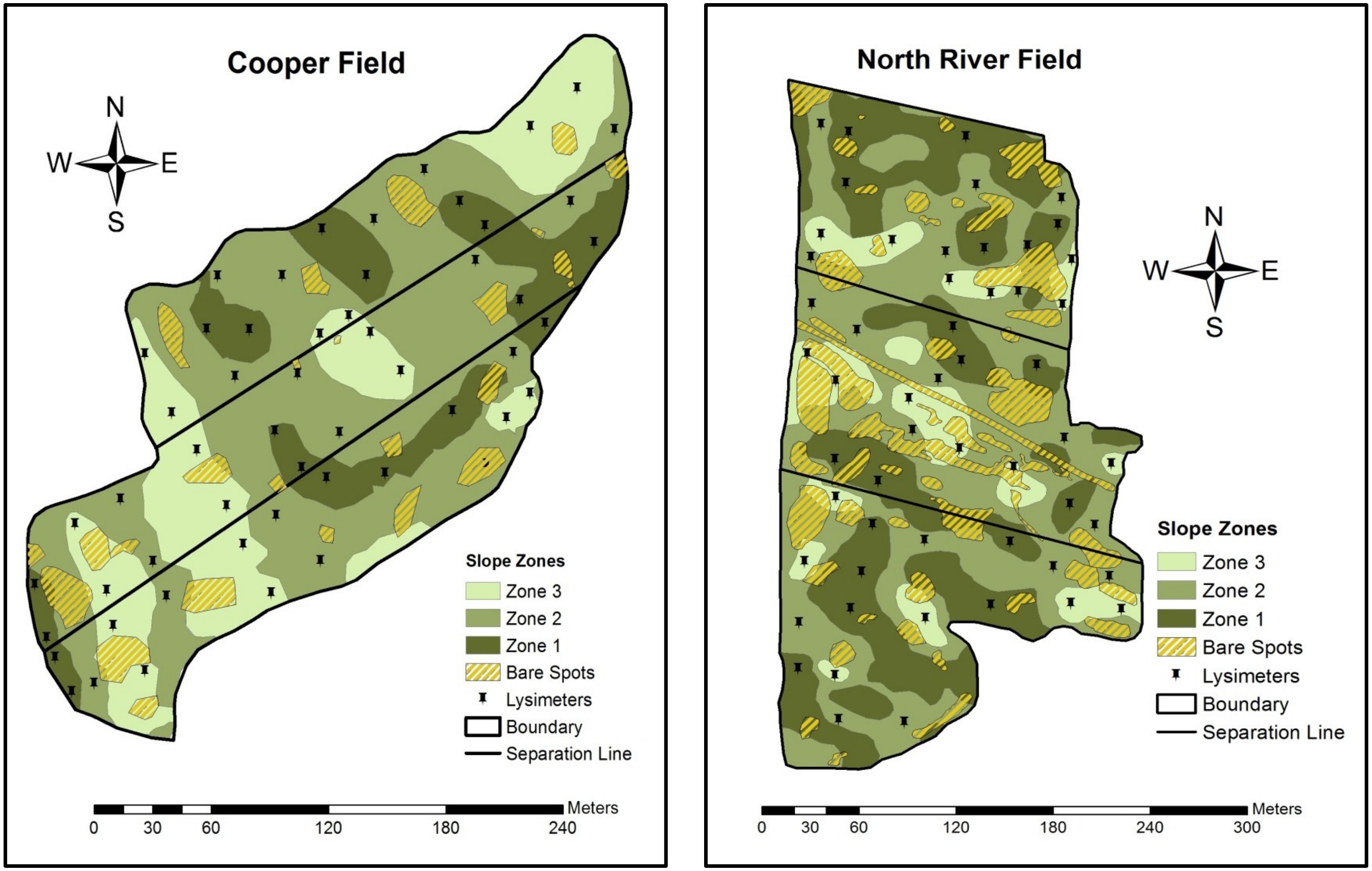

Figure 3-9. Lysimeter locations within both fields.

was completely wet. The samples were placed in digestion blocks and the temperature was increased to 140 $^{\circ}$C; the digestion was continued until the volume of sample was reduced to 1 mL. Five mL of 1% HNO_3 was added to the sample and the solution was passed through Whatman No. 42 filter paper to get the filtrate for further analysis (Percival and Privé, 2002).

Inductively coupled plasma emission spectrometry (ICPES) was used for analysis of all leaf nutrients expect N (Percival and Privé, 2002). Nitrogen content of oven dried leaf samples was determined using LECO CNS-1000 (LECO Corp., St. Joseph, MI). The weighed leaf sample was placed in a sample holder, and the sample was fed into the combustion chamber, where the high temperature (950°C) and flow of oxygen gas caused the sample to combust. Any elemental N, carbon, and sulfur were converted into CO_2, SO_2, and N_2, respectively, by combustion process. These gases were passed over thermal conductivity cell to determine N gas (Rutherford et al., 1993). All the leaf samples were analyzed at the Nova Scotia Department of Agriculture Laboratory, Truro, Nova Scotia, Canada.

3.10 Plant Growth Parameters

Plant growth parameters were measured from both experimental sites during the sprout years to quantify the effect of VRS, UR, and URS fertilization on plant density, plant height, number of branches per stem, and number of flower buds per stem. Plant growth parameters were measured in mid-December, 2012 from Cooper field and in 2013 from North River field from selected locations. A 15 × 15 cm steel quadrant was placed on the ground at each sampling location and numbers of upright stems were counted inside the quadrant to measure the plant density. Six plants from the steel quadrant were randomly selected and the heights of these six plants were measured to get an average height of the plants. The same six plants were used to record the buds per stem and number of branches per stem.

3.11 Fruit Yield

Fruit yield was measured in August, 2013 from Cooper field. A 0.5 × 0.5 m steel frame was placed at each sampling location and wild blueberry fruit was harvested using a hand rake. Harvested blueberries were separated from debris (grass, weeds, and leaves). The cleaned blueberries were transferred into labeled sampling bags and weighed using a balance.

CHAPTER 4

QUANTIFICATION OF AMMONIA VOLATILIZATION LOSSES FROM VARIABLE RATE SPLIT AND UNIFORM FERTILIZER APPLICATIONS

4.1 Introduction

Concerns associated with the environmental losses from agrochemicals have increased, while agricultural practices are contributing more toward ammonia emissions (Bovis and Touchton, 1998). Ammonia volatilization refers to the emission of ammonia from the soil in a gaseous form into the atmosphere. Ammonia gas is often volatilized into the atmosphere following the surface application of fertilizers containing N (Hoff et al., 1981; Black et al., 1985 and 1989; Schimel et al., 1986; Brunke et al., 1988). In agricultural fields, both ammonia volatilization and denitrification cause the loss of significant amounts of plant available N (Jones et al., 2007). Highest volatilization occurs within the first week after fertilization then declines due to absorption of ammonium by the soil colloids (Black et al., 1985; Fenn and Hossner, 1985; Stevens et al., 1989). Excessive use of fertilizers in agriculture fields ma cause environmental pollution as well as the economic losses (Zaman et al., 2010). Yield can be increased with the use of soil-applied fertilizers (Percival and Privé, 2002), but the type and magnitude of environmental losses are largely unidentified. These losses can be reduced by using fertilizers more efficiently and using alternative N fertilizers.

Traditionally, fertilizer is applied uniformly during the sprout year of the biennial production cycle of the wild blueberry cropping system to improve the fruit yield (Yarborough et al., 1986) with little consideration to substantial variation in soil/plant characteristics and topographic features. Uniform fertilization can cause the over- or under-supply of nutrients due to the undulating topography of typical of wild blueberry fields. Over-supply of nutrients deteriorates water and air quality, promotes weed growth, and reduces profit margins (Saleem et al., 2013), while under-supply restricts yield and fruit quality (Percival and Sanderson, 2004; Saleem et al., 2013). Topography has an important role in wild blueberry fields in terms of the spatial variability in soil properties and crop yield (Farooque et al., 2012). Topography influences the redistribution of soil particles, organic matter, and soil nutrients which collectively may lead to large spatial variations in soil properties within selected site (Changere and Lal, 1997). The substantial variations in soil and plant characteristics, topographic features, and fruit yield (Eaton, 1988; Farooque et al., 2012) within wild blueberry fields emphasize the need for site-specific management of agrochemicals to maximize profit and reduce environmental pollution (Zaman et al., 2009; Saleem et al., 2013). The problems associated with the variations in topography, and over- and under-fertilization can be addressed using VR fertilization. Saleem et al. (2013) implemented VR fertilization in wild blueberry fields indicated an increase in nutrient leaching in low lying areas as compare to steep and moderate slope areas of wild blueberry fields. Their results also suggested that the single VR application of fertilizers in wild blueberry fields can result in downslope nutrient movement after heavy rainfall events which can result in the nutrient depletion of the upslope and enrichment of the downslope areas. Therefore, the use of VRS fertilization regime has the potential to increase input use efficiency for optimum plant growth by providing nutrients throughout the spring of vegetative year.

The N is one of the essential elements for plant growth and usually applied in excess amount to increase crop productivity (Bouwmeester et al., 1985). Excessive amount of applied N exceeds plant uptake and metabolic requirements or the exchange capacity of the soil, which can affect the environment through volatilization (Jones and Jacobsen, 2005). Both ammonia volatilization and denitrification causes the loss of considerable amounts of plant available N from agricultural fields (Jones et al., 2007). The total global ammonia emission has been estimated over 50 metric tons N per year (Mt N yr^{-1}) (Schlesinger and Hartley, 1992). After fertilization, all ammonia based fertilizers have the potential to volatilize and the rate of ammonia volatilization depends on the hydrolysis of fertilizer (Jones et al., 2007). The significant amount of ammonia volatilization losses in fertilized wild blueberry fields not only affects the nutrient availability for plants but also contaminates the environment (Thyssen et al., 2006). However, Thyssen et al. (2006) did not consider the VRS fertilization to compare the ammonium volatilization losses with UR fertilization in wild blueberry cropping system. The ammonium volatilization losses can be reduced with VRS fertilization using GPS-guided prescription maps (Miller et al., 2004; Derby et al., 2007).

The VRS fertilization may increase fertilizer use efficiency and reduce the N losses through reduction in ammonia volatilization (López-Bellidoa et al., 2012). Literature suggests that VRS fertilization is one of the most effective methods for achieving relatively high yields and fertilizer use efficiency for different crops (Wilson et al., 1989; Huang et al., 1999; Zaman et al., 2005). Very limited attention has been given to VRS fertilization in wild blueberry cropping systems. Therefore, this present study was designed to examine the impact of VRS fertilization on ammonia volatilization in wild blueberry fields. It is hypothesized that VRS fertilization in the wild blueberry fields can reduce the ammonia volatilization loss as compared to UR fertilization. The objective of this study was to quantify the ammonia volatilization losses from UR (200 kg ha^{-1}) and

VRS (100*, 150*, 200*, and kg ha^{-1}) fertilizer applications within the selected wild blueberry fields.

4.2 Materials and Methods

Two wild blueberry fields were selected in central Nova Scotia to examine the impact of VRS and UR application of fertilizer on ammonia volatilization. Over the past decade, both fields had been under commercial management and received inorganic fertilizer with weed and disease management practices. The field boundaries, bare spots, weeds, and grasses were mapped using RTK-GPS. Slope variability was determined and mapped using SMMS at the onset of the experiment during sprout year for both experimental fields and slope maps were generated in ArcGIS 10 software (Figure 3.2, Chapter 3). Three MZs (zone-1 (Z1), zone-2 (Z2), and zone-3 (Z3)) were delineated on the basis of slope variation within the selected fields. A portable weather station was installed at each field during the experiment.

Prescription maps were generated for VRS fertilization in developed MZs. The VRS sections were fertilized with different fertilizer rates based on the developed MZs (33 kg ha^{-1} in low slope, 50 kg ha^{-1} in moderate slope, and 66 kg ha^{-1} in steep slope areas) and zero rate was allocated to bare spots, weeds, and grasses (Figure 3.5, Chapter 3). The VRS sections were fertilized three times during the sprout year. The UR sections including bare spots and weed patches were fertilized only once with conventional fertilizer rates (200 kg ha^{-1}).

The impact of different fertilizer rates on the environment through ammonia volatilization was examined using the vented chamber method (Selles, 2005). Immediately following the first fertilization, trials were established to quantify the ammonia volatilization losses from VRS and URS fertilizer treatments (Figure 3.6, Chapter 3). Twelve ammonia huts were installed in different fertilizer rates. Three huts were installed in each rate of fertilization (Figure 3.7, Chapter 3). The polyfoam squares sponges soaked in a standard solution (200 mL of 5% phosphoric acid) were used to collect the ammonia volatilization losses from installed huts (Grant et al., 1996). Two sponges (one at the top and other at the bottom) were placed in each ammonia hut. The sponges were replaced from huts on days 1, 2, 4, 7, 10, and 12 after fertilization. The top sponge was removed and discarded whereas the lower sponge was collected and placed immediately in a labeled Ziploc© bag. Sponges were kept in a cooler at 4ºC until the ammonia was extracted by following a standard method (Selles, 2005). Same procedure was repeated after second and third fertilization in the VRS sections. The soil temperature and soil moisture content were measured on sampling days from each hut using digital pocket thermometer and TDR meter, respectively. Detailed procedure is explained in Chapter 3.

4.3 Statistical Analysis

The effect of different fertilizer rates (100*, 150*, 200* and 200 kg ha^{-1}) on ammonia volatilization was examined using a completely randomized design model. The only factor of interest was the rate of fertilizer application with four levels (100*, 150*, 200* and 200 kg ha^{-1}). The response variable was the amount of ammonia volatilized after fertilizer application. The ammonia volatilization losses from different fertilizer rates were compared using repeated measure analysis of variance (RM ANOVA). The analysis of the collected data was performed using Mixed and general linear model (GLM) procedure of SAS (SAS, 2010) at the 5% level of significance. The validity of model assumptions (normal distribution, independence, and constant variance of the error terms) were verified by examining the residuals as described in Montgomery (Montgomery, 2013). When the assumptions were violated, appropriate transformations were applied to the response measurements, but the means reported in the tables and in figures were back-transformed to the original scale to report results. Since the effect of the fertilizer rates was significant on the responses (ammonia volatilization), the multiple means comparison of the fertilizer rates was completed using least significant difference (LSD) at the 5% level of significance. The statistical analysis was performed using Minitab 16 (Minitab Inc. NY, USA) and SAS 9.3 (SAS Institute Inc., NC, USA) statistical software. Graphs were generated in Microsoft® Excel 2010, Minitab, and Sigma Plot 11 (Systat Software, CA, USA) software.

4.4 Results and Discussion

4.4.1 Cooper Field

The results of RM ANOVA for Cooper field showed that the cumulative ammonium volatilization losses were significantly different ($p < 0.05$) for all fertilizer rates. The cumulative ammonium losses from VRS application of 100*, 150*, and 200* kg ha^{-1} were 0.579, 0.961, and 1.389 kg NH_4^+-N ha^{-1} respectively, which were found to be significantly lower than UR fertilization (1.588 kg NH_4^+-N ha^{-1}) (Table 4-1). During the twelve days span of the experiment, lowest ammonium loss (3.55% of the applied N) was observed from 100* kg ha^{-1}, which was 26.24% lower than those in the rate of 200 kg ha^{-1}. The reduction in volatilization loss might be due to lower application rate (100* kg ha^{-1}) as compare to uniform fertilization (200 kg ha^{-1}).

Three fertilizer rates (100*, 150*, and 200* kg ha^{-1}) were used in VRS section, and the average of cumulative ammonium losses from these rates was 0.976 kg NH_4^+-N ha^{-1} which was lower than the UR section (Table 4-2). The average of total ammonium volatilization loss from all split fertilizer rates (used in VRS section) was 38.52% lower than the uniform fertilization over the twelve day period for Cooper field. Fertilizer rate and method of fertilization (UR and VRS fertilization) found to have an effect on the ammonium volatilization losses, as the highest loss (4.81% of applied N) was recorded under UR fertilization, suggesting that the ammonium volatilization loss increase with the increase in the amount of fertilizer (Table 4-1). The total ammonium loss from VRS section increased from 0.579 to 1.389 kg NH_4^+-N ha^{-1} by increasing rate of fertilizer from 100* to 200* kg ha^{-1} (Table 4-1). More than 70% of the total volatilization loss was recorded within four days after the fertilization for both sections (VRS and UR). In the Cooper field, the losses measured from VRS section increased from 3.55 to 4.21% of the applied N when the rate of application of N was increased from 16.5 to 33 kg N ha^{-1}.

Overall, highest ammonium volatilization loss occurred within the first two sampling days of the experiment, and then a decreasing trend was observed for sampling on latter days, except sampling day 4 (Figures 4-1 and 4-2). The decreasing trend in ammonium volatilization loss could be due to nitrification, the reduction of ammonia concentration in the soil, and absorption of ammonium by the soil colloids (Black et al., 1985; Fenn and Hossner, 1985; Stevens et al., 1989). The cumulative ammonium loss from split application of 200* kg ha^{-1} in VRS section and uniform application of 200 kg ha^{-1} in UR section were almost similar on sampling day 10 and 12 (Figures 4-1 and 4-2).

Temperature can influence the rate of volatilization by affecting the rate of evaporation from the soil surface, the equilibrium between NH_3 and NH_4^+, chemical and biological processes occurring simultaneously in the soil environment, which can have an impact on the rate of hydrolysis of fertilizer (Weerden and Jarvis, 1997; He et al., 1999).

Table 4-1. Cumulative NH_4^+-N losses from different fertilizer rates over twelve day period at the Cooper field.

Fertilizer Rate (kg ha^{-1})	Day 1	Day 2	Day 4	Day 7	Day 10	Day 12	Cumulative
	kg NH_4^+-N ha^{-1}						
100*	0.251a	0.103a	0.122a	0.052a	0.036a	0.016a	0.579a
150*	0.280a	0.189b	0.225b	0.135b	0.079a	0.052a	0.961b
200*	0.377b	0.282c	0.320c	0.175c	0.136b	0.100b	1.389c
200	0.437c	0.333d	0.353c	0.212d	0.153b	0.100b	1.588d
Treatment Factor			RM-ANOVA				
Effect							p-value
Fertilizer Rate							<0.001

Means in the same column followed by the same letter are not significantly different at the 5% level of significance using LSD.
*Rates were divided into three equal amounts and applied three times in VRS section.

Table 4-2. Mean values of total cumulative NH_4^+-N losses from VRS and UR sections.

	VRS sections (kg NH_4^+-N ha^{-1})		UR sections (kg NH_4^+-N ha^{-1})	
	Mean	**n**	**Mean**	**n**
Cooper field	0.976	9	1.588	3
North River field	0.915	9	1.538	3

n = number of ammonia huts used to calculate the mean values.

The rate of volatilization loss on sampling day four was higher than sampling day two because the average soil temperature was higher on sampling day four (Figure 4-1). Beside the soil temperature, the soil moisture content can also influence volatilization (Al-Kanani et al., 1991). The average soil moisture content on sampling day two was lower than the day one, which could be the reason of low volatilization rate on sampling day two, suggesting that the ammonium volatilization losses increased with the increase in soil moisture (Figure 4-2). The combination of higher soil moisture and temperature might be the reason of higher ammonium emissions for Cooper field. These results were in agreement with the findings of Thyssen et al. (2006). Ammonium volatilization losses can be influenced by other environmental factors such as rainfall (Bouwmeester et al., 1985), soil pH (Oenema and Velthof, 1993), organic matter (Vitosh, 1990) and several other soil properties (Fenn and Hossner, 1985).

The percentage of N volatilized from the field increased with the increase in the rate of fertilization (Figure 4-3). The highest loss was found to be 4.81% (1.588 kg NH_4^+-N ha^{-1}) of the applied N from the uniform rate of 200 kg ha^{-1}. The percentage of N volatilized from the split application of 100*, 150*, and 200* kg ha^{-1} were 3.51, 3.88, and 4.21%, respectively (Figure 4-3).

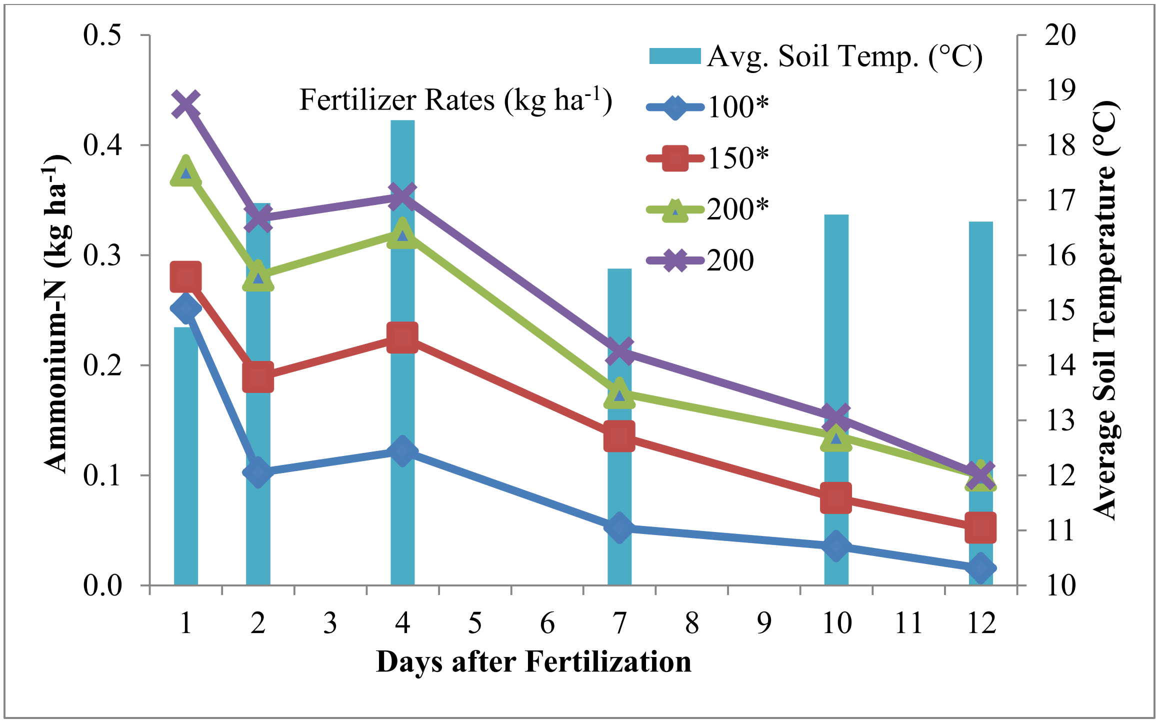

Figure 4-1. Ammonium volatilization losses from different fertilizer rates at the Cooper field, with the average soil temperature.

*Rates were divided into three equal amounts and applied three times in VRS section.

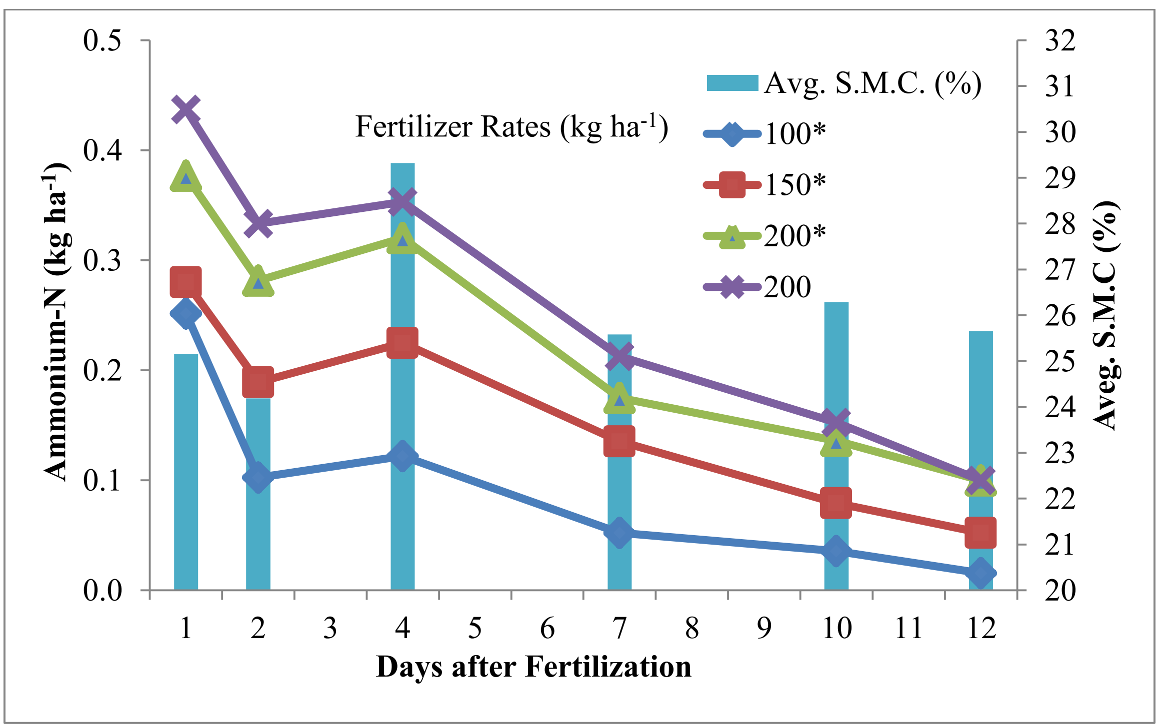

Figure 4-2. Ammonium volatilization losses from different fertilizer rates at the Cooper field, with the average soil moisture content.

*Rates were divided into three equal amounts and applied three times in VRS section.

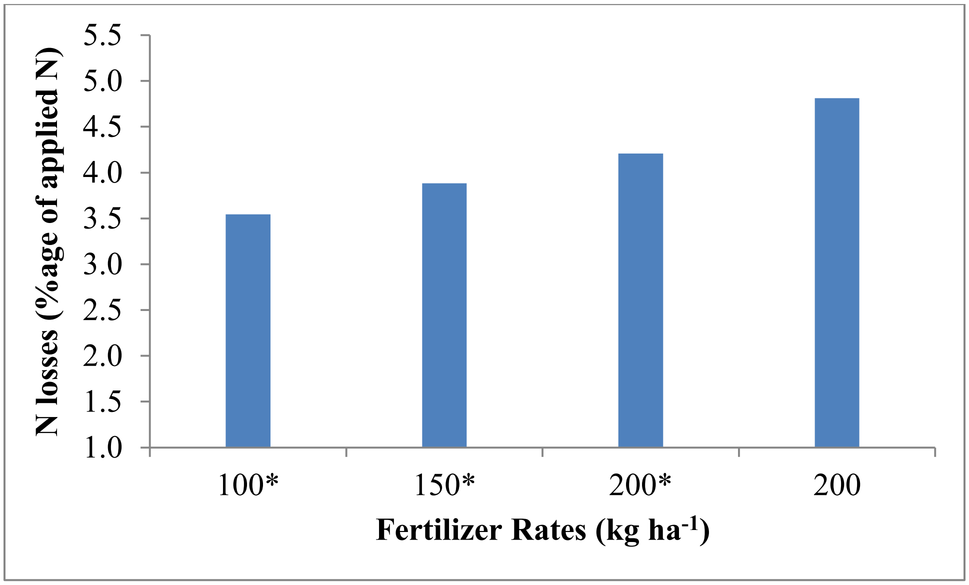

Figure 4-3. Effect of different fertilizer rates on the percentage of applied N lost by volatilization at the Cooper field.
*Rates were divided into three equal amounts and applied three times in VRS section.

4.4.2 North River Field

The summary of RM ANOVA statistics revealed that the cumulative ammonium volatilization form different fertilizer rates were significantly ($p < 0.05$) different at the North River field. The cumulative ammonium volatilization loss from the UR fertilization (200 kg ha^{-1}) was found to be 1.538 kg NH_4^+-N ha^{-1}. The ammonium volatilization losses from the VRS application of 100*, 150*, and 200* kg ha^{-1} were 0.557, 0.927, and 1.261 kg NH_4^+-N ha^{-1}, respectively (Table 4-3). The volatilization loss from VRS section was found to be significantly lower than UR fertilization (Table 4-2). Split fertilizer rates in VRS section might be the reason for lower ammonia emission as compared to UR fertilization. Throughout the twelve days period of the experiment, highest ammonium

Table 4-3. Cumulative NH_4^+-N losses from different fertilizer rates over twelve day period at the North River field.

Fertilizer Rate (kg ha^{-1})	Day 1	Day 2	Day 4	Day 7	Day 10	Day 12	Cumulative
	kg NH_4^+-N ha^{-1}						
100*	0.150a	0.199a	0.068a	0.150a	0.050a	0.021a	0.557a
150*	0.198b	0.264b	0.157b	0.125b	0.121b	0.061b	0.927b
200*	0.235c	0.342c	0.255c	0.195c	0.148bc	0.086c	1.261c
200	0.324d	0.416d	0.303d	0.235d	0.160c	0.100c	1.538d
Treatment Factor			RM-ANOVA				
Effect							p-value
Fertilizer Rate							<0.001

Means in the same column followed by the same letter are not significantly different at the 5% level of significance using LSD.
*Rates were divided into three equal amounts and applied three times in VRS section.

volatilization loss (4.66% of the applied N) was observed from the UR fertilizer of 200 kg ha^{-1}, which was 26.75% higher than those in the split rate of 100 kg ha^{-1} (Figure 4-4). Additional volatilization loss from the UR (200 kg ha^{-1}) might be due to higher fertilizer rate as compare to split rate of 100 kg ha^{-1}, suggesting the lower environmental risks in VRS section.

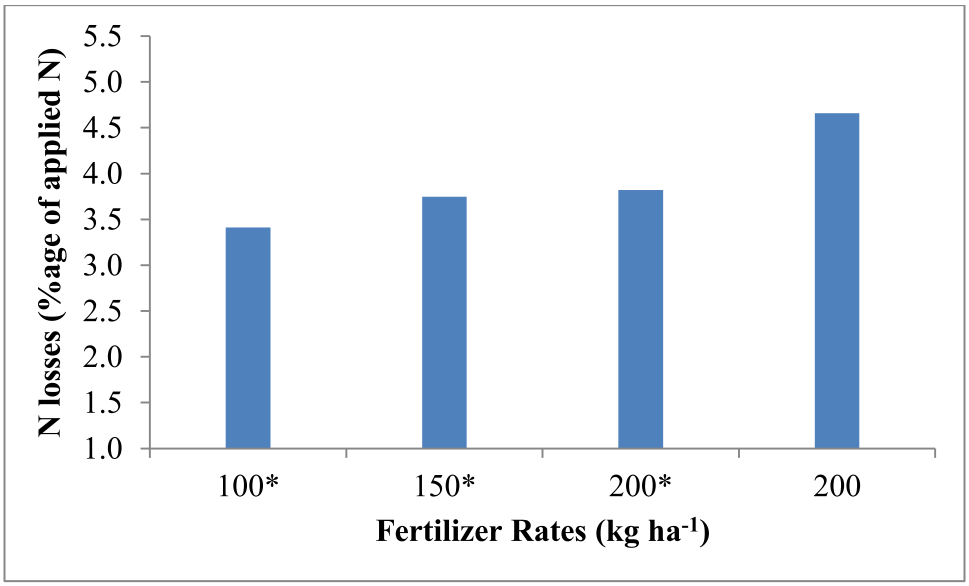

Figure 4-4. Effect of different fertilizer rates on the percentage of applied N lost by volatilization at the North River field.
*Rates were divided into three equal amounts and applied three times in VRS section.

Similar to the Cooper field, the VRS section of the North river field received three fertilizer rates (100*, 150*, and 200* kg ha^{-1}). The average of cumulative ammonium volatilization loss from these rates was 0.915 kg NH_4^+-N ha^{-1} which was 40.31% lower than those in the UR section of the North River field (200 kg ha^{-1}) (Table 4-2). The results suggested that the UR section contributed more towards ammonium volatilization as compared to the VRS section for the North River site. The ammonium volatilization loss measured from VRS section increased from 3.41 to 3.82% of the applied N when the rate of application of N increased from 16.5 to 33 kg N ha^{-1}, suggesting that the ammonium volatilization increased with the an increase in the amount of applied N (Figure 4-4). This observation was in agreement with the results of Ernst and Massey (1960) and Hargrove et al. (1977).

Analysis of weather data indicated the possible effects of soil temperature and soil moisture content on the losses in the North River field. Comparison of the results in Table 4-3 with those in Figure 4-5 and Figure 4-6 indicated that the magnitude of ammonium volatilization losses is related to the soil temperature and soil moisture contents. Overall, low ammonium volatilization losses were recorded from the North River field when compared with the Cooper field. The possible reason could be the lower number of rainfall events throughout the experiment in North River field, which might have restricted the hydrolysis of fertilizer. The restriction in hydrolysis resulted in the transportation of fertilizer into the soil matrix as a dissolved component of the soil water (Fenn and Miyamoto, 1981; Bouwmeester et al., 1985). The average soil moisture content and soil temperature on sampling day two were higher than the sampling day one, which resulted in higher ammonium volatilization loss on sampling day two as compared to sampling day one (Figures 4-5 and 4-6). These results suggest that the combination of higher soil moisture contents and soil temperature might be the reason of higher ammonium volatilization losses within the wild blueberry fields.

Overall the results for this study demonstrated that there was less ammonium volatilization loss for VRS treatment, while the UR fertilization was at higher risk of

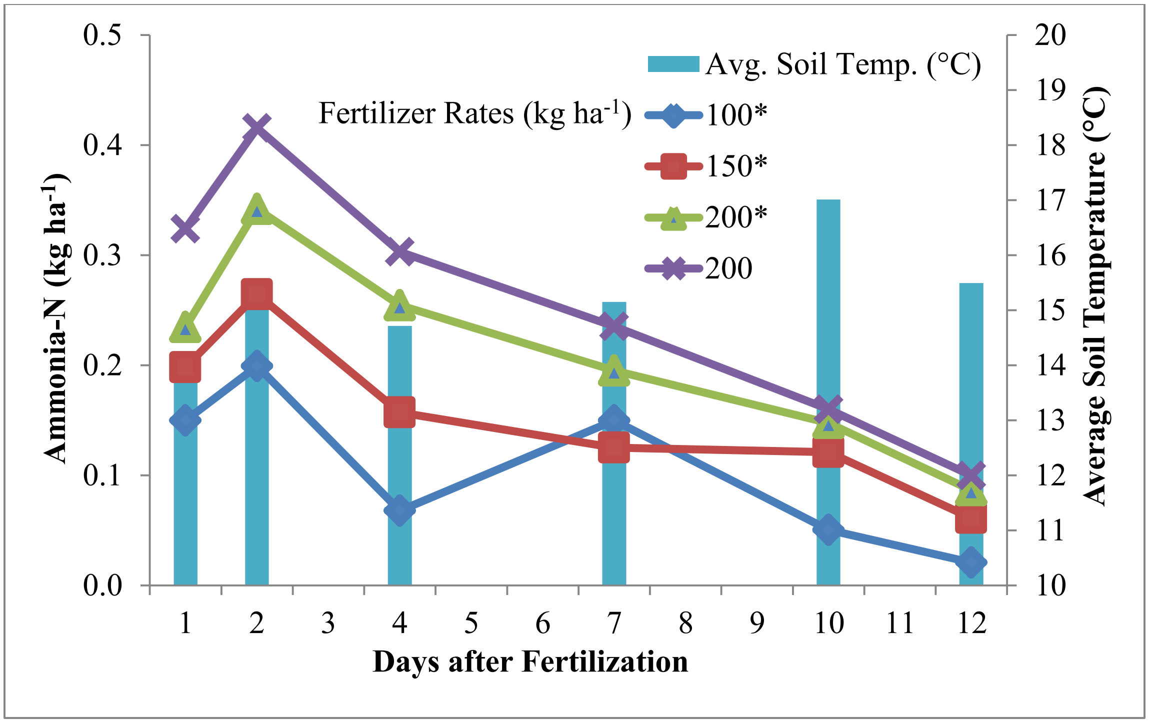

Figure 4-5. Ammonium volatilization losses from different fertilizer rates at the North River field, with average soil temperature.
*Rates were divided into three equal amounts and applied three times in VRS section.

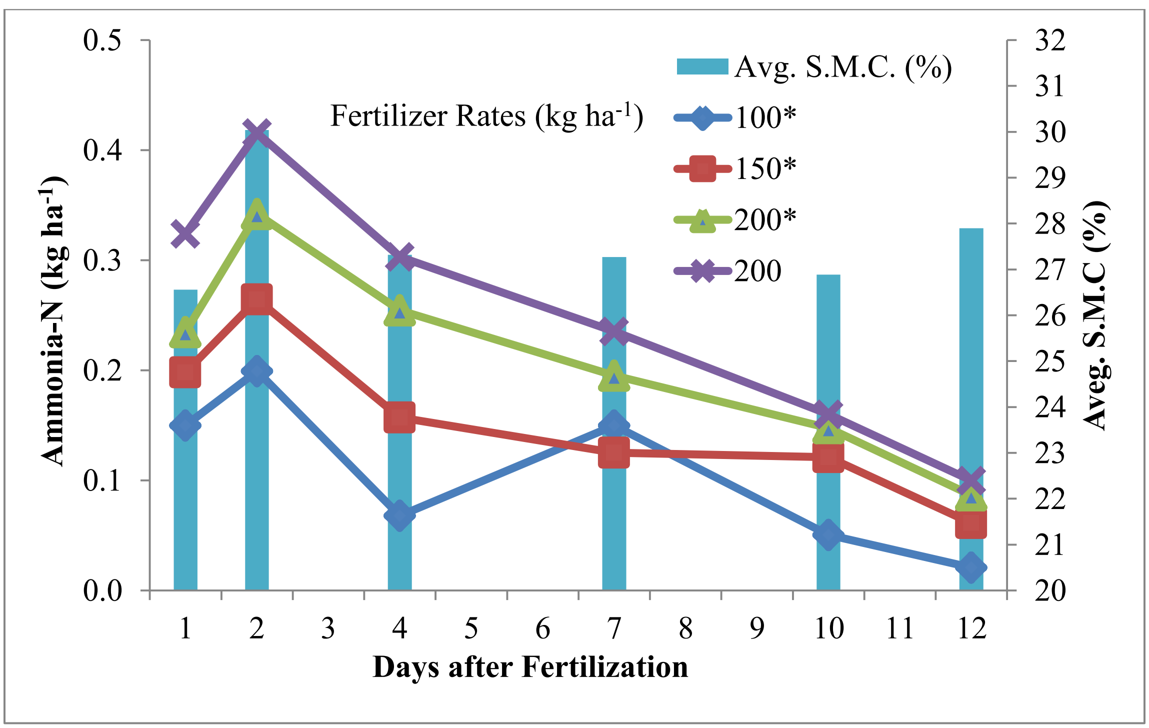

Figure 4-6. Ammonium volatilization losses from different fertilizer rates at the North River field, with average soil moisture content.
*Rates were divided into three equal amounts and applied three times in VRS section.

ammonium volatilization, suggesting the need for VRS fertilization in wild blueberry field to protect the environment from contamination. Due to the low input requirements and narrow plant nutrients range, there is the potential to adopt VRS technologies for wild blueberry cropping systems. Saleem et al. (2013) reported that the application of lower fertilizer rates based on the slope variation within wild blueberry fields can result in reduction of environmental contaminations. These results also support the hypothesis of Zaman et al. (2010) that unnecessary or over-fertilization in low lying areas may contaminate the environment and increase the cost of production. The results from both sites suggested that the VRS fertilization in wild blueberry fields can minimize the ammonium volatilization losses and can result in the reduction of environmental threats.

4.5 Summary and Conclusions

Considerable amount of ammonium volatilization losses were present in wild blueberry fields followed by fertilization, and the magnitude of these losses increased with the increase in the rate of fertilization. The ammonium volatilization loss was significantly lower in VRS sections when compared with the UR fertilization within the selected wild blueberry fields. The combinations of higher soil temperature and soil moisture content were contributed to higher ammonium volatilization losses within the selected sites. Lower fertilizer rates were used in VRS fertilizer sections as compared to the UR fertilizer sections which resulted in lower ammonium volatilization loss as well as economic saving. The results of this study indicated that the VRS fertilization based on the slope variation can be used in the wild blueberry cropping system to reduce the ammonium volatilization losses. This practice can also result in saving of significant amount of fertilizer and can improve environmental quality.

CHAPTER 5

THE IMPACT OF DIFFERENT FERTILIZER TREATMENTS ON SUBSURFACE WATER QUALITY

5.1 Introduction

Over the past several decades, increase in the use of fertilizer inputs has resulted in the rapid intensification of agriculture production. Apart from increasing the food production, environmental pollution has steadily increased due to off-farm agriculture inputs into the environment. In agriculture systems, N is an essential element for plant growth and N fertilizer is one of the main agricultural inputs used to increase food production in the past 50 years (Di and Cameron, 2002). Applications of N fertilizers to soils beyond the plant requirement for N can adversely affect the environment (Zhao et al., 2001). The major proportion of applied N fertilizer (organic and inorganic) becomes a part of soil organic matter, added into the surface water and groundwater through subsurface leaching, or is lost to atmosphere through volatilization (Di and Cameron, 2002). Leaching of N to the groundwater and surface water systems due to excessive application of N fertilizer has become a major concern for sustainable production. Some researchers have defined the leaching as a medium for the removal of nutrients completely out of soil profile, while others consider leaching as the translocation of nutrients within soil profile (Owens et al., 2000). Nitrate leaching is also a significant source of acidification (Havlin et al., 1999). Application of fertilizers to mineral soils has resulted in an increased leaching of nutrients to surface water systems (Van et al., 1998; Willems and Boers, 2004) and groundwater (Fraters et al., 1998). Mostly leaching of the N is in NO_3^--N form (Owens et al., 2000; Zhao et al., 2001) due to mobility of NO_3^--N in soils. Nutrients that are leached through the root zone are unavailable for plant uptake, and therefore lost from the soil-plant system. In most agricultural systems, NH_4^+ and NO_3^- are the main forms of inorganic N available to plants (Keeney and Walsh, 1972). The problem of N leaching and the contamination of groundwater are more severe in developed countries, due to the extensive use of N fertilizers (Spalding and Exner, 1993; Cameron et al., 1997). Recently, groundwater contamination caused by nutrients leaching has also been identified in developing countries where agricultural production has improved with the increasing use of fertilizers (Singh et al., 1995).

The majority of wild blueberry fields are situated in acidic soils, which are low in mineral nutrients and have gentle to severe topography (Trevett, 1962; Zaman et al., 2008a). Wild blueberries are considered to be inefficient users of nitrate (Townsend anf Hell, 1970) resulting in elevated losses of N either denitrification or leaching (Eaton and Patriquin, 1989). Wild blueberries have a narrow optimal range for nutrients; therefore, excessive N may cause the leaching of NH_4^+-N and NO_3^--N within wild blueberry fields (Thyssen and Percival, 2006). The rooting depth of the wild blueberry is very shallow (15 cm below the soil surface) (Trevett, 1962). High rainfall in combination with shallow rooting depth of can result in high leaching of inorganic N during blueberry production (Trevett, 1959; Thyssen and Percival, 2006). Substantial variation in soil/plant characteristics and topographic features of wild blueberry fields emphasize the need of site-specific management of fertilizers to maximize profit and reduce the risk of groundwater contamination (Saleem, 2012). The site-specific fertilization on the basis of variation in topography can reduce the risk of groundwater contamination. Saleem et al., (2013) implemented site-specific fertilization inputs by VR fertilization in wild blueberry fields. Results of their study indicated that higher rates of nutrient leaching were possible in low lying areas when compared with steep and moderate slope areas. Their results also suggested that the single variable rate application of fertilizers in wild blueberry fields can result in downslope nutrient movement due to heavy rainfalls, resulting in the nutrient depletion in the upslope and enrichment in the downslope areas. Therefore, VRS fertilization have the potential to decrease the nutrient leaching in low lying areas by providing nutrients throughout the spring of vegetative, year and also increase the input use efficiency for optimum plant growth of wild blueberries. Little efforts have been made to examine the nutrient leaching losses caused by the fertilization within selected blueberry fields. In this study, it was hypothesized that VRS fertilization on the basis of slope variation could decrease subsurface leaching when compared to URS and UR fertilization. Therefore, the objective of this research was to compare the impact of different fertilizer treatments on subsurface water quality.

5.2 Materials and Methods

To determine the effect of different fertilizer treatments on the nutrient leaching, two wild blueberry fields were selected and each field was divided into three sections (UR, URS, and VRS). Management zones were delineated on the basis of slope variation within the selected wild blueberry fields (Figure 3-4, Chapter 3). Prescription maps were generated for VRS fertilization in developed MZs (Figure 3-5, Chapter 3). The VRS sections were fertilized at different rates based on the prescription maps. The URS sections were fertilized at a constant fertilizer rate of 66 kg ha^{-1}. The VRS and URS sections were fertilized three times during the sprout year. The UR sections were fertilized only once including bare spots and weed patches, with a conventional rate of 200 kg ha^{-1}. Immediately following the first fertilization equal numbers of lysimeters were installed in each section of both fields at different strategic locations to cover the slope variability (Figure 3-9, Chapter 3). Leachate samples were collected from lysimeters after every heavy rainfall event (> 15 mm) using a manual vacuum pump. A vacuum of 0.8 kPa was created in lysimeter system prior to, and after rainfall events. Leachate samples were collected in 125 mL Nalgene sampling containers. Leachate samples were immediately stored in a freezer at 4 °C until they were analyzed at the Water Quality Research Laboratory, Department of Environmental Sciences, Faculty of Agriculture, Dalhousie University. The leachate samples were analyzed for NH_4^+-N and NO_3^--N using Technicon auto-flow analyzer. Detailed materials and methods are discussed in Chapter 3.

5.3 Statistical Analysis

The experimental design used for this experiment was split-plot design with fertilizer treatment as a main plot and slope as sub plot, and sampling date was considered as a repeated measure factor. The response variables were the concentrations of NH_4^+-N and NO_3^--N in soil leachates after fertilizer application. As the leachate samples from the lysimeters were collected after every heavy rainfall event, the concentrations of NH_4^+-N and NO_3^--N in the soil leachates from different fertilizer treatments were compared using RM ANOVA. The analysis of the collected data was performed using Mixed and GLM procedure of SAS (SAS, 2010) at the 5% level of significance. The validity of model assumptions (normal distribution, independence, and constant variance of the error terms) were verified by examining the residuals as described in Montgomery (Montgomery, 2013). Transformations were applied to the response measurements if the assumptions were violated and were back-transformed to the original scale for reporting results. Furthermore, MMC was completed for significant ($p < 0.05$) effects of the fertilizer treatments using the LSD at the 5% level of significance. The statistical analysis was performed using SAS 9.3 and Minitab 16 statistical software.

5.4 Results and Discussion

5.4.1 Nitrate Nitrogen Leaching

5.4.1.1 Cooper Field

Results of RM ANOVA revealed that the overall mean NO_3^--N concentrations in the leachate samples were significantly ($p < 0.05$) different for all fertilization treatments (Table 5-1). The mean NO_3^--N concentration in the VRS fertilization treatment section was significantly lower than the URS and UR fertilization treatment sections of the Cooper field. The mean NO_3^--N concentrations in leachate samples for VRS fertilization ranged from 2.54 to 3.95 mg L^{-1}, while mean values of NO_3^--N concentrations for URS and UR fertilization ranged from 3.99 to 7.71 mg L^{-1} and 4.12 to 7.92 mg L^{-1}, respectively (Table 5-1). Thus, there is the possibility of potential adverse impact of NO_3^--N on the subsurface water. This problem may be reduced by the VRS fertilization treatment. Higher concentrations of NO_3^--N were recorded under UR fertilization than URS fertilization, but non-significantly different for all MZs throughout the experiment period. In Z1, the concentrations of NO_3^--N for all fertilization treatments were similar with the mean values ranged from 3.95 and 4.12 mg L^{-1} (Table 5-1). The same fertilizer rate could be the reason for non-significant difference in NO_3^--N concentrations in Z1 of all treatment sections. In Z2, the mean values of NO_3^--N in the leachate samples were found to be significantly lower in VRS fertilization treatment section as compare to UR fertilization treatment section, throughout the monitoring period. The possible reason

Table 5-1. Effects of the VRS, URS, and UR fertilization treatments on mean NO_3^--N concentrations in leachates for the Cooper field.

Slope Zone	**Fertilization Method**	**June 27 (mg L^{-1})**	**July 24 (mg L^{-1})**	**August 12 (mg L^{-1})**	**August 28 (mg L^{-1})**	**September 9 (mg L^{-1})**	**Mean (mg L^{-1})**
Zone 1	VRS	2.42ab	3.27b	4.73b	5.09b	4.26b	3.95c
	URS	2.35ab	3.29b	4.85b	5.14b	4.33b	3.99c
	UR	2.44ab	3.56b	4.89b	5.31b	4.39b	4.12c
Zone 2	VRS	2.52ab	3.27b	4.51b	4.81b	4.16b	3.85c
	URS	2.95ab	4.98a	7.35a	10.92a	9.33a	7.11b
	UR	3.16ab	5.15a	7.53a	11.25a	9.79a	7.38ab
Zone 3	VRS	2.29b	2.81b	2.37c	2.67c	2.58c	2.54d
	URS	3.11ab	5.46a	8.21a	11.86a	9.89a	7.71ab
	UR	3.38a	5.67a	8.33a	12.18a	10.06a	7.92a
Mean	VRS	2.41a	3.11b	3.87b	4.19b	3.67b	3.45b
	URS	2.80a	4.58a	6.80a	9.31a	7.85a	6.27a
	UR	2.99a	4.79a	6.92a	9.58a	8.08a	6.47a

RM ANOVA

Effect	DF	F-value	p-value
Fertilization Method (F)	2	171.01	0.0001
Slope Zone (S)	2	84.98	<0.0001
Time (T)	4	138.23	<0.0001
F × S	4	45.61	<0.0001
F × T	8	15.06	<0.0001
F × S × T	16	4.09	<0.0001

Means in the same column followed by the same letter are not significantly different at the 5% level of significance using LSD.

for the lower concentrations of NO_3^--N could be due to lower fertilizer application rate in VRS section when compared with UR section. Similar trend was observed for Z3 suggesting the significant difference of NO_3^--N concentrations between VRS and UR fertilization treatments with the mean values of 2.54 and 7.92 mg L^{-1}, respectively (Table 5-1). The enrichment of NO_3^--N concentrations for UR fertilization might be due to higher fertilizer application rate (200 kg ha^{-1}) in Z3 as compare to VRS (100 kg ha^{-1}). Other possible reason for higher NO_3^--N concentrations for UR fertilization in Z3 could be the accumulation of nutrients in low lying areas. In general, for Z2 and Z3 the NO_3^--N concentration in the leachate samples were significantly different for VRS and UR fertilization treatments (Table 5-1). These results were in agreement with the findings of Saleem et al. (2013) and Chattha (2013) who stated higher values of NO_3^--N in low lying areas of wild blueberry fields. Significant difference in NO_3^--N concentrations, with respect to the slope variation suggested that the VRS fertilization in wild blueberry fields can minimize the NO_3^--N leaching. Results suggested that the VRS fertilization is a better option to reduce the subsurface contamination through nutrient leaching (Table 5-1).

Lower fertilizer rates were used in different MZs of the VRS section, which resulted in lower N leaching as compare to URS and UR sections. Throughout the study period, the mean values of NO_3^--N were 3.45, 6.27, and 6.47 mg L^{-1}, for VRS, URS and UR sections, respectively (Table 5-1). Results suggested that VRS sections contributed less towards N leaching. Split fertilizer rates might be the reason for lower nutrient leaching in the VRS as compare to UR and URS treatments. The concentrations of NO_3^--N in leachates increased with the time in the URS and UR sections, possibly due to the nitrification process in wild blueberry fields during the growing season. Results were found in agreement with the findings of Thyssen and Percival (2006) who reported the increase in NO_3^--N concentration with the passage of time in wild blueberry soils. Although the acidic nature of the wild blueberry field causes a reduction in nitrification process, nitrification still proceeds slowly. Low pH conditions and presence of widespread blueberry plants can enhance the activity of the autotrophic nitrifying bacteria which play a vital role in the generation of NO_3^--N. Based on these results, it can be concluded that the nitrifying activities may be contributing to NO_3^--N leachate in wild blueberry fields. These results were also supported by other researchers (Noyes and Conner, 1919; Meek and Lipman, 1922).

Overall, NO_3^--N leaching from the VRS treatment section was significantly lower than the URS and UR treatment sections of the Cooper field. Lower fertilizer rates for VRS fertilization resulted in lower NO_3^--N leaching loss as well as in economic saving. These results were also supported by previous studies for different cropping systems (Shahandeh et al., 2005; Zaman et al., 2006).

5.4.1.2 North River Field

Results of RM ANOVA statistics revealed that the NO_3^--N concentrations in leachate samples were significantly different ($p < 0.05$) for VRS, URS, and UR fertilization treatments in North River field (Table 5-2). The mean values of NO_3^--N concentrations were found to be 2.77, 6.51, and 6.76 mg L^{-1} for the VRS, URS, and UR fertilization treatments, respectively (Table 5-2). The NO_3^--N concentration in VRS treatment section ranged from 2.43 to 2.85 mg L^{-1}. Split fertilizer rates might be the reason for lower NO_3^--N concentrations in leachate samples as compare to URS and

Table 5-2. Effects of the VRS, URS, and UR fertilization treatments on mean NO_3^--N concentrations in leachates for the North River field.

Slope Zone	**Fertilization Method**	**May 25 (mg L^{-1})**	**June 29 (mg L^{-1})**	**July 23 (mg L^{-1})**	**August 10 (mg L^{-1})**	**Mean (mg L^{-1})**
Zone 1	VRS	1.73c	2.22b	3.58c	3.86c	2.85c
	URS	1.83c	2.33b	3.79c	3.80c	2.93c
	UR	1.95c	2.40b	3.91c	3.74c	3.00c
Zone 2	VRS	1.45c	3.13b	3.80c	3.78c	3.04c
	URS	3.21b	7.12a	10.02b	10.36b	7.68b
	UR	3.47ab	7.19a	10.30b	10.64b	7.90b
Zone 3	VRS	1.12c	2.16b	3.15c	3.28c	2.43c
	URS	3.99ab	8.19a	11.81ab	11.63ab	8.91a
	UR	4.39a	8.64a	12.21a	12.32a	9.39a
Mean	VRS	1.43b	2.51b	3.51b	3.64b	2.77b
	URS	3.01a	5.88ab	8.54a	8.60a	6.51a
	UR	3.27a	6.07a	8.81a	8.90a	6.76a

RM ANOVA

Effect	DF	F-value	p-value
Fertilization Method (F)	2	205.00	<0.0001
Slope Zone (S)	2	185.77	<0.0001
Time (T)	3	138.20	<0.0001
F × S	4	52.57	<0.0001
F × T	6	9.18	<0.0001
F × S × T	12	2.51	0.0089

Means in the same column followed by the same letter are not significantly different at the 5% level of significance using LSD.

UR sections. The NO_3^--N concentrations in leachate samples collected from UR treatment section were higher than the URS treatment section. However, both treatments were found to be non-significantly different from each other for all MZs throughout the experiment period. The NO_3^--N concentrations from VRS and UR fertilization sections were found to be significantly different except in Z1. Same fertilizer application rate in Z1 might have resulted in non-significant difference among both treatments (Figure 3-5, Chapter 3). Overall, the mean values for NO_3^--N concentrations in leachate samples for UR fertilization treatment were higher than the VRS fertilization treatment with the mean values of 6.76 and 2.77 mg L^{-1}, respectively (Table 5-2). These results suggest that the VRS fertilization would have a lower risk of subsurface water contamination as compared to UR and URS fertilization. In general, an increasing trend of NO_3^--N concentration was observed throughout the monitoring period, suggesting the slow process of nitrification (Table 5-2).

The mean values of NO_3^--N concentrations in Z1, Z2 and Z3 of VRS section were found to be non-significantly different from each other (Table 5-2). Whereas, the mean NO_3^--N concentrations in all three slope zones of URS and UR fertilization treatments were significantly different from each other (Table 5-2). Similar to the Cooper field, the UR fertilization treatment showed significantly higher values of NO_3^--N concentrations as compared to VRS fertilization treatments in Z2 and Z3 (Table 5-2). Differences in the fertilizer rates for Z3 of UR (200 kg ha^{-1}) and VRS (100 kg ha^{-1}) sections could be one of the reasons for higher concentration of NO_3^--N leaching. Other possible reasons for higher mean values of NO_3^--N in Z3 for UR treatment could be the erosion of soil particles and accumulation of nutrients from steep slopes to low lying areas due to heavy rainfall. The results of this study are in agreement with the findings of Saleem et al. (2013) in wild blueberry cropping systems. They reported that the NO_3^--N leaching losses in a variable fertilization sections were significantly lower than the uniformly fertilized fields.

Overall the results demonstrated that there was lower leaching of NO_3^--N under VRS treatment sections. However, the URS and UR treatment sections were at higher risk of NO_3^--N leaching. These results also support the hypothesis of Zaman et al. (2010) that unnecessary fertilization in low lying areas may deteriorate groundwater quality and increase the cost of production within wild blueberry fields. Therefore, the VRS fertilization based on slope variation may help to reduce the groundwater contamination.

5.4.2 Ammonium Nitrogen Leaching

5.4.2.1 Cooper Field

Results of RM ANOVA showed a significant differences ($p < 0.05$) in the mean values of NH_4^+-N concentrations for all fertilization treatments (VRS, URS, and UR). Overall, at the beginning of the growing season the NH_4^+-N concentrations were higher and the mean values on the first sampling day (June 27) were 3.58, 5.26, and 5.88 mg L^{-1} for VRS, URS, and UR fertilization treatments, respectively (Table 5-3). The NH_4^+-N concentrations in leachate samples were higher for UR section than URS section; however, both treatments were found to be non-significantly different for all MZs. The mean NH_4^+-N concentrations in all three slope zones of VRS treatment section were lower ranging from 1.60 to 3.32 mg L^{-1}, as compared to URS and UR treatment sections. Split fertilizer rates might be the reason for lower NH_4^+-N concentrations in leachate samples for VRS sections as compare to URS and UR sections. In Z1, the NH_4^+-N

Table 5-3. Effects of the VRS, URS, and UR fertilization treatments on mean NH_4^+-N concentrations in leachates for the Cooper field.

Slope Zone	**Fertilization Method**	**June 27 (mg L^{-1})**	**July 24 (mg L^{-1})**	**August 12 (mg L^{-1})**	**August 28 (mg L^{-1})**	**September 9 (mg L^{-1})**	**Mean (mg L^{-1})**
Zone 1	VRS	4.62d	4.35e	4.13d	2.02de	1.49bcd	3.32c
	URS	4.88cd	4.65de	4.57cd	2.23d	1.34cd	3.53c
	UR	5.26cd	4.90cde	4.67c	2.93cd	1.63bc	3.88c
Zone 2	VRS	3.56e	3.04f	2.83e	1.64e	1.04de	2.42d
	URS	5.19c	5.23bc	4.82bc	2.41d	1.61bc	3.85c
	UR	5.70b	5.33b	5.06bc	3.99b	1.94ab	4.40b
Zone 3	VRS	2.56f	1.97g	1.60f	1.03f	0.84e	1.60e
	URS	5.70b	5.52b	5.32b	3.38c	1.76bc	4.34b
	UR	6.68a	6.40a	6.17a	5.47a	2.26a	5.39a
Mean	VRS	3.58b	3.12b	2.85b	1.56b	1.12b	2.45b
	URS	5.26a	5.13a	4.90a	2.67ab	1.57ab	3.91a
	UR	5.88a	5.54a	5.30a	4.13a	1.94a	4.56a

RM ANOVA

Effect	DF	F-value	p-value
Fertilization Method (F)	2	401.69	<.0001
Slope Zone (S)	2	4.74	0.0112
Time (T)	4	113.33	<.0001
F × S	4	83.13	<.0001
F × T	8	14.36	<.0001
F × S × T	16	2.50	0.0036

Means in the same column followed by the same letter are not significantly different at the 5% level of significance using LSD.

concentrations in leachate samples were non-significantly different for VRS, URS, and UR treatment with the mean values of 3.32, 3.53, and 3.88 mg L^{-1}, respectively (Table 5-3). Similar fertilizer rates (200 kg ha^{-1}) in Z1 of all treatments could be the reason for similar results in Z1. Values for NH_4^+-N were three times higher in Z3 of the UR fertilization treatment as compared to VRS fertilization treatment with the mean values of 5.39 and 1.60 mg L^{-1}, respectively (Table 5-3). The lower concentrations of NH_4^+-N in Z3 might be due to 50% reduction in the amount of applied fertilizer for VRS treatment section as compare to UR treatment section. The other possible reason for higher mean values of NH_4^+-N in Z3 for UR section could be the accumulation of nutrients from steep slopes to low lying areas. Overall, the fertilization treatments were found to be significantly different for all slope zones with the interaction of slope zone and time (Table 5-3). These results were in agreement with the findings of Saleem (2012).

A decreasing trend in NH_4^+-N concentrations was observed after every rainfall event, throughout the experiment period (Table 5-3). This reduction in NH_4^+-N concentrations might be due to plant uptake, ammonia volatilization, ammonium loss in runoff, leaching, and nitrification (Saleem et al., 2013). The results of this study were also in agreement with the findings of Thyssen and Percival (2006) who reported the decrease in the concentration of NH_4^+-N and increase in nitrate concentration with the passage of time within wild blueberry fields. In the wild blueberry fields, Farooque (2010) reported the increase in the soil pH below root zone. Increase in the soil pH can speed up the process of nitrification of the ammonium ions which ultimately leave the root zone and can cause groundwater pollution.

5.4.2.2 North River Field

The NH_4^+-N concentrations in leachate samples for UR fertilization treatment were significantly ($p < 0.05$) higher than VRS treatment section with the mean values of 3.80 and 2.10 mg L^{-1}, respectively (Table 5-4). The NH_4^+-N concentrations in leachate samples were higher for UR treatment when compared with the URS treatment. These concentrations were non-significantly different for all MZs throughout the monitoring period. All treatments were non-significantly different in Z1 with the mean values of 2.61, 2.94, and 3.22 mg L^{-1} for VRS, URS, and UR treatments, respectively (Table 5-4). The concentrations of NH_4^+-N in Z2 and Z3 of VRS treatment were significantly lower than UR fertilization treatment throughout the study period. The mean values of NH_4^+-N concentrations in Z2 and Z3 of VRS treatment were 2.15 and 1.53 mg L^{-1}, respectively. In UR treatment section, the mean values of NH_4^+-N concentrations were 3.71 and 4.45 mg L^{-1} in Z2 and Z3, respectively (Table 5-4). Lower fertilizer rates used in Z2 and Z3 of VRS treatment might be the reason for lower NH_4^+-N concentrations leachate samples when compared with UR treatment section. Overall, throughout the study period (May 25, 2013 to August 10, 2013) decreasing trends for NH_4^+-N concentrations was observed for all treatments (VRS, URS, and UR) (Table 5-4). At the start of the experiment, the mean values of NH_4^+-N concentrations for VRS fertilization treatment were 4.35, 3.30, and 2.80 mg L^{-1} for Z1, Z2, and Z3, respectively, (Table 5-4). These results indicated that the magnitude of NH_4^+-N concentration in the leachates decreased with the decrease in the rate of fertilizer application.

Table 5-4. Effects of the VRS, URS, and UR fertilization treatments on mean NH_4^--N concentrations in leachates for the North River field.

Slope Zone	Fertilization Method	May 25 (mg L^{-1})	June 29 (mg L^{-1})	July 23 (mg L^{-1})	August 10 (mg L^{-1})	Mean (mg L^{-1})
Zone 1	VRS	4.35c	2.87de	1.90de	1.32ef	2.61c
	URS	4.73bc	3.33cde	2.21cd	1.48ef	2.94c
	UR	5.01bc	3.67bcd	2.55bcd	1.67de	3.22c
Zone 2	VRS	3.30d	2.69e	1.42ef	1.20f	2.15d
	URS	5.05bc	3.53cde	2.66bc	1.88cd	3.28c
	UR	5.43b	4.16bc	3.12ab	2.15bc	3.71c
Zone 3	VRS	2.80d	1.56f	1.00f	0.78g	1.53e
	URS	6.51a	4.22ab	3.13ab	2.25b	4.03b
	UR	6.84a	4.88a	3.47a	2.61a	4.45a
Mean	VRS	3.48b	2.37b	1.44b	1.10b	2.10b
	URS	5.43a	3.69a	2.66a	1.87ab	3.41a
	UR	5.76a	4.24a	3.04a	2.14a	3.80a

RM ANOVA

Effect	DF	F-value	p-value
Fertilization Method (F)	2	155.35	0.0002
Slope Zone (S)	2	8.81	0.0004
Time (T)	3	282.24	<0.0001
F × S	4	27.62	<0.0001
F × T	6	4.16	0.0013
F × S × T	12	1.17	0.3249

Means in the same column followed by the same letter are not significantly different at the 5% level of significance using LSD.

5.4.3 Impact of Soil Properties on Nutrient Leaching

5.4.3.1 Cooper Field

Results of ANOVA suggested that the sand content was significantly different ($p < 0.05$) in Z1 and Z3 of the different treatments (Table 5-5). The mean comparison showed that the sand content in Z3 of VRS treatment section was significantly lower as compared to Z1 and Z2, with mean values of 50.5, 61.8, and 57.8%, respectively (Table 5-5). Under URS and UR treatment sections, non-significant differences were observed between sand contents of Z1 and Z2. Whereas, sand contents in Z1 and Z2 were found to be significantly higher than Z3 of URS and UR treatment sections (Table 5-5). The comparison of mean clay contents in all slope zones of URS and UR treatment sections indicated non-significant difference with mean value ranging from 7.8 to 12.4%. The mean values for clay content in VRS treatment section were 7.3, 9.0, and 13.1% for Z1, Z2, and Z3, respectively indicating higher clay content in low lying areas when compared to steep slope areas of the field. Movement of smaller and lighter particles and their accumulation in low lying areas of the field with surface runoff might be the reason for the higher values of clay contents in Z3 as compare to Z1 and Z2. The silt content in all three slope zones of VRS, URS, and UR treatment sections were non-significantly different from each other. The silt content in Z1 of VRS, URS, and UR treatment sections was significantly lower as compared to silt content in Z3 of the same treatment sections (Table 5-5).

For the VRS, URS, and UR treatment sections, the comparison of mean values for SOM content in all three slope zones indicated that the Z3 contained significantly higher values of SOM with mean values of 9.9, 9.8, and 9.9%, respectively (Table 5-5).

Table 5-5. Comparisons of soil properties between different slope zones for the Cooper field.

Slope Zone	Fertilization Method	Soil Properties							
		Sand (%)	Clay (%)	Silt (%)	SOM (%)	EC (BF) (µS cm^{-1})	EC (AF) (µS cm^{-1})	Soil pH (BF)	Soil pH (AF)
Zone 1	VRS	61.8a	7.3c	30.9c	7.9b	55.0b	65.6c	4.7a	4.6a
	URS	59.7ab	8.7bc	31.6c	7.8b	54.7b	67.8c	4.8a	4.8a
	UR	60.3ab	7.8c	31.8c	7.9b	54.8b	68.4c	4.7a	4.6a
Zone 2	VRS	57.8ab	9.0abc	33.1bc	8.1b	55.7ab	69.5b	4.9a	4.8a
	URS	56.4b	9.5abc	34.1abc	8.2b	55.9ab	70.9ab	4.7a	4.6a
	UR	58.4ab	8.0c	33.6abc	8.0b	56.1ab	71.9ab	4.7a	4.8a
Zone 3	VRS	50.5c	13.09a	36.5ab	9.9a	57.4a	72.0ab	4.8a	4.8a
	URS	51.0c	12.4ab	36.5ab	9.8a	57.7a	74.0a	4.9a	4.8a
	UR	51.7c	11.4abc	36.8a	9.9a	58.2a	75.2a	4.8a	4.7a

Means in the same column followed by the same letter are not significantly different at the 5% level of significance using LSD.
BF= Before Fertilization
AF= After Fertilization

Whereas, the mean values of SOM in Z1 and Z2 were found to non-significantly different for all three treatment sections (Table 5-5). These results were in agreement with the findings of Beckie et al. (1997), Zaman et al. (2009), Saleem (2012), and Chattha (2013). Higher clay contents and SOM in low lying areas can results in the enrichment of soil nutrients in these areas of the fields. Before fertilization, the mean values of soil EC in Z3 of VRS, URS, and UR treatment sections were significantly higher with mean value 57.39, 57.72, and 58.19 $\mu S\ cm^{-1}$, respectively. After fertilization the mean values of EC in Z1, Z2, and Z3 of VRS treatment section were 65.60, 69.48, and 72.02 $\mu S\ cm^{-1}$, respectively indicating higher EC in low lying areas as compare to steep slope areas of the Cooper field (Table 5-5). After fertilization, the URS and UR treatment sections also showed the higher values of EC in low lying areas (Z3) with mean value 73.96 and 75.20 $\mu S\ cm^{-1}$, respectively. The soil pH showed non-significant difference, before and after fertilization in all three slope zones of VRS, URS, and UR sections (Table 5-5). Results suggested that fertilization has not affected the soil pH under all three fertilization treatments (Table 5-5).

The statistical analysis of soil NO_3^--N in all three slope zones of each treatment section before and after fertilization showed significantly higher values of soil NO_3^--N in Z3 of each treatment section (Table 5-6). However, the soil NO_3^--N in Z1, Z2, and Z3 of all treatment sections were found to be non-significantly different from each other before fertilization. The mean values of NO_3^--N in Z1 and Z2 of the VRS treatment section before fertilization were 2.53 and 2.94 mg kg^{-1}, while in Z3 the mean values of NO_3^--N was 3.82 mg kg^{-1}, indicating higher amount of nutrient in low lying areas of the field (Table 5-6). The presence of higher amounts of clay and SOM in Z3 also seems

Table 5-6. Comparison of mean soil NO_3^--N and NH_4^+-N with mean NO_3^--N and NH_4^+-N concentration in leachates for the Cooper field.

Slope Zone	**Fertilization Method**	**NO_3^--N (BF)** (mg kg^{-1})	**NO_3^--N (AF)** (mg kg^{-1})	**Mean NO_3^--N leaching** (mg L^{-1})	**NH_4^+-N (BF)** (mg kg^{-1})	**NH_4^+-N (AF)** (mg kg^{-1})	**Mean NH_4^+-N leaching** (mg L^{-1})
Zone 1	VRS	2.53b	4.04d	3.95c	3.54a	5.04e	3.32c
	URS	2.59b	4.13d	3.99c	3.60a	5.20de	3.53c
	UR	2.56b	4.25cd	4.12c	3.65a	5.31de	3.88c
Zone 2	VRS	2.94ab	4.32cd	3.85c	3.70a	5.72cd	2.42d
	URS	2.98ab	5.26b	7.11b	3.68a	6.25cd	3.85c
	UR	2.96ab	5.65b	7.38ab	3.75a	6.80bc	4.40b
Zone 3	VRS	3.82a	5.10b	2.54d	3.89a	6.33cd	1.60e
	URS	3.87a	6.16a	7.71ab	3.99a	7.81ab	4.34b
	UR	3.89a	6.62a	7.92a	3.93a	8.23a	5.39a

Treatment Factor	Mixed ANOVA					
Fertilization Method (F)	NS	*	***	NS	**	***
Slope Zone(S)	***	***	***	NS	***	*
F x S	NS	NS	***	NS	NS	***

Means in the same column followed by the same letter are not significantly different at the 5% level of significance using LSD.
BF= Before Fertilization
AF= After Fertilization
*Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level
NS = Non-significant

to be contributing in retention of nutrients in low lying areas. It could be due to the accumulation of nutrients from steep slopes to the low lying areas with surface runoff. Before fertilization, the soil NH_4^+-N concentrations in all three slope zones of each treatment section showed non-significant differences. After fertilization, the trend for soil NH_4^+-N were similar to those obtained for soil NO_3^--N (Table 5-6). Overall, an increase in soil NO_3^--N and NH_4^+-N was observed after fertilization. These results emphasize the need for VRS fertilization in wild blueberry fields on the basis of slope variability.

5.4.3.2 North River Field

Results showed that the soil properties in different slope zones were significantly different ($p < 0.05$) for the North River field (Table 5-7). The sand contents in Z1 were 56.63, 54.80, and 55.95% for VRS, URS, and UR treatment sections, respectively. A reduction in sand content was observed moving from Z1 to Z3 of the field with mean sand contents of 51.89, 51.38, and 50.93% in Z3 of VRS, URS, UR treatment sections, respectively (Table 5-7). The clay contents were significantly increased from Z1 to Z3 in the VRS, URS, and UR treatment sections with mean values of 11.18, 11.43, and 11.33% in Z3, respectively. However, silt content in all three slope zones of VRS, URS, and UR treatment sections were non-significantly different from each other, except for Z2 of VRS, URS, and UR treatment sections. The silt content in Z2 of VRS, URS, and UR treatment sections was significantly lower as compared to silt content in Z3 of the same sections (Table 5-7). The SOM was significantly higher in Z3 under VRS, URS, and UR treatment sections as compared to Z1 and Z2 (Table 5-7). Higher values of SOM and clay content in low lying areas can result in higher nutrients retention in low lying areas of the fields. The trends of variation in the mean values of soil EC were similar to

Table 5-7. Comparisons of soil properties between different slope zones for the North River field.

Slope Zone	Fertilization Method	Soil Properties							
		Sand (%)	**Clay (%)**	**Silt (%)**	**SOM (%)**	**EC (BF) (µS cm^{-1})**	**EC (AF) (µS cm^{-1})**	**Soil pH (BF)**	**Soil pH (AF)**
Zone 1	VRS	56.6a	9.1c	34.3abc	8.1b	54.6b	66.3c	5.1a	4.8a
	URS	54.8abc	9.7c	35.5abc	8.0b	55.3b	68.8bc	5.0a	4.9a
	UR	56.0ab	8.4c	35.6abc	7.9b	55.9ab	70.3abc	5.0a	4.9a
Zone 2	VRS	55.6abc	11.1b	33.3c	8.0b	55.3b	69.5bc	5.0a	4.9a
	URS	54.0abc	12.9a	33.1c	8.1b	55.9ab	73.6ab	4.9a	4.9a
	UR	54.0abc	12.4a	33.7bc	8.2b	55.5b	74.3ab	4.9a	4.9a
Zone 3	VRS	51.9bcd	11.2b	36.9ab	9.9a	56.9a	72.8ab	4.9a	5.0a
	URS	51.4cd	11.4b	37.2ab	9.6a	57.6a	75.1ab	5.0a	5.0a
	UR	50.9d	11.3b	37.7a	9.3a	57.7a	76.2a	4.9a	5.0a

Means in the same column followed by the same letter are not significantly different at the 5% level of significance using LSD.
BF= Before Fertilization
AF= After Fertilization

the Cooper field (Table 5-7). Similar to the Cooper field, the soil pH showed non-significant differences before and after fertilization in all three slope zones of VRS, URS, and UR treatment sections.

Before fertilization, the soil NH_4^+-N in all three slope zones of each treatment section showed a non-significant difference (Table 5-8). However, after fertilization the mean values for soil NH_4^+-N were increased significantly in Z3 under VRS, URS, and UR treatment sections as compared to Z1 with mean values of 5.80, 6.47, and 7.63 mg kg^{-1}, respectively (Table 5-8). Overall, the concentration of soil NH_4^+-N increased after fertilization in all treatment sections. Before fertilization, significant difference in soil NO_3^--N among all three slope zones were observed for VRS, URS, and UR treatment sections, with Z3 having the highest and Z1 was having the lowest soil NO_3^--N. The mean values for soil NO_3^--N in Z3 before fertilization were 3.82, 3.87, and 3.89 mg kg^{-1} for VRS, URS, and UR treatment sections, respectively (Table 5-8). Whereas, in Z1 before fertilization the mean values for soil NO_3^--N were 2.62, 2.66, and 2.73 mg kg^{-1} for VRS, URS, and UR treatment sections, respectively (Table 5-8). After fertilizer application, the soil NO_3^--N was increased in all slope zones of treatment sections. Overall, results showed that the fertilization increased the values of soil NH_4^+-N and NO_3^--N (Table 5-8). Low lying areas of the field showed relatively higher values of soil NO_3^--N and NH_4^+-N which can lead to subsurface water contamination through NO_3^--N and NH_4^+-N leaching (Saleem et al., 2013). Therefore, VR fertilization based on the slope variation in conjunction with VRS may be useful in wild blueberry cropping system to increase nutrient uptake efficiency and to reduce subsurface water contamination through nutrient leaching.

Table 5-8. Comparison of mean soil NH_4^+-N and NO_3^--N with mean NH_4^+-N and NO_3^--N concentration in leachates for the North River field.

Slope Zone	**Fertilization Method**	**NO_3^--N (BF) (mg kg^{-1})**	**NO_3^--N (AF) (mg kg^{-1})**	**Mean NO_3^--N leaching (mg L^{-1})**	**NH_4^+-N (BF) (mg kg^{-1})**	**NH_4^+-N (AF) (mg kg^{-1})**	**Mean NH_4^+-N leaching (mg L^{-1})**
Zone 1	VRS	2.62b	4.18d	2.85c	3.70a	5.11d	2.61c
	URS	2.66b	4.36cd	2.93c	3.76a	5.29cd	2.94c
	UR	2.73b	4.62cd	3.00c	3.81a	5.58cd	3.22c
Zone 2	VRS	2.97ab	4.55cd	3.04c	3.81a	5.37cd	2.15d
	URS	3.04ab	5.06cd	7.68b	3.93a	5.77bcd	3.28c
	UR	3.13ab	5.64bc	7.90b	4.00a	6.95ab	3.71c
Zone 3	VRS	3.82a	5.14cd	2.43c	3.95a	5.80bc	1.53e
	URS	3.87a	6.68ab	8.91a	4.07a	6.47ab	4.03b
	UR	3.89a	7.74a	9.39a	4.26a	7.63a	4.45a
Treatment Factor		Mixed ANOVA					
Fertilization Method (F)		NS	**	***	NS	**	***
Slope Zone(S)		***	***	***	NS	**	*
F x S		NS	NS	***	NS	NS	***

Means followed by different letters are significantly different at a significance level of 0.05.
BF= Before Fertilization
AF= After Fertilization
*Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level
NS = Non-significant

5.5 Summary and Conclusions

The VRS fertilization significantly ($p < 0.05$) decreased NO_3^--N and NH_4^+-N loading in subsurface water as compared to the URS and UR treatments within selected fields. The concentrations of NO_3^--N and NH_4^+-N in the leachate samples were higher in low lying areas of URS and UR fertilization treatments as compared to VRS treatment in selected fields. Higher quantities of clay, SOM, and EC were observed in low lying areas as compared to steep slope and moderate slope areas of both fields. This could be the reason for higher values of NO_3^--N and NH_4^+-N in the leachates samples.

Based on these results it is proposed that MZs based on slope can be used to implement VRS fertilization in wild blueberry fields. It is also suggested that the VRS fertilization may increase nutrient uptake efficiency by providing the nutrients to plants throughout the sprout year. Moreover, we can infer that VRS fertilization will reduce cost of production and groundwater contamination by reducing the inorganic nitrogen leaching through the root zone for wild blueberry cropping system.

CHAPTER 6

IMPACT OF DIFFERENT FERTILIZER TREATMENTS ON PLANT GROWTH AND FRUIT YIELD

6.1 Introduction

Crop yields vary both spatially and temporally within wild blueberry fields on the same farm. The factors affecting the crop quality and yield may include site characteristics, soil properties, climate, and crop management practices (Farooque, 2010; Wong and Asseng, 2006). The identification of the spatial variability of soil properties is essential to determine appropriate management practices. The determination of the spatial variability of soil properties is also important to achieve better understanding of the complex interactions between soil and environmental factors. Zaman et al. (2009) found that the spatial variability of soil properties emphasized the need of site-specific crop management to increase the profit margins and mitigate environmental risks. There are number of management practices and environmental conditions that seem to have influence on fruit yield in wild blueberry cropping systems. Management practices may include weed control, insect and disease control, fertilizer applications, and pruning (Hall et al., 1979). The differences in soil conditions (Trevett, 1972) and natural variation within stands can also have a significant impact on fruit yield (Hepler and Yarborough, 1991). Site-specific management of agricultural practices refers to applying inputs in accordance with the specific requirements of crop and soil (Wong and Asseng, 2006). In wild blueberry cropping system, growers are usually well aware of spatial variability within fields (Zaman et al., 2008 and 2010a); however, they do not have adequate tools to characterize, quantify, and manage their fields on the basis of this variability. To manage the spatial variability within wild blueberry fields, precision agriculture technologies can be used.

Currently, crop management practices are implemented uniformly without considering the substantial variation in soil/plant characteristics, presence of bare spots, topographic features, and fruit yield (Zaman et al., 2008a). Uniform fertilization may result in over-fertilization or under-fertilization due to the gentle to severe topography of typical wild blueberry fields. Uniform fertilization can also reduce nutrient uptake efficiency, and increase the potential of ground water contamination. Over-fertilization can lead to deterioration in water and air quality, promote weed growth, and reduce profit margins (Saleem et al., 2013); while, under-fertilization restricts yields and reduces fruit quality (Percival and Sanderson, 2004; Saleem et al., 2013). Topography plays an important role in wild blueberry fields in terms of the spatial variability of soil properties and crop yield (Farooque et al., 2012). The substantial variations in soil and plant characteristics, topographic features, and fruit yield (Eaton, 1988; Farooque et al., 2012) within wild blueberry fields emphasize the need for site-specific management to maximize the fruit yield and reduce environmental pollution (Zaman et al., 2010; Saleem et al., 2013). The problems associated with the variations in topography, over-fertilization, and under-fertilization can be addressed using variable rate fertilization which also increases the agronomic and environmental efficiency. Saleem et al. (2013) implemented variable rate fertilization in wild blueberry fields. The results of their study indicated an increase in nutrient leaching in low lying areas of wild blueberry fields compared to the steeper and moderate slope areas. The results also suggested that a single, variable rate application of fertilizers in wild blueberry fields can result in downslope nutrient movement after heavy rainfall events which can result in the nutrient depletion of the upslope areas and enrichment of the downslope areas. Therefore, the VRS fertilization can increase input use efficiency for optimum plant growth by providing nutrients throughout the spring of vegetative year and it also decreases environmental pollution. Literature suggests that VRS fertilization has proven to be one of the most effective method for achieving relatively high yields and fertilizer use efficiency for different crops (Wilson et al., 1989; Huang et al., 1999; Zaman et al., 2005). The introduction of precision agriculture technologies in wild blueberry fields can also help to increase the fruit yield through VRS fertilization. Very limited attention has been paid to VRS fertilization in wild blueberry cropping systems. Therefore, the objective of this study was to examine the impact of VRS, URS, and UR fertilization on plant growth parameters, leaf nutrients, and fruit yield.

6.2 Materials and Methods

Experimental trials were established on wild blueberry fields in central Nova Scotia, Canada. The selected fields were divided into three sections based on fertilization treatments i.e. VRS, URS, and UR section. The VRS fertilization was performed in VRS sections of Cooper and North River fields by following the prescription maps (Figure 3-5, Chapter 3). The URS sections were fertilized with a constant fertilizer rate of 66 kg ha^{-1}. The VRS and URS sections were fertilized three times during the sprout year. Whereas, the UR sections received uniform fertilization (200 kg ha^{-1}), including bare spots and weed patches, only once. The impact of VRS, UR, and URS fertilization on wild blueberry leaf was determined by performing leaf sampling. Leaf samples were collected at tip-dieback stage (third week of July) in the sprout year from both experimental sites. Leaf samples were collected from the selected soil sampling locations. The leaf samples were analyzed for N, P K, and other micronutrients. Plant growth parameters were measured from both experimental sites during the sprout years to quantify the effect of VRS, UR, and URS fertilization treatments on the crop health. The plant growth parameters include plant density, plant height, number of branches per stem, and number of flower buds per stem. Plant growth parameters were measured in mid-December, 2012 from Cooper field and in last week of November, 2013 from North River field from selected sampling locations. Fruit samples were collected in August 2013 from the Cooper Field. Detailed materials and methods are discussed in Chapter 3.

6.3 Statistical Analysis

In order to quantify the impact of the three fertilizer treatments on the crop health, the leaf nutrient concentrations, plant growth parameters, and fruit yield were compared for VRS, URS, and UR treatment sections. The experimental design used for this study was split-plot design with fertilizer treatment as a main plot and slope as subplot. The response variables for subsequent statistical analysis were the leaf nutrient concentrations, plant growth parameters, and fruit yield. The analysis of the collected data was performed using Mixed and GLM procedure of SAS (SAS, 2010) at the 5% level of significance. The validity of model assumptions (normal distribution, independence, and constant variance of the error terms) were verified by examining the residuals as described in Montgomery (Montgomery, 2013). When violated, an appropriate transformation was applied to the response measurements; however, the means reported in the tables and in figures were back-transformed to the original scale. Furthermore, multiple means comparison was completed for significant ($p < 0.05$) effects of the fertilizer treatments using LSD at the 5% level of significance. The statistical analysis was performed using SAS 9.3 and Minitab 16 statistical software.

6.4 Results and Discussion

6.4.1 Effect of Different Fertilizer Treatments on Leaf Nutrients

6.4.1.1 Cooper Field

The results of ANOVA showed that the VRS fertilization treatment significantly ($p < 0.05$) influenced the leaf N, P, and K concentrations as compared to URS and UR fertilization treatments in the Cooper field (Table 6-1). The leaf micro nutrients such as Ca, Fe, and Mn showed non-significant differences between all treatment sections, except leaf Mg. However, leaf Mg showed significantly different value under all treatment sections. The leaf N in Z1 of VRS treatment section showed lower value as compared to the URS and UR treatment sections with mean value 1.81, 1.92, and 1.88%, respectively (Table 6-1). The leaf N concentrations in the leaf samples collected from URS treatment section were higher than UR treatment section but were not significantly different for all slope zones. The leaf N concentrations in Z2 and Z3 of VRS treatment section were found to be significantly lower as compared to the URS and UR treatment sections (Table 6-1). Lower fertilizer rates used in Z2 and Z3 of VRS treatment section might be the reason of lower leaf N concentration in leaf samples as compared to URS and UR treatment sections. The leaf N concentration in Z2 and Z3 of URS and UR treatment sections were significantly higher than Z1 of URS and UR treatment sections (Table 6-1). The reason for this significant difference might be the accumulation of nutrients moving from up-slope positions to lower slop areas of the fields with surface runoff. The mean values of leaf N in Z2 of VRS, URS, and UR treatment section were 1.84, 2.05, and 2.04%, respectively. However, in Z3 of VRS, URS, and UR treatment sections the mean

Table 6-1. Effect of VRS, URS, and UR fertilization treatments on wild blueberry leaf nutrients at the Cooper field.

Slope Zone	Fertilization Method	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Mn (ppm)
Zone 1	VRS	1.81c	0.118d	0.44f	0.42c	0.19a	36.88a	1439a
	URS	1.92c	0.128cd	0.50cde	0.43bc	0.19a	35.53a	1588a
	UR	1.88c	0.125cd	0.48ef	0.35d	0.16b	37.85a	1584a
Zone 2	VRS	1.84c	0.125cd	0.47def	0.45abc	0.19a	36.07a	1333a
	URS	2.05b	0.148b	0.58b	0.48ab	0.18ab	33.28a	1342a
	UR	2.04b	0.146b	0.53bcd	0.44bc	0.15b	34.86a	1495a
Zone 3	VRS	1.90c	0.131c	0.48def	0.45abc	0.19a	37.14a	1545a
	URS	2.24a	0.159a	0.66a	0.44bc	0.20a	38.35a	1259a
	UR	2.22a	0.152ab	0.55bc	0.51a	0.16b	38.34a	1580a
Treatment Factor		Mixed ANOVA						
Fertilization Method(F)		***	**	***	NS	***	NS	NS
Slope Zone(S)		***	***	***	***	NS	*	NS
F x S		**	**	***	***	NS	NS	NS

Means in the same column followed by the same letter are not significantly different at the 5% level of significance using LSD.
*Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level
NS = Non-significant

values of leaf N were 1.90, 2.24, and 2.22%, respectively (Table 6-1). Similar trends were observed for the leaf P and K concentrations (Table 6-1). The leaf N concentrations for VRS treatment in all three slope zones were within the proposed standards set by Eaton et al. (2009) (Table 6-2). These results were in agreement with findings of Saleem et al. (2013), who used the same rates for variable rate fertilization and reported similar results. Under URS and UR treatment sections, the leaf N concentrations in Z2 and Z3 were more than the proposed standards (1.6 - 2.0) set by Eaton et al. (2009) (Table 6-1). The leaf P concentrations in all slope zones of VRS treatment section were within the proposed standards set by Eaton et al. (2009). However, in Z2 and Z3 of URS and UR treatment section the leaf P were more than the proposed standards (Table 6-2). Like leaf P, the leaf K concentrations also showed the same results in all slope zones of three treatment sections. The higher leaf N, P, and K concentrations in Z2 and Z3 could be due to the erosion of nutrients from steep slope to the low slope areas with surface runoff during heavy rainfalls.

Table 6-2. Recommended ranges for wild blueberry leaf nutrients in Nova Scotia, Canada (Eaton et al., 2009).

	Nova Scotia leaf nutrient ranges	
	Minimum	**Maximum**
N (%)	1.6	2.0
P (%)	0.11	0.144
K (%)	0.41	0.52
Ca (%)	0.32	0.47
Mg (%)	0.15	0.19
Zn (ppm)	16	22
Fe (ppm)	32	46
Mn (ppm)	1169	1834

Other micro nutrients indicated non-significant behavior under all slope zones of all treatment sections except leaf Mg concentration (Table 6-1). The mean leaf concentrations of Ca, Mg, Mn, and Fe were within the optimal ranges under all slope zones of VRS, URS, and UR treatment section except leaf Ca concentration (Table 6-1). The leaf Ca concentration was more than the proposed standards in Z3 of the UR treatment section.

6.4.1.2 North River Field

The leaf N, P, and K concentrations were significantly different ($p < 0.05$) for VRS, URS, and UR treatment section in North River field (Table 6-3). The leaf N concentrations in Z1 and Z2 of all treatment sections showed a non-significant difference. However, in Z3 of VRS treatment section leaf N concentrations were significantly lower than those in Z3 of URS and UR treatment sections (Table 6-3). The leaf N concentrations in Z1, Z2, and Z3 of VRS treatment were also within the proposed standards set by Eaton et al. (2009) with mean values of 1.88, 1.91, and 1.95%, respectively. Under URS and UR treatment sections the leaf N concentrations in Z2 and Z3 were more than proposed maximum leaf standards. The mean leaf N concentrations in Z1, Z2, and Z3 of URS treatment section were 1.94, 2.06 and 2.29%, respectively, while the leaf N concentrations in Z1, Z2, and Z3 for UR treatment section were 1.89, 2.06 and 2.24%, respectively (Table 6-3). Higher fertilizer rates used in Z2 and Z3 of URS and UR treatment sections might be the reason of significantly higher leaf N concentrations in the leaf samples as compared to VRS treatment section. The higher nutrients uptake by plants in URS and UR treatment section can increase vegetative growth which could ultimately reduce fruit yield. Wild blueberries are low input systems with a narrow optimal

Table 6-3. Effect of VRS, URS, and UR fertilization treatments on wild blueberry leaf nutrients at the North River field.

Slope Zone	**Fertilization Method**	**N (%)**	**P (%)**	**K (%)**	**Ca (%)**	**Mg (%)**	**Fe (ppm)**	**Mn (ppm)**
Zone 1	VRS	1.88c	0.120c	0.44d	0.37c	0.19a	36.28a	1384a
	URS	1.94c	0.128c	0.50bcd	0.40bc	0.19a	36.96a	1447a
	UR	1.89c	0.124c	0.48cd	0.37c	0.17ab	37.85a	1440a
Zone 2	VRS	1.91c	0.123c	0.47d	0.42bc	0.19a	39.72a	1366a
	URS	2.06bc	0.147ab	0.57b	0.45abc	0.18ab	39.66a	1384a
	UR	2.06bc	0.146ab	0.53bcd	0.41bc	0.16b	40.33a	1400a
Zone 3	VRS	1.95c	0.131bc	0.49cd	0.46ab	0.18ab	42.10a	1590a
	URS	2.29a	0.154a	0.63a	0.47a	0.19a	40.32a	1356a
	UR	2.24ab	0.151a	0.55bc	0.47ab	0.17ab	42.02a	1391a
Treatment Factor				Mixed ANOVA				
Fertilization Method(F)		***	***	***	NS	*	NS	NS
Slope Zone(S)		***	***	***	***	NS	NS	NS
F x S		NS	NS	*	NS	NS	NS	NS

Means in the same column followed by the same letter are not significantly different at the 5% level of significance using LSD.

*Significant at the 0.05 probability level

*** Significant at the 0.001 probability level

NS = Non-significant

range of plant nutrients; damaging effects of excess N occur when too much N is applied (Percival and Sanderson, 2004). The results were in agreement with the findings of Saleem et al. (2013). Similar to the Cooper field, under VRS treatment section, the leaf P and K concentrations in all slope zones were within the recommended ranges. However, in low lying areas (Z3) of URS and UR treatment sections the leaf P and K concentrations were more than the proposed standards. These results were similar to the finding of Zaman et al. (2009), who reported higher leaf N concentrations in the low lying areas within wild blueberry fields. The leaf Ca, Mg, Fe and Mn were within proposed standards in all slope zones of VRS, URS, and UR treatment sections (Table 6-3).

6.4.2 Effect of Different Fertilizer Treatments on Plant Growth Parameters

6.4.2.1 Cooper Field

The ANOVA results revealed that plant density and number of branches per stem were non-significantly different between VRS, URS, and UR treatment sections (Table 6-4). The plant height and number of buds per stem showed significant ($p < 0.05$) results for all treatment sections. The plant height in Z1 of VRS, URS, and UR treatment section showed non-significant differences having mean values of 20.1, 23.1, and 22.7 cm, respectively (Table 6-4). Rate of fertilizer application was same in Z1 of all treatment sections and this might be the reason for the non-significant differences in plant height in Z1 of all treatment sections. The plant height in Z2 and Z3 of VRS treatment section were significantly lower as compared to the URS and UR treatment sections (Table 6-1). Lower fertilizer rates used in Z2 and Z3 of VRS treatment section might be the reason of lower plant height as compared to URS and UR treatment sections. Under all treatment sections the number of branches per stem was found to be non-significantly different from each other for all slope zones. Overall, the numbers of branches per stem in Z3 of all treatment section were higher than those in Z1 of all treatment sections. This might be due to higher soil fertility status in Z3 as compared to Z1 in the Cooper field (Table 5-5).

Table 6-4. Effect of VRS, URS, and UR fertilization treatments on wild blueberry plant growth parameters at the Cooper field.

Slope Zone	Fertilization Method	Plant Density	Plant Height (cm)	Branches per Stem	No. of Buds per Stem
Zone 1	VRS	12a	20.0ef	2a	5.1c
	URS	13a	23.1cde	2a	4.6d
	UR	13a	22.7de	2a	4.6d
Zone 2	VRS	13a	22.1ef	2a	5.6b
	URS	13a	26.1b	2a	5.1c
	UR	13a	25.1bc	2a	5.0c
Zone 3	VRS	14a	25bcd	2a	6.1a
	URS	13a	30.8a	2a	5.8b
	UR	13a	29.9a	2a	5.7b
Treatment Factor		Mixed ANOVA			
Fertilization Method (F)		NS	**	NS	*
Slope Zone(S)		NS	***	NS	***
F x S		NS	NS	NS	NS

Means in the same column followed by the same letter are not significantly different at the 5% level of significance using LSD.
*Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level
NS = Non-significant

Under all three slope zones for all treatments, a significantly different number of buds per stem were observed, ranging from 4.6 to 6.1 buds per stem. For the VRS treatment section, the mean values for number of buds per stem in Z1, Z2, and Z3 were 5.1, 5.6, and 6.1, respectively (Table 6-4). However, the mean values for number of buds per stem in Z1, Z2, and Z3 of UR treatment section were 4.6, 5.0, and 5.72, respectively (Table 6-

4). Under URS treatment section, the mean values of number of buds per stem in Z1, Z2, and Z3 were higher than UR treatment section but not significantly different.

6.4.2.2 North River Field

The summary of ANOVA statistics revealed that the plant density and number of branches per stem were non-significantly different under VRS, URS, and UR treatment sections of the North River field (Table 6-5). Significant differences were observed for plant height and number of buds per stem between VRS, URS, and UR treatment sections (Table 6-5). The plant height in Z1 of VRS, URS, and UR treatment section showed non-significant differences with the mean value of 18.5, 22.5, and 21.9 cm, respectively (Table 6-5). The plant heights were increased in Z2 and Z3 for all treatment sections. The plant height in Z3 of VRS treatment section was significantly lower as compared to the URS and UR treatment sections with mean values of 24.4, 30.9, and 29.7 cm, respectively (Table 6-1). Lower fertilizer rates used in Z2 and Z3 of VRS treatment section might be the reason of lower plant height as compared to URS and UR treatment sections. Like the Cooper field, the number of branches per stem showed non-significant differences in all three slope zones for VRS, URS, and UR treatment sections. Numbers of buds per stem for VRS treatment were 5.3, 5.6, and 6.0 in Z1, Z2, and Z3, respectively, while for UR treatment section the number of buds per stem were 4.6, 5.1, and 5.7 in Z1, Z2, and Z3, respectively (Table 6-5). Similar to Cooper field, under URS and UR treatment sections the numbers of buds per stem in all slope zones showed non-significant difference. These results were in agreement with the findings of Saleem (2012).

The presence of higher SOM in Z3 as compared to Z1 might be the reason for higher values of plant growth parameters in low lying areas of the fields (Table 5-7). These results are in agreement with the findings of Farooque (2010) who found that

Table 6-5. Effect of VRS, URS, and UR fertilization treatments on wild blueberry plant growth parameters at the North River field.

Slope Zone	Fertilization Method	Plant Density	Plant Height (cm)	Branches per Stem	No. of Buds per Stem
Zone 1	VRS	12a	18.5d	2a	5.3cde
	URS	13a	22.5cd	2a	4.7e
	UR	12a	21.9cd	2a	4.6e
Zone 2	VRS	13a	22.0cd	2a	5.6bcd
	URS	12a	25.6bc	2a	5.2cde
	UR	13a	25.0c	2a	5.1de
Zone 3	VRS	14a	24.4c	2a	6.0a
	URS	14a	30.9a	2a	5.8ab
	UR	14a	29.7ab	2a	5.7bc
Treatment Factor		Mixed ANOVA			
Fertilization Method (F)		NS	***	NS	**
Slope Zone(S)		NS	***	NS	***
F x S		NS	NS	NS	NS

Means in the same column followed by the same letter are not significantly different at the 5% level of significance using LSD.
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level
NS = Non-significant

within wild blueberry field the plant growth parameters are correlated with the fertility status of the field. Similar results were observed in another study conducted on variable rate fertilization effects on wild blueberry yield components by Saleem (2012).

6.4.3 Effect of Different Fertilizer Treatments on Fruit Yield

6.4.3.1 Cooper Field

The results of ANOVA statistics revealed that statistically the fruit yield was non-significant between all treatment sections of Cooper field (Table 6-6). The mean values of fruit yield in Z1 of VRS, URS, and UR treatment sections were 4567, 4497, and 4472 kg ha^{-1}, respectively. Unlike Z1, in Z2 of VRS, URS, and UR treatment sections the fruit yield showed increasing trend with mean values of 4877, 4748, and 4781 kg ha^{-1}. The blueberry fruit yield in Z3 of URS and UR treatment sections were low as compared to Z3 of VRS treatment section with mean values of 4847, 4788, and 5159 kg ha^{-1}, respectively (Table 6-6). Overall, fruit yield was more in Z3 of all treatment sections as compared to Z1. These results were in agreement with Farooque (2010) and Saleem (2012), who reported higher blueberry fruit yield in low lying areas as compared to steep slope areas of the field.

Table 6-6. Effect of VRS, URS, and UR fertilization treatments on wild blueberry fruit yield at the Cooper field.

Slope Zone	Fertilization Method	Fruit Yield (kg ha^{-1})
Zone 1	VRS	4567
	URS	4497
	UR	4472
Zone 2	VRS	4877
	URS	4748
	UR	4781
Zone 3	VRS	5159
	URS	4847
	UR	4788
Mean	VRS	4868
	URS	4697
	UR	4680
Treatment Factor		Mixed ANOVA
Fertilization Method (F)		NS
Slope Zone(S)		NS
F x S		NS

NS = Non-significant

The mean value of fruit yield for VRS treatment section was 4868 kg ha^{-1}, while for URS and UR treatment sections the produced fruit yield were 4697 and 4680 kg ha^{-1} (Table 6-6). These results suggesting the marginal increase in the fruit yield from VRS section, when compared with URS and UR treatment sections, indicated the positive effect of VRS fertilization on fruit yield. These results were in agreement with finding of

Saleem (2012) who used variable rate fertilizer application and reported higher fruit yield in low lying areas of variable rate section as compared to UR section. Visual observations also indicated that vegetative growth was more in low lying areas of URS and UR treatment sections of both fields as compared to steep slope areas. More vegetative growth in low lying areas might result in less fruit yield (Percival and Sanderson, 2004). The results of this study indicated that variable rate fertilization based on the slope variation, in conjunction with split application should be used in wild blueberry cropping system to increase wild blueberry fruit field.

6.5 Summary and Conclusions

The leaf macronutrients (N, P, and K) were within the recommended ranges in Z1 of all treatment sections. In Z2 and Z3 of VRS treatment section the leaf N, P, and K were also within the recommended ranges, while in Z2 and Z3 of URS and UR treatment sections the mean values of leaf macronutrients were higher than the recommended ranges. Leaf micronutrients (Ca, Mg, Mn, and Fe) were within the optimal ranges under all slope zones of VRS, URS, and UR treatment sections within the selected wild blueberry fields. Plant density and plant height were non-significantly different under all slope zones of VRS, URS, and UR treatment sections. In Z3 of URS and UR section, mean plant height exceeds the optimum plant height of 15 -27 cm. The numbers of buds per stem in Z3 of VRS treatment section were higher than those in Z3 of URS and UR treatment sections. However, under URS and UR treatment sections the numbers of buds per stem in all slope zones showed non-significant difference. There were non-significant differences for fruit yield in all slope zones of VRS, URS, and UR fertilization treatments. The mean value of fruit yield for VRS treatment section was 4868 kg ha^{-1}, whereas under URS and UR treatment section the produced fruit yield were 4697 and 4680 kg ha^{-1}.

The results of this study indicated that variable rate fertilization based on the slope variation, in conjunction with split application should be used in wild blueberry cropping system to increase nutrient uptake efficiency, which ultimately increase the fruit yield. This practice may also result in saving of significant amount of fertilizer, without affecting the fruit yield.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The main objective of this project was to determine the impact of VRS fertilization treatment on ammonia volatilization losses, subsurface water quality, and crop productivity in wild blueberry fields. The results of this study showed that considerable amount of ammonium volatilization losses were present in wild blueberry fields followed by fertilization, and the magnitude of these losses increased with the increase in the rate of fertilization. The VRS fertilization has significantly ($p < 0.05$) decreased the amount of ammonium volatilization loss as compared to the UR fertilization. Lower fertilizer application rates were used in VRS treatment sections as compared to UR treatment sections might be the reason for lower ammonium volatilization loss. The cumulative ammonium volatilization losses for VRS and UR sections from Cooper field were 0.976 and 1.588 kg NH_4^+-N ha^{-1}, respectively. However, from North River field the cumulative ammonium volatilization losses for VRS and UR sections were 0.915 and 1.538 kg NH_4^+-N ha^{-1}, respectively. These results suggested that within both experimental fields the VRS treatment sections contributed less towards ammonium volatilization as compared to the UR treatment sections. Split fertilizer rates in VRS section might be the reason for lower ammonium emission as compared to uniform fertilization. The cumulative ammonium volatilization losses from VRS treatment section was 38.52% lower than the UR treatment section over the twelve day period within a Cooper field. Whereas, in North River field the cumulative ammonium volatilization losses from VRS treatment section was 40.31% lower than the UR treatment section. Almost 40% less fertilizer was applied in VRS sections for both fields as compared to UR sections could be the reason of lower ammonium volatilization in VRS treatment sections.

An experiment was also conducted to see the impact VRS, URS, and UR fertilization treatment on nutrient leaching losses in wild blueberry fields. The VRS fertilization significantly ($p < 0.05$) decreased NO_3^--N and NH_4^+-N loading in subsurface water as compared to the URS and UR treatments within selected wild blueberry fields. The nutrient leaching losses were very high in low lying areas of URS and UR treatment sections as compared to VRS treatment section. Higher fertilizer rates were used in low lying areas of URS and UR treatment sections as compared to the VRS treatment section might be the reason of higher nutrients leaching. The higher amount of clay, soil organic matter, and soil inorganic nitrogen could be the other reasons for higher NO_3^--N and NH_4^+-N in the leachate samples collected from the low lying areas. Based on these results it is proposed that the VRS fertilization may reduce cost of production and groundwater contamination by reducing the nitrate and ammonium leaching through the root zone.

The VRS fertilization treatment was also significantly effects the leaf macro nutrients in wild blueberry fields. The leaf macronutrients (N, P, and K) were within the recommended ranges in all slope zones of VRS treatment section for both fields. However, in moderate slope and low lying areas of URS and UR treatment sections the mean values of leaf macronutrients were higher than the recommended ranges. Leaf micronutrients (Ca, Mg, Mn, and Fe) were within the optimal ranges under all slope zones of VRS, URS, and UR treatment sections within the selected wild blueberry fields. Plant density and plant height were non-significantly different under all slope zones of VRS, URS, and UR treatment sections for both fields. The numbers of buds per stem in low lying areas of VRS treatment section were higher than those in low lying areas of URS and UR treatment sections. There was non-significant difference for fruit yield in all slope zones of VRS, URS, and UR fertilization treatments, while the mean fruit yield was higher in VRS treatment sections as compared to URS and UR treatment sections. Literature suggested that wild blueberry has a narrow optimal range for plant nutrients therefore, higher nutrient level may increase vegetative growth and reduce fruit yield, as demonstrated in current study.

Based on these results, it can be concluded that VRS fertilization on the basis of slope should be used in wild blueberry cropping system to reduce the cost of production, the environmental contamination, and to increase the crop productivity. Further research should be undertaken to increase producer's confidence in VRS fertilization treatments. The government should be encouraged to place emphasis on the VRS fertilization treatment in wild blueberry cropping system in order to improve the crop productivity and to reduce the environmental contaminations.

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