Variable Rate Fertilization in Wild Blueberry Fields to Improve Crop Productivity and Reduce Environmental Impacts

by

Shoaib Rashid Saleem

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The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled “Variable Rate Fertilization in Wild Blueberry Fields to Improve Crop Productivity and Reduce Environmental Impacts” by Shoaib Rashid Saleem in partial fulfillment of the requirements for the degree of Master of Science.

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Supervisors: ______________________________

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Readers:

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AUTHOR: SHOAIB RASHID SALEEM

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Signature of Author

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ABSTRACT

Two wild blueberry fields were selected to evaluate the impact of variable rate (VR) fertilization on crop productivity, surface and subsurface water quality. Management zones were delineated based on slope variability, and different fertilizer rates were applied according to prescription maps. Runoff collectors were place in the fields to measure the nutrient losses in surface runoff, while lysimeters were installed to evaluate the impact of VR fertilization (VRF) on subsurface water quality. The VR treatment significantly decreased phosphorus and nitrogen loadings in surface runoff as compared to uniform treatment. The concentrations of nutrients in subsurface water samples were also significantly lower for VR treatment as compared to uniform treatment. The excessive nutrients enhanced vegetative growth in low lying areas of uniform fertilization, while berry yield was less. Based on these results, it can be concluded that VRF in wild blueberry fields improved the crop productivity and potential environmental impacts.

LIST OF ABBREVIATIONS AND SYMBOLS USED

AMC – Antecedent moisture condition
ANOVA – Analysis of Variance
B – Boron
Ca – Calcium
cm – Centimeter
CN – Curve number
CT – Control
Cu – Copper
C. V. – Coefficient of variation
DEM – Digital elevation model
DGPS – Differential global positioning system
DRP – Dissolved reactive phosphorus
EC – Electrical conductivity
Fe – Iron
GIS – Geographical information system
GPS – Global positioning system
ha – Hectare
K – Potassium
KCL – Potassium chloride
kg – Kilogram
L – Liter
m – Meter
Mg – Magnesium
mg – Milligram
Mn – Manganese
N – Nitrogen
NH_4^+ -N – Ammonium nitrogen
NO_3^--N – Nitrate nitrogen
NS – non-significant
PP – Particulate phosphorus
P – Phosphorus
Q – Flow
θ_v – Volumetric water content
r – Coefficient of correlation
R^2 – Coefficient of determination
RMSE – Root mean square error
S – Retention parameter
SCS – Soil conservation services
SOM – Soil organic matter
SWAT – Soil and water assessment tool
TDR – Time domain reflectometry
TP – Total phosphorus
TSS – Total suspended solids
UN – Uniform

VRT – Variable rate technology
VR – Variable rate
Z1 – Zone-1
Z2 – Zone-2
Z3 – Zone-3
Zn – Zinc
~ – Ranges from

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CHAPTER 1

INTRODUCTION

Wild blueberries are an important economical crop of northeastern North America, with over 86,000 ha under management, producing 112 million kg of fruit valued at $470 million annually (Yarborough, 2009). Blueberry fields are developed on deforested farmland by removing forest and other vegetation (Eaton, 1988). The majority of wild blueberry fields are situated in acidic soils (pH 4.5-5.5), low in mineral nutrients, having poor water holding capacities, and having significant bare spots and weeds (Trevett, 1962). Traditionally, agrochemicals are applied uniformly without considering the substantial variation in soil/plant characteristics, topographic features, high proportion of bare spots and weeds, and fruit yield in wild blueberry fields. Uniform applications of agrochemicals, therefore, result in either over- or under-application. Wild blueberries are low input systems with a narrow optimal range of plant nutrients; detrimental effects of excess N occur when too much N is applied (Percival and Sanderson, 2004). Wild blueberry fields have gentle to severe topography (Zaman et al., 2008 b), therefore, the risk of nutrient runoff from fields increases with the steepness of the slope (Zheng, 2005). Over-fertilization in low lying areas of the field may deteriorate water quality and reduce profit, while under-fertilization in steep slope areas may restrict crop yield (Zaman et al., 2010). Spatial mapping of topography, soil properties and fruit yield will help to develop site-specific management programs to maximize profit and minimize environmental impacts.

Soil properties, aerial photographs, topography, and yield maps are currently used to divide spatially variable fields into management zones (Schepers et al., 2004). There is extensive literature that suggests the possibility of using topography to delineate practical, an agronomically meaningful field management zones (Hanna et al., 1982; Wibawa et al., 1993; Beckie et al., 1997; Franzen et al., 1998). Zaman et al. (2010) related slope variability of 0.8 to 31.0 degrees with soil properties, leaf nutrients and berry yield in wild blueberry fields. They suggested slope maps could be used to develop management zones for variable rate (VR) fertilization to improve productivity and reduce groundwater contamination.

Commercial fertilizer affects many aspects of blueberry plant development including stem length, number of buds, and bloom and berry yield (Eaton and Nams, 2006). Variable rate fertilization is a fertilizer conserving technique available for spatially variable fields and VR spreaders are available as standard commercial equipment for handling dry granular fertilizer (Miller et al., 2004; Schumann et al., 2006). Miller et al. (2004) and Derby et al. (2007) showed that the variable rate fertilizer spreaders performed well for site-specific fertilizer application in citrus and corn, using GPS-guided prescription maps within a field in different cropping systems. As a result, technological barriers to managing fields with variable rate fertilization have largely been overcome. Also, previous studies in different cropping systems found variable rate application of fertilizers to be superior to the uniform rate in terms of economic and water quality benefits (Schnitkey et al., 1996; Babcock and Pautsch, 1998; English et al., 1999).

The **hypothesis** of this study was that variable rate fertilization, based on steepness of slope, could increase crop productivity and reduce surface water and groundwater contamination, when compared with uniform fertilization in wild blueberry production systems. Variable rate fertilization based on developed management zones can increase input use efficiency, reduce cost of production, improve crop growth, increase fruit yield and ultimately reduce contamination of surface water and groundwater.

1.1 Goal and Objectives

The objectives of this study were to:

a) Examine the effect of variable rate fertilization on nutrient losses in surface runoff,

b) Quantify the impact of variable rate fertilization on subsurface water quality, and

c) Examine the impact of two different management practices on soil nutrient level, plant growth parameters, leaf nutrients and blueberry yield.

CHAPTER 2

LITERATURE REVIEW

2.1 Nutrient Runoff and Topography

Understanding the variability of soil and landscape properties, and their effects on crop yield are important components of site-specific management systems (Li et al., 2008). In agricultural fields, yield variability is partly caused by soil variability and topographic features of the field. Topography has an important role in agricultural fields in terms of spatial variability of soils, surface and subsurface hydrology and crop yield (Iqbal et al., 2005). Rainfall amount and intensity also has a direct influence on runoff and soil loss (Kumar et al., 2002). The chances of nutrient loss with surface runoff and soil erosion increase with steepness of slope (Zaman et al., 2008a), as eroded soil sediments may contain significant amount of nutrients (Flanagan and Foster, 1989). Runoff and erosion deteriorate soil quality and its productivity potential due to loss of topsoil and nutrients, loss of organic matter, and loss of the soil's capacity to retain nutrients and water (Hudson, 1993). The runoff produced from upslope may have a very significant effect on the runoff and sediment production at lower slope (Qiangguo, 1999). Zheng (2005) found that soil nutrient losses increased linearly with increasing soil erosion intensity, proposing an empirical model for nutrient losses and soil erosion intensity.

Yung et al. (2008) determined that slope effect on fertility and available soil nutrients are closely related to surface runoff and erosion. Topography influences the redistribution of soil particles, organic matter, soil nutrients and this redistribution along a landscape may lead to large spatial variability of soil properties (Hanna et al., 1982;

Ovalles and Collins, 1988; Changere and Lal, 1997). The soil organic matter, nutrients, and moisture content are more prominent in areas with no slope (Balasundram et al., 2006). The differences in elevation and topography also affect water availability to crops and hence their productivity (Kaleita et al., 2007). Due to their role in influencing soil and yield variability, topographic attributes can be used to map areas of high and low productivity within a field. Therefore, it is important to investigate the combined effect of soil properties and field topography on crop yield.

It has been shown that the topographic variables, such as elevation, terrain slope, and curvature can explain 6 to 54% of corn and soybean yield variability (Kravchenko and Bullock, 2000). Slope derivation may be used as a common procedure for delineating management zones for site-specific management of agricultural inputs (Jiang and Thelen, 2004). Jiang and Thelen (2004) also reported 30 to 85% yield variability due to the combined effect of soil properties and topography for corn and soybean. Yang et al. (1998) showed that topographic variables such as elevation and slope alone can explain 15 to 35% of wheat (*Triticum aestivum* L.) yields variability at the whole-field scale. In addition, they reported that topographic features could account for 49 to 84% of the yield variability in some areas of the wheat field.

Most agricultural runoff studies focused on N and P losses since these nutrients are the limiting nutrients in aquatic ecosystems (Zhang et al., 2003). Most of the agricultural systems have intensified in recent years and it has become apparent that the increase in losses of N and P from agricultural land causes serious detrimental effects on water quality and the environment (Hart et al., 2004). Transport of P from agricultural lands to surface water system is primarily by surface runoff and erosion, and P concentration may be affected by surface soil P content and the method, rate, and timing of P fertilizer application (Sharpley et al., 1993). The amount of P and N losses in surface runoff depends on slope, fertilizer application rate, application timing, soil water conservation practices, vegetative cover, other soil properties, and precipitation time and intensity (Walker and Branham, 1992).

Estimating direct runoff from fields is important both from water quantity and quality perspectives (Kalin et al., 2003). There are several approaches to assess surface runoff from agricultural watersheds but defining catchment areas is very important to get the representative nutrient loads (Chen et al., 2003). Traditionally, catchment areas were manually delineated from topographic maps. Contour lines were used to represent points of constant elevations and lines were drawn perpendicular from maximum elevation points of each contour line to draw the catchment boundaries (Ammann and stone, 1991). Although, manual delineation from topographic maps provided good results (Moore et al., 1991), these methods were time consuming and require extensive labor.

Currently, Geographic Information Systems (GIS) and Digital Elevation Models (DEMs) are utilized to delineate watersheds and their stream networks (Kalin et al., 2003). Terrain attributes, such as slope gradient, profile and contour curvature are computed from DEMs (Smith et al., 2006). The resolution of DEMs plays an important role in accurate delineation of watershed area and flow path. Many studies have shown the effect of DEM resolution on the spatial pattern of terrain attributes (Arnold and Allen, 1993; Galzki, 2009). Topographical features related to catchment hydrology are strongly sensitive to the DEM resolution (Brasington and Richards, 1998). Galzki (2009) used DEM of 1 m resolution for surface water routing and concluded that a high resolution

DEM can be used to successfully estimate surface runoff. Suir (1999) also used 1 m resolution DEM for a GIS based model and successfully calibrated and validated the AGNPS model to calculate surface runoff and sediments transport. Several hydrological models need DEMs as input variables to delineate sub-basin areas. Soil and Water Assessment Tool (SWAT) also uses DEM alongside soil and plant data to delineate sub-basin (Arnold and Allen, 1993). SWAT uses ArcHydro module for ArcGIS to delineate sub-basins. ArcHydro is not a simulation model itself, but it is geospatial and temporal data model that supports others hydrologic simulation models. The structure of a hydrologic system is based on the stream geometric network in ArcHydro, in which links and junctions are defined (Olivera et al., 2002). However, all of the elements of ArcHydro are not included in the SWAT data structure but SWAT includes a number of elements not considered in ArcHydro. Channel cross sections and profile lines, the stream geometric network, and those that are unnecessarily included as hydrographic elements and as drainage elements in SWAT model. On the other hand, SWAT data structure includes many land and stream parameters to model the soil water balance, and plant growth that are not included in ArcHydro (Olivera et al., 2006). Watershed is first divided into a number of sub-basins on the basis of slope in a SWAT model (Gassman et al., 2007). SWAT can successfully delineate the watershed into sub-basins (Arnold et al., 1998). Surface runoff can be computed from other manual techniques.

2.2 Surface Runoff

Several methods are used to calculate the surface runoff including Rational Formula, tabular method, unit hydrograph method, and soil conservation services (SCS) curve number (CN) method (Trommer et al., 1996). The Rational Formula is one of the oldest methods for computing runoff from a rainfall event. The rational method uses an empirical linear equation to compute the peak runoff rate from a selected period of uniform rainfall intensity (Lee and Heaney, 2003). This method was developed more than 100 years ago. Rational Formula cannot compute runoff volumes unless the user assumes total storm duration and is suitable for the areas with less soil and slope variability (Stephenson and Meadows, 1986).

The modified Rational Formula is a recent form of the Rational Formula that can also estimate runoff volumes and hydrographs alongside compute peak runoff rates (Rico et al., 2001). Same input data and coefficients are used as the Rational Formula along with the further assumption that, for the selected storm frequency, the duration of peak-producing rainfall is also the entire storm duration. Modified Rational Formula should be used for drainage areas less than 8 hectares with generally uniform surface cover and topography (Borah and Bera, 2003). The tabular hydrograph method is based upon a series of unit discharge hydrographs that were developed by the NRCS in the late 1970's but this method is used for areas where topography is uniform (Dymond, 2010).

The Soil Conservation Service curve number (SCS-CN) Method (SCS, 1985) is one of the most popular and widely used methods for computing surface runoff volume for a given rainfall event from small agricultural, forest and urban watersheds (Mishra and Singh, 2004). The traditional SCS-CN Method is a rainfall-runoff model that originally was developed for computing surface runoff volumes from ungauged watersheds (Rallison, 1980). Since CN indicates the runoff producing potential of a watershed, several other characteristics should also take into account which significantly affects runoff, such as drainage density and slope (Gardiner and Gregory, 1982). Initial values of CN are based on soil hydrologic group, crop type and crop coverage. SCS soil hydrologic groups are divided into four categories, based on infiltration and transmission rates, from A to D with poor runoff potential to high runoff potential, respectively (Wood and Blackburn, 1984). Typical curve number values for average moisture conditions are provided in the tables provided by SCS (SCS, 1986). Over time SCS-CN Method was modified to adjust curve number according to moisture condition of the soil (Mishra et al., 2004). The SCS-CN Method uses adjustment of curve numbers of antecedent moisture condition II (CN-II) of a storm event to those of antecedent moisture condition I (CN-I) or antecedent moisture condition III (CN-III) based on the total precipitation of the previous five days. AMC I refer to the dry condition, AMC II to the normal or average condition, and AMC III to the wet condition of the watershed (Slack and Welch, 1980). The curve numbers provided in the tables are usually adjusted for less than 5% slope (Williams, 1995). Williams (1995) developed an equation to adjust the curve number according to the slope. The moisture content and slope adjustments made SCS-CN Method very accurate and reliable (Mishra et al., 2004).

2.3 Nutrient Leaching

The transport of N from agricultural soils to groundwater through leaching is also of environmental concern and a potential risk to human health (Gaynor and Findlay, 1995; Owens et al., 2000; Zhao et al., 2001). Leaching is the translocation of solutes beyond the rooting zone. Some researchers define leaching as the removal of nutrients entirely out of soil profile, while others reported leaching as the translocation of nutrients with in soil profile (Owens et al., 2000). Saffigna and Phillips (2002) considered leaching as downward movement of nutrients with drainage water. When nutrients are leached down, it is unavailable for plant uptake, and therefore, is lost from the soil-plant system. Depending on the amount of water draining out of the rooting zone, the leached nutrients may accumulate at depth in the soil or may pollute the groundwater. Over-application of fertilizers can provide too much plant available N and increase the potential for nitrogen leaching (Jaynes et al., 2001). Ammonium and nitrate are the major forms of inorganic nitrogen available to plants in most agricultural systems (Keeney and Walsh, 1972). Most of the N is leached in nitrate nitrogen (NO_3^--N) form (Owens et al., 2000; Zhao et al., 2001), because NO_3^--N is very mobile in most soils, it can be leached from agricultural fields into groundwater (Keeney, 1989). NO_3^--N concentrations in drinking water guidelines of 10 mg NO_3^--N L^{-1} is used in many countries, including Canada (Health and Welfare Canada, 1996). A variety of factors control nutrient losses by leaching from agricultural systems, including climate, soil structure, texture, organic matter, and agricultural management practices (Burt and Arkell, 1987). The plant communities also influence the nitrogen leaching by altering seepage rates and soil nitrogen concentrations through nitrogen uptake and supply by nitrogen fixing legumes (Scherer-Lorenzen et al., 2003). Fertilizer types also influence the nitrogen leaching (Gordon et al., 2005). Many studies have shown that site specific application of fertilizers can reduce the amounts of nutrients leaching down through the root zone. For example, NO_3^--N leaching from soil decreases by variable rate application of N fertilizers (Ersahin, 2001). Zaman et al. (2006) showed a reduction of NO_3^--N concentration in soil solution from 28.5 to 1.5 and from 14.0 mg L^{-1} to 4.5 mg L^{-1} under small and large size citrus trees, respectively by using variable rate (VR) precision fertilization.

Acidity of the soil influences the quantities of nitrate and ammonium leaching as nitrification process is very slow at low pH of the soil, there are chances to find ammonium N in leachates (Alexander, 1977). Zhou et al. (2006) indicated that approximately 16% of total ammonium fertilizer applied leached down from sandy loam soil and high concentrations of NH_4^+-N can easily be leached from bare spots, weeds, and grasses.

2.4 Global Positioning System (GPS)

The inclusion of GPS and GIS in agricultural systems has laid the foundation of precision agriculture. GPS helps to record the spatially variable field data, and GIS makes it possible to store and generate complex view of fields and to make valid agro-technical decisions (Pecze, 2001). GPS is used for field mapping, soil sampling locations, tractor guidance, variable rate applications, precision seeding and precision harvesting (Hurn, 1993).

The GPS is based on a radio navigation system capable of determining 3-dimensional location data (longitude, latitude, and elevation) from a constellation of orbiting satellites. A GPS receiver determines the location of the point using pseudo random signals from at least four satellites, more satellite signals giving higher accuracy (Morgan and Ess, 1997). The GPS satellites continuously broadcast signals, allowing the GPS receiver, while in motion, to determine the location of the point in real-time. Any deviation can cause error since the GPS receiver uses the time taken by signals from a satellite to the receiver (Hurn, 1993). The differential global positioning system (DGPS) is an advanced version of GPS and used to compensate the timing errors, to reduce noise in the medium, and the electronic noise in the receiver (Saunders et al., 1996).

Recent development in real-time kinematics (RTK) based GPS system have made it possible to determine positions with a horizontal accuracy of 1 cm (Ehsani et al., 2004). RTK GPS data were used to create a highly accurate digital elevation model (DEM) (Mitasova et al., 2004). The position information obtained from RTK GPS can be used for both guidance and other applications such as seed mapping, traffic control, and tillage control (Li et al., 2009). A RTK GPS and GIS could be used to derive topographic features and relate them with hydrologic attributes (Iqbal et al., 2005). Zaman et al. (2005) used GPS guided prescription map for variable rate fertilization in citrus.

2.5 Soil Sampling

Soil is the primary source in crop production systems, and soil characterization is necessary when making management decisions on field operations and agrochemical inputs (Lark et al., 2003). Technological advances in GPS and GIS directed agricultural producers to design more intensive soil sampling pattern and to use this information for fertilizer management decisions. Fields are generally divided into either zones or grids when a soil sampling plan is developed. Samples can be collected randomly or at the intersection within those zones or grids (Srinivasan, 2006). A single estimate for the entire field is obtained for soil test values from random and grid sampling. This value may then be used to calculate fertilizer application rates. Random sampling techniques are used for uniform fields. Samples are collected from the same points in subsequent years to examine long term trends in soil nutrient data and these points should be georeferenced with GPS (Logsdon et al., 2008). Grid sampling is useful when there is a prior knowledge of within field variability. This technique also avoids sampling bias that could result from the collection of an unrepresentative sample due to a high number of samples collected from the same region (Chung et al., 1995). Grid sampling technique is divided into grid cell and grid point method. Grid cell soil sampling randomly collects one or multiple subsamples throughout the cell for a composite sample, while grid point soil sampling collects one or multiple subsamples around a georeferenced point within a grid or at a grid intersection (Pocknee et al., 1996).

Zone sampling is used when each field contains different soils with unique soil properties and crop characteristics, and therefore, should be separated into unique management zones (Fleming et al., 2000). Regions of fields that have had different crop history, yield or fertilizer treatments, or that vary substantially in slope, texture, elevation are good examples for zone sampling and should be separately sampled. The number of zones and their shape and size will depend on the degree of field variability, while in grid sampling a fix pattern is used for sampling without considering field variability (Mallarino and Wittry, 2004). Zone sampling also reduces the number of soil samples compared to grid or random sampling and allows for variable rate fertilizer applications (Tan, 2005). Topographic sampling is a type of zone sampling in which the variability of natural features such as elevation, hilltops, slopes or depressions are considered. It is assumed that these features differ in soil characteristics and therefore, uses these features to establish unique zones. Area based and point based samplings are two different types of topographic sampling. Area based soil sampling means that more than one soil sample is collected and composited from near the center of each topographic zone, whereas point based soil sampling only collects one sample from the center of each topographic zone (Franzen et al., 1998). Only one soil sampling strategy is used for all tested nutrients for practical reasons, however, the method that is most accurate for that nutrient should be used if one nutrient consistently limits yield. For example, area based topographic sampling is better than grid sampling at estimating nitrogen (N) concentrations (Franzen et al., 1998). The grid approach is the best approach for measuring P in heavily fertilized fields, whereas both the grid and management zone approaches are good at measuring potassium (K) levels (Mallarino and Wittry, 2004). However, the management zone approach is the best approach for measuring organic matter and pH variability (Mallarino and Wittry, 2004). Grid and management zone sampling are equally good at determining nutrient variability across all fields, if a similar weight is given to all standard soil parameters (Mallarino and Wittry, 2004). Although the management zone approach takes more planning time, it generally results in fewer soil samples than the grid approach. The best strategy is to first determine the degree of variability within a field, and use grid sampling if variability is low, otherwise zone sampling is preferred if variability is high (Fleming et al., 2000).

2.6 Management Zones

Management practices are implemented uniformly with inadequate attention being given to substantial variation in soil and plant characteristics, topographic features and fruit yield. Uniform management could increase the cost of production and may also pollute surface water as well as groundwater systems. Site specific management of agricultural inputs is becoming a popular approach for producers to manage field variability (Duffera et al., 2007).

Identification of management zones is one of the approaches to apply precision agriculture in spatially variable soils to optimize crop production. Management zones can be useful for variable rate application of crop inputs using the spatial analysis tools of precision agriculture for improved crop management (Ferguson et al., 2003). A management zone is defined as a sub-region of a field with homogeneous yield potential for which a single rate of crop input is appropriate (Doerge, 1999). Sub-region determination is difficult due to complex combination of soil, biotic and climatic factors. Spatial information sources are basics for development of management zones that are stable or predictable over time and related to crop yield (Doerge, 1999).

Management zones can be delineated logically on the basis of soil properties, soil survey maps, aerial photographs, topography, or yield maps (Schepers et al., 2004). Initially fields are divided on the basis of soil type and applying variable rate fertilization to contrasting soils can enhance the yield (Carr et al., 1991). Fleming et al. (2004) divided fields into management zones on the basis of soil color and soil electrical conductivity, and both methods of developing management zones identified homogeneous regions within fields. Other researchers also identified soil electrical conductivity as a parameter to delineate management zones and related it with other features such as texture and landscape (Sudduth et al., 1995; Johnson et al., 2001; Ferguson et al., 2003). Series of yield maps can be used to classify the fields in different management zones on yield variation basis (Blackmore, 2000). Long et al. (1994) used aerial imagery for delineation of management zones by estimating yield.

Franzen et al. (2002) used topographic information for successful delineation of management zone and Fraisse et al. (2001) found that management zones were associated with yield and soil water availability, and were influenced by topography. In-field topographic variation influences the soil properties and crop productivity (Mzuku et al., 2005). Crop yield variation within a field was 1.0 to 6.7 Mg ha^{-1} in east-central Alberta, Canada (Goddard and Grant, 2001). Mulla and Bhatti (1997) found correspondence of low, medium, and high organic matter zones with top, middle, and bottom slope landscape position.

2.7 Variable Rate Technology

Variable rate technology (VRT) aims to improve fertilizer use efficiency and reduce nutrient losses by varying fertilizer rates on an as needed basis within a field (Yang, 2001). The basic idea of variable rate fertilizer application is to allocate inputs more efficiently by exploring spatial variation in soil type, topographic features, fertility levels, and other field characteristics (Miller et al., 2004). Variable rate applicators utilize GPS and GIS map-based, "on-the-go" sensors, or a combination of maps and sensors (Miller et al., 2004; Schumann et al., 2006). Precision farming techniques enable agricultural producers to improve crop production efficiency and reduce environmental impacts by adjusting rates of fertilizer in a site-specific fashion. These are achieved by identifying spatial variability of soil properties, topographic features and crop yield (Yang, 2001; Khosla et al., 2002; Schumann et al., 2006; Patzold et al., 2008).

Accurate estimation of field characteristics is very important for the successful implementation of VRT. Increased sampling density allows the input application to be better tailored to individual site characteristics. VRT can also reduce the amount of nutrients applied in fields and control the variability of nutrients within the field (Wittry and Mollarino, 2004; Schuman et al., 2006). Variable rate fertilizer application, based on within-field variability in soil properties, has the potential to reduce under- and over-application of fertilizers, and subsequently improve fertilizer use efficiency, crop yields and net farm returns (Fiez et al., 1994). Variable rate fertilization in different crops has shown positive economic and environmental impacts (Thrikawala et al., 1999; Intarapapong et al., 2002). Yang et al. (2001) studied variable rates by applying nitrogen (N) and phosphorus (P) fertilizer to sorghum. These results showed that VR application increased yield and raised economic returns.

Development of technologies for variable rate deliveries of crop inputs such as granular and liquid fertilizers, seed, pesticides, and irrigation water have strengthen the cause of precise application (Robert, 2002). These technologies have provided many opportunities for researchers to evaluate of the economics and environmental benefits of VRTs. Wang et al. (2003) evaluated economic and water quality effects of variable rate nitrogen and lime applications in corn fields. They reported VRT to be more profitable than uniform fertilization in 75% of the cases. Similarly, Thrikawala et al. (1999) compared VRT and uniform management and reported the reduction in leaching from a minimum of 4.2% to maximum of 36.3% in corn fields, while yield was not affected. Roberts et al. (2001) compared VRT with uniform management in 63 fields and reported lower nitrogen losses to environment with VRT. Whitley et al. (2000) studied the differences in nitrogen leaching under uniform management and VRT, based on slope and soil organic matter. Their result showed that VRT improved crop yield and reduce nitrogen leaching. Variable rate P application resulted in 12 to 41 % less fertilizer application and reduced soil-test P (STP) variability as compared to uniform rate fertilizer application (Wittry and Mallarino, 2004). Schumann et al. (2006) investigated the performance characteristics of a VRT spreader during fertilization of a commercial citrus grove and reported improved profitability and reduced nitrate contamination of groundwater as compared to uniform application. Zaman et al. (2005) showed a 40%

reduction in fertilizer use with VRT in a citrus orchard as compared to uniform application.

A comprehensive review of many research articles concluded that VRT maintains farm profitability and also protect environment, when compared to uniform management (Bongiovanni and Lowenberg-Deboer, 2004).

2.8 Wild Blueberries

Wild blueberry (*Vaccinium Angustifolium Ait.*) has become an important horticultural crop in northeastern North America. The total area under production is 86,000 ha located in Atlantic Canada, the Province of Quebec, and the State of Maine (Yarborough, 2009). Wild blueberry fields are developed by removing forest and rocks from areas that have already sufficient coverage of blueberries (Travett, 1962). Unlike other crops, the soil type of these fields is similar to forest ecosystem (Eaton, 1988). These soils are generally sandy loam and are well drained and have high organic matter (Travett, 1962). Wild blueberry canopy expands by underground rhizome system that is 70% to 85% of total weight (dry wt. basis) of the plant (Jeliazkova and Percival, 2003).

Wild blueberry is naturally a perennial crop but to enhance the floral bud initiation, fruit production and ease of mechanical harvesting, it is forced into biennial production system by pruning in alternating years (Hall et al., 1979). Pruning helps the blueberry to remain dominant by controlling weeds (Travett, 1959). During first year, plant grows vegetatively after pruning, and initiates floral buds from July to October, followed by winter dormancy (Hall et al., 1979). Wild blueberries are tolerant of low temperature (Quamme et al., 1972). Floral buds further develop in spring, and bloom occurs in May and June. After pollination, fruit start developing in June and ripens usually in August (Hall et al., 1979). Over the past 100 years, blueberry was harvested by metal hand racks similar to cranberry scoop (Kinsman, 1993). Currently, mechanical harvesters are used for harvesting the fruit.

Half of the wild blueberry fields are harvested each year because of biennial production system (Yarborough, 2007). Production in the Provinces of Atlantic Canada has significantly increased over the past 30 years (Hall et al., 1979). This yield has increased due to improved fertility management and honey bees introduction to blueberry fields (Yarborough, 2007).

Fertilizers are applied after pruning in vegetative year. Various combinations of nitrogen, phosphorus, potassium, boron, magnesium and zinc are used and results suggest that blueberry responds to fertilizer application by increased vegetative growth and yield potential (Eaton, 1988). Grasses and other weeds were also adapted to fertilizers and their growth restricted wild blueberry growth (Yarborough and Ismail, 1985). After the introduction of herbicides, the combination of fertilizers and herbicides are used by producers (Yarborough et al., 1986). Most of the fertilizers contained only nitrogen, but recent fertilizer have also included phosphorus in formulation such as 13-26-5, 14-18-10, or 18-46-0 (Eaton et al., 1997). Litten et al. (1997) showed that diammonium phosphate (DAP) increased yield components such as stem length, number of floral buds, and yield, from 4900 to 6235 kg ha^{-1}.

Townsend and Hall (1970) observed leaf nutrient level during four consecutive years. In sprout year nitrogen concentrations increased from July 22 to September 22, while its level decreases from July 22 to September 22 in crop year suggesting that nitrogen was translocate from leaves to fruit. Trends were similar in both vegetative and crop year for all other nutrients.

Wild blueberry fields, especially in early years of production, have significant proportions of bare spots (30 to 50%) (Zaman et al., 2008b). Uniform blanket application of fertilizers and other agrochemicals to wild blueberry fields without considering these bare spots and weed patches will not only increase the cost of production, but also, can increase environmental pollution (Zhang et al., 2010).

2.9 Growth Parameters

Wild blueberry plants are woody shrubs about 10 cm tall with an alternate bot orientation and a floral inflorescence that is unbranched, indeterminate and bears pedicellate flowers (Barker et al., 1964). A wild blueberry stem length varies from 10 to 30 cm, and has only one vegetative flush. Flowers are usually and white in color having four or five petals and can only produce one berry per flower (Bell et al., 2003). Wild blueberry root system is shallow and laterally spread (McMahon et al., 2002).

During the sprout year, vegetative stems grow until tip dieback stage, usually end of July to first week of August (Hall et al., 1972). Previous studies on different physiological traits and yield components regarding the effects of nitrogen, phosphorus and potassium fertilization in wild blueberry fields have provided conflicting results (Percival and Sanderson, 2004). Some studies showed positive responses of fertilization in wild blueberry fields (Benoit et al., 1984; Jeliazkova and Percival, 2003), while other studies could not find significant impact of fertilization on fruit yield (Warman, 1987; Percival and Sanderson, 2004). These conflicts were due to spatial variability and type of nutrients investigated (Bourguignon et al., 2006).

Starast et al. (2007) found a significant impact of fertilization on numbers of shoots per plant and fruit yield in blueberry, while fertilization has not significantly affected berry weight. In another study on wild blueberry yield components response to fertilization, Sanderson and Eaton (2004) reported that fertilization significantly increased stem length, number of buds per stem and total stems per blossom. Bourguignon et al. (2006) found that nitrogen can increase the percentage of side branching but due to variable nutrient levels in blueberry fields fertilization should be site specific.

2.10 Data Management

GIS in combination with geostatistics is used to characterize and quantify the spatial variation of soil properties, topographic features and yield. Blackmore (1994) stated GIS as: "A software application that is designed to process, manipulate and display the spatial data." A farming GIS database comprises of layers on field topography, soil types, surface and subsurface drainage, rainfall, irrigation, chemical application rates, and crop yield. The gathered information can be analyzed to understand relationships between different parameters that affect crop production in a specific location (Ahmadi and Mollazade, 2009).

The GIS deals with data in layers, each of which has its own characteristics. The maps developed by GIS can be raster based (i.e. stored as individual cells) or may be vector based (i.e. stored as coordinate points and linking boundary lines). The vector format defines the location of points (x-y coordinates) by using a continuous coordinate system allowing geo-referencing to be more accurate than raster format (Morgan and Ess, 1997). The GIS is helpful in implementing the input decisions using variable and spatially precise doses of fertilizers or pesticides based on the maps developed.

Slope variability is a key element in site-specific nutrient management. Variability in space and time can give valuable insight into the dynamic nature of soil properties within a field's boundary (Cox et al., 2003). Delineation of management zones depends on distribution of topographical parameters and these zones should be practically manageable. Once these zones are delineated, relationships between spatial variation in soil/crop parameters and yield can be examined (Pilesjö et al., 2005). Many researchers divided their fields into management zones based on topographic and other soil variation in different cropping systems (Thrikawala et al., 1999; Whitley et al., 2000; Goddard and Grant 2001; Yang et al., 2001; Mzuku et al., 2005), and found good positive results of these divisions on crop yield and environment.

Coefficients of variability (CVs) provide overall variability among different crop and soil parameters. The analysis of variance (ANOVA) F-Test can be used for the analysis of data. An ANOVA controls the overall error by testing all the means against each other at the same time. The means can be compared using PROC MIXED (Hopkins, 2000).

2.11 Summary

Wild blueberry fields have gentle to severe topography. Topography plays an important role in the plant growth especially in rain fed areas. The chance of nutrient erosion increases with the slope and elevation and these eroded nutrients significantly affect the plant growth and yield. Wild blueberry crops have narrow fertilizer application windows. If the quantity of available nutrients increases from the optimum level there will be more vegetative growth but fruit yield will be reduced, and if the quantity of available nutrients is less than optimum level then it will obviously have detrimental effects on yield. These nutrients can also accumulate in low lying areas in fields and leaching of these nutrients can cause groundwater contamination. Currently, the fertilizer application in wild blueberry fields is uniform without considering the topographical variation in field. The uniform application in these extremely spatially variable fields is resulting in detrimental effects on berry production and environment. Although, wild blueberry producers are aware of these spatial variations but due to lack of technologies and research, they apply agrochemicals uniformly. The advancement of precision agriculture technologies in wild blueberry fields will help the site specific management. Precision agriculture techniques are useful in developing management zones for site-specific fertilization to apply required amounts of nutrients on the basis of topography. The successful development of topographically delineated zones can be helpful in saving costly fertilizer and it can also protect the environment by reducing groundwater contamination.

CHAPTER 3

MATERIALS AND METHODS

3.1 Description of Experimental Sites

Two wild blueberry fields were selected in central Nova Scotia to evaluate the effect of variable rate (VR) fertilization on nutrient losses in surface runoff, nutrient leaching, and fruit yield. The first selected site was Kemptown Field (45^0 31’ 50” N and 63^0 07’ 45” W), Nova Scotia. This field was in its vegetative sprout year in 2010. The field was divided into two sections, one section received VR fertilization and in the second section, uniform fertilization was applied. The second selected site was the Cattle Market Field (45^0 22’ 37” N and 63^0 13’ 7” W), Nova Scotia. This field was also in its vegetative year in 2011. Control (no fertilization) section was also added in Cattle Market Field as a reference. The soil at both experimental sites is classified as sandy loam (Orthic Humo-Ferric Podzols), which is a well-drained acidic soil (Webb et al., 1991).

3.2 Topographic Maps

3.2.1 Slope Data and Map

Slope variability was assessed with a slope measurement and mapping system (SMMS) at the start of the experiment in sprout year for both experimental sites. The system consists of a tilt sensor that determines the tilt of the vehicle in any orientation on the slope. A Trimble AgGPS-332 DGPS antenna (Trimble Navigation Limited, CA, USA) was mounted on the all-terrain vehicle (ATV) to determine the location of the point. A laptop computer, with a custom developed software, recorded georeferenced slope data from the tilt sensor and GPS in real-time within the fields (Figure 3-1).

Detailed procedures for measurement and mapping of slope are outlined in Zaman et al. (2010a).

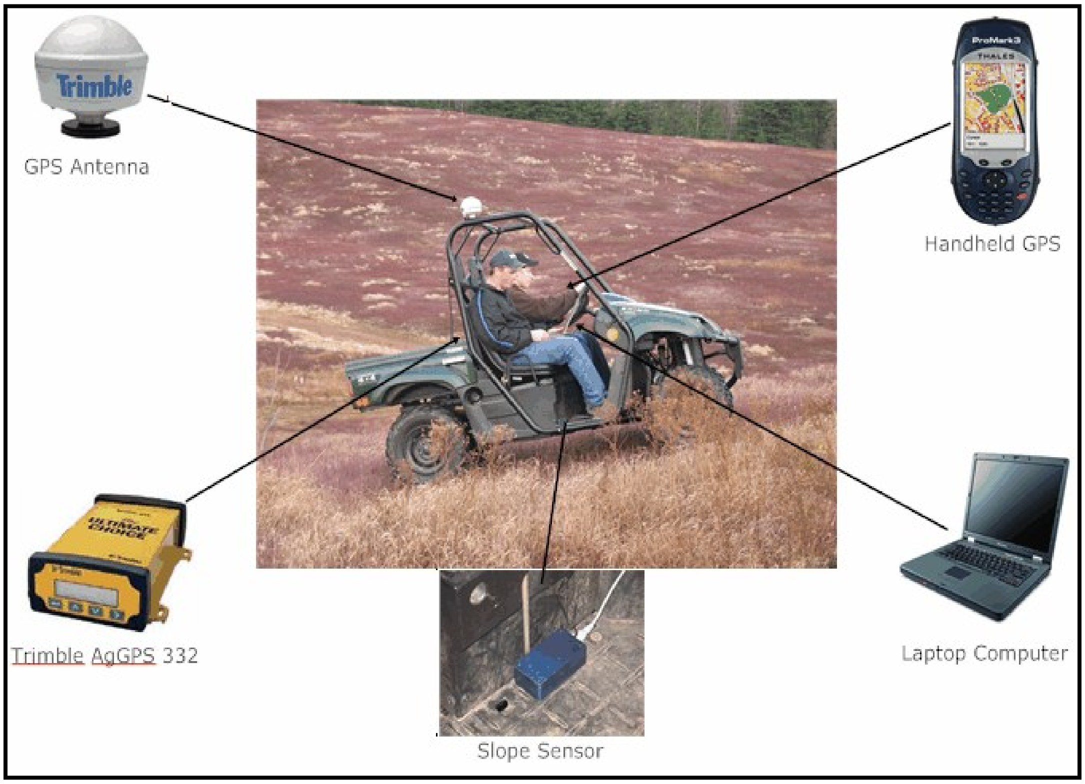


Figure 3-1. Slope Measuring and Mapping System (Zaman et al., 2010).

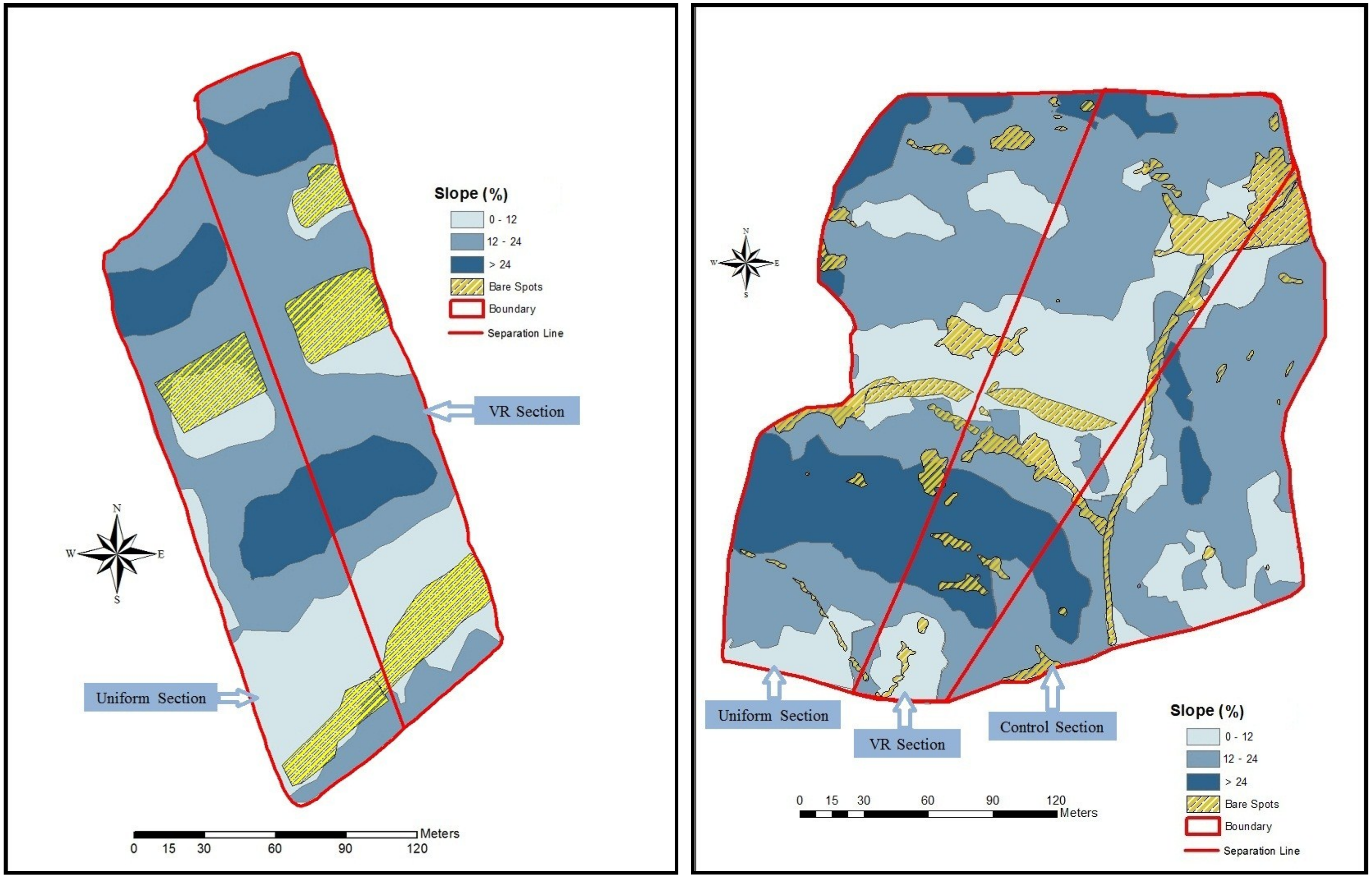
Slope map of each field was generated in Arc GIS 9.3 software using kriging interpolation technique. Geostatistical analysis was performed using GS+ Geostatistics for the Environmental Sciences Version 9 software (Gamma Design Software, LLC, MI, USA) to measure nugget, sill and range of influence. Nugget semi-variance is the variance at zero distance. Range is the lag distance between measurements at which one value of a variable does not influence neighboring values, and the plateau the variogram reaches at the range is called sill. Sill is used to estimate the range (Oliver, 1987). These semiveriogram parameters were used in kriging interpolation technique to generate smooth krigged slope maps. The bare spots, weeds and grasses were also mapped in each field using Topcon HiPer Lite+ RTK-GPS (Topcon positioning Systems, Inc., CA, USA). Each field was divided into three slope categories. Figure 3-2 (a and b) shows the slope maps for Kemptown Field and Cattle Market Field.

3.2.2 Elevation Data and Map

Relative elevation from mean sea level was obtained from both fields using a RTK-GPS receiver. The GPS receiver has vertical accuracy of 1 to 2 cm (Topcon HiPer Lite+ Operation Manual, 2004). A reference base station was established prior to logging elevation data in each field. Data were logged using an FC-200 Field Computer (Topcon Positioning Systems, Inc., CA, USA). The rover antenna was mounted on top of the ATV. A constant speed of 2 m s^{-1} was maintained. The slope data and corresponding DGPS (x and y coordinates) were collected at 3-m intervals. Elevation maps for both fields (Figure A1 a and b, Appendix A) were generated in Arc GIS 9.3 software using kriging interpolation technique, which was discussed earlier in section 3.2.1.

3.3 Variable Rate Fertilization

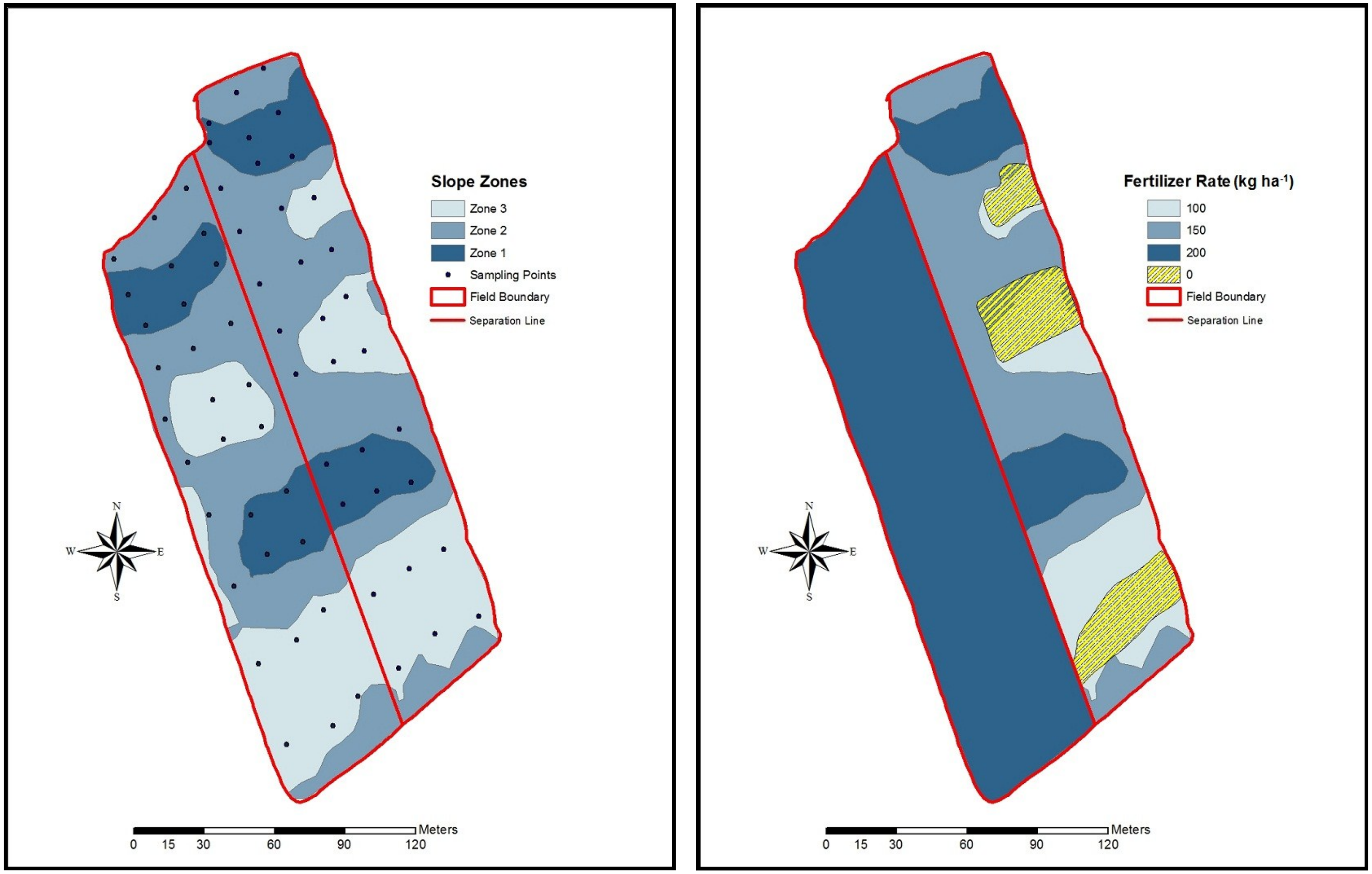
Three different management zones (zone-1 (Z1), steep slope; zone-2 (Z2), moderate slope; and zone-3 (Z3), low lying area) were delineated based on variation in slope within the selected fields. Prescription maps were generated for VR fertilization in developed management zones of VR sections. The 7.32 meters wide boom Valmar 1255 pull type granular applicator (Valmar Airflo Inc. MB, Canada) equipped with Rawson™ Accu-Rate® variable rate controller system (Trimble Navigation Ltd. CA, USA), GPS and an electro hydraulic metering drive unit was utilized to apply different fertilizer rates in management zones within wild blueberry fields.



(a)

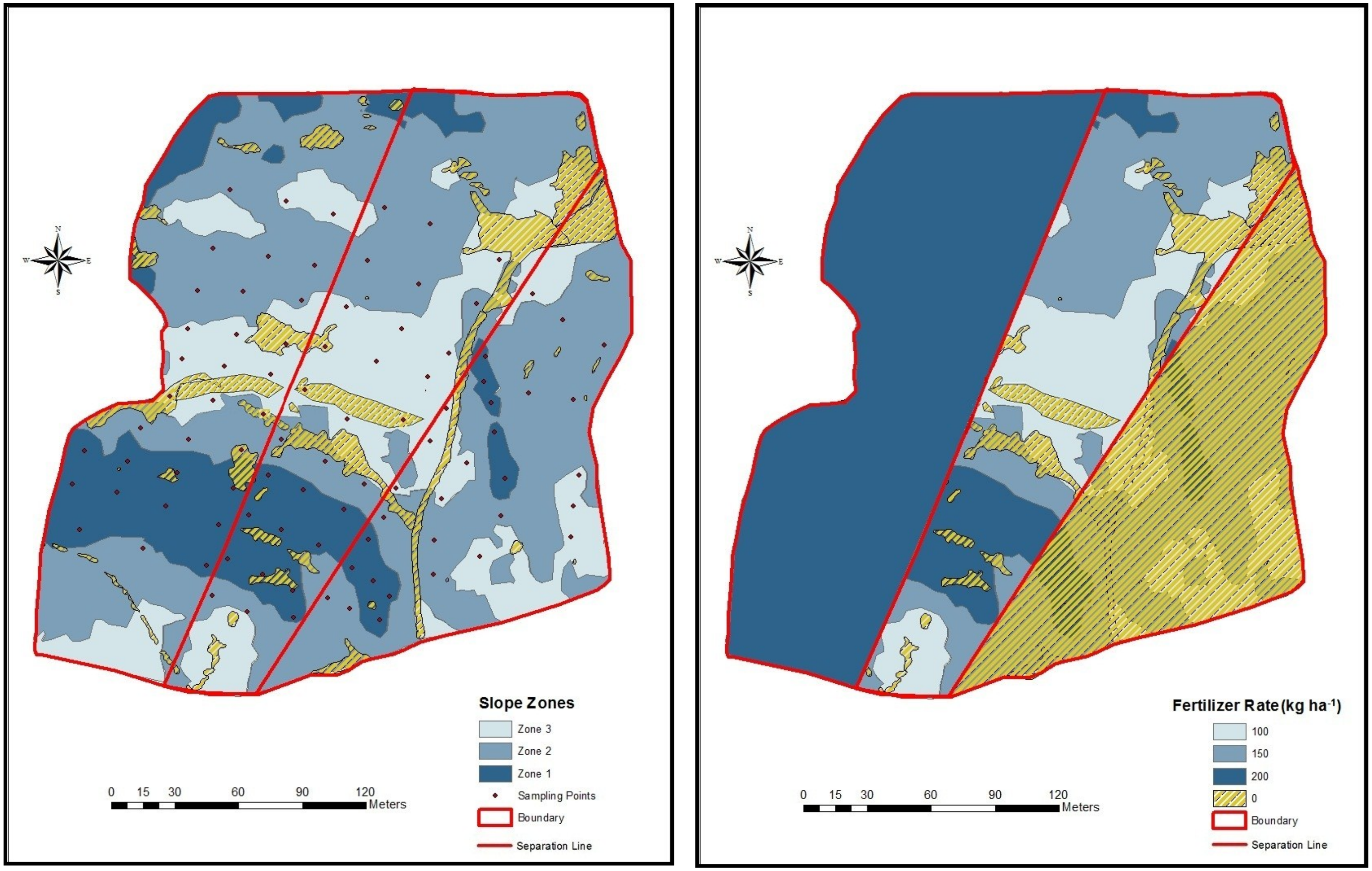
(b)

Figure 3-2. Slope maps for (a) Kemptown Field (b) Cattle Market Field.



(a) (b)

Figure 3-3. (a) Slope zones and sampling points for Kemptown Field. (b) Prescription map for Kemptown Field



(a)

(b)

Figure 3-4. (a) Slope zones and sampling points for Cattle Market Field. (b) Prescription map for Cattle Market Field

The fertilizer (NPK: 16.5 – 34.5 – 4.5, respectively), constituted of ammonium sulphate (NPK: 21 – 0 – 0), di-ammonium phosphate (NPK: 18 – 46 – 0), muriate of potash (NPK: 0 – 0 – 60), was applied in the third week of May 2010 for Kemptown Field and third week of May 2011 for Cattle Market Field, during the sprout years. In each field, the highest N rate, equals to the grower's previous uniform rate (200 kg ha^{-1}) was allocated to the Z1, and the remaining two management zones received diminishing amounts of N down to a minimum of 50% of the maximum (Figure 3-3 a and b; Figure 3-4 a and b). Bare spots were defined as a separate class in the developed management zones and zero rates was applied in bare spots. These rates were selected on the basis of results of Zaman et al. (2009), who found that excessive leaf nutrients and vegetative growth, and less fruit yield was observed in low lying areas of the field as compared to steep slope areas. The grower's uniform fertilizer rate 200 kg ha^{-1} was applied in uniform fertilizer sections of each field for comparison. No fertilizer was applied in the control section of Cattle Market Field as shown in Figure 3-4 b.

3.4 Soil Sampling

Soil samples were collected from each field to evaluate the effect of VR and uniform treatment on soil nutrients, and to determine selected physical and chemical properties. A sampling pattern was established on the basis of slope map to collect equal number of soil samples from each management zone (Figure 3-3 a; Figure 3-4 a). Soil samples were collected before the fertilizer application in 3rd week of May 2010 and 2011 for Kemptown Field and Cattle Market Field, respectively. The 2nd soil sampling was performed in 3rd week of July 2010 and 2011 for Kemptown Field and Cattle Market Field, respectively. Soil samples were collected from 0-15 cm below soil surface at each sampling point. Five cores were collected from each sampling point to make a representative sample (Brouder et al., 2005). Each soil sample was then divided into two sub-samples and secured in two sampling bags properly labeled for the respective treatments. Both bags were labeled with same name. For all soil samples, one bag was immediately stored in the refrigerator at 4 ^{0}C for ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^--N) analysis, and the other bag was air dried for two weeks. The air dried soil samples were grounded using a soil grinding machine (Nasco Farm and Ranch Co, WI, USA) to pass through 2 mm sieve. These soil samples were analyzed for soil organic matter (SOM), electrical conductivity (EC), pH, and soil texture. The SOM and texture were measured once at the onset of the experiment. Other parameters such as soil pH, EC, soil NH_4^+-N and NO_3^--N were measured twice, before and after the fertilization. The coordinates of each sampling point were recorded using RTK-GPS.

3.5 Soil Analysis

3.5.1 Soil Organic Matter Content (SOM)

Loss on ignition method was used to determine SOM (Davies, 1974). Ten grams (g) of soil was placed into a ceramic crucible and dried in oven at 105 ^{0}C. Samples were taken out of the oven and weighed. The weighed samples were dried in a muffle furnace at 450 ^{0}C for 8 hours. The samples were re-weighed and % SOM was measured using the following formula (Davies, 1974):

$$\%SOM = \frac{S_D - S_{MFD}}{S_D} \times 100 \tag{3.1}$$

Where S_D = Oven dried soil (g)

S_{MFD} = Muffle furnace dried soil (g)

3.5.2 Electrical Conductivity (EC)

A conventional EC meter, Accument 50 (Fisher Scientific, NH, USA), was calibrated for determining EC of soil using a 1:2 soil: water suspension (Mann, 2009). The soil and water mixture were prepared in Dixie cups and these cups were placed on the shaker for 40 minutes. EC was measured by inserting the EC electrode (probe) that was connected with EC meter in the soil water suspension. Meter readings were recorded once the EC values were stable on LCD.

3.5.3 pH

The pH meter Corning 450 (Corning, Incorporated, NY, USA) was calibrated for determining pH of the soil using a 1:2.5 soil: water ratio. The soil and water solution were placed on shaker for thirty to forty minutes and pH were measured by inserting the pH electrode that was connected with the pH meter in the soil water suspension (McLean, 1982).

3.5.4 Volumetric Moisture Content (θ_v)

TDR-300 (Spectrum Technologies, Inc, IL, USA) was inserted 15 cm below the soil surface to record θ_v. Three TDR readings were recorded at each sampling point to get an average value of θ_v. The θ_v was determined twice per month, and also before and after rainfall events.

3.5.5 Ammonium-N and Nitrate-N

A Technicon auto-flow analyzer (Technicon Autoanalyzer-2, Terry Town, NY, USA) was used to determine NH_4^+-N and NO_3^--N using 2.0 *M* Potassium Chloride (KCl) solution. The 2.0 *M* KCl solution was prepared by mixing one liter distilled water with

150 g of KCl crystals. Twenty grams of wet soil was weighed and poured 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. This solution was passed through Whatman No. 42 filter paper and collected in 20 ml scintillation vials. When the extract reached up to 3/4th level of the vial, the vial was capped and secured in a freezer for the further analysis (Voroney et al., 1993).

The NO_3^--N in the soil was determined by using Technicon auto-flow analyzer nitrate method (Technicon Industrial Systems, 1978). In this method, initially by using copper/cadmium reduction chamber, the nitrate concentration in the sample is reduced to nitrite. The extract is then mixed with the reagents to form reddish purple color, NO_3^--N in the sample is determined calorimetrically. NH_4^+-N in the soil was also determined by using Technicon auto-flow analyzer ammonium method (Technicon Industrial Systems, 1973). In this method the ammonium ions are heated with reagents to produce blue color, which is proportional to the ammonia concentration in the solution and the amount of NH_4^+-N in the sample is determined.

3.5.6 Soil Texture

A standard hydrometer (ASTM. No. 1-152H) was used to measure the particle size distribution (Day, 1965). Forty g of oven dried soil from each sample was transferred into a 600 mL cylinder, and 300 mL of distilled water and 100 mL of calgon (Sodium Hexameta-phosphate solution diluted with water in 1: 20 ratio) solution was added to the cylinder. The sample was soaked overnight to properly mix with solution. This solution was mixed in shaker for 5-10 minutes to completely mix the soil with the solution. The mixture was then poured into a graduated cylinder and distilled water was added until the total volume inside the cylinder reached 1 L. The cylinder was then covered with a rubber plunger and inverted 6 to 12 times. The hydrometer was placed in the cylinder, and the first reading was recorded after 40 seconds and the second reading was recorded after 7 hours. The % silt, %sand, and %clay was determined. Detailed procedure is provided in Day (1965).

3.5.7 Bulk Density

Bulk density of the soil was determined using a coring rig using the standard procedure (Grossman and Reinsch, 2002):

$$\rho = \frac{S_D}{Volume\ of\ soil\ core} \tag{3.2}$$

where ρ is bulk density of the soil in g cm^{-3}.

3.6 Hydraulic Conductivity

The Guelph Permeameter (Reynolds et al., 1985) was used to measure the saturated hydraulic conductivity (K_{sat}). Guelph permeameter is an easy to use instrument for quickly and accurately measuring in *situ* hydraulic conductivity. Guelph permeameter measurements can be made at the unsaturated soil surface. A hole was augured and cleaned properly and lower tube of Guelph permeameter is placed inside and acrylic tube at the top is lifted to allow the water to move in the hole. Steady flow was produced after some time and reading are started to take at a regular interval. The hydraulic conductivity is determined by standard equation (Reynolds et al., 1985).

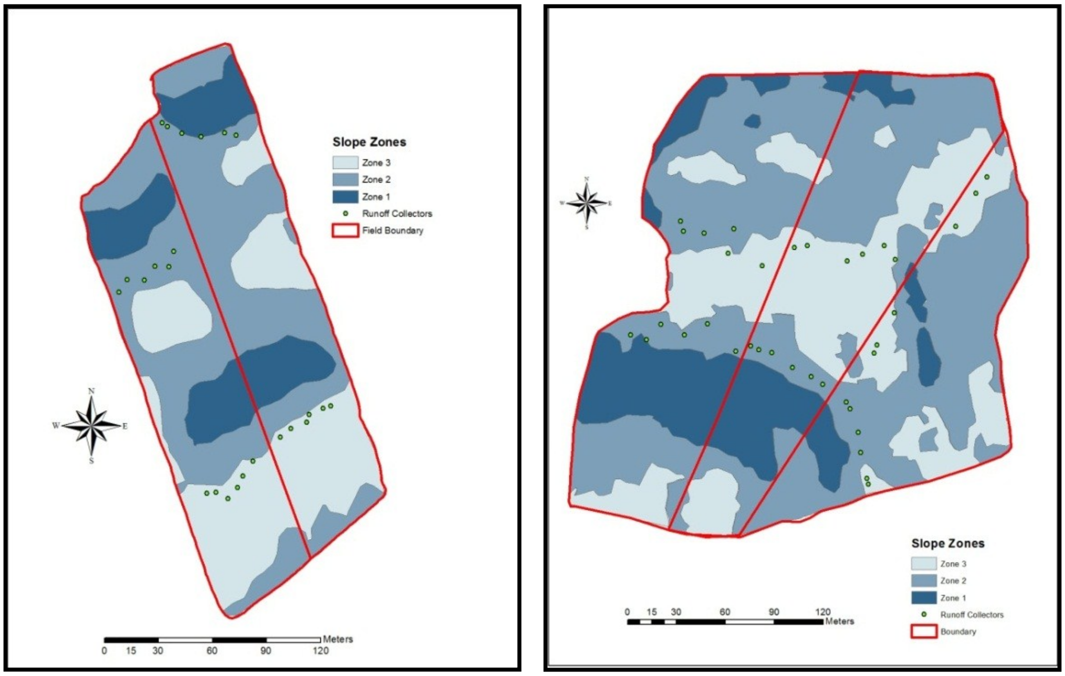
$$K = \frac{\Delta L\ (cm)}{\Delta T (min)}\ x\ 60 \frac{(min)}{(hr)}\ x\ C* \tag{3.3}$$

Where K is the hydraulic conductivity in cm hr^{-1}, ΔL is the decrease in water level inside tube, ΔT is the time interval, and C is the constant.

3.7 Surface Runoff Water Collection

3.7.1 Runoff Collectors

In Kemptown Field, surface water sample were collected from twenty four surface runoff collectors placed at different locations in both variable and uniform rate sections, with each section having 12 runoff collectors (Figure 3-5 a). The locations of the runoff collectors were selected on the basis of slope variation in the fields. Thirty six runoff collectors (12 in each section, VR, uniform and control) were installed in the Cattle Market Field to collect surface runoff (Figure 3-5 b).



(a) (b)

Figure 3-5. Runoff collectors in (a) Kemptown Field (b) Cattle Market Field.

3.7.2 USDA-NRCS runoff plots

The runoff collectors (Figure 3-5) placed in both fields collected surface runoff water from unknown areas. Although, catchment areas of each surface runoff collector could be delineated using GIS techniques. However, besides the runoff collectors, USDA-NRCS runoff plots were placed for ground truthing and to measure the surface runoff volumes from known areas in each management zone (Figure 3-6). The locations of these USDA plots were determined on the basis of contour map. Micro topography of the catchment areas was conducted using a RTK-GPS to determine the area of the USDA runoff plots. Total area and average slope of the catchment was used to calculate the catchment areas of runoff collectors using eq. 3.4 (Tomer et al., 2003):

$$E = \left[\frac{A}{22.13}\right]^{0.6} \times \left[\frac{Sin \propto}{0.0896}\right]^{1.3} \tag{3.4}$$

Where E = Catchment area of the runoff plot (m^2)
A = Total catchment area (m^2), and
α = Average slope of the area (degrees)

The descriptions of USDA-NRCS plots are provided (Table 3-1). The USDA runoff plots VRO, UNO, and CTO were open from the top to collect combine runoff from all three management zones, while other runoff plots were closed from the upstream end.

Table 3-1. Description of USDA-NRCS runoff plots in the Cattle Market Field.

USDA-NRCS Plot	Description	Area (m^2)
CTS	USDA Runoff plot in Z1 of control section; closed	57.00
CTM	USDA Runoff plot in Z2 of control section; closed	45.75
CTL	USDA Runoff plot in Z3 of control section; closed	8.15
CTO	USDA Runoff plot in Z3 of control section; open	41.00
VRS	USDA Runoff plot in Z1 of VR section; closed	97.00
VRM	USDA Runoff plot in Z2 of VR section; closed	44.20
VRL	USDA Runoff plot in Z3 of VR section; closed	30.00
VRO	USDA Runoff plot in Z3 of VR section; open	60.86
UNS	USDA Runoff plot in Z1 of uniform section; closed	96.50
UNM	USDA Runoff plot in Z2 of uniform section; closed	47.90
UNL	USDA Runoff plot in Z3 of uniform section; closed	14.00
UNO	USDA Runoff plot in Z3 of uniform section; open	52.30

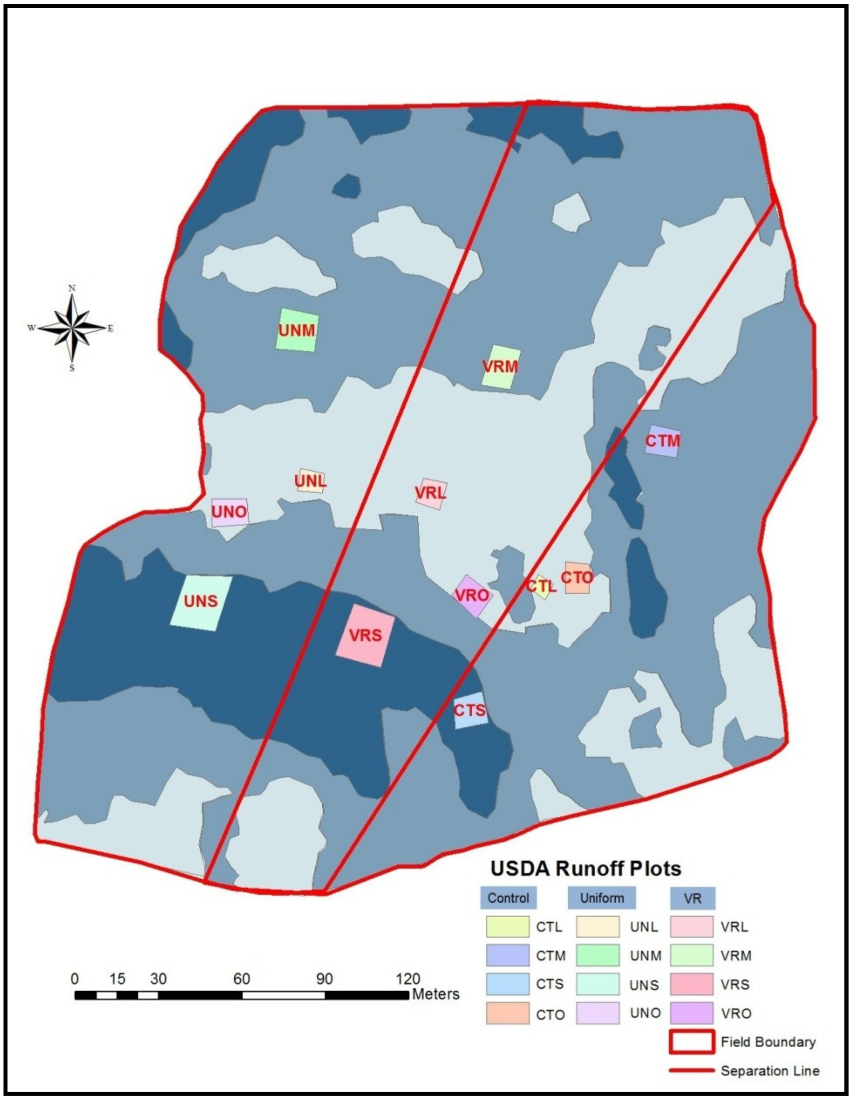


Figure 3-6. Locations of USDA runoff plots in the Cattle Market Field.

3.7.2.1 Construction of runoff plots

First, wooden sheets (2.44 × 1.52 m) were cut into variable size lengths and 0.3 m width boards. Trenches were dug in the ground, and boards were placed at appropriate locations at a depth of 0.15 m below the ground surface in order to avoid entry of flow from the outside of the constructed plots.

Collections buckets were placed at the end of each runoff plot to collect the surface runoff from the plot areas. These buckets were covered with plastic sheets to block the direct rainfall or other debris from entering into the buckets. After every rainfall event the runoff samples were collected from June to October 2011. Runoff samples from every plot were immediately stored into the refrigerator for further analysis. The schematic diagram of the USDA runoff plot shows the mechanism of runoff collection (Figure 3-7).

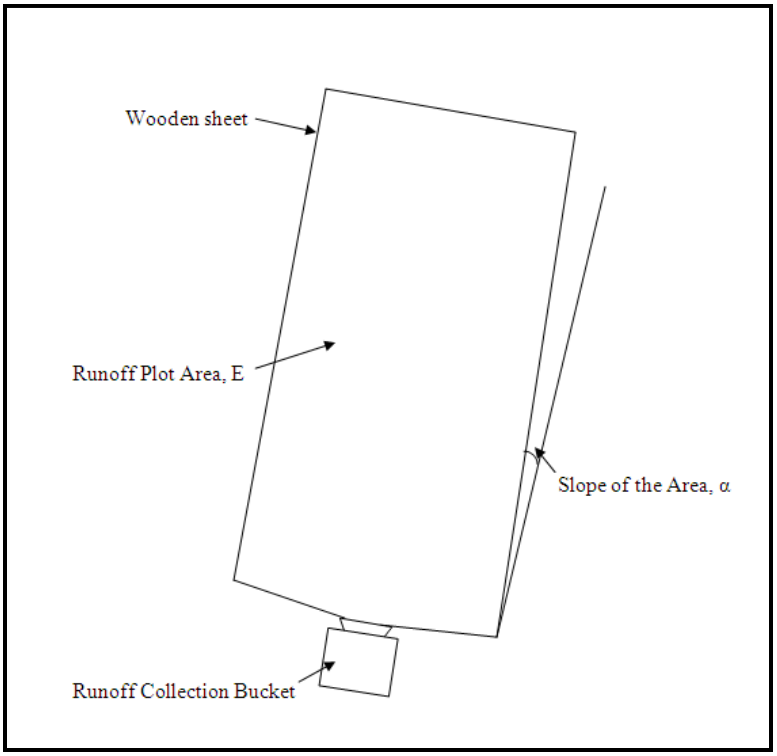


Figure 3-7. Schematic diagram for USDA-NRCS runoff plots.

3.7.3 SCS-CN method

To calculate the surface runoff losses SCS-CN method was used. A 0.5 m resolution DEM was constructed on the basis of elevation data collected from each field. The elevation data from the RTK-GPS was imported to ArcGIS 9.3 software and DEM was constructed by using 'Topo to Raster' extension under 'Spatial Analyst' module. For each section a separate DEM was constructed in each field. The SWAT model used

DEMs to delineate each runoff collector catchment area. Elevation of Kemptown Field ranged from 215 to 236 m, while elevation range for Cattle Market Field was 34 to 60 m. The SCS-CN equation is (SCS, 1972).

$$Q = \frac{(P - I_a)^2}{P - I_a + S)} \tag{3.5}$$

Where Q is the runoff produced (mm), P is the amount of rainfall (mm), I_a is the initial abstractions, S is the retention factor. Retention parameter was calculated as:

$$S = \frac{25400}{CN} - 254 \tag{3.6}$$

Where CN is the curve number for that day. Researchers related I_a with S and found a relationship that $I_a = 0.2S$, and eq. (3.5) becomes (VO2 reference manual, 2011).

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S)} \tag{3.7}$$

From the literature review, it has been found that for lower CN values, a lower I_a should be used (VO2 reference manual, 2011). Suggested guidelines are as follows:

$CN \leq 70$	$I_a = 0.075S$
$CN > 70 \leq 80$	$I_a = 0.10S$
$CN > 80 \leq 90$	$I_a = 0.15S$
$CN > 90$	$I_a = 0.2S$

For SCS-CN method, CN selection is very important. The CN value should be carefully selected from the tables provided by SCS (1986). The selection of curve number is based on soil hydrologic group, type of crop, and crop coverage in the study area.

The selected CN value was for average antecedent moisture condition (AMC-II), while AMC-I is referred as dry condition (wilting point) and AMC-III is referred as wet condition (field capacity). CN_1 was used for AMC-I and CN_3 was used for AMC-III. The equations to calculate CN_1 and CN_3 are:

$$CN_1 = CN - \frac{20(100 - CN)}{(100 - CN + e^{[2.533 - 0.0636(100 - CN)]})} \tag{3.8}$$

$$CN_3 = CN * e^{[0.00673(100 - CN)]} \tag{3.9}$$

In order to calculate the event CN value, retention parameter (S) should be calculated on the basis of variation in soil profile moisture condition (Neitsch et al., 2005).

$$S_d = S_1\left(1 - \frac{SWC}{[SWC + e^{(d-f*SWC)}]}\right) \tag{3.10}$$

Where S_d was the retention for a given day (mm), S_1 was the maximum value for retention parameter for that day, d and f were shape coefficients, SWC (mm) was available soil water content excluding soil water content at wilting point (mm). S_1 was the retention parameter at AMC-I, and was calculated by inserting the value of CN_1 in eq. 3.6. The shape coefficients were determined by (Neitsch et al., 2005):

$$d = ln\left[\frac{FC}{1 - S_3{S_1}^{-1}} - FC\right] + f * FC \tag{3.11}$$

$$f = \frac{\left(ln\left[\frac{FC}{1 - S_3{S_1}^{-1}} - FC\right] - ln\left[\frac{SAT}{1 - 2.54{S_1}^{-1}} - SAT\right]\right)}{SAT - FC} \tag{3.12}$$

Where d and f are first and second shape factors respectively, FC was moisture content of the soil profile at the field capacity (mm), S_3 was the retention parameter at

AMC-III, and was calculated by inserting the value of CN_3 in eq. 3.6, *SAT* was the amount of water in soil profile when completely saturated. The pedotransfer function was used estimate the *FC* and *SAT* from soil texture and bulk density by using standard equations (Pollacco, 2008). Event curve number after adjusting retention parameter was calculated.

$$CN_R = \frac{25400}{S_d + 254} \tag{3.13}$$

Where CN_R was event curve number value adjusted for moisture content, CN_{3R} was calculated for CN_R adjusted curve number by replacing *CN* with CN_R in eq. 3.9. The CN selected from the tables are for slope up to 5%. The curve number values were adjusted for slope by using the following equation (Williams, 1995).

$$CN_s = \frac{(CN_{3R} - CN_R)}{3}\left[1 - 2e^{-13.86\,S}\right] + CN_R \tag{3.14}$$

Where CN_S was the event curve number value after adjusting moisture condition and slope, which was inserted into eq. 3.6 to calculate adjusted value for retention parameter S_S. S_S was used in eq. 3.5 to calculate runoff produced from the rainfall event.

3.7.4 Surface runoff sample analysis

The surface runoff samples were analyzed for total phosphorus (TP), dissolved reactive phosphorus (DRP) and inorganic nitrogen. TP was analyzed using total a phosphorus channel in a Technicon auto-flow analyzer (Technicon Autoanalyzer-2, NY, USA) and surface runoff samples were filtered using 0.45 µm filter paper and analyzed to quantify DRP (Edwards and Withers, 1998). Particulate phosphorus (PP) was quantified by subtracting DRP from TP (Haygarth and Sharpley, 2000). Total suspended solids were determined gravimetrically (Pote et al., 2009).

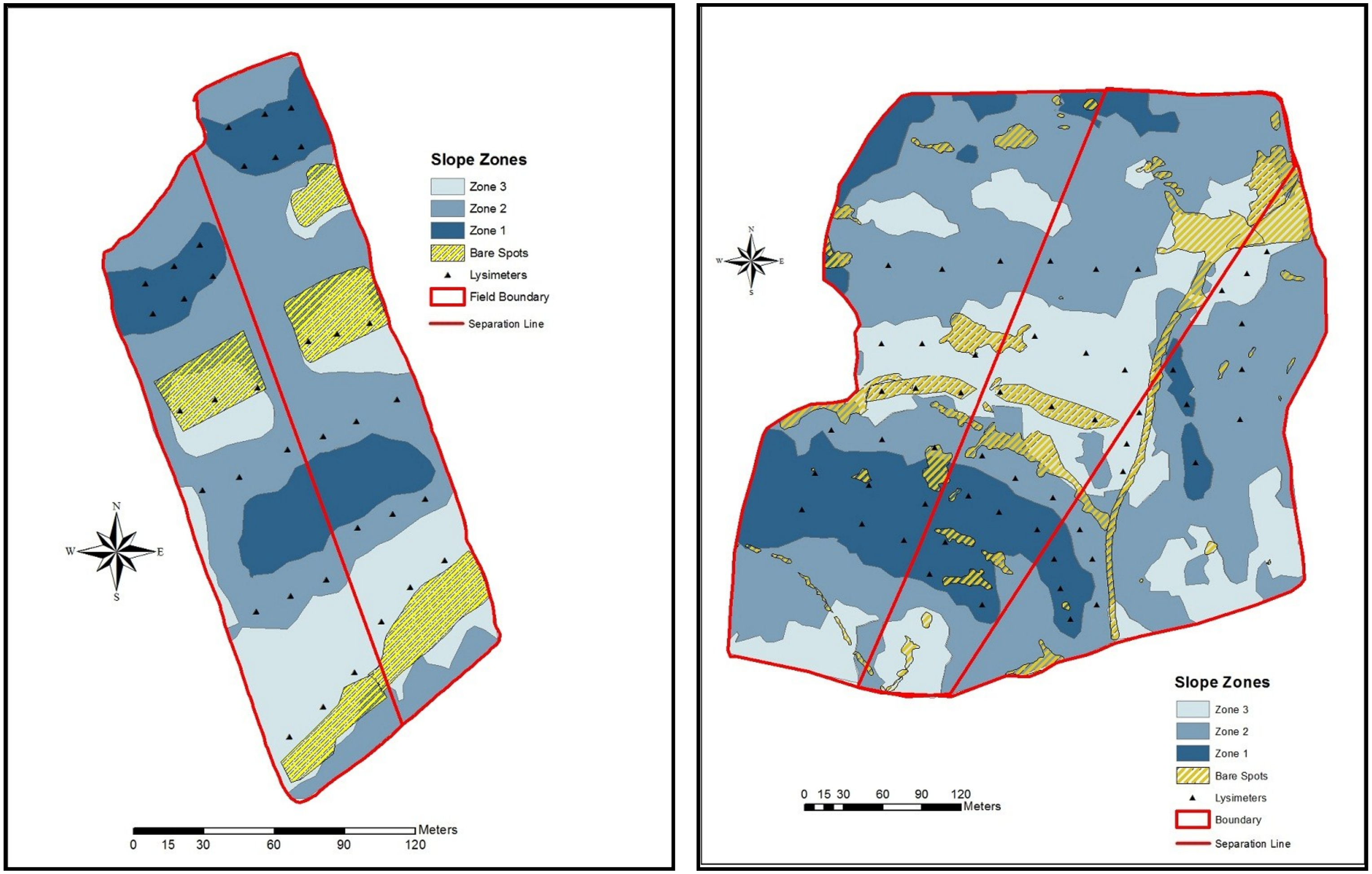
3.8 Subsurface Water Collection

Thirty six vacuum lysimeters were installed in eighteen paired locations in each field to collect subsurface water samples from Kemptown Field (Figure 3-8 a). These lysimeters were installed in last week of May, 2010 for Kemptown Field. 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. The leachate samples were extracted from each lysimeter using a vacuum pump. The subsurface water samples were analyzed for NH_4^+-N and NO_3^--N using a Technicon auto-flow analyzer.

In the Cattle Market Field, 54 lysimeters were installed in last week of May, 2011. Eighteen lysimeters were installed in each section, having six lysimeters in each management zone (Figure 3-8 b). The subsurface water samples were analyzed for NH_4^+-N and NO_3^--N using a Technicon auto-flow analyzer.

3.9 Leaf Sampling

Leaf sampling was performed in 3rd week of July at tip-dieback stage during sprout year in each slope zone of both fields to determine the impact of VR and uniform fertilization on wild blueberry leaf nutrients. The leaf samples were analyzed for nitrogen (N), phosphorus (P), potassium (K), Calcium (Ca), Magnesium (Mg), Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn) and Boron (B) using inductivity coupled plasma emission spectrometry (ICPES) (Percival and Prive, 2002). The wild blueberry leaves were collected at four to six locations at each sampling point (Figures 3-3 a and 3-4 a) from 20 randomly selected blueberry plants to cover variability.



(a)

(b)

Figure 3-8. Lysimeter locations for (a) Kemptown Field (b) Cattle Market Field.

The leaves were detached gently by holding the stem from its base. The leaves were placed in the labeled paper bag. The bags were labeled for each grid point. The leaf bags were placed in the greenhouse for 7-10 days to dry out leaves. In order to complete the drying process the leaves were placed in the oven at 65^0 C for 8-10 hours (Percival and Prive, 2002) until constant dry weights were achieved.

3.9.1 Leaf Grinding and Digestion

Wild blueberry leaf samples were grinded using Wiley Mill (Arthur H. Thomas Co, Philadelphia, PA). The 2 mm sieve was fixed to get the grinded material in the bottom bin. Two grams of the ground leaf sample was used and 10 mL of concentrated nitric acid (HNO_3) was added in pre-conditioned digestion tube (250 mL), and swirled gently to ensure that the sample was completely wet. The samples were placed in the digestion block at 100 ^{0}C for 45 minutes; temperature was increased to 140 ^{0}C until the digestate became clear of particulate matter. The digestion continued until the volume was reduced to 1 mL. Five mL of 1% HNO_3 was added to the digestate. Whatman No. 42 filter paper was used to get the filtrate for further analysis (Percival and Prive, 2002).

3.9.2 Analysis of Leaf Samples for Nitrogen Concentration

The total nitrogen (N) was measured using LECO-CNS-1000 (LECO-Corporation, MI, USA). In this method N present in the sample was converted into NO_2 gas at 950 ^{0}C and the amount of N present in the sample was recorded (Rutherford et al., 1993). Each sample was also analyzed for Ca, Mg, P, K, Mn, Cu, Zn, and B using ICPES. All the leaf samples were analyzed at the Nova Scotia Department of Agriculture Laboratory, Truro, Nova Scotia.

3.10 Plant Growth Parameters

The plant growth parameters were measured in mid-December, 2010 for Kemptown Field and last week of November in 2011 for Cattle Market Field, during the vegetative years to quantify the impact of variable rate and uniform fertilization on plant density, plant height, branches and number of flower buds. A 15 × 15 cm steel quadrant was placed at each sampling location to measure the plant growth parameters for both fields. Numbers of upright stems were counted inside the quadrant to measure the plant density. Six plants from the steel quadrant were randomly selected by cutting them from ground level using a knife. The height of the six plants measured to get an average height of the plants within the grid. The number of flower buds and branches of those six plants were also recorded.

3.11 Berry Yield

Berry yield was measured in August 2011 for Kemptown Field. A steel frame of 0.5 × 0.5 m was placed on the ground at the sampling location and wild blueberry fruit was harvested using a hand rake. Fruits were transferred into labeled sampling bags. Blueberries were separated from debris including leaves, grass, and weeds for each sample and weighed at the time of harvest.

CHAPTER 4

IMPACT OF VARIABLE RATE FERTILIZATION ON NUTRIENTS LOSS IN SURFACE RUNOFF

4.1 Introduction

Establishment and maintenance of wild blueberry fields require substantial inputs including nutrients, pesticides, and irrigation water (Travett, 1962). Excessive supply of nutrients risks ground and surface water quality (Balogh et al., 1992). There is an increasing concern on proper agricultural management including nutrient, soil, and water, to minimize the point sources of pollution contaminating (Santhi et al., 2006). This requires quantifying the nutrients loss in the surface runoff and the impact of VR fertilization on surface water quality (Harmel et al., 2004).

A major portion of the fertilizer applied in the wild blueberry fields is phosphorus (P) (70 kg ha^{-1}) in form of Di-ammonium phosphate (NPK: 18 – 46 – 0) (Percival and Sanderson, 2004). Phosphorus is the major element found in the surface runoff samples from the agricultural fields (Sharpley et al., 1987). Leaching of P is negligible in most soils and P mostly accumulates in surface soil layers, due to its chemistry (Cook, 1988; Kleinman et al., 2003). P concentrations in soils are inherently low and are a limiting factor for plant growth and development and crop production, as P is an essential element for all living organisms. The other essential and limiting nutrient in the soil is nitrogen (N), which is applied in the form of ammonium sulphate (NPK: 21 – 0 – 0) in the wild blueberry fields. Because of the acidic nature of the wild blueberry soils, nitrification process is slow and chances of presence of ammonium nitrogen are more than nitrate in surface runoff.

The amount of surface runoff produced from a field can be calculated with different techniques. Soil Conservation Services curve number (SCS-CN) method is the simplest and widely used method to compute runoff from the fields (Williams, 1995; Mishra and Singh, 2004; Mishra et al., 2004). Surface runoff from agricultural fields consists of N and P. The phosphorus is present in form of dissolve reactive phosphorus (DRP) and particulate phosphorus (PP) in the surface runoff. To date, no research has been conducted to investigate P losses in the surface runoff from the wild blueberry fields. However, the research has been conducted in pasture and other crops to investigate P losses. Shuman (2002) reported up to 15% loss of the applied P fertilizer in runoff from plot-scale studies in a pasture field. A major portion of P losses from these pastures consists of DRP due to crop cover and no tillage. Several researchers correlated TP in surface runoff with soil-test phosphorus (STP) (Pote et al., 1996; Hooda et al., 2000), and applied VR fertilization on the basis of STP. Wittry and Mallarino (2004) studied the impact of VR and uniform fertilizer application on corn field and found that VR had improved crop productivity and reduced soil STP. In another study on uniform and VR fertilization, Harmel et al. (2004) found that VR fertilization had potential to decrease nutrient loads in surface runoff as compared to uniform fertilization without affecting the yield.

The topographic and soil variability of the wild blueberry fields are very high (Zaman et al., 2010). Wild blueberry fields have also significant amount of bare spots. Researchers have found that the nutrients level is higher in the low lying areas of the wild blueberry fields (Eaton, 1988; Zaman et al., 2010). Zaman et al. (2009) investigated the relationship of soil nutrients and plant growth and suggested that the field slope can be used as a variable to apply VR fertilization. The introduction of precision agriculture technologies in agricultural fields helps the producers to supply nutrients to soil according to the plant nutrient requirements. The VR fertilizer spreaders are readily available and are replacing the conventional spreaders. No intention has been paid on the VR fertilization in the wild blueberry fields. It is hypothesized that VR fertilization in the wild blueberry fields can reduce the nutrients loss in the surface runoff as compared to uniform fertilization.

4.2 Materials and Methods

Two wild blueberry fields were selected in central Nova Scotia to quantify the nutrient runoff losses from wild blueberry fields and to compare VR and uniform treatments. Slope and elevation data were recorded using SMMS and RTK-GPS, respectively, and slope maps were generated in ArcGIS 9.3. Management zones (zone-1, Z1; zone-2, Z2; and zone-3, Z3) were delineated on the basis of slope and prescription maps were generated. Bare spots were also mapped using RTK GPS and zero rate were allocated to them in prescription map for VR section. VR fertilizer spreader was used to fertilize the VR sections according to prescription maps (Figures 3-3 b and 3-4 b, Chapter 3). The other section received grower's uniform fertilizer rate of 200 kg ha^{-1}. A weather station was installed in the Cattle Market Field and rain gauge was installed in Kemptown Field.

Surface runoff collectors were placed in both fields and their catchment areas were delineated using the SWAT model. Due to unavailability and high cost of tipping bucket system for automatic measuring the surface runoff volume, only surface runoff samples were collected from these runoff collectors, while SCS-CN Method was used to calculate the surface runoff volume produced for every runoff collector. The surface runoff volumes for the rainfall events were not measured from the Kemptown Field in 2010 due to early rainfall events and late assembling of mechanism to measure surface runoff volumes. In the Cattle Market Field in 2011, besides the surface runoff collectors, USDA-NRCS runoff plots were established to measure the surface runoff volumes from known areas at each slope zone. The runoff volumes collected from USDA-NRCS runoff plots were used to calibrate and validate SCS-CN Method. SCS-CN Method for surface runoff calculation was evaluated by coefficient of determination, R^2, root mean square error, RMSE, and by plotting the measured and calculated surface runoff volumes. The RMSE was taken as an index of agreement for comparative evaluation of SCS-CN Method performance, between measured and calculated values of surface runoff (Mishra et al., 2006). It is expressed as:

$$RMSE = \sqrt{\frac{\sum_{i=0}^{N}(Q_{meas} - Q_{calc})^2}{N}} \tag{4.1}$$

where Q_{meas} is the measure surface runoff volume (m^3), Q_{calc} is the calculated surface runoff volume (m^3), N is the total number of observations, and i is an integer varying from 1 to N. The lower the RMSE, the better is the performance of the SCS-CN Method. Other studies have also used RMSE as a parameter to evaluate SCS-CN Method (Madsen et al., 2002; Itenfisu et al., 2003).

Surface runoff samples were collected after every runoff producing rainfall event from the surface runoff collectors and USDA-NRCS runoff plots. These samples were analyzed for TP, DRP and inorganic nitrogen. Detailed materials and methods are discussed in Chapter 3 (Materials and Methods).

4.3 Statistical Analysis

The experimental design was a split-plot with two fertilizer treatments and two slope zones in six replications. The design was modeled with fertilizer treatment as a main plot and slope as sub plot, and sampling date as a repeated measure factor. Response variables for subsequent statistical analysis were TP, DRP, PP, and inorganic nitrogen losses in surface runoff. The SAS (SAS Institute Inc., NC, USA) was used to perform repeated measures analysis of variance (RM ANOVA) by using mixed-model procedure and significance probability (P) of 5 %. The replications were regarded as random effects. The assumptions of normality of residuals were verified using Shapiro-Wilk test. If the normality of any data set was violated, data was transformed to normalize using proper transformations procedures. The variance and covariance of the data exhibited a structure matched one of those available in PROC MIXED. Means comparisons were conducted using a LSD for significantly different treatments ($P<0.05$). Regression was performed using Minitab to find the relationships between measured and calculated runoff. Graphical representations were generated in Microsoft® Excel 2007, Minitab (Minitab Inc., PA, USA), and SigmaPlot 11 (Systat Software, CA, USA) software.

4.4 Results and Discussion

4.4.1 Climatic Conditions

Average daily air temperatures during the study period measured by Environment Canada for Kemptown in 2010, and average daily temperature measured by vantage pro 2 (Davis Instruments, CA, USA) in the Cattle Market Field for 2011 did not deviate much from mean air temperature of last forty years (Table A1). Average monthly temperatures of 2010 for Kemptown were 14°C (June), 19°C (July), 18°C (August), 15°C (September), and 8°C (October).

The average temperature in 2011 for Cattle Market Field were 13°C (June), 18°C (July), 18°C (August), 15°C (September), and 9°C (October), recorded during the growing season. Kemptown Field received 538 mm of precipitation during the 5 month of surface runoff and lysimeter sampling from June to October 2010, while Cattle Market Field received 610 mm of precipitation from June to October 2011.

4.4.2 SCS-CN Method Calibration and Validation

The hydrologic calibration was performed by comparing the measured surface runoff and calculated surface runoff by SCS-CN Method. Seven rainfall events produced runoff at the Cattle Market Field in 2011. These rainfall events were categorized on the basis of antecedent moisture conditions (AMC), which is an index of basin wetness. The antecedent moisture classes AMC I, AMC II and AMC III, representing dry, average and wet conditions (Table 4-1). The rainfall/runoff events from June 15 to August 2, 2011 were used to calibrate, whereas the events from August 22 to October 2, 2011, were used to validate SCS-CN Method.

Table 4-1. Seasonal rainfall limits for AMC (NEH-4, 1964).

AMC class	Total 5-day antecedent rainfall (mm)	
	Dormant season	Growing season
I	<13	<36
II	13 - 28	36 - 53
III	>28	>53

The values for slope and measured volumetric moisture content (θ_v) for every rainfall event (Table A2, Appendix ‘A’) were used in the equations for SCS-CN Method

(Section 3.7.3, Chapter 3) to calculate the surface runoff volumes of every USDA runoff plot after each rainfall event. The curve number was used as a calibration parameter, while other parameters were fixed. Wild blueberry is considered as a shrub crop (Yarborough et al., 1986). Because of the well-drained nature of wild blueberry soils, soil hydrologic group 'A' was selected (NRCS Soil Survey Staff, 1996). Initially, the CN value of 39 for shrub crops with good land coverage under the hydrologic group 'A' was selected in this study from the tables provided by SCS (1986). The CN values were adjusted by a trial and error method within the permissible limits to achieve a good comparison between the measured and calculated runoff volumes. The final calibrated value of CN was 46 selected for SCS-CN Method. The sum of measured and calculated surface runoff volumes from all USDA-NRCS plots for each rainfall event used in calibration (Figure 4-1).

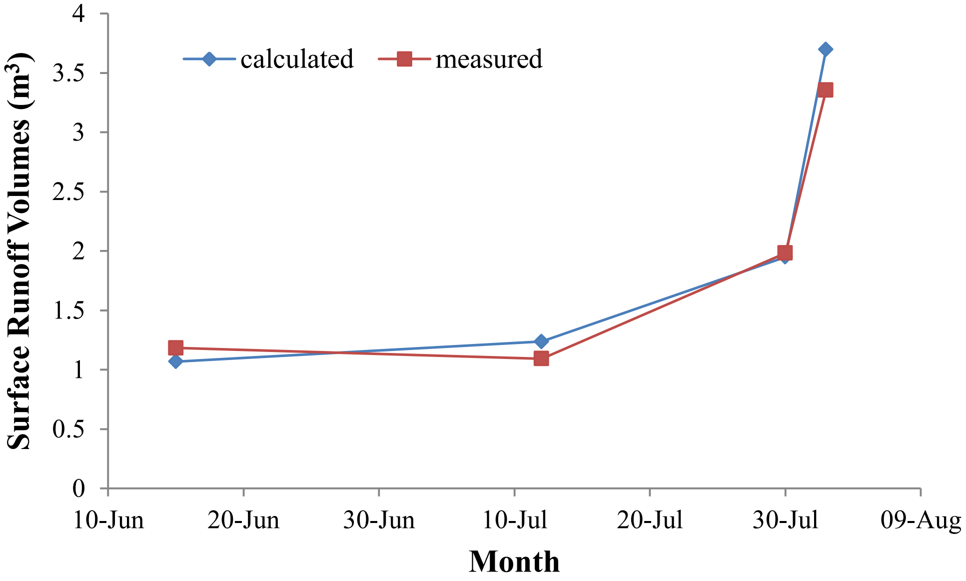


Figure 4-1. Measured and calculated surface runoff volumes for the calibration period in the Cattle Market Field.

It was clear that there was a very good agreement between the measure and calculated runoff volumes (Figure 4-1). Although there are under- and over- estimation for the rainfall events used to calibrate the SCS-Method, SCS-CN Method values for surface runoff volume followed the measured runoff trends very well. The RMSE for the overall dataset used in calibration was 0.028 m^3 (Table 4-2).

Table 4-2. Performance evaluation of the SCS-CN Method for all rainfall events used in calibration for the Cattle Market Field.

Area (ha)	No. of Events	No. of Calibration Points	Average Measured Runoff Volume (m^3)	Average Calculated Runoff Volume (m^3)	RMSE	R^2
0.06	4	48	1.903	1.989	0.028	0.95

Area (ha) is the sum of the areas of all USDA-NRCS runoff plots

The 1:1 scatter plot between measured and calculated surface runoff volumes also showed a strong relationship (Figure 4-2).

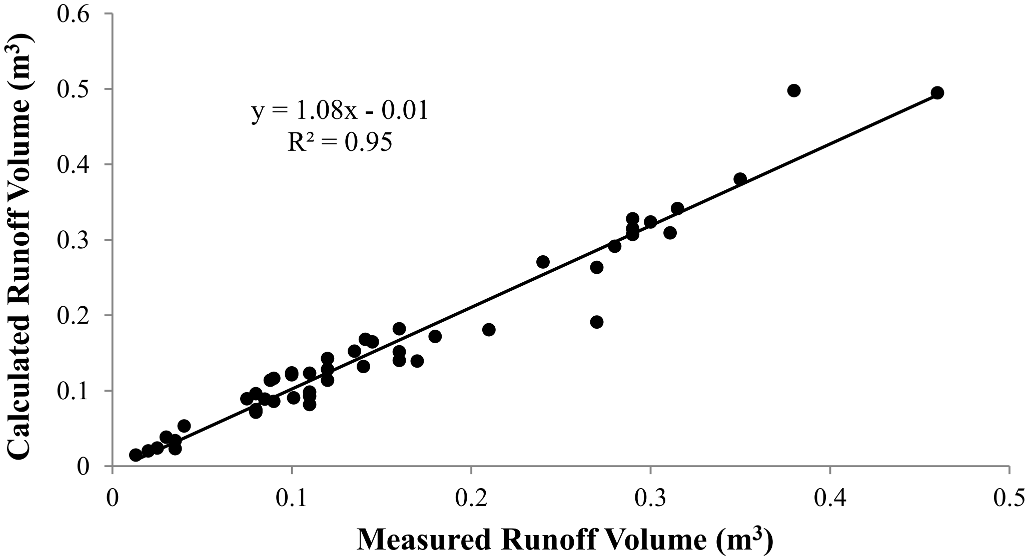


Figure 4-2. Scatter plot of measured and calculated surface runoff volumes for the calibration events in the Cattle Market Field.

It can be concluded that the SCS-CN Method could be used for calculating the surface runoff volumes for the Cattle Market Field (Figures 4-1 and 4-2).

To test the calibrated SCS-CN Method, rainfall events of August 22, September 15, and October 2, 2011, were used to conduct a temporal validation. The comparison of measured and calculated surface runoff volumes showed good results (Figure 4-3). It was clear that calculated surface runoff for SCS-CN Method adequately matched the measured surface runoff volume. The RMSE (Table 4-3) for the overall dataset used in validation was 0.080 m^3.

Table 4-3. Performance evaluation of the SCS-CN Method for rainfall events used in validation for the Cattle Market Field.

Area (ha)	No. of Events	No. of Validation Points	Average Measured Runoff Volume (m^3)	Average Calculated Runoff Volume (m^3)	RMSE	R^2
0.06	3	36	2.887	2.513	0.080	0.90

Area (ha) is the sum of the areas of all USDA-NRCS runoff plots

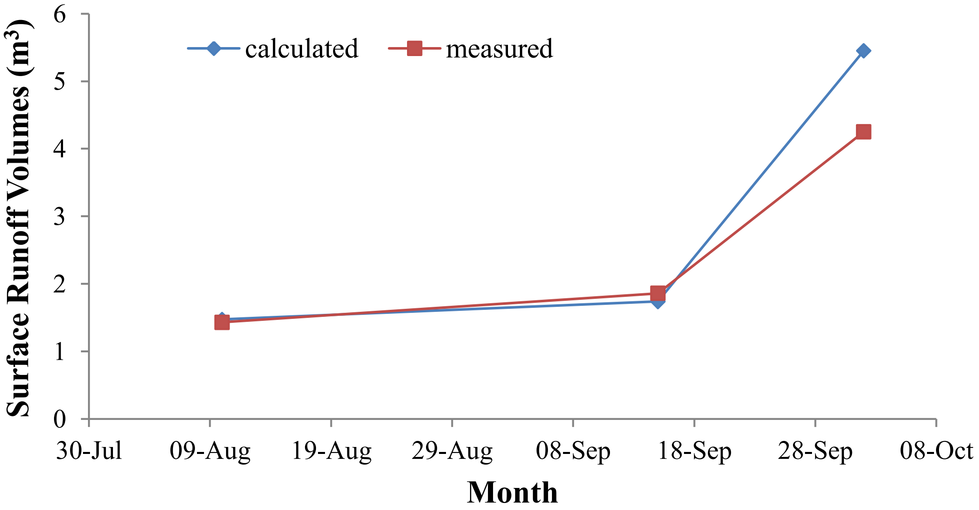


Figure 4-3. Measured and calculated surface runoff volumes for the validation period in the Cattle Market Field.

The 1:1 scatter plot also illustrated a very good relationship between the measured and calculated surface runoff volumes (Figure 4-4). This relationship confirms that the SCS-CN Method for the Cattle Market Field was adequate for calculating the surface runoff volumes.

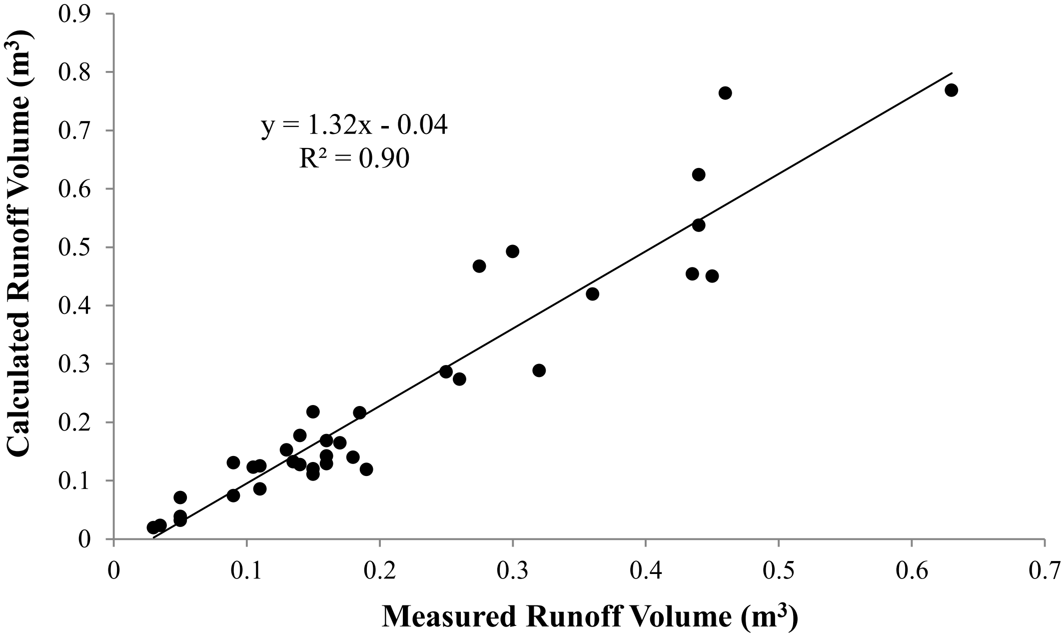


Figure 4-4. Scatter plot of measured and calculated surface runoff volumes for the validation events in the Cattle Market Field.

4.4.3 Surface Runoff Calculation for Runoff Collectors

4.4.3.1 Runoff Collectors Catchment Area

The catchment areas for runoff collectors for both fields were delineated using SWAT model. The delineation of VR section of the Cattle Market Field showed areas of each runoff collector (Figure 4-5). The delineated maps for uniform and control section are presented in Appendix ‘A’ (Figure A2 a and b). The catchment areas delineation for runoff collectors placed in VR and uniform section of the Kemptown Field are shown in Figure A3 (a and b) (Appendix ‘A’).

4.4.3.2 Cattle Market Field

The runoff volumes were calculated for every runoff collector using the SCS-CN Method. The Cattle Market Field was divided into three slope categories (Figure 3-2 b, Chapter 3). The runoff collectors 1-6 were placed to collect the runoff from Z1 entering in Z2, while runoff collectors 7-12 were placed to collect the combine runoff from all three slope zones. The runoff volumes produced from the control section, VR section, and uniform section after the first rainfall of June 15, 2011 is shown (Table 4-4). The runoff volumes were calculated by SCS-CN Method for every rainfall event. The runoff volumes of all other rainfall events are provided in the Appendix ‘A’ (Table A3 to Table A8).

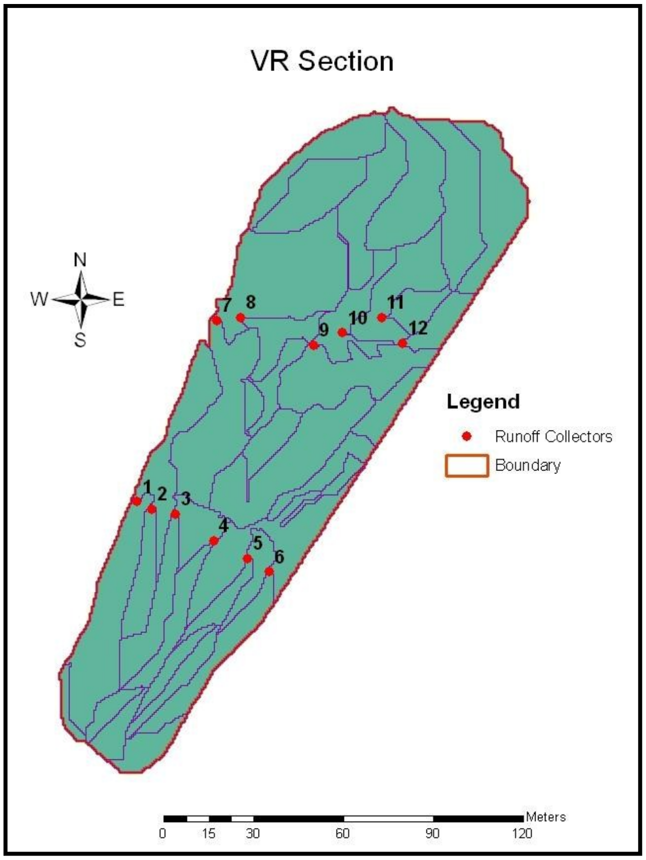


Figure 4-5. Runoff collector’s catchment area delineation for VR section in the Cattle Market Field

Table 4-4. Runoff volumes for runoff collectors from June 15, 2011 rainfall event in the Cattle Market Field.

Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)
VR-1	0.088	1.92	UN-1	0.107	2.34	CT-1	0.014	0.30
VR-2	0.027	0.60	UN -2	0.081	1.77	CT-2	0.022	0.48
VR-3	0.038	0.83	UN -3	0.021	0.46	CT-3	0.044	0.97
VR-4	0.066	1.44	UN -4	0.093	2.04	CT-4	0.012	0.26
VR-5	0.058	1.27	UN -5	0.030	0.65	CT-5	0.058	1.27
VR-6	0.041	0.89	UN -6	0.065	1.42	CT-6	0.019	0.42
VR-7	0.117	2.03	UN -7	0.057	0.97	CT-7	0.018	0.30
VR-8	0.026	0.44	UN -8	0.080	1.36	CT-8	0.032	0.54
VR-9	0.037	0.65	UN -9	0.046	0.79	CT-9	0.022	0.38
VR-10	0.054	0.93	UN -10	0.036	0.62	CT-10	0.067	1.13
VR-11	0.019	0.32	UN -11	0.083	1.41	CT-11	0.037	0.62
VR-12	0.020	0.35	UN -12	0.059	1.02	CT-12	0.058	0.98

VR= Variable, UN= Uniform, CT= Control

4.4.3.3Kemptown Field

The rainfall events in 2010 were categorized on the basis of antecedent moisture conditions (NEH-4, 1964). Five rainfall events produced runoff in the Kemptown Field. Three rainfall events were under AMC-II and two rainfall events were under AMC-III (Table 4-1). The soil properties and slope conditions of Kemptown Field were very similar to that of the Cattle Market Field (Tables B1 and B2, Appendix B), and also the monthly temperatures of both fields were similar. On these bases, the surface runoff volumes for Kemptown Field were calculated using SCS-CN Method with curve number of 46. The surface runoff volumes produced from the runoff collectors placed in the VR section and uniform section after the rainfall event of June 3, 2010 is presented in the Table 4-5. The runoff volumes of other rainfall event are provided in the Appendix 'A' (Table A9 to Table A12).

Table 4-5. Runoff volumes for runoff collectors from June 3, 2010 rainfall in the Kemptown Field.

Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)
VR-1	0.007	0.63	UN-1	0.020	0.98
VR-2	0.045	3.97	UN -2	0.132	6.31
VR-3	0.017	1.46	UN -3	0.118	5.66
VR-4	0.017	1.47	UN -4	0.067	3.19
VR-5	0.077	6.77	UN -5	0.013	0.60
VR-6	0.030	2.60	UN -6	0.030	1.45
VR-7	0.016	2.01	UN -7	0.023	1.22
VR-8	0.090	11.61	UN -8	0.105	5.52
VR-9	0.008	1.09	UN -9	0.020	1.04
VR-10	0.121	15.65	UN -10	0.020	1.03
VR-11	0.861	111.40	UN -11	0.695	36.69
VR-12	0.007	0.92	UN -12	0.072	3.78

VR= Variable, UN= Uniform

4.4.4 TP and DRP Losses in Surface runoff

4.4.4.1 Runoff Collectors

4.4.4.1.1 Kemptown Field

The RM ANOVA showed significantly different results for total P and DRP losses in surface runoff between uniform and VR treatments (Tables 4-6 and 4-7). In terms of main effect, TP and DRP losses in surface runoff were affected most by sampling date followed by fertilizer treatment. In contrast, slope zone did not affect TP and DRP losses in surface runoff.

The interaction of fertilizer treatment with date of sampling showed significant results indicating decreases in TP and DRP losses with time. In general, TP and DRP losses in surface runoff showed decreasing trends for both uniform and VR treatments throughout the growing season. The interaction of fertilization treatment with zone and date of sampling also showed significant results explaining the decreasing trend of TP losses in fertilizer treatment as well as slope with time. No research has been conducted to quantify surface runoff losses from blueberry fields. However, Bierman et al. (2010)'s study on turfgrass was in agreement with current study that higher fertilizer rates produced higher TP losses in runoff and vice versa.

The experimental results showed that DRP represented about 50% of TP loss in surface runoff (Tables 4-6 and 4-7). The DRP losses in surface runoff determined clearly by the soil's potentially mobile P reserves. Therefore, DRP loss in surface runoff was linked to soil fertility in terms of phosphorus. The DRP loss in surface runoff was directly in a bioavailable form and it can pollute the surface water resources. The total phosphorus losses for VR and uniform treatments were 1.05 % and 1.92 %, respectively,

Table 4-6. Total phosphorus losses in the surface runoff from the Kemptown Field for runoff collectors in 2010.

Zone	Fertilization Method	June 03 (g ha^{-1})	June 06 (g ha^{-1})	July 14 (g ha^{-1})	August 05 (g ha^{-1})	September 17 (g ha^{-1})	Cumulative (g ha^{-1})
Zone-1 to zone-2	Variable	319.9^{a}	231.6^{a}	144.2^{a}	49.9^{a}	22.5^{a}	768.2^{a}
	Uniform	365.8^{a}	262.4^{a}	159.8^{a}	57.1^{a}	26.5^{a}	871.8^{a}
Combine	Variable	296.6^{a}	242.7^{a}	136.5^{a}	42.0^{a}	19.6^{a}	737.6^{a}
	Uniform	518.7^{b}	399.4^{b}	291.1^{b}	104.3^{b}	32.3^{b}	1345.7^{b}

RM ANOVA

Effect	DF	F- Value	P-Value
Fertilization Method	1	10.59	0.0053
Zone	1	4.11	0.0606
Sampling Date	4	136.01	<0.0001
Fertilization Method × Zone	1	5.33	0.0356
Fertilization Method × Sampling Date	4	10.19	0.0003
Fertilization Method × Zone× Sampling Date	8	6.23	0.0012

Means followed by different letters are significantly different at a significance level of 0.05.
Significant at $P < 0.05$

Table 4-7. Dissolved reactive phosphorus losses in the surface runoff from the Kemptown Field for runoff collectors in 2010.

Zone	Fertilization Method	June 03 (g ha^{-1})	June 06 (g ha^{-1})	July 14 (g ha^{-1})	August 05 (g ha^{-1})	September 17 (g ha^{-1})	Cumulative (g ha^{-1})
Zone-1 to zone-2	Variable	152.7^{a}	122.3^{a}	65.9^{a}	21.2^{a}	6.3^{a}	368.6^{a}
	Uniform	164.2^{a}	146.3^{a}	72.7^{a}	23.2^{a}	8.3^{a}	414.9^{a}
Combine	Variable	165.2^{a}	140.4^{a}	64.2^{a}	13.3^{b}	7.6^{a}	389.7^{a}
	Uniform	320.3^{b}	223.2^{b}	126.1^{b}	33.9^{c}	12.8^{b}	716.4^{b}

RM ANOVA

Effect	DF	F- Value	P-Value
Fertilization Method	1	9.00	0.0090
Zone	1	6.82	0.0196
Sampling Date	4	69.20	<0.0001
Fertilization Method × Zone	1	5.07	0.0397
Fertilization Method × Sampling Date	4	3.09	0.0485
Fertilization Method × Zone× Sampling Date	8	2.96	0.0333

Means followed by different letters are significantly different at a significance level of 0.05.
Significant at $P < 0.05$

of the total phosphorus applied in wild blueberry fields (70 kg ha^{-1}).

4.4.4.1.2 Cattle Market Field

The experimental results for TP and DRP losses in surface runoff showed significantly different results between VR, uniform, and control treatment (Tables 4-8 and 4-9). The slope zone also showed significant differences. The cumulative TP and DRP losses from the VR treatment in the combine zone were 36.12 % and 39.88 %, respectively, less as compared to uniform treatment. The TP and DRP losses were negligible from the control treatment. The experimental results for interaction of fertilization treatment and sampling date indicating higher TP and DRP losses in surface runoff after June 15, 2011 rainfall, while these losses were negligible in October 2, 2011 rainfall event. The possible reason could be the utilization of phosphorus by the blueberry plants and also absorption in the subsoil.

Throughout the monitoring period, the TP and DRP losses in surface runoff showed decreasing trends among all three treatments and slope zones as indicated by the interaction of sampling date, slope zone and fertilizer treatment. The total phosphorus losses for VR and uniform treatments were 1.43 % and 2.22 %, respectively, of the total phosphorus applied in wild blueberry fields (70 kg ha^{-1}).

The losses of DRP in surface runoff for current study were in agreement with the studies of different researchers on different cropping systems such as turfgrass and corn (Heathwaite et al., 1998; Wilcock et al., 1999; Quinn and Stroud, 2002). Runoff DRP is usually higher from bushes and pastures than from cropland, due to the filtration effect of the vegetation on suspended particles high in particulate phosphorus (PP) (Hollman, 2006), similar to the findings of current study. The amount of DRP decreased later in the

Table 4-8. Total phosphorus losses in the surface runoff from the Cattle Market Field for runoff collectors in 2011.

Zone	Fertilization Method	June 15 (g ha^{-1})	July 12 (g ha^{-1})	July 30 (g ha^{-1})	August 02 (g ha^{-1})	August 10 (g ha^{-1})	September 15 (g ha^{-1})	October 02 (g ha^{-1})	Cumulative (g ha^{-1})
Zone-1 to zone-2	Variable	240.3^a	226.2^a	180.8^a	138.9^a	97.2^a	36.1^a	31.4^a	950.9^a
	Uniform	251.2^a	220.6^a	195.4^a	146.6^a	101.1^a	39.1^a	42.6^a	996.6^a
	Control	8.3^b	7.6^b	5.3^b	4.6^b	5.2^b	4.1^b	3.8^b	38.9^b
Combine	Variable	261.7^a	236.5^a	190.6^a	121.3^a	109.6^a	43.2^a	35.6^a	998.5^a
	Uniform	420.7^c	372.5^c	259.7^c	211.2^c	159.5^c	70.4^c	69.2^c	1563.2^c
	Control	9.2^b	8.2^b	6.1^b	5.7^b	5.4^b	5.3^b	4.9^b	44.8^b

RM ANOVA

Effect	DF	F- Value	P-Value
Fertilization Method	2	518.18	<0.0001
Zone	1	39.88	<0.0001
Sampling Date	6	444.77	<0.0001
Fertilization Method × Zone	2	30.36	<0.0001
Fertilization Method × Sampling Date	12	111.78	<0.0001
Fertilization Method × Zone × Sampling Date	18	6.54	<0.0001

Means followed by different letters are significantly different at a significance level of 0.05.
Significant at $P < 0.05$

Table 4-9. Dissolved reactive phosphorus losses in the surface runoff from the Cattle Market Field for runoff collectors in 2011.

Zone	Fertilization Method	June 15 (g ha^{-1})	July 12 (g ha^{-1})	July 30 (g ha^{-1})	August 02 (g ha^{-1})	August 10 (g ha^{-1})	September 15 (g ha^{-1})	October 02 (g ha^{-1})	Cumulative (g ha^{-1})
Zone-1 to zone-2	Variable	161.4^{a}	139.6^{a}	95.4^{a}	53.3^{a}	45.6^{a}	15.2^{a}	11.1^{a}	521.6^{a}
	Uniform	173.5^{a}	153.8^{a}	102.3^{a}	64.6^{a}	52.6^{a}	18.6^{a}	19.8^{a}	585.2^{a}
	Control	5.4^{b}	4.3^{b}	3.2^{b}	1.1^{b}	2.5^{b}	2.6^{b}	1.8^{b}	20.9^{b}
Combine	Variable	175.1^{a}	121.9^{a}	83.1^{a}	52.6^{a}	42.8^{a}	19.6^{a}	10.6^{a}	505.7^{a}
	Uniform	310.9^{c}	195.7^{c}	117.4^{c}	85.1^{c}	63.4^{c}	39.4^{c}	29.2^{c}	841.1^{c}
	Control	6.2^{b}	5.6^{b}	3.5^{b}	2.6^{b}	2.7^{b}	2.3^{b}	2.1^{b}	25.0^{b}

RM ANOVA

Effect	DF	F- Value	P-Value
Fertilization Method	2	600.11	<0.0001
Zone	1	23.56	<0.0001
Sampling Date	6	437.99	<0.0001
Fertilization Method × Zone	2	27.22	<0.0001
Fertilization Method × Sampling Date	12	109.12	<0.0001
Fertilization Method × Zone × Sampling Date	18	5.61	<0.0001

Means followed by different letters are significantly different at a significance level of 0.05.
Significant at $P < 0.05$

study period and PP contributed most of the TP loss from the field. The reason for less DRP was might be due to plant utilization. The higher PP losses in surface runoff as compared to DRP might be due to the fact that PP is mostly insoluble and not readily available for plant uptake.

4.4.4.2 USDA-NRCS Runoff Plots

The results showed that TP and DRP losses in the samples collected from USDA-NRCS runoff plots were significantly different for VR, uniform, and control treatments (Tables B3 and B4, Appendix B). The VR treatment showed 7.16 % and 11.37 % lower TP and DRP losses as compared to uniform treatment for USDA runoff plots placed in Z1, while control treatment showed negligible losses for TP and DRP in Z1 as compared to VR and uniform treatment. The results suggested that TP losses for VR treatment were 28.80 %, 42.61 %, and 38.50 % lower than uniform treatment in samples collected from USDA plots placed in Z2, Z3 and combine, respectively.

In general, the comparison of the TP and DRP losses for runoff collectors and USDA runoff plots showed similar results (Tables B3 and B4, Appendix B), suggesting SCS-CN Method adequate calculated the surface runoff volumes in the Cattle Market Field.

4.4.5 Total Suspended Solids and Particulate Phosphorus Losses

4.4.5.1 Runoff Collectors

4.4.5.1.1 Kemptown Field

The TSS losses from the samples collected from all twenty four surface runoff collectors for the rainfall events in the Kemptown Field were plotted in SigmaPlot 11 (Systat Software, CA, USA) (Figure 4-6). Overall, a low percentage of TSS losses were observed. There were higher TSS losses in the runoff collected during June 3, 2010 rainfall compared to all other events because of the high rainfall intensity. The rainfall event of August 5, 2010 produced the lowest TSS loss than other rainfall events. The main reason for lower yield of TSS after August 5 rainfall could be low intensity and less rainfall.

The results showed that there were significant losses of PP for both fertilizer treatments in the Kemptown Field (Table 4-10). The PP losses between different slope zones were non-significant, while the interaction of fertilizer treatments and slope zones showed significant results. These results were in agreement with McDowell and Sharpley (2002), they found in that TSS in the runoff was a significant source of PP loss. The lack of TSS in runoff in the current experiment may have caused lower TP losses and higher DRP losses than reported in the studies on row crops (Warren et al., 2006).

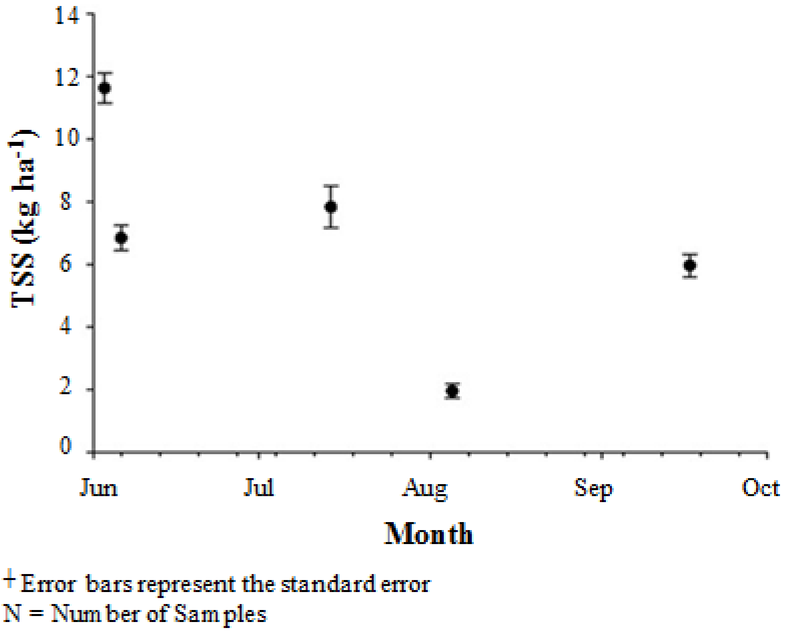


Figure 4-6. TSS losses in surface runoff from the Kemptown Field.

Table 4-10. Particulate phosphorus losses in the surface runoff for runoff collectors from the Kemptown Field in 2010.

Zone	Fertilization Method	June 03 (g ha^{-1})	June 06 (g ha^{-1})	July 14 (g ha^{-1})	August 05 (g ha^{-1})	September 17 (g ha^{-1})	Cumulative (g ha^{-1})
Zone-1 to zone-2	Variable	167.1^{a}	109.2^{a}	78.3^{a}	28.6^{a}	16.1^{a}	399.5^{a}
	Uniform	201.6^{b}	116.1^{a}	87.0^{a}	33.9^{a}	18.2^{a}	456.9^{ab}
Combine	Variable	131.4^{a}	102.3^{a}	72.3^{a}	28.7^{a}	13.0^{a}	347.8^{a}
	Uniform	198.3^{b}	176.2^{b}	165.0^{b}	70.1^{b}	19.5^{a}	629.3^{b}

RM ANOVA

Effect	DF	F- Value	P-Value
Fertilization Method	1	10.45	0.0056
Zone	1	1.30	0.2725
Sampling Date	4	122.64	<0.0001
Fertilization Method × Zone	1	4.60	0.0487
Fertilization Method × Sampling Date	4	12.61	0.0001
Fertilization Method × Zone× Sampling Date	8	10.43	<0.0001

Means followed by different letters are significantly different at a significance level of 0.05.
Significant at P < 0.05

The PP losses in the surface runoff were lower than the DRP losses at the start of the experiment, while the PP losses were higher than the DRP losses after September 17, 2010 rainfall (Table 4-10). The interaction of sampling date and fertilizer treatment showed that there was significant decrease in PP losses with time. Overall, decreasing trends were observed for PP losses in all three slope zone for both VR and uniform treatments throughout the growing season as shown by the interaction of time, fertilizer treatment and slope zone. These results were in agreement with the findings of Penn (2004).

4.4.5.1.2 Cattle Market Field

The TSS losses in the Cattle Market Field for samples collected from all thirty six surface runoff collectors were plotted in SigmaPlot 11 (Systat Software, CA, USA) (Figure 4-7).

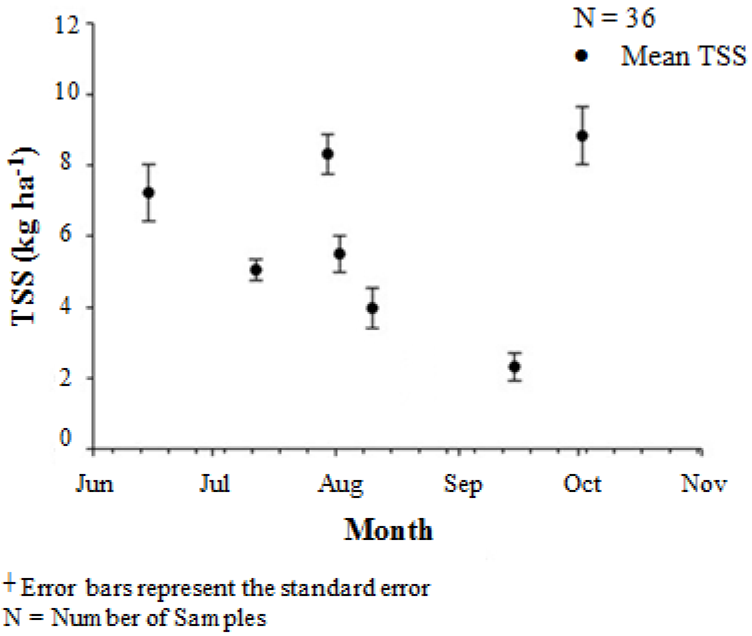


Figure 4-7. TSS losses in surface runoff from the Cattle Market Field.

There were significantly lower TSS losses in the runoff collected during August 22 and September 15 rainfall events compared to all other events. October 2 rainfall produced the highest TSS loss than other rainfall events because of the high intensity rainfall.

The experimental results showed that PP losses were significant for uniform and VR treatment. The cumulative PP losses from control treatment in the combine zone were 19.6 g ha^{-1} as compared to 492.8 g ha^{-1} and 722.0 g ha^{-1} for VR and uniform treatments, respectively (Table 4-11). The reason for this difference is the no fertilization in control treatment. Similar to the Kemptown Field, the losses of PP from the uniform and VR treatments were higher at the start of the experiment. The PP losses from the VR and uniform treatments were significantly different than the control treatment after fertilizer application, but these losses were negligible after the October 2, 2011 rainfall event (Table 4-11). In general, PP losses in surface runoff showed decreasing trends in all three slope zones among VR, uniform, and control treatment throughout the growing season as explained by the significant value ($P \leq 0.0001$) for sampling date.

4.4.5.2 USDA-NRCS Runoff Plots

The results showed that PP losses in the samples collected from USDA-NRCS runoff plots were significant for different fertilizer treatments (Table B5, Appendix B). The cumulative PP losses for VR, uniform, and control treatments from combine plot were 473.9 g ha^{-1}, 666.2 g ha^{-1}, and 23.3 g ha^{-1}, respectively. In general, PP showed decreasing trends throughout the monitoring period in the Cattle Market Field as described by the significant results for the sampling date (Table B5, Appendix B).

Table 4-11. Particulate phosphorus losses in the surface runoff for runoff collectors from the Cattle Market Field in 2011.

Zone	Fertilization Method	June 15 ($g\ ha^{-1}$)	July 12 ($g\ ha^{-1}$)	July 30 ($g\ ha^{-1}$)	August 02 ($g\ ha^{-1}$)	August 10 ($g\ ha^{-1}$)	September 15 ($g\ ha^{-1}$)	October 02 ($g\ ha^{-1}$)	Cumulative ($g\ ha^{-1}$)
Zone-1 to zone-2	Variable	78.9^{a}	86.6^{a}	85.4^{a}	85.6^{a}	51.6^{a}	20.9^{a}	20.3^{a}	429.3^{a}
	Uniform	77.7^{a}	66.8^{ab}	93.1^{a}	82.0^{a}	48.5^{a}	20.5^{a}	22.7^{a}	411.3^{a}
	Control	2.9^{b}	3.3^{b}	2.1^{b}	3.5^{b}	2.7^{b}	1.5^{b}	2.0^{b}	18.0^{b}
Combine	Variable	86.6^{a}	114.6^{a}	107.5^{a}	68.7^{a}	66.8^{a}	23.6^{a}	25.0^{a}	492.8^{a}
	Uniform	109.7^{c}	176.8^{c}	142.3^{c}	126.1^{c}	96.1^{c}	31.0^{a}	40.0^{c}	722.0^{c}
	Control	2.9^{b}	2.6^{b}	2.6^{b}	3.1^{b}	2.7^{b}	3.0^{b}	2.7^{b}	19.6^{b}

RM ANOVA

Effect	DF	F- Value	P-Value
Fertilization Method	2	242.25	<0.0001
Zone	1	39.13	0.0015
Sampling Date	6	49.64	<0.0001
Fertilization Method × Zone	2	27.42	<0.0001
Fertilization Method × Sampling Date	12	12.67	<0.0001
Fertilization Method × Zone × Sampling Date	18	3.07	<0.0001

Means followed by different letters are significantly different at a significance level of 0.05.
Significant at $P < 0.05$

4.4.6 Inorganic Nitrogen Losses in Surface Runoff

4.4.6.1 Runoff Collectors

4.4.6.1.1 Kemptown Field

The results of study revealed that inorganic nitrogen losses in surface runoff were significantly different for VR treatment as compared to uniform treatment (Table 4-12). The cumulative inorganic nitrogen losses from zone-1 to zone-2 were similar for uniform and VR treatment with mean values of 2.10 kg ha^{-1} and 2.24 kg ha^{-1}, respectively. In the combine zone the inorganic nitrogen losses from uniform treatment were significantly higher as compared to VR treatment with mean values of 2.34 kg ha^{-1} and 3.91 kg ha^{-1}, respectively (Table 4-12).

The significant differences were also observed within slope zones. The interaction of sampling date and fertilizer treatment also showed significant differences. The total inorganic nitrogen losses in surface runoff for VR and uniform treatments were 7.09 % and 11.85 %, respectively, of the total nitrogen applied (33 kg ha^{-1}) in the wild blueberry fields. Overall, decreasing trends were observed in inorganic nitrogen losses for both treatments in all three slope zones throughout the growing season as described by sampling date ($P \leq 0.0001$) (Table 4-12). The decrease in inorganic nitrogen losses might be due to utilization of nitrogen by plants, absorption in soil, and nitrogen leaching. These results are in agreement with the results of the study conducted in pasture fields (Kuykendall et al., 1999).

4.4.6.1.2 Cattle Market Field

Similar to Kemptown Field, the inorganic nitrogen losses in surface runoff showed similar trends for Cattle Market Field (Table 4-13). There was non-significant

Table 4-12. Inorganic nitrogen losses in the surface runoff for runoff collectors from the Kemptown Field in 2010.

Zone	Fertilization Method	June 03 (kg ha^{-1})	June 06 (kg ha^{-1})	July 14 (kg ha^{-1})	August 05 (kg ha^{-1})	September 17 (kg ha^{-1})	Cumulative (kg ha^{-1})
Zone-1 to zone-2	Variable	0.75^{a}	0.63^{a}	0.39^{a}	0.21^{a}	0.12^{a}	2.10^{a}
	Uniform	0.81^{a}	0.67^{a}	0.42^{a}	0.19^{a}	0.15^{a}	2.24^{a}
Combine	Variable	0.79^{a}	0.72^{a}	0.45^{a}	0.25^{a}	0.13^{a}	2.34^{a}
	Uniform	1.31^{b}	1.12^{b}	0.80^{b}	0.47^{b}	0.21^{b}	3.91^{b}

RM ANOVA

Effect	DF	F- Value	P-Value
Fertilization Method	1	10.49	0.0055
Zone	1	13.45	0.0023
Sampling Date	4	703.83	<0.0001
Fertilization Method × Zone	1	7.55	0.0150
Fertilization Method × Sampling Date	4	11.92	0.0001
Fertilization Method × Zone× Sampling Date	8	8.51	0.0002

Means followed by different letters are significantly different at a significance level of 0.05.
Significant at $P < 0.05$

Table 4-13. Inorganic nitrogen losses in the surface runoff for runoff collectors from the Cattle Market Field in 2011.

Zone	Fertilization Method	June 15 (kg ha^{-1})	July 12 (kg ha^{-1})	July 30 (kg ha^{-1})	August 02 (kg ha^{-1})	August 10 (kg ha^{-1})	September 15 (kg ha^{-1})	October 02 (kg ha^{-1})	Cumulative (kg ha^{-1})
Zone-1 to zone-2	Variable	0.69^{a}	0.52^{a}	0.32^{a}	0.28^{a}	0.17^{a}	0.11^{a}	0.07^{a}	2.16^{a}
	Uniform	0.72^{a}	0.56^{a}	0.35^{a}	0.31^{a}	0.18^{a}	0.14^{a}	0.09^{a}	2.35^{a}
	Control	0.06^{b}	0.06^{b}	0.04^{b}	0.04^{b}	0.03^{b}	0.04^{b}	0.03^{b}	0.30^{b}
Combine	Variable	0.65^{a}	0.58^{a}	0.35^{a}	0.30^{a}	0.18^{a}	0.12^{a}	0.08^{a}	2.26^{a}
	Uniform	1.09^{c}	0.95^{c}	0.76^{c}	0.65^{c}	0.32^{c}	0.23^{c}	0.19^{c}	4.19^{c}
	Control	0.09^{b}	0.08^{b}	0.06^{b}	0.05^{b}	0.05^{b}	0.04^{b}	0.04^{b}	0.41^{b}

RM ANOVA

Effect	DF	F- Value	P-Value
Fertilization Method	2	959.92	<0.0001
Zone	1	136.60	<0.0001
Sampling Date	6	379.76	<0.0001
Fertilization Method × Zone	2	144.69	<0.0001
Fertilization Method × Sampling Date	12	84.77	<0.0001
Fertilization Method × Zone × Sampling Date	18	7.11	<0.0001

Means followed by different letters are significantly different at a significance level of 0.05.
Significant at $P < 0.05$

differences for VR and uniform treatments in zone-1 to zone-2 throughout the growing season while control treatment showed significantly lower losses. Three treatments showed significantly different results in combine zone with cumulative inorganic losses of 2.26, 4.19, and 0.41 kg ha^{-1} from VR, uniform, and control treatments, respectively (Table 4-13). The experimental results revealed that there was a decreasing trend in inorganic nitrogen losses in surface runoff from June 15, 2011 rainfall event to October 2, 2011 rainfall event (Table 4-13). The total inorganic nitrogen losses in surface runoff for VR and uniform treatments were 6.85 % and 12.70 %, respectively, of the total nitrogen applied in wild blueberry fields (33 kg ha^{-1}). These results emphasize the need of VR fertilization on the basis of slope variation in the wild blueberry fields.

4.4.6.2 USDA-NRCS Runoff Plots

The inorganic nitrogen losses were similar between uniform and VR treatments for USDA-NRCS in zone-1, while significant differences were observed in all other USDA-NRCS runoff plots. The cumulative inorganic nitrogen losses in combine zone were 2.17, 4.02, and 0.41 kg ha^{-1} for VR, uniform, and control treatments. In general, the losses of inorganic nitrogen were high at the start of the experiment. The amount of inorganic nitrogen in surface runoff rapidly decreased after the second rainfall (Table B6, Appendix B). Overall, the inorganic nitrogen losses in surface runoff showed decreasing trends throughout the growing season as described by the significant results of sampling date ($P \leq 0.0001$) (Table B6, Appendix B). The inorganic nitrogen losses in the combine zone were in combine zone 0.61, 1.02, and 0.08 kg ha^{-1} for VR, uniform, and control treatments in June 15, 2011 rainfall event, which decreased to 0.08, 0.18, and 0.03 kg ha^{-1} for VR, uniform, and control treatments after October 2, 2011 rainfall event.

4.5 Summary and Conclusions

The surface runoff volumes were successfully calculated using SCS-CN Method. The calibrations and validations were also successful with R^2 values of 0.95 and 0.90 for calibration and validation period, respectively. The losses of TP, DRP, PP, and inorganic nitrogen were significantly higher for uniform treatment as compared to VR treatment for both fields. The DRP was strongly related to TP content and more than 50% of DRP contributed to TP loss in surface runoff. The possible reason for higher DRP losses as compared to PP losses might be low amount of TSS losses in the surface runoff as compared to those for other crops reported in literature due to better crop cover produced by wild blueberry plants. The PP losses were low as compared to DRP losses at the start of the growing season, but PP contributed more to TP loss later in the season. The inorganic nitrogen losses in surface runoff also showed significant differences for all treatments, the losses were very high during early stages of the growing season. The mean values for total inorganic nitrogen losses for VR and uniform treatments from Kemptown Field were 2.34 and 3.91 kg ha^{-1}, while 2.26 and 4.19 kg ha^{-1} for Cattle Market Field. The mean values for total phosphorus losses for VR and uniform treatments from Kemptown Field were 0.74 kg ha^{-1} and 1.35 kg ha^{-1}, while 0.98 kg ha^{-1} and 1.56 kg ha^{-1} for Cattle Market Field.

Due to the significant differences of TP and inorganic nitrogen between uniform treatment and VR treatment from the wild blueberry fields, management efforts to reduce phosphorus and inorganic nitrogen loading in surface runoff from these fields should be directed. Phosphorus and nitrogen are essential elements for wild blueberry plant growth but it should be applied according to plant nutrient requirements. Application of fertilizer based on slope variation of field reduced the concentration of nitrogen and phosphorus in surface runoff. The VR fertilization also reduced 40 % of the fertilizer applied in VR treatment as compared to uniform treatment. The VR has successfully reduced the nutrient losses in surface runoff.

CHAPTER 5

QUANTIFYING THE IMPACT OF VARIABLE RATE FERTILIZATION ON SUBSURFACE WATER QUALITY

5.1 Introduction

Nitrogen is an essential element for plant growth. However, excessive application of nitrogen (N) to soil can exceed plant metabolic requirements or the capacity of the soil to immobilize it resulting into adverse environmental impacts (Zhao et al., 2003). Negatively charged NO_3^--N ions are highly soluble in percolating water and are carried out with influxes of water to contaminate groundwater (Scholefield et al., 1993). Agriculture is a dominant point source polluter of water resources worldwide (Power and Schepers, 1989). Most of previous studies focused on NO_3^--N in normal soils (Owens et al., 2000; Di and Cameron, 2002). Since the wild blueberry fields are acidic in nature (Travett, 1962) and the autotrophic nitrifiers are severely restricted at low pH (Lodhi, 1982). The most of the inorganic N occurs as NH_4^+-N in acid soils (Alexander, 1977). Nevertheless some nitrification is also reported in acidic soils (Vitousek and Melillo, 1979). Previous studies indicate that the plant community has high impact upon nutrient cycling and leaching losses in agricultural systems (Hooda et al., 1998; Loiseau et al., 2001; Bouman et al., 2010). Wild blueberry is considered as inefficient user of nitrate (Townsend, 1969) resulting in either denitrification or leaching (Eaton and Patriquin, 1989). The chance of leaching of both NH_4^+-N and NO_3^--N is present in wild blueberry soils (Thyssen and Percival, 2006). Other major factors that increase N leaching under field conditions are higher N application rates than plant requirements (Zhu et al., 2003). Also the rooting depth of the wild blueberry is very shallow, with few roots 15 cm below the soil surface (Trevett, 1962). The combination of high rainfall and shallow rooting depth of wild blueberry results in high NO_3^--N and NH_4^+-N leaching risk during blueberry production (Trevett, 1959; Thyssen and Percival, 2006). These nutrients have adverse effects on human health as methemoglobinemia in infants and stomach cancer in adults are caused by elevated levels of NO_3^--N (> 10 mg L^{-1}) in drinking water (Addiscott, 1996).

There is a need for site specific management of fertilizer inputs to reduce the risk of groundwater contamination. Site specific management of fertilizer inputs can result in better fertilize use efficiency, enhanced crop growth and less environmental impacts. Wild blueberry fields are developed on deforested farmlands that have gentle to severe topography. The site specific management on the basis of topography can reduce the risk of groundwater pollution. Dampney et al. (1999) found a reduction in NO_3^--N leaching in winter wheat when comparing uniform rate (UR) and variable rate (VR) N fertilizer application. Kitchen et al. (1995) reported that the use of VR N fertilizer on corn decreased the amount of N in the soil profile at the end of the season as compared with UR fertilizer.

Nitrogen could be managed according to slope variability classes to achieve better N use efficiency and reduce NO_3^--N and NH_4^+-N leaching potential. Organic matter (OM) content has also been shown to be related to landscape position and N level in the soil (Franzen et al., 2002) with higher N level associated with higher organic matter. It is important to consider leaching of both NO_3^--N and NH_4^+-N in acidic soils.

Little efforts have been made on quantification of leaching losses in wild blueberry fields. It was hypothesized that variable rate fertilization on the basis of slope variation could decrease leaching losses as compared to conventional uniform rate fertilization. The proper management of fertilizer inputs in these slope zones can result in higher production and less impacts on groundwater. Therefore, the objective of this research was to quantify the impact of variable rate fertilization on subsurface water quality.

5.2 Materials and Methods

Equal numbers of suction lysimeters were installed in every section of both fields at different strategic locations to cover the slope variability (Figure 3-8 a and b, Chapter 3). Subsurface water samples were collected from suction lysimeters after every heavy rainfall event. A vacuum of 0.8 kPa was created in lysimeter system just prior to, or after rainfall events using a manual vacuum pump. After the vacuum application, subsurface water samples were collected in 125 mL Nalgene sampling containers 24 to 48 hours. Collected samples were immediately stored in a freezer to prevent volatilization of analytes until they were analyzed at the Water Quality Research Laboratory, Department of Environmental Sciences of the NSAC. These samples were analyzed for NH_4^+-N and NO_3^--N. Detailed methods and materials are discussed in Chapter 3. The experimental design was a split-plot with two fertilizer treatments and three slope zones in six replications. The design was modeled with fertilizer treatment as a main plot and slope as sub plot, and sampling date as a repeated measure factor. Response variables for subsequent statistical analysis were NH_4^+-N and NO_3^--N losses in soil leachates. The SAS (SAS Institute Inc., NC, USA) was used to perform repeated measures analysis of variance (RM ANOVA) by using mixed-model procedure and significance probability (P) of 5 %. The replications were regarded as random effects. The assumptions of normality of residuals were verified using Shapiro-Wilk test. If the normality of any data set was violated, data was transformed to normalize using proper transformations procedures. The variance and covariance of the data exhibited a structure matched one of those available in PROC MIXED. Means comparisons were conducted using a LSD for significantly different treatments ($P<0.05$).

5.3 Results and Discussion

5.3.1 Nitrate Nitrogen Leaching

5.3.1.1 Kemptown Field

The results of RM ANOVA suggested that the overall mean NO_3^--N concentrations in uniform treatment were significantly different than VR treatment. The mean NO_3^--N concentrations in soil leachate samples ranged from 2.61 to 3.76 mg L^{-1} for VR treatment, while mean values for uniform treatment ranged from 2.90 to 8.94 mg L^{-1}, respectively (Table 5-1). The higher concentrations of NO_3^--N in leachates might continue moving downwards through the porous soil until they reach the surficial groundwater. Thus the leachates leaving the root zone indicate the potential impact of NO_3^--N pollutants on groundwater. The NO_3^--N concentrations were similar in zone 1 (Z1) between VR and uniform treatments with mean values of 1.94 and 1.88 mg L^{-1}, respectively (Table 5-1). Similar result for NO_3^--N was due to same fertilizer rate applied in both VR and uniform treatment in Z1 (Figure 3-3 b, Chapter 3). The values for NO_3^--N were found to be significantly lower in VR treatment as compared to uniform treatment for zone 2 (Z2) throughout the monitoring period. The possible reason for the lower means values may be due to lower fertilizer application rate in VR section as compared to uniform section (Figure 3-3 b, Chapter 3). Similar trends were observed for zone 3 (Z3) suggesting three times higher values for NO_3^--N with mean value of 8.94 and 2.61 mg L^{-1} for uniform and VR treatment, respectively. The higher fertilizer application rate in uniform treatment (200 kg ha^{-1}) as compared to VR treatment (100 kg ha^{-1}) in Z3 might be one of the reasons for more concentration of the NO_3^--N in soil leachates for uniform treatment. Also, the accumulation of nutrients in low lying area might be another reason for higher mean values of NO_3^--N in Z3 for uniform treatment. The variation in NO_3^--N for soil leachate samples with respect to slope suggested the potential of the slope to develop management zones for VR fertilization in wild blueberry fields to mitigate leaching of nutrient to subsurface water (Table 5-1).

In general NO_3^--N for all three slope zones was significantly different for both treatments during the study period (Table 5-1). These results were in agreement with the findings of Farooque et al. (2012), they suggested higher values for NO_3^--N in low lying areas and vice versa for wild blueberry fields.

The mean comparison of the soil leachate samples collected from bare spots showed higher values of NO_3^--N for uniform treatment as compare to VR treatment in all slope zones with mean NO_3^--N values of 1.09 and 8.12 mg L^{-1} for VR and uniform treatments, respectively (Table 5-2). These results suggested that bare spots were at higher risk of NO_3^--N leaching in uniform treatment. The lysiemeters installed in VR section were found to be at minimal risk of groundwater contamination.

Experimental results showed that uniformly fertilized section contained higher concentration of NO_3^--N in soil leachates during late in the growing season were evident of nitrification process in wild blueberry fields. Thyssen and Percival (2006) also suggested that nitrate level in blueberry soils increases with time. Although the acidic

Table 5-1. Effects of uniform and VR fertilization on mean NO_3^--N concentrations in soil leachates for Kemptown Field.

Slope Zone	Fertilization Method	June 03 (mg L^{-1})	July 14 (mg L^{-1})	August 05 (mg L^{-1})	September 17 (mg L^{-1})	Mean (mg L^{-1})
Zone 1	Variable	1.94^a	3.85^a	3.37^a	2.44^a	2.90^a
	Uniform	1.88^a	4.00^a	3.31^a	2.42^a	2.90^a
Zone 2	Variable	1.60^a	4.74^a	4.85^a	3.83^a	3.76^a
	Uniform	3.62^b	7.47^b	12.06^b	9.90^b	8.26^b
Zone 3	Variable	1.12^a	2.99^a	4.02^a	2.31^a	2.61^a
	Uniform	4.43^b	8.75^b	12.39^b	10.21^b	8.94^b
Mean	Variable	1.55^a	3.86^a	4.08^a	2.86^a	3.09^a
	Uniform	3.31^b	6.74^b	9.25^b	7.51^b	6.70^b

RM ANOVA

Effect	DF	F-value	P-value
Fertilization Method (F)	1	143.17	< 0.0001
Slope Zone(S)	2	72.78	< 0.0001
Sampling Date (D)	3	55.26	< 0.0001
F × S	2	56.09	< 0.0001
D × F	3	10.93	< 0.0001

Means followed by different letters are significantly different at a significance level of 0.05.
Significant at $P < 0.05$

Table 5-2. Comparison of mean NO_3^--N concentration between uniform and VR fertilization for lysimeters placed in bare spots of Kemptown Field.

Nutrient	Fertilization Method	June 03 (mg L^{-1})	July 14 (mg L^{-1})	August 05 (mg L^{-1})	September 17 (mg L^{-1})	Mean (mg L^{-1})
NO_3^--N	Variable	0.73^a	1.51^a	1.26^a	0.86^a	1.09^a
	Uniform	3.81^b	8.16^b	11.37^b	9.15^b	8.12^b

nature of the field reduces nitrification process, however in bulk, nitrification still goes on slowly. The autotrophic nitrifying bacteria are the main contributors to nitrate production due to widespread presence and adaptation to low pH conditions. These results revealed that the apparent acidity as such could not restrict nitrifying activities. Other studies also supported these results (Noyes and Conner, 1919; Meek and Lipman, 1922). Other factors affecting the nitrate concentrations are temperature, soil type, organic matter and crop characteristics (Tiedje et al., 1982). Bremner and Shaw (1958) concluded that the denitrification rates rises exponentially as air temperature goes above 40° C. In current study the maximum temperature recorded during study period was 35° C indicating the restriction in denitrification process. Denitrification process is also influenced by lower quantities of organic matter (Tiedje et al., 1982). The monitoring wild blueberry fields were enriched with organic matter suggesting the lower denitrification process. Therefore, denitrification in lowbush blueberry soils results in only small losses of nitrogen from most stands. These results were in agreement with the findings of Eaton and Patriquin (1989). The factors such as temperature, organic matter and soil type results in restricted denitrification may have an impact on NO_3^--N concentration in soil leachates. In general, NO_3^--N leaching losses in VR fertilizer application were significantly lower than uniformly fertilized fields. Previous studies for different cropping systems also supported these results (Shahandeh et al., 2005; Zaman et al., 2006).

5.3.1.2 Cattle Market Field

The experimental results revealed that NO_3^--N concentrations in leachates showed significant differences for VR, uniform and control treatment in Cattle Market field

(Table 5-3). The control treatment in all three slope zones was found to have lower mean values ranging from 1.25 to 3.03 mg L^{-1}. There was a decreasing trend for NO_3^--N in control treatment during the study period suggesting the lowest concentrations in soil leachates for fifth sampling mean values ranging from 2.57 to 1.38 mg L^{-1}. The lower concentration of NO_3^--N in control treatment was due to no fertilization. The NO_3^--N concentrations for VR and uniform sections were significantly different except Z1. The non-significance among the uniform and VR treatment in Z1 was due to similar fertilizer application rate (Figure 3-4 b, Chapter 3). In general, the mean values for NO_3^--N concentrations in subsurface water for uniform treatment were higher than VR treatment with mean values of 6.33 and 3.35 mg L^{-1}, respectively (Table 5-3). These results suggested that the VR treatment was at lower risk of leaching as compare to uniform treatment.

The mean concentrations of NO_3^--N for VR treatment were 2.17, 2.68 and 2.19 mg L^{-1} for Z1, Z2 and Z3, respectively, indicating non-significant differences for June 15, 2011 sampling event (Table 5-3). The NO_3^--N was found to be non-significantly different in VR treatment for Z1 and Z2, while NO_3^--N for Z3 was significantly different than Z1 and Z2. In general, there was an increasing trend for NO_3^--N from first to last sampling suggesting the slow process of nitrification as shown by the significant value of sampling date (Table 5-3). The uniform treatment showed higher values for NO_3^--N as compare to VR and control treatment in Z2 and Z3 slope zones. All three slope zones showed significant differences for NO_3^--N concentrations in uniform treatment. The higher values of NO_3^--N in Z2 and Z3 were due to same fertilizer rate and erosion of soil particles from steep slopes to low lying areas. The trends for the variations of NO_3^--N in uniform treatment for soil leachate samples was similar to VR treatment. The NO_3^--N values in all slope zones were significantly different, and also the interaction of fertilization method and slope zone was significant (Table 5-3). The results of this study is in agreement with Shahandeh et al. (2005) and Zaman et al. (2006), who found nitrate leaching losses in a VR fertilizer application was significantly lower than NO_3^--N leaching levels under uniformly fertilized fields in different cropping systems.

Overall the results for this study demonstrated that there was less leaching of NO_3^--N for VR treatment, while the uniform treatment was at higher risk of leaching, suggesting the need for VR fertilization in wild blueberry field to protect subsurface water quality. There is a potential to adopt VR technologies in wild blueberry cropping systems with low input use and narrow range of plant nutrients. These results also testify Zaman et al. (2010)'s hypothesis that unnecessary or over-fertilization in low lying areas may deteriorate groundwater quality and increase the cost of production. Based on these results it is proposed that management zones based on slope can be used to implement VR fertilization to optimize productivity and reduce groundwater pollution.

Similar to Kemptown field, the concentrations of NO_3^--N in leachates in bare spots were found to be higher in uniform treatment with the mean value of 7.78 mg L^{-1} in low lying areas (Z3), and the lower in VR section with the mean value of 1.52 mg L^{-1} over the season (Table 5-4). The results from the both sites suggested that the variable rate fertilization in wild blueberry fields can mitigate the leaching losses and can have reduction in environmental threats. Based on these results it is proposed to allocate zero fertilizer to the bare spots, weed and grasses by defining a separate class in the delineated management zone. The fertilizer recommendations in the developed management zones

Table 5-3. Effects of uniform and VR fertilization on mean NO_3^--N concentrations in soil leachates for Cattle Market Field.

Slope Zone	Fertilization Method	June 15 (mg L^{-1})	July 12 (mg L^{-1})	August 02 (mg L^{-1})	September 15 (mg L^{-1})	October 02 (mg L^{-1})	Mean (mg L^{-1})
Zone 1	Variable	2.17^a	3.14^a	4.73^a	4.85^a	3.94^a	3.76^a
	Uniform	2.37^a	3.24^a	4.62^a	4.76^a	4.11^a	3.99^a
	Control	2.10^a	1.95^b	1.76^b	1.59^b	1.25^b	1.73^b
Zone 2	Variable	2.68^a	3.62^a	4.02^a	4.61^a	4.00^a	3.79^a
	Uniform	3.00^a	5.28^c	7.53^c	11.39^c	9.70^c	7.38^c
	Control	2.59^a	2.03^a	1.87^b	1.62^b	1.39^b	1.90^b
Zone 3	Variable	2.19^a	2.18^a	2.50^b	2.89^b	2.69^b	2.49^b
	Uniform	3.37^a	5.65^c	8.05^c	12.05^c	9.87^c	7.80^c
	Control	3.03^a	2.21^a	2.02^b	1.87^b	1.51^b	2.13^b
Mean	Variable	2.35^a	2.98^a	3.75^a	4.12^a	3.54^a	3.35^a
	Uniform	2.91^a	4.72^c	6.73^c	9.40^c	7.89^c	6.33^c
	Control	2.57^a	2.06^a	1.88^b	1.69^b	1.38^b	1.92^b

RM ANOVA

Effect	DF	F-value	P-value
Fertilization Method (F)	2	389.65	<0.0001
Slope Zone (S)	2	34.29	<0.0001
Sampling Date (D)	4	42.04	<0.0001
F × S	4	54.80	<0.0001
D × F	8	35.64	<0.0001

Means followed by different letters are significantly different at a significance level of 0.05.
Significant at $P < 0.05$

Table 5-4. Comparison of mean NO_3^--N concentration between uniform and VR fertilization for lysimeters placed in bare spots of Cattle Market Field.

Nutrient	Fertilization Method	June 15 (mg L^{-1})	July 12 (mg L^{-1})	August 02 (mg L^{-1})	September 15 (mg L^{-1})	October 02 (mg L^{-1})	Mean (mg L^{-1})
NO_3^--N	Variable	1.41^a	1.28^a	1.52^a	1.81^a	1.60^a	1.52^a
	Uniform	3.42^b	5.72^b	8.04^b	12.37^b	9.36^b	7.78^b
	Control	1.31^a	1.39^a	1.42^a	1.69^a	1.38^a	1.44^a

based on slope can be helpful in increasing input use efficiency, crop productivity and increase farm profitability.

5.3.2 Ammonium Nitrogen Leaching

5.3.2.1 Kemptown Field

Overall, NH_4^+-N concentrations were very high at the beginning of the growing season with mean concentration of 1.90 mg L^{-1} and 3.57 mg L^{-1} for VR and uniform fertilized treatments, respectively (Table 5-5). The NH_4^+-N in zone 1 (Z1) were similar for all leachate samples between VR and uniform treatments with mean values of 2.06 and 2.90 mg L^{-1}, respectively (Table 5-5). Same fertilizer rate (200 kg ha^{-1}) applied in Z1 for both VR and uniform treatments could be the reason for similar results. The values for NH_4^+-N in subsurface water samples were 2.21 and 3.84 mg L^{-1} for VR and uniform treatments. Lower fertilizer application rate in VR section as compare to uniform treatment might be the reason for less NH_4^+-N concentrations in soil leachates for VR treatment (Figure 3-3 b, Chapter 3). Three times higher values for NH_4^+-N were recorded in Z3 for uniform treatment as compared to VR treatment with mean values of 4.76 and 1.42 mg L^{-1} for uniform and VR treatments, respectively. The lower concentrations of NH_4^+-N in leachates for VR treatment in Z3 might be due to 50% reduction in applied fertilizer amount as compared to uniform treatment (Figure 3-3 b, Chapter 3). The accumulation of nutrients in low lying areas of the field might be another reason for higher amount of NH_4^+-N in uniform treatment as compared to VR treatment. The concentrations of $NH4^+$-N were higher in 1st sampling as compared to other sampling events. This might be due to ammonium based fertilizer applied in wild blueberry fields.

These results were in agreement with the findings of Hong et al., 2006, who found significantly lower NH_4^+-N concentration in subsurface water for VR treatment as compared to uniform treatment. In general, NH_4^+-N concentrations in all slope zones were significantly different for both treatments during the growing season (Table 5-5). The variability in soil properties and slope may be due to the intrinsic and extrinsic sources. Intrinsic variability is due to natural variations in soil, and extrinsic variability is caused in the field as part of crop management operations (Cemek et al., 2007). These results also probably reflect the influence of temporal dynamics on the measured parameters due to sampling at different times during the study.

The concentrations of NH_4^+-N kept on decreasing after every lysimeter sampling (Table 5-5). This decrease in NH_4^+-N might be due to plant uptake, ammonium loss in runoff and leaching, and conversion of ammonium to nitrate form. Wild blueberry plants utilize ammonium form of the nitrogen applied as most of other species grown on acidic soils. Although the nitrification process is very slow but still in acidic soils it is well documented. The results of current study were in agreement with Thyssen and Percival (2006), they found that ammonium level decreases with time, while nitrate levels were elevated. Farooque (2010) found that pH increases in the soil below root zone in the wild blueberry fields. This increase in pH can increase the nitrification process of the ammonium ions that leave the root zone and could pollute groundwater reservoirs.

The mean comparison of NH_4^+-N concentrations showed significant results for samples collected from the lysimeters placed in bare spots between uniform and VR treatment in all slope zones (Table 5-6). These results suggested that unnecessary fertilization in bare spots increased the risk of NH_4^+-N leaching for uniform treatment.

Table 5-5. Effects of uniform and VR fertilization on mean NH_4^+-N concentrations in soil leachates for Kemptown Field.

Slope Zone	Fertilization Method	June 03 (mg L^{-1})	July 14 (mg L^{-1})	August 05 (mg L^{-1})	September 17 (mg L^{-1})	Mean (mg L^{-1})
Zone 1	Variable	4.35^a	2.51^a	1.73^a	1.11^a	2.06^a
	Uniform	4.43^a	2.56^a	1.81^a	1.13^a	2.90^a
Zone 2	Variable	3.63^{ab}	2.51^a	1.54^a	1.01^a	2.21^a
	Uniform	4.27^a	3.18^b	2.23^b	1.70^b	3.84^b
Zone 3	Variable	2.78^c	1.12^c	0.79^c	0.67^c	1.42^c
	Uniform	6.74^b	4.19^b	3.36^b	2.55^b	4.76^b
Mean	Variable	3.59^a	2.21^a	1.36^a	0.93^a	1.90^a
	Uniform	5.15^b	3.31^b	2.47^b	1.79^b	3.57^b

RM ANOVA

Effect	DF	F-value	P-value
Fertilization Method (F)	1	143.17	0.0005
Slope Zone(S)	2	72.78	0.0004
Sampling Date (D)	3	55.26	< 0.0001
F × S	2	56.09	< 0.0001
D × F	3	10.93	0.3582

Means followed by different letters are significantly different at a significance level of 0.05.
Significant at $P < 0.05$

Table 5-6. Comparison of mean NH_4^+-N concentration between uniform and VR fertilization for lysimeters placed in bare spots of Kemptown Field.

Nutrient	Fertilization Method	June 03 (mg L^{-1})	July 14 (mg L^{-1})	August 05 (mg L^{-1})	September 17 (mg L^{-1})	Mean (mg L^{-1})
NH_4^+-N	Variable	0.82^a	0.70^a	0.58^a	0.48^a	0.64^a
	Uniform	6.41^b	4.43^b	3.31^b	2.46^b	4.15^b

The results of current study in agreement with Zaman et al. (2009) who suggested that fertilization in the bare spots should be avoided for wild blueberry fields. No fertilization in bare spots will lower input costs and reduce NH_4^+-N leaching.

5.3.2.2 Cattle Market Field

The mean values for NH_4^+-N concentrations in subsurface water for uniform treatment were significantly higher than VR and control treatment with mean values of 3.24, 2.05, and 0.37 mg L^{-1}, respectively. The NH_4^+-N concentrations for VR and uniform sections were similar in Z1. The concentrations of NH_4^+-N in Z2 and Z3 of VR treatment were lower than uniform treatment throughout the study period. The mean NH_4^+-N concentrations values in Z2 and Z3 for VR treatment were 2.29 and 1.22 mg L^{-1}, respectively, while for uniform treatment values were 3.24 and 3.74 mg L^{-1}, respectively. Higher fertilizer application rate in Z2 and Z3 for uniform treatment as compared to VR might be the reason for significant differences (Figure 3-4 b, Chapter 3). In general, decreasing trends were observed for both VR and uniform treatments from June 15, 2011 sampling to October 02, 2011 sampling event as described by P-value of sampling date (Table 5-7). The NH_4^+-N concentrations in subsurface water samples for control treatment were 81.95 % and 88.58 % lower than VR and uniform treatments, respectively. No fertilization in control treatment was the reason for lower quantities of NH_4^+-N in soil leachates.

The mean concentrations of NH_4^+-N for VR treatment were 4.77, 3.41, and 1.74 mg L^{-1} for Z1, Z2, and Z3, respectively, at the start of the experiment (Table 5-7). These results explained the decrease in NH_4^+-N concentration with decrease in fertilizer application rates. Lower NH_4^+-N concentrations in soil leachates among all slope zones were observed for control treatment throughout the monitoring period (Table 5-7). Lower values of NH_4^+-N were observed for the soil leachate samples collected from bare spots in VR treatment as compare to uniform treatment in all slope zones with overall mean values of 0.63 and 3.57 mg L^{-1}, respectively (Table 5-8). These results suggested that fertilization in bare spots can increase the risk of NH_4^+-N leaching. These results were in agreement with the findings of Burwell et al. (1976), who found lower concentrations of NH_4^+-N in subsurface water for low fertilizer inputs as compared to high fertilizer inputs in different cropping systems.

5.3.3 Impact of Soil Properties on Nutrient Leaching

5.3.3.1 Kemptown Field

The mean comparison of sand in different slope zones suggested non-significant differences between Z1 and Z2, while sand content was found to be significantly lower for Z3 with mean value of 48.52 and 47.77 % for VR and uniform treatment, respectively, as compared to 57.04 % and 57.54 % for Z1 (Table B1, Appendix B). The mean values for clay content in VR section were 9.18, 9.43 and 11.85 % for Z1, Z2 and Z3, respectively indicating higher clay content in low lying areas as compare to steep slope. The main reason for the lower values of clay and sand contents in Z3 might be due to movement of lighter particle with surface runoff and accumulation in low lying areas of the field.

The mean values for SOM in Z1 and Z2 were 7.30 and 8.10 %, while the values of SOM were 11.85 % in Z3 for VR treatment. The SOM was significantly different in all three slope zones with mean values of 7.35, 8.54, and 9.71 % in Z1, Z2, and Z3, respectively, for uniform treatment. These results were in agreement with the findings of

Table 5-7. Effects of uniform and VR fertilization on mean NH_4^+-N concentrations in soil leachates for Cattle Market Field.

Slope Zone	Fertilization Method	June 15 (mg L^{-1})	July 12 (mg L^{-1})	August 02 (mg L^{-1})	September 15 (mg L^{-1})	October 02 (mg L^{-1})	Mean (mg L^{-1})
Zone 1	Variable	4.77^{a}	3.62^{a}	2.48^{a}	1.54^{a}	0.88^{a}	2.66^{a}
	Uniform	4.58^{a}	3.70^{a}	2.52^{a}	1.81^{a}	1.19^{a}	2.76^{a}
	Control	0.38^{b}	0.37^{b}	0.28^{b}	0.31^{b}	0.32^{b}	0.33^{b}
Zone 2	Variable	3.41^{a}	3.22^{a}	2.11^{a}	1.20^{a}	1.51^{a}	2.29^{a}
	Uniform	4.98^{a}	4.62^{a}	2.62^{a}	2.23^{c}	1.75^{a}	3.24^{c}
	Control	0.39^{b}	0.35^{b}	0.35^{b}	0.36^{b}	0.32^{b}	0.35^{b}
Zone 3	Variable	1.74^{c}	1.61^{c}	1.16^{c}	0.87^{a}	0.69^{a}	1.22^{a}
	Uniform	6.13^{d}	4.88^{d}	3.20^{d}	2.53^{c}	1.90^{c}	3.73^{c}
	Control	0.46^{b}	0.40^{b}	0.36^{b}	0.39^{b}	0.47^{b}	0.42^{b}
Mean	Variable	3.31^{a}	2.82^{a}	1.92^{a}	1.20^{a}	1.03^{a}	2.05^{a}
	Uniform	5.23^{c}	4.40^{c}	2.78^{c}	2.19^{c}	1.62^{c}	3.24^{c}
	Control	0.41^{b}	0.37^{b}	0.33^{b}	0.35^{b}	0.37^{b}	0.37^{b}

RM ANOVA

Effect	DF	F-value	P-value
Fertilization Method (F)	2	493.43	<0.0001
Slope Zone (S)	2	3.66	0.0276
Sampling Date (D)	4	172.09	<0.0001
F × S	4	54.48	<0.0001
D × F	8	45.83	<0.0001

Means followed by different letters are significantly different at a significance level of 0.05.
Significant at $P < 0.05$

Table 5-8. Comparison of mean NH_4^+-N concentration between uniform and VR fertilization for lysimeters placed in bare spots of Cattle Market Field.

Nutrient	Fertilization Method	June 15 (mg L^{-1})	July 12 (mg L^{-1})	August 02 (mg L^{-1})	September 15 (mg L^{-1})	October 02 (mg L^{-1})	Mean (mg L^{-1})
NH_4^+-N	Variable	0.93^{a}	0.82^{a}	0.63^{a}	0.39^{a}	0.39^{a}	0.63^{a}
	Uniform	5.97^{b}	4.75^{b}	3.31^{b}	2.35^{b}	1.45^{b}	3.57^{b}
	Control	0.83^{a}	0.78^{a}	0.54^{a}	0.43^{a}	0.33^{a}	0.58^{a}

Beckie et al. (1997) and Zaman et al. (2009), they found higher clay contents and SOM, and lower sand contents in low lying areas of the fields as compared to steep slope areas. Higher SOM and clay contents in low lying areas can results in higher retention of soil nutrients in these areas of the fields. Analysis of variance results suggested that soil EC was significantly lower for Z1 than Z2 and Z3 in VR treatment before fertilization. The values for EC in all three slope zones for VR treatment after fertilization were 60.20, 67.27, and 71.38 $\mu S\ cm^{-1}$ (Table B1, Appendix B). The mean values for EC in uniform treatment were significantly different for all three slope zones before and after fertilizer application. The soil properties including pH and silt contents showed non-significant difference in all slope zones for both uniform and VR treatments. These results suggested that fertilization has not affected the pH of the soil in both treatments (Table B1, Appendix B). These results are in agreement with the findings of Farooque et al. (2011).

The mean values for NO_3^--N in Z1 and Z2 of VR treatment before fertilization were 2.89 and 3.19 mg kg^{-1}, while mean soil NO_3^--N in Z3 was 5.41 mg kg^{-1}, indicating higher amount of nutrient in low lying areas due to movement of nutrients with runoff (Table B1, Appendix B). Similar trends were observed in all three slope zones after fertilization for VR section. Soil NH_4^+-N also showed similar trend before and after fertilization (Table B1, Appendix B). This might be due to accumulation of nutrients in low lying areas. The presence of higher clay and SOM in Z3 also seems to be contributing in retention of nutrients in low lying areas. Farooque (2010) also found the similar trends for available nitrogen in wild blueberry fields. The mean values of soil NH_4^+-N before fertilization in uniform treatment were 3.78 and 3.95 mg kg^{-1} for Z1 and Z2, respectively. The low lying zone was found to have higher soil NH_4^+-N as compare to Z1 and Z2. After fertilization, the amounts of soil NH_4^+-N were 5.15, 6.03, and 9.27 mg kg^{-1} for Z1, Z2, and Z3, respectively.

The mean comparison of soil NO_3^--N showed significantly different values for all slope zones before fertilization in uniform treatment (Table B1, Appendix B). After fertilization, the mean values of soil NO_3^--N were increased to 4.32, 5.09, and 7.45 mg kg^{-1} for Z1, Z2, and Z3, respectively. In general, low lying area (Z3) showed higher values of soil NO_3^--N and NH_4^+-N before and after the fertilization indicating the accumulation of nutrients in these areas (Table B1, Appendix B). The results of this study indicated that topography plays an important role in determining the spatial distribution of nutrient pools and fluxes. The presence of higher soil nutrients can results in high concentration of nutrients in soil leachates. The results were in agreement with findings of Tsui and Chen (2010) and Frank et al. (1994); they also observed more nitrogen in soil at low lying areas as compare to steep slope areas of the field. These results emphasize the need of VR fertilization in wild blueberry fields according to slope variability.

After fertilizer application, mean values of soil nutrients as well as NO_3^--N and NH_4^+-N concentration in subsurface water samples were similar in Z1 for VR and uniform treatments (Table 5-9). The values of soil NO_3^--N after fertilization and NO_3^--N in subsurface water samples were 5.97 mg kg^{-1} and 2.61 mg L^{-1} for VR treatment, while 7.45 mg kg^{-1} and 8.94 mg L^{-1} for uniform treatment (Table 5-9). Soil NH_4^+-N were similar between uniform and VR treatment with mean values of 9.27 mg kg^{-1} and 7.74 mg kg^{-1}, while NH_4^+-N in leachates were 4.76 mg L^{-1} and 1.42 mg L^{-1}, respectively (Table 5-9). These results suggested that uniform fertilization in Z2 and Z3 of uniform treatment increased the soil inorganic nitrogen but it also results in three times higher

Table 5-9. Comparison of mean soil NH_4^+-N and NO_3^--N with mean NH_4^+-N and NO_3^--N concentration in soil leachates for Kemptown 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	Variable	2.89^a	4.22^a	2.90^a	3.79^a	5.11^a	2.06^a
	Uniform	2.91^a	4.32^a	2.90^a	3.78^a	5.15^a	2.90^a
Zone 2	Variable	3.19^a	4.32^a	3.76^b	3.92^a	5.28^a	2.21^a
	Uniform	3.22^a	5.09^b	8.26^c	3.95^a	6.03^{ab}	3.84^{ac}
Zone 3	Variable	4.27^b	5.97^b	2.61^a	5.41^b	7.74^b	1.42^b
	Uniform	4.22^b	7.45^c	8.94^c	5.43^b	9.27^c	4.76^c
Treatment Factor		Mixed ANOVA					
Fertilization Method (F)		NS	*	***	NS	*	***
Slope Zone(S)		***	***	***	***	***	*
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

quantities of NO_3^--N and NH_4^+-N in leachates as compared to VR treatment (Table 5-9).

5.3.3.2 Cattle Market Field

The mean comparison of soil properties in different slope zones revealed significantly different values for soil properties except soil pH and silt content in Cattle Market Field (Table B2, Appendix B). The sand contents in Z1 were 61.83, 60.18, and 61.81 % for VR, uniform, and control treatments, respectively. The sand contents were decreased in Z3 with mean values of 51.12, 51.34, and 50.35 % for VR, uniform, and control treatments, respectively (Table B2, Appendix B). The clay contents were increased from Z1 to Z3 in all treatments, while silt showed non-significant differences for all three slope zones in VR, uniform and control treatments (Table B2, Appendix B). The SOM was higher in Z3 among all three treatments as compared to Z1. Lower values of SOM were observed in Z1 with mean values of 7.89, 7.70, and 7.92 % for VR, uniform, and control treatment, respectively, while Z3 showed higher SOM with mean values of 9.51, 9.63, and 9.90 % for VR, uniform, and control treatment, respectively (Table B2, Appendix B). The mean values for soil EC were low for Z1 as compared to Z2 and Z3 for all treatments before fertilization. After the fertilization, the values of soil EC were increased in all three slope zones for VR, and uniform treatments. The soil EC was lowered in control treatment due to no fertilizer application. The different slope zones did not significantly affected the values for soil pH for VR, uniform, and control treatments before and after the fertilizer application (Table B2, Appendix B). The presence of higher clay content and SOM results in higher nutrients retention in low lying areas of the fields.

The mean values for soil NH_4^+-N before fertilization in Z1 were 3.47, 3.45, and 3.43 mg kg^{-1} for VR, uniform, and control treatment, respectively. The soil NH_4^+-N in Z3 was higher before fertilization with mean values of 5.43, 5.40, and 5.45 mg kg^{-1} for VR, uniform, and control treatments, respectively. The amount of soil NH_4^+-N increased after fertilization in VR treatment but showed non-significant results among the slope zones. Increasing trends were also observed in control treatment from Z1 to Z3, while decreases in soil NH_4^+-N were observed in all slope zones due to no fertilization. The mean values for soil NO_3^--N in Z1 were 2.43, 2.48, and 2.46 mg kg^{-1} for VR, uniform, and control treatment, respectively, before fertilization. The mean values for soil NO_3^--N in Z3 before fertilization were 3.71, 3.75, and 3.76 mg kg^{-1} for VR, uniform, and control treatments, respectively. After fertilizer application, similar trends were observed among all slope zones for all treatments. In general, fertilization increased the values of soil NH_4^+-N and NO_3^--N (Table B2, Appendix B). The higher soil inorganic nitrogen can results in higher concentrations of NH_4^+-N and NO_3^--N in soil leachates.

The results showed non-significant differences for soil NH_4^+-N and NO_3^--N in VR, uniform, and control treatments before the fertilizer application (Table 5-10). After the fertilizer application, similar results were observed in Z1 for soil inorganic nitrogen as well as NH_4^+-N and NO_3^--N concentrations in soil leachates between uniform and VR treatment. The values of soil NH_4^+-N and NO_3^--N were 2.14 and 2.79 mg kg^{-1} in control treatment, while NH_4^+-N and NO_3^--N in leachates were 1.73 and 0.33 mg L^{-1}, respectively (Table 5-10). The concentrations of NH_4^+-N and NO_3^--N in leachates for control treatment were much lower than uniform and VR treatments. Similar trends for soil NH_4^+-N and NO_3^--N in VR, uniform, and control treatments were observed in Z2,

Table 5-10. Comparison of mean soil NH_4^+-N and NO_3^--N with mean NH_4^+-N and NO_3^--N concentration in soil leachates for Cattle Market 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	Variable	2.43^a	3.79^a	3.76^a	3.47^a	5.05^a	2.66^a
	Uniform	2.48^a	3.76^a	3.99^a	3.45^a	5.09^a	2.76^a
	Control	2.46^a	2.14^b	1.73^b	3.43^a	2.79^b	0.33^b
Zone 2	Variable	2.84^a	3.57^a	3.79^a	4.11^a	5.17^a	2.29^a
	Uniform	2.87^a	4.03^a	7.38^c	4.10^a	6.05^c	3.24^c
	Control	2.89^a	2.31^b	1.90^b	4.13^a	3.17^b	0.35^b
Zone 3	Variable	3.71^b	5.02^c	2.49^{ab}	5.43^b	7.50^c	1.22^{ab}
	Uniform	3.75^b	6.26^d	7.80^c	5.40^b	8.22^d	3.73^c
	Control	3.76^b	3.36^a	2.13^{ab}	5.45^b	4.67^a	0.42^b
Treatment Factor		Mixed ANOVA					
Fertilization Method (F)		NS	***	***	NS	***	***
Slope Zone(S)		***	***	***	***	***	NS
F x S		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

while the quantities of NH_4^+-N and NO_3^--N in leachates were 3.24 and 7.38 mg L^{-1} for uniform treatment as compared to 2.29 and 3.79 mg L^{-1} for VR treatment (Table 5-10). The mean values of both soil inorganic nitrogen and NH_4^+-N and NO_3^--N concentrations in leachates showed significantly lower values for VR as compared to uniform treatment in Z3 (Table 5-10). The inorganic nitrogen losses in leachates for Z3 were nearly three times more for uniform treatment as compared to VR treatment (Table 5-10). The differences were might be due to lower rate of fertilizer applied in Z3 of VR section and no fertilizer application in control section. Another reason could be the higher quantities of SOM, clay contents, and soil NH_4^+-N and NO_3^--N in Z3 (Table 5-10). Previous studies in different cropping systems also showed similar results (Shahandeh et al., 2005; Zaman et al., 2009).

5.4 Summary and Conclusions

The VR fertilization significantly ($p \leq 0.05$) decreased nitrate and ammonium loading in subsurface water as compared to the uniform treatment from wild blueberry fields. The concentrations of NO_3^--N and NH_4^+-N were higher in low lying areas of uniform treatments as compared to VR treatment in both the Kemptown Field and Cattle Market Field. Higher quantities of SOM, clay, EC, soil inorganic nitrogen were observed in low lying areas as compared to steep slope areas of both fields. It could be a reason for higher quantities of NH_4^+-N and NO_3^--N in soil leachates. Soil inorganic nitrogen in Z2 were non-significant between the two treatments, while the NO_3^--N and NH_4^+-N concentrations in leachates were significantly higher in uniform treatment as compared to VR treatment. Although, uniform fertilization in Z3 of uniform treatment increased soil inorganic nitrogen but it also results in three times higher quantities of NO_3^--N and NH_4^+-

N in leachates as compared to VR treatment for both fields. Control treatment showed less NO_3^--N and NH_4^+-N in leachates as compared to uniform and VR treatment. The reason might be due to no fertilization for the control treatment.

Based on the results of this study, it is recommended that fertilizers should be applied on the slope basis to increase nutrient uptake efficiency, reduce cost of production and reduce nitrate and ammonium leaching through the root zone to avoid groundwater contamination.

CHAPTER 6

QUANTIFICATION OF THE IMPACT OF VARIABLE RATE FERTILIZATION ON PLANT GROWTH AND BERRY YIELD IN WILD BLUEBERRY CROPPING SYSTEM

6.1 Introduction

The intensification of agricultural inputs over the last few decades have increased the food production, but polluting the environment at the same time (Tilman et al., 1996). The agricultural intensification can further increase NO_3^--N and phosphorus-driven eutrophication of water bodies in the environment during the next 50 years (Tilman et al., 1996). Currently, crop management practices are implemented uniformly with inadequate attention being given to substantial variation in soil/plant characteristics, topographic features and fruit yield (Zaman et al., 2008a). Uniform fertilization may result in over-fertilization and under-fertilization by decreasing fertilizer use efficiency, and increased potential for contamination of surface water and groundwater systems (Link et al., 2006). Babcock (1992) suggests that the uniform fertilization is profitable where the nutrient variability was not high and assuming that yield was not reduced by over application of nitrogen fertilizer. Spatial variability of soil type, topography, crop history, soil physical and chemical properties, and nutrient availability are causes of yield variation (Wibawa et al., 1993).

Wild blueberry fields are developed from deforested lands and were found to have substantial variation in soil and plant characteristics, topographic features, and fruit yield (Eaton, 1988; Farooque et al., 2011). These variations within blueberry fields emphasize the need for precise site-specific crop management to maximize profit and mitigate environmental risks (Malay, 2000; Zaman et al., 2009).

Yield must be increased and inputs must be lowered to overcome the increased costs of sampling and mapping for VR fertilization, while making assumptions that variability is present and can be accurately mapped. An applicator with VR control can be used to automatically change application rates in the field (Searcy, 1997). Several researchers have compared VR and uniform fertilization (Mulla et al., 1992; Wibawa et al., 1993). Wibawa et al., 1993 showed that the VR treatments produced greater yields than the uniform treatments, in the very hilly, highly variable field, in two of three years. Mulla et al. (1992) fertilized wheat according to different management zones and found that two of the three zones had less N and P fertilizer applied than the uniformly applied section, yield was not significantly different. Paz et al. (1999) showed that grid cell level N management used lower amounts of fertilizer and produced higher yields than uniform fertilizer application. Mallarino et al. (1998) found that VR fertilization decreased considerable amount of fertilizer as compared to uniform fertilization and increased yield. Fraser et al. (1999) and Thrikawala et al. (1999) concluded that due to spatial variability within the field, uniform N application resulted in over- and under fertilization in parts of the fields, whereas over fertilization increased the probability of nitrate leaching and under fertilization may limit yield (Paz et al., 1997). Dampney et al. (1999) found a reduction in nitrate leaching in winter wheat when comparing uniform rate with VR N management. If less fertilizer is applied, even if no economic benefits are realized, there may still be environmental benefits (Sawyer, 1994).

The objective of this study was to examine the impact of VR and uniform fertilization on plant growth parameters, leaf nutrients, and fruit yield.

6.2 Materials and Methods

Research was conducted on two wild blueberry fields in central Nova Scotia, Canada. VR fertilizer was applied in both Kemptown and Cattle Market Fields according to the prescription maps in one section, while other section received uniform fertilization for comparison. Control section was added in Cattle Market Field as reference in 2011. Crop parameters such as plant density, plant height, number of side branches, and number of buds were collected in mid-December at both 2010 for Kemptown Field, and 2011 at the Cattle Market Field. Fruit samples were collected in August 2011 from the Kemptown Field. The relationships between the soil properties and plant growth parameters were determined using correlation analysis in Minitab 15 statistical software. The degree of linear association between two variables when other variables are fixed is indicated by coefficient of correlation (r). The analysis of variance (ANOVA) with PROC MIXED (SAS Institute, Cary, NC, USA) was used to compare the means of leaf nutrients, plant growth parameters, and fruit yield in both fields. The replications were regarded as random effects. The assumptions of normality of residuals were verified using Shapiro-Wilk test. If the normality of any data set was violated, data was transformed to normalize using proper transformations procedures. Residuals were plotted to check the constant variance. Means comparisons were conducted using a LSD for significantly different treatments ($P<0.05$). Detail procedure can be adopted from Chapter 3.

6.3 Results and Discussion

6.3.1 Relationship of Plant Parameters with Soil Properties

6.3.1.1 Kemptown Field

Relationships between plant growth parameters and soil properties were determined using correlation analysis. The correlation analysis revealed significant relationships among plant growth parameters and soil properties for both VR and uniform treatments (Tables 6-1 and 6-2). In general, the soil parameters such as SOM, clay, EC, and inorganic nitrogen were significantly correlated with plant heights and number of buds per stem in VR treatment. Plant density showed non-significant correlation with soil properties. The sand was negatively correlated with plant density, suggesting that plant density is less in the areas where sand contents are high. The plant height was found to be significantly correlated with SOM (r = 0.55), NH_4^+-N (r = 0.68), NO_3^--N (r = 0.38), clay (r = 0.57), and EC (r = 0.72) in VR treatment. These significant correlations of plant height with the soil properties indicated that the plant height was affected by the availability of soil NH_4^+-N and NO_3^--N, SOM, clay and EC of the soil. The significant positive correlations among the plant height and soil inorganic nitrogen suggested that the applied nitrogen have a direct influence on plant height. The relationships of plant height with pH and silt content were non-significant, suggesting that these properties are less variable and do not influence plant height. The negative correlation of the plant height with the sand content (r = -0.13) showed that the plant height was more in the areas having less sand content (Table 6-1), this may be due to less retention of nutrients.

The number of branches per stem were also found to be significantly correlated with soil NH_4^+-N (r = 0.42) and soil NO_3^--N (r = 0.39) in VR treatment (Table 6-1).

These positive correlations of number of branches per stem indicating that fertilization have a direct influence on development of branches. The correlation analysis of number of buds per stem with soil properties suggested significant correlations between number of buds per stem with soil NH_4^+-N, SOM, clay content, and EC (r ~ 0.37 to 0.65).

The correlation analysis among plant growth parameters suggested significant correlations between plant height, number of branches per stem, and number of buds per stem (r ~ 0.42 to 0.55) in VR treatment (Table 6-1). This indicates that plant height had a positive impact on number of branches per stem and number of buds per stem in VR treatment. Overall the relationships among the soil properties and plant growth parameters suggested that the nutrient uptake by the plants was affected by the soil properties, which may have an influence on the crop yield.

Similar relationships were observed between plant parameters and soil properties for the uniform treatment in the Kemptown Field (Table 6-2). Plant density showed non-significant relationships with soil properties. Plant height showed positive correlation with soil inorganic nitrogen, SOM, EC, and clay contents (r ~ 0.47 to 0.71). The number of branches per stem also showed positive relationships with soil inorganic nitrogen. Similar to VR treatment, number of buds per stem showed positive correlation with soil properties such as soil NH_4^+-N, SOM, clay content, and EC (r ~ 0.41 to 0.51) in uniform treatment.

The general comparison of uniform and VR treatment for correlation of soil inorganic nitrogen with plant growth showed that soil NH_4^+-N and NO_3^--N were more positively correlated with plant height and number of branches per stem in uniform

Table 6-1. Correlation matrix among the soil properties and plant parameters for VR treatment of Kemptown Field.

	NH_4^+-N	NO_3^--N	Plant Density	Plant Height	Branches	Buds	Sand%	Clay%	Silt%	OM%	EC
NO_3^--N	0.64***										
Plant Density	0.11^{NS}	-0.04^{NS}									
Plant Height	0.68***	0.38*	0.004^{NS}								
Branches	0.42**	0.39*	-0.29^{NS}	0.50**							
Buds	0.65***	0.25^{NS}	0.06^{NS}	0.55***	0.42*						
Sand%	-0.20^{NS}	-0.20^{NS}	-0.13^{NS}	-0.12^{NS}	0.06^{NS}	-0.19^{NS}					
Clay%	0.42 *	0.34*	0.07^{NS}	0.57***	0.23^{NS}	0.39*	-0.25^{NS}				
Silt%	0.07^{NS}	0.10^{NS}	0.11^{NS}	-0.11^{NS}	-0.13^{NS}	0.14^{NS}	0.95***	-0.07^{NS}			
SOM%	0.57***	0.44**	0.08^{NS}	0.55***	0.09^{NS}	0.37*	0.12^{NS}	0.17^{NS}	-0.18^{NS}		
EC	0.34*	0.33^{NS}	0.26^{NS}	0.72***	-0.04^{NS}	0.54***	-0.14^{NS}	0.59***	0.13^{NS}	0.62***	
pH	0.06^{NS}	0.04^{NS}	-0.01^{NS}	0.07^{NS}	-0.06^{NS}	-0.19^{NS}	0.15^{NS}	0.09^{NS}	-0.183^{NS}	0.29^{NS}	0.02^{NS}

Significance of correlations indicated by *, ** and ***, are equivalent to $p = 0.05$, $p = 0.01$ and $p = 0.001$.
NS, non-significant at $p = 0.05$.

Table 6-2. Correlation matrix among the soil properties and plant parameters for uniform treatment of Kemptown Field.

	NH_4^+-N	NO_3^--N	Plant Density	Plant Height	Branches	Buds	Sand%	Clay%	Silt%	OM%	EC
NO_3^--N	0.61***										
Plant Density	-0.19^{NS}	-0.15^{NS}									
Plant Height	0.71***	0.67***	-0.05^{NS}								
Branches	0.53**	0.40*	-0.70***	0.47**							
Buds	0.51**	0.23^{NS}	-0.22^{NS}	0.41*	0.40*						
Sand%	-0.42*	-0.39*	-0.06^{NS}	-0.50**	-0.22^{NS}	0.06^{NS}					
Clay%	0.43*	0.65***	-0.06^{NS}	0.52**	0.35^{NS}	0.41*	-0.39*				
Silt%	0.32^{NS}	0.22^{NS}	0.09^{NS}	0.37^{NS}	0.13^{NS}	-0.14^{NS}	-0.96***	0.10^{NS}			
SOM%	0.47**	0.36*	-0.004^{NS}	0.49**	0.06^{NS}	0.50**	-0.14^{NS}	-0.09^{NS}	0.18^{NS}		
EC	0.51**	0.43*	0.20^{NS}	0.47**	0.12^{NS}	0.42*	-0.43*	0.29^{NS}	0.37*	0.19^{NS}	
pH	0.11^{NS}	0.47^{NS}	-0.07^{NS}	0.09^{NS}	0.14^{NS}	0.23^{NS}	-0.11^{NS}	0.45**	-0.03^{NS}	-0.09^{NS}	-0.24^{NS}

Significance of correlations indicated by *, ** and ***, are equivalent to p = 0.05, p = 0.01 and p = 0.001.
NS, non-significant at p = 0.05.

treatment. These results suggested that soil inorganic nitrogen has more impact on vegetative growth for uniform treatment. This might be due to higher soil inorganic nitrogen level in uniform treatment as compared to VR treatment (Table B1, Appendix B). The number of buds per stem correlation with soil NH_4^+-N and NO_3^--N were in VR treatment (r = 0.65) as compared to uniform treatment (r = 0.51) (Tables 6-1 and 6-2). These results indicated that VR fertilization has a positive impact on floral buds, suggesting that excessive vegetative growth can result in less floral buds count. These results were in agreement with findings of Percival and Sanderson (2004).

6.3.1.2 Cattle Market Field

The correlation analysis showed significant relationships among plant growth parameters and the soil properties in the Cattle Market Field (Tables 6-3, 6-4, 6-5). In general the plant density showed non-significant relationship with all soil properties for VR, uniform, and control treatments of Cattle Market Field. The plant height was significantly correlated with soil inorganic nitrogen, SOM, sand contents, clay contents, and soil fertility in all three treatments (Tables 6-3, 6-4, 6-5). In VR treatment, the relationships of plant height with soil properties suggested that the amount of plant height was dependent upon soil NH_4^+-N and NO_3^--N, SOM, EC, and clay contents (r ~ 0.46 to 0.80). The relationships of plant height showed negative relationships with sand contents. The soil pH and silt contents were non-significant indicating that these properties had not affected the plant height in VR treatment of the Cattle Market Field (Table 6-3).

The numbers of branches per stem were also found to be significantly correlated with soil properties such as soil NH_4^+-N, EC, and clay contents in VR treatment of the Cattle Market Field. These relationships indicated that these soil properties increased the number of branches per stem (Table 6-3). The number of buds per stem with showed positive correlation with soil inorganic nitrogen, SOM, and clay contents. The number of buds per stem showed negative relationships with sand (r = -0.51) and silt contents (r = -0.01) in VR treatment (Table 6-3). These negative correlations suggested that less nutrients availability in the areas with high sand contents may influence number of buds per stem.

The relationships for plant height with soil properties in the uniform treatment of the Cattle Market Field (r ~ 0.16 to 0.67) were similar to the VR treatment (Table 6-4). The relationships of number of branches per stem with soil NH_4^+-N (r = 0.39) and EC (r = 0.38) were significantly correlated indicating higher soil ammonium level has a positive impact on number of branches per stem (Table 6-4). The number of buds per stem also showed significant correlation with soil NH_4^+-N and NO_3^--N, SOM, and clay for uniform treatment contents (r ~ 0.38 to 0.62) in the Cattle Market Field (Table 6-4).

The control treatment also showed similar relationships for soil properties and plant growth parameters for plant height, number of buds per stem, and number of branches per stem (Table 6-5). Overall the correlation analysis suggested that the soil properties have a direct influence on the plant growth, which may have an influence crop yield.

6.3.2 Effect of Fertilizer Treatments on Leaf Nutrients

6.3.2.1 Kemptown Field

The analysis of variance results using mixed-procedure showed that VR treatment significantly (p>0.05) influenced the leaf N, P, and K concentrations as compared to

Table 6-3. Correlation matrix among the soil properties and plant parameters for VR treatment of Cattle Market Field.

	NH_4^+-N	NO_3^--N	Plant Density	Plant Height	Branches	Buds	Sand%	Clay%	Silt%	OM%	EC
NO_3^--N	0.46**										
Plant Density	0.11^{NS}	0.05^{NS}									
Plant Height	0.80***	0.46*	-0.08^{NS}								
Branches	0.44*	0.26^{NS}	-0.46*	0.62***							
Buds	0.81***	0.45*	-0.01^{NS}	0.71***	0.57***						
Sand%	-0.56***	-0.23*	-0.22^{NS}	-0.47**	-0.23^{NS}	-0.51**					
Clay%	0.60***	0.37*	-0.03^{NS}	0.53**	0.38*	0.56***	-0.70***				
Silt%	0.09^{NS}	0.05^{NS}	0.23^{NS}	0.25^{NS}	0.15^{NS}	-0.01^{NS}	-0.50**	0.28^{NS}			
OM%	0.48**	0.52**	0.09^{NS}	0.48**	0.15^{NS}	0.59***	-0.53***	0.41*	0.11^{NS}		
EC	0.51**	0.31^{NS}	0.20^{NS}	0.62***	0.38*	0.14^{NS}	0.03^{NS}	0.32^{NS}	-0.09^{NS}	0.04^{NS}	
pH	0.11^{NS}	0.47^{NS}	-0.07^{NS}	0.09^{NS}	0.36^{NS}	0.34^{NS}	-0.34^{NS}	0.41*	-0.03	0.17^{NS}	0.18^{NS}

Significance of correlations indicated by *, ** and ***, are equivalent to $p = 0.05$, $p = 0.01$ and $p = 0.001$.
NS, non-significant at $p = 0.05$.

Table 6-4. Correlation matrix among the soil properties and plant parameters for uniform treatment of Cattle Market Field.

	NH_4^+-N	NO_3^--N	Plant Density	Plant Height	Branches	Buds	Sand%	Clay%	Silt%	OM%	EC
NO_3^--N	0.63***										
Plant Density	0.09^{NS}	0.07^{NS}									
Plant Height	0.65***	0.50**	0.22^{NS}								
Branches	0.39*	0.10^{NS}	-0.38*	0.53**							
Buds	0.62***	0.38*	0.12^{NS}	0.39*	0.08^{NS}						
Sand%	-0.59***	-0.52**	-0.22^{NS}	-0.20^{NS}	0.18^{NS}	-0.48**					
Clay%	0.74***	0.46*	0.10^{NS}	0.52**	0.15^{NS}	0.53**	-0.67***				
Silt%	0.40*	0.22^{NS}	0.05^{NS}	0.23^{NS}	0.05^{NS}	-0.01^{NS}	-0.68***	0.48**			
OM%	0.66***	0.34^{NS}	-0.02^{NS}	0.50**	0.22^{NS}	0.57***	-0.34^{NS}	0.66***	0.17^{NS}		
EC	0.49**	0.39*	-0.31^{NS}	0.67***	0.38*	0.14^{NS}	0.03^{NS}	0.32^{NS}	0.08^{NS}	0.37*	
pH	0.36^{NS}	0.15^{NS}	-0.17^{NS}	0.16^{NS}	0.36^{NS}	0.34^{NS}	-0.34^{NS}	0.41*	0.11^{NS}	0.22^{NS}	0.35^{NS}

Significance of correlations indicated by *, ** and ***, are equivalent to $p = 0.05$, $p = 0.01$ and $p = 0.001$.
NS, non-significant at $p = 0.05$.

Table 6-5. Correlation matrix among the soil properties and plant parameters for control treatment of Cattle Market Field.

	NH_4^+-N	NO_3^--N	Plant Density	Plant Height	Branches	Buds	Sand%	Clay%	Silt%	OM%	EC
NO_3^--N	0.06^{NS}										
Plant Density	0.39*	0.17^{NS}									
Plant Height	0.77***	-0.05^{NS}	0.37*								
Branches	0.22^{NS}	-0.02^{NS}	-0.01^{NS}	0.22^{NS}							
Buds	0.87***	0.17^{NS}	0.32^{NS}	0.38*	-0.01^{NS}						
Sand%	-0.56***	-0.08^{NS}	-0.25^{NS}	-0.57***	-0.34^{NS}	-0.45*					
Clay%	0.50**	0.18^{NS}	0.17^{NS}	0.48**	0.20^{NS}	0.48**	-0.84***				
Silt%	0.49**	0.10^{NS}	0.22^{NS}	0.22^{NS}	0.36^{NS}	0.28*	-0.89***	0.64***			
OM%	0.43*	0.29^{NS}	0.40*	0.23^{NS}	0.01^{NS}	0.57***	-0.45^{NS}	0.40*	0.43*		
EC	0.39*	0.18^{NS}	-0.03^{NS}	0.37*	0.30^{NS}	0.04^{NS}	0.05^{NS}	-0.03^{NS}	0.07^{NS}	0.10^{NS}	
pH	0.32^{NS}	-0.09^{NS}	0.21^{NS}	0.23^{NS}	0.15^{NS}	0.37*	0.14^{NS}	-0.09^{NS}	-0.13^{NS}	0.22^{NS}	-0.13^{NS}

Significance of correlations indicated by *, ** and ***, are equivalent to $p = 0.05$, $p = 0.01$ and $p = 0.001$.
NS, non-significant at $p = 0.05$.

uniform fertilization in the Kemptown Field (Table 6-6). The micro leaf nutrients such as Ca, Mg, Fe, and Mn showed non-significant differences between VR and uniform fertilization. The leaf N showed non-significant results for both uniform and VR treatment in Z1 (Table 6-6). The leaf N concentrations were found to be significantly different in Z2 and Z3 for VR and uniform treatments (Table 6-6). The mean values of leaf N (%) was 1.91 and 1.99 in Z2 and Z3 for VR treatment, respectively, while in uniform treatment leaf N (%) concentrations were 2.03 and 2.27 for Z2 and Z3, respectively (Table 6-6).

Table 6-6. Effect of VR and uniform fertilization on wild blueberry leaf nutrients in the Kemptown Field.

Slope Zone	Fertilization Method	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Mn (ppm)
Zone 1	Variable	1.77^{a}	0.123^{a}	0.47^{a}	0.36^{a}	0.16^{a}	36.15^{a}	1650^{a}
	Uniform	1.76^{a}	0.124^{a}	0.45^{a}	0.35^{a}	0.16^{a}	37.85^{a}	1692^{a}
Zone 2	Variable	1.91^{b}	0.133^{b}	0.47^{a}	0.43^{b}	0.15^{a}	42.29^{a}	1845^{a}
	Uniform	2.03^{c}	0.142^{c}	0.56^{b}	0.44^{b}	0.15^{a}	38.67^{a}	1820^{a}
Zone 3	Variable	1.99^{bc}	0.142^{c}	0.55^{b}	0.43^{b}	0.17^{a}	43.79^{a}	1471^{a}
	Uniform	2.27^{d}	0.16^{d}	0.66^{c}	0.53^{c}	0.15^{a}	37.52^{a}	1845^{a}
Treatment Factor		Mixed ANOVA						
Fertilization Method(F)		***	***	**	NS	NS	NS	NS
Slope Zone(S)		***	***	***	***	NS	NS	NS
F x S		***	**	*	NS	NS	NS	NS

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

The reason for significant differences for leaf N might be due to lower amount of fertilizer applied in VR treatment as compared to uniform treatment in Z2 and Z3 (Figure

3-3 b, Chapter 3). The accumulation of nutrients in low lying areas of the fields might be another reason for the significant differences. Similar trends were observed for the leaf P and K concentrations (Table 6-6). The leaf N concentrations for VR treatment in all three slope zones were within the proposed standards by Trevett (1972). The leaf N concentrations in Z2 and Z3 for uniform treatment were more than the proposed standards (Table 6-6). The leaf P concentrations in Z1 and Z2 were within the proposed standards for both VR and uniform treatments. The mean value for leaf P exceeded the proposed standards (0.110 - 0.144) in Z3 of uniform treatment, while mean value for leaf P was within standards for VR treatment. Leaf K concentrations in Z1 for both VR and uniform treatments were within standards set by Trevett (1972). In Z2, leaf K concentrations for VR treatment were within proposed standards, while leaf K concentrations were more than standards for uniform treatment. The leaf K concentrations were more than proposed standard values in Z3 for both VR and uniform treatments (Table 6-6).

Leaf Ca, Mg, Fe and Mn concentrations were within proposed standards in all slope zones under both VR and uniform treatments (Table 6-6). The leaf Ca concentration was more than the proposed standards in Z3 of the uniform treatment.

6.3.2.2 Cattle Market Field

Leaf macro nutrients (N, P, K) were significantly different for uniform, VR, and control treatments in the Cattle Market Field (Table 6-7). The VR treatment showed significantly lower leaf N concentrations in Z2 and Z3 as compared to uniform treatment, while non-significant differences were observed in Z1 for both VR and uniform treatments. The leaf N concentrations for VR treatment in all slope zones were also within the proposed standards by Trevett (1972). The leaf N concentrations in Z2 and Z3 for uniform treatment were more than proposed leaf standards. The mean leaf N concentrations in Z2 and Z3 for VR treatment were 1.93 and 1.97 %, respectively, while leaf N concentrations were 2.07 and 2.29 % in Z2 and Z3 for uniform treatment, respectively (Table 6-7). The lower rates of applied fertilizer in Z2 and Z3 of VR treatment could be the reason of these significant differences.

Table 6-7. Effect of VR, uniform, and control fertilization on wild blueberry leaf nutrients in the Cattle Market Field.

Slope Zone	Fertilization Method	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Mn (ppm)
Zone 1	Variable	1.85^{b}	0.123^{b}	0.47^{a}	0.36^{a}	0.19^{a}	37.74^{a}	1650^{a}
	Uniform	1.86^{b}	0.120^{b}	0.48^{a}	0.35^{a}	0.19^{a}	37.85^{a}	1452^{ab}
	Control	1.53^{a}	0.097^{a}	0.36^{b}	0.38^{a}	0.17^{a}	38.34^{a}	1338^{ab}
Zone 2	Variable	1.93^{bc}	0.131^{bc}	0.48^{a}	0.46^{ab}	0.18a	39.91^{a}	1331^{ab}
	Uniform	2.07^{c}	0.137^{c}	0.53^{c}	0.47^{ab}	0.18^{a}	41.34^{a}	1506^{ab}
	Control	1.65^{ab}	0.102^{a}	0.39^{b}	0.40^{a}	0.18^{a}	37.17^{a}	1453^{ab}
Zone 3	Variable	1.97^{bc}	0.143^{d}	0.52^{c}	0.46^{ab}	0.18^{a}	43.79^{a}	1528^{ab}
	Uniform	2.29^{c}	0.155e	0.58^{d}	0.51^{b}	0.19^{a}	40.67^{a}	1502^{ab}
	Control	1.76^{ab}	0.112^{ab}	0.43^{ab}	0.45^{ab}	0.18^{a}	42.34^{a}	1261^{b}
LSD ($p<0.05$)		0.08	0.008	0.03	0.03	0.01	6.90	190.3
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 followed by different letters are significantly different at a significance level of 0.05.
*Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level
NS = Non-significant

Leaf N concentrations for control treatment were less than proposed standards by Trevett (1972) and Eaton et al. (2009) except in Z3, where it was within standard values.

Repeated applications of fertilizers in lowbush blueberry fields could result in increases levels of leaf macro nutrients especially in the low lying areas of the field. The results were in agreement with findings of Eaton and Patriquin (1989). Leaf P and K concentrations showed similar trends. Leaf Ca, Mg, Fe and Mn were within proposed standards in all slope zones for both uniform and VR treatments (Table 6-7). These results were similar to the finding of Zaman et al. (2009), they found higher leaf N and P concentrations in the low lying areas of the wild blueberry fields.

6.3.3 Effect of Fertilizer Treatments on Plant Growth

6.3.3.1 Kemptown Field

The analysis of variance results using mixed-procedure showed that there were non-significant differences for plant density, number of branches per stem, and number of buds per stem between uniform and VR treatment (Table 6-8). The plant height showed significant ($p \leq 0.05$) results for fertilizer treatment between uniform and VR treatments. The plant height showed non-significant differences for both treatments in Z1 with the mean value of 20.41 and 20.25 cm for VR and uniform treatment, respectively. The plant height showed significant differences for plant height in Z2 and Z3 of both VR and uniform treatments. Non-significant differences were observed for number of branches per stem among all three slope zones, although Z3 showed higher number of branches per stem as compared to Z1 and Z2 (Table 6-8).

Number of buds per stem showed significant differences for all three slope zones. The mean values for number of buds per stem in Z1, Z2, and Z3 for VR treatment were 5.07, 5.34, and 6.05, respectively, while the mean values for number of buds per stem in Z1, Z2, and Z3 for uniform treatment were 4.89, 5.91, and 5.83, respectively (Table 6-8).

In general, Z3 showed higher values for plant height, number of branches stem^{-1}, and number of buds per stem as compared to Z1. This might be due to higher soil fertility status in Z3 as compared to Z1 in the Kemptown Field (Table B1, Appendix B).

Table 6-8. Effect of VR and uniform fertilization on wild blueberry plant growth in the Kemptown Field.

Slope Zone	Fertilization Method	Plant Density	Plant Height (cm)	Branches per Stem	No. of Buds per Stem
Zone 1	Variable	12^{a}	20.41^{a}	1.93^{a}	5.07^{ab}
	Uniform	13^{a}	20.25^{a}	1.83^{a}	4.89^{a}
Zone 2	Variable	13^{a}	21.45^{a}	1.77^{a}	5.34^{b}
	Uniform	14^{a}	23.55^{ab}	1.70^{a}	5.91^{c}
Zone 3	Variable	14^{a}	25.68^{b}	2.31^{a}	6.05^{c}
	Uniform	13^{a}	30.34^{c}	2.11^{a}	5.83^{bc}
LSD ($p<0.05$)		2.32	2.49	0.48	0.50
Treatment Factor		Mixed ANOVA			
Fertilization Method (F)		NS	*	NS	NS
Slope Zone(S)		NS	***	NS	*
F x S		NS	NS	NS	NS

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

6.3.3.2 Cattle Market Field

There were non-significant for the plant density in VR, uniform, and control treatments of the Cattle Market Field. Significant differences were observed for plant height, number of branches per stem, and number of buds per stem between VR, uniform, and control treatments (Table 6-9).

The plant heights were 19.34 and 18.83 cm for VR and uniform treatments in Z1, respectively, while 13.93 cm for control treatment. The plant heights were increased in

Z2 and Z3 for both treatments. In Z3, plant heights were 25.61, 30.21, and 18.35 cm for VR, uniform, and control treatments (Table 6-9). Number of branches per stem and number of buds per stem showed non-significant differences in all three slope zones for VR and uniform treatments. Numbers of buds per stem for VR treatment were 4.53, 4.58, and 5.78 in Z1, Z2, and Z3, respectively, while for uniform treatment number of buds per stem 4.78, 4.88, and 5.58 in Z1, Z2, and Z3, respectively (Table 6-9). The control treatment showed significant decreased in number of branches per stem and number of buds per stem as compared to uniform and VR treatments among all three slope zones.

Table 6-9. Effect of VR, uniform, and control fertilization on wild blueberry plant growth in the Cattle Market Field.

Slope Zone	Fertilization Method	Plant Density	Plant Height (cm)	Branches per Stem	No. of Buds per Stem
Zone 1	Variable	12^{a}	19.34^{a}	1.63^{b}	4.53^{a}
	Uniform	13^{a}	18.83^{a}	1.54^{b}	4.78^{a}
	Control	11^{a}	13.93^{b}	1.26^{a}	2.80^{b}
Zone 2	Variable	14^{a}	21.15^{c}	1.82^{c}	4.58^{a}
	Uniform	14^{a}	23.21^{cd}	1.78^{c}	4.88^{b}
	Control	13^{a}	14.86^{b}	1.19^{a}	3.34^{b}
Zone 3	Variable	15^{a}	25.61^{cd}	2.05^{d}	5.78^{c}
	Uniform	13^{a}	30.21^{d}	2.09^{d}	5.58^{c}
	Control	14^{a}	18.35^{a}	1.31^{a}	4.73^{a}
Treatment Factor			Mixed ANOVA		
Fertilization Method (F)		NS	***	***	**
Slope Zone(S)		NS	***	NS	***
F x S		NS	NS	NS	NS

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

The presence of higher SOM and soil inorganic nitrogen 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 B1, Appendix B). These results are in agreement with the findings of Farooque (2010), they found in the study conducted on wild blueberries that plant growth parameters were correlated with the fertility status of the field. Similar results were observed in another study conducted on fertilizer effect on wild blueberry yield components by Bourguignon (2006).

6.3.4 Effect of Fertilizer Treatments on Berry Yield

The berry yield was statistically non-significant between VR and uniform treatment in Kemptown field (Table 6-10). The mean values of berry yield in Z1 were 4061.82 and 4040.00 kg ha^{-1} for VR and uniform treatment, respectively. In Z2, the berry yield showed increasing trend for as compared to the Z1 for both VR and uniform treatments with mean value of 4509.09 kg ha^{-1} and 4304.00 kg ha^{-1}, respectively. The berry yield in Z3 was low in uniform treatment as compared to VR treatment with mean values of 4416.00 and 5185.45 for VR and uniform treatment (Table 6-10). In general, berry yield was recorded more in Z3 as compared to Z1, suggesting that less nutrients were present in Z1. These results were in agreement with Farooque (2010), he found higher yield in low lying areas of the field as compared to steep slope areas.

The mean berry yield for VR treatment was 4585.45 kg ha^{-1}, while uniform treatment produced yield of 4253.33 kg ha^{-1}, suggesting VR treatment increased the berry yield as compared to uniform treatment. Previous studies have also shown that VR treatments results in increased the productivity. Similar to the current study, Malo and Worcestor (1975) showed that yield was less in low lying areas of the field although plant height and leaf nutrients were very high. Wang et al. (2003) also found similar relation and concluded that VR fertilization increased profitability by 75%. Visual observations also revealed that vegetative growth was more in low lying areas of uniform treatments of both fields as compared to Z1. Percival and Sanderson (2004) reported that more vegetative growth might result in less berry yield. These results emphasize the need of VR according to the slope of the wild blueberry fields.

Table 6-10. Effect of VR and uniform fertilization on wild blueberry berry yield in the Kemptown Field.

Slope Zone	Fertilization Method	Berry Yield ($kg\ ha^{-1}$)
Zone 1	Variable	4061.82
	Uniform	4040.00
Zone 2	Variable	4509.09
	Uniform	4304.00
Zone 3	Variable	5185.45
	Uniform	4416.00
Mean	Variable	4585.45
	Uniform	4253.33
Treatment Factor		Mixed ANOVA
Fertilization Method (F)		NS
Slope Zone(S)		NS
F x S		NS

*Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level
NS = Non-significant

6.4 Summary and Conclusions

There were significant correlation between soil NH_4^+-N with plant height, number of branches per stem, and number of buds per stem. The correlation between plant density and soil NH_4^+-N was non-significant. Soil NO_3^--N showed good relationship with number of buds per stem but soil NO_3^--N showed non-significant relationship with plant density, plant height, and number of branches per stem. All plant parameters were very high in Z3 of uniform fertilization as compared to VR fertilization. In Z3 of uniform fertilization, mean plant height of 30.21 cm exceeds the optimum height of 15 -27 cm. There was non-significant difference for berry yield between VR and uniform treatment. In Z1, mean yield was same, but in Z2 and Z3 VR section produced more yield as compared to uniform fertilization. The average berry yield for VR section was 4585.45 kg ha^{-1}, while uniform section produced yield of 4253.33 kg ha^{-1}.

Based on the results of this study, it can be concluded that VR treatment reduce the amount of nutrients in surface runoff as compared to uniform fertilization. Also, nutrient leaching was less in VR section. Although the plant height and other plant parameters were relatively higher in uniform section but the berry yield in uniform section was lower than VR section.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The main objective of this project was to determine the impact of variable rate (VR) fertilization on crop productivity, surface and subsurface water quality in wild blueberry fields. The results of the study illustrated that VR fertilization have significantly lower the amount of TP, DRP, PP, and inorganic nitrogen in surface water samples as compared to uniform fertilization. Lower fertilizer application rates in VR treatments as compared to uniform treatment could be the reason for lower nutrient losses in surface runoff. The mean values of total inorganic nitrogen losses for VR and uniform treatments from Kemptown Field were 2.34 and 3.91 kg ha^{-1}, while total inorganic nitrogen losses for VR and uniform treatments were 2.26 and 4.19 kg ha^{-1} for Cattle Market Field. The mean values for TP losses for VR and uniform treatments from Kemptown Field were 0.74 and 1.35 kg ha^{-1}, while TP losses for VR and uniform treatments 0.98 and 1.56 kg ha^{-1} for Cattle Market Field. The TP losses from the Kemptown Field for VR and uniform treatments were 1.05 % and 1.92 %, respectively, of the total phosphorus applied in wild blueberry fields (70 kg ha^{-1}). The TP losses from for Cattle Market Field for VR and uniform treatments were 1.43 % and 2.22 %, respectively. Although, the differences of TP losses between VR and uniform treatment were less, however, 40 % less fertilizer was applied in VR section for both fields as compared to uniform section.

The VR fertilization also lowered the inorganic nitrogen loading in subsurface water as compared to uniform treatment in both fields. The inorganic nitrogen losses were very high in low lying areas of uniform fertilization as compared to VR fertilization.

This might be due to higher fertilizer rates in uniform treatment as compared to VR treatment. The higher amount of soil organic matter, clay content, and soil inorganic nitrogen could be the other reasons for higher NH_4^+-N and NO_3^--N in leachates from the low lying areas of the field. Uniform fertilization in Z3 of uniform treatment increased soil inorganic nitrogen, however, it also results in three times higher quantities of NO_3^--N and NH_4^+-N in leachates as compared to VR treatment for both fields. The NO_3^--N and NH_4^+-N losses in leachates were very low in control treatment as compared to uniform and VR treatment. The VR fertilization on the basis of slope variation resulted in lower quantities of inorganic nitrogen in subsurface water samples.

The results suggested that higher quantities of soil nutrients increased the vegetative components of wild blueberry plant. Literature suggested that wild blueberry has a narrow range for fertilizer application. Higher nutrient level could result in more vegetative growth, as demonstrated in current study. Leaf nitrogen concentrations were more in the low lying areas as compared to steep slope areas. Leaf nitrogen in low lying areas of uniform fertilization exceeded the proposed standard ranges for wild blueberry leaves, while leaf nutrient were within the proposed ranges in VR treatment for all slope zones. The plant parameters such as plant density, number of branches per stem, and number of buds per stems showed non-significant differences for VR and uniform treatment, while plant height was more in low lying area of uniform treatment as compared to VR treatment. The berry yield showed non-significant differences for VR and uniform treatment, although mean yield was higher in VR treatment as compared to uniform treatment. The variety of factors other than soil properties have not been addressed, which are partially contributing to yield variability. Disease and insect damage are obvious examples. Weeds competing with wild blueberry, pollination with bees, winter kill, and seasonal variability can also have a negative impact on fruit yield. Based on these results, it can be concluded that VR fertilization on the basis of slope variation reduced the cost of production, increased the crop productivity, and also improved the water quality. Further research should be undertaken to increase producers' confidence in VR fertilization. In order for society at large to benefit from the fertilization that based on nutrient requirement of the soil rather than uniform fertilization, these VR technologies must first be of benefit to the farmers who produce our food. Government should be encouraged to place emphasis on the VR fertilization in order to improve the crop productivity and water quality.

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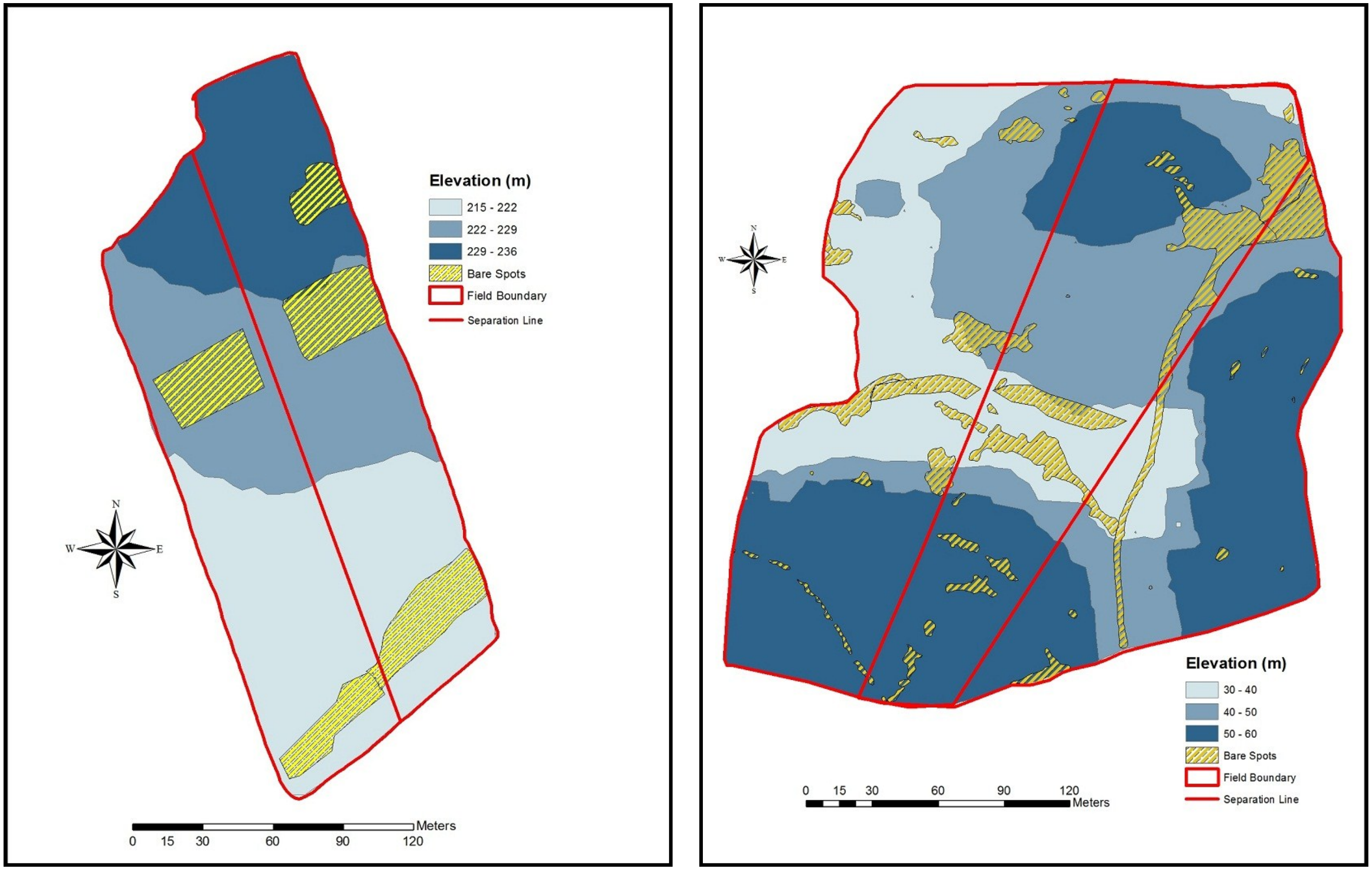
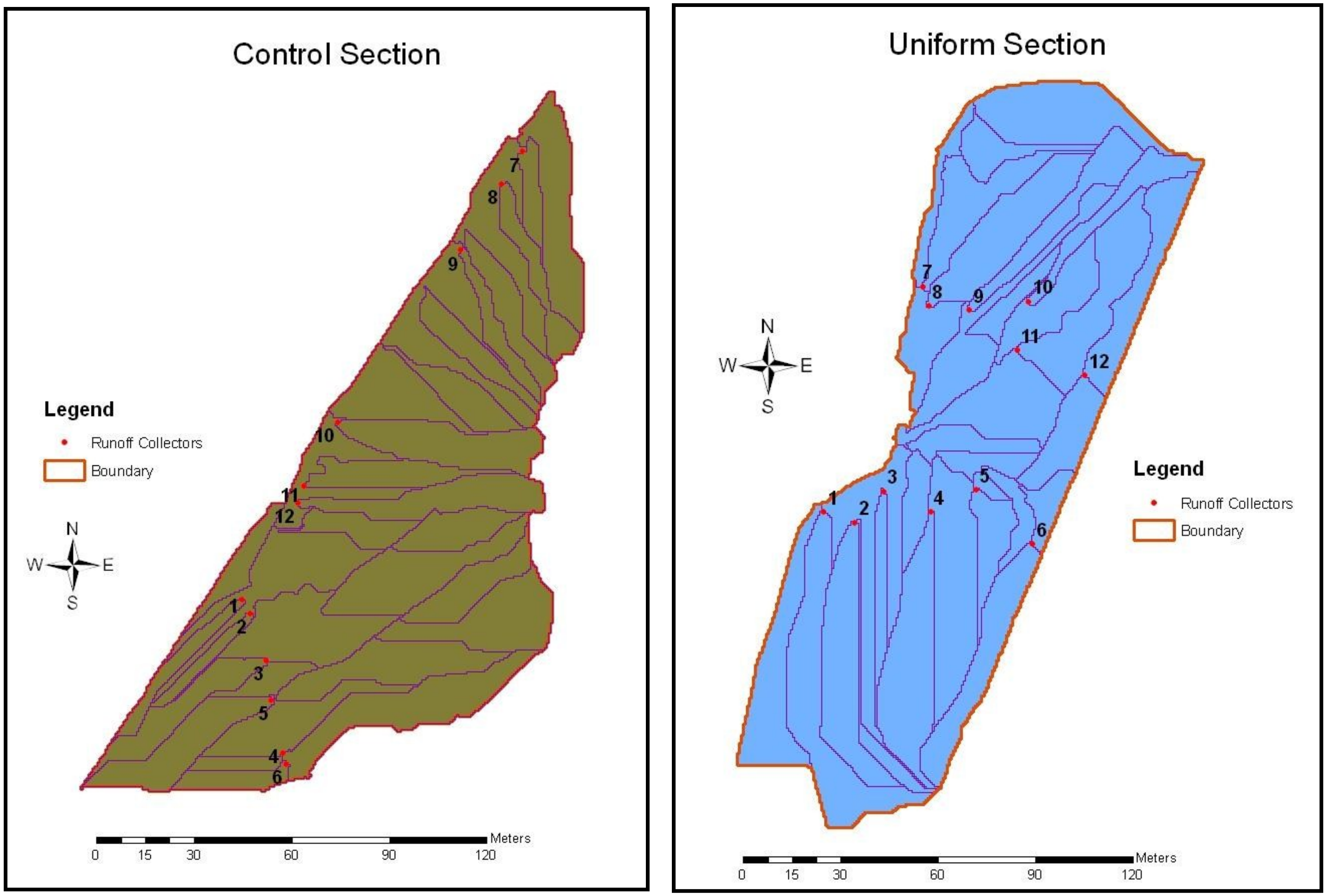
APPENDIX ‘A’



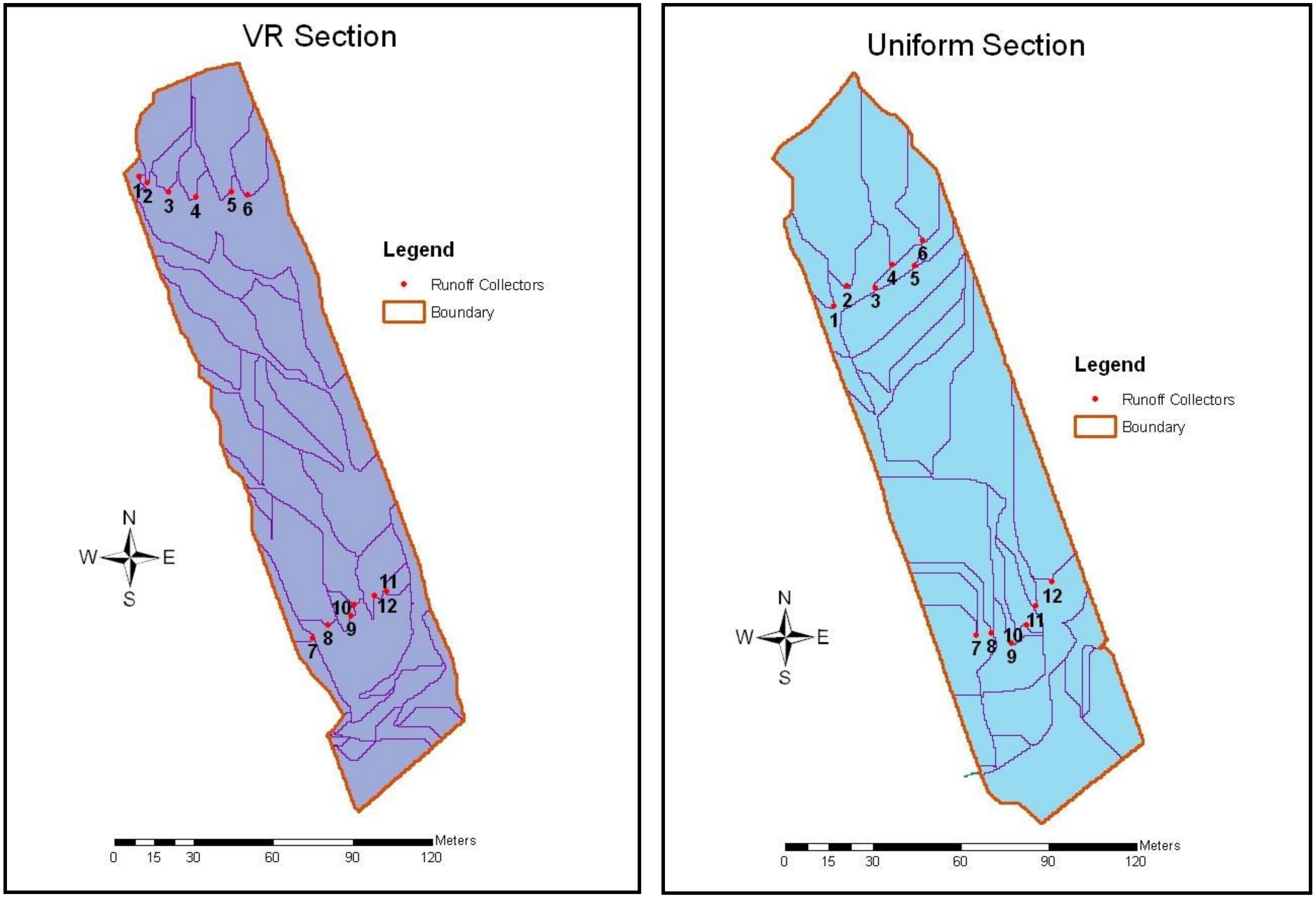
(a) (b)

Figure A1. Elevation maps for (a) Kemptown Field (b) Cattle Market Field.



(b) (b)

Figure A2. Runoff collectors catchment areas delineation in the Cattle Market Field (a) Control section (b) Uniform section.



(a) (b)

Figure A3. Runoff collectors catchment areas delineation in the Kemptown Field (a) VR section (b) Uniform section.

Table A1. Weather Conditions during study period compared to average climatic conditions (1971-2009) for Central Nova Scotia

Month	Kemptown Field (2010)		Cattle Market Field (2011)		Average Climatic Conditions in Central Nova Scotia (1971-2009)	
	Precipitation (mm)	Temperature (^{0}C)	Precipitation (mm)	Temperature (^{0}C)	Precipitation (mm)	Temperature (^{0}C)
January	38.1	-4.8	61.5	-6.0	103.0	-6.9
February	18.2	-3.7	103.8	-7.7	61.0	-6.5
March	39.2	1.1	30.8	-1.6	89.0	-1.8
April	37.9	6.2	65.4	4.1	72.0	3.9
May	28.7	9.8	83.7	11.3	85.0	9.8
June	215	14.5	84.7	13.5	81.0	14.7
July	121.9	19.8	90.4	18.1	78.0	18.4
August	68.3	18.5	108.8	18.3	71.0	17.8
September	96.7	15.8	63.4	15.1	118.0	13.4
October	145.3	8.2	215.2	9.1	118.0	7.7
November	174.5	3.3	-	-	101.0	2.8
December	161.6	0.8	-	-	114.0	-3.5

(Source: Environment Canada http://www.climate.weatheroffice.gc.ca. Accessed: March 05, 2011).

Table A2. The volumetric moisture content after every rainfall and slope for each USDA-NRCS runoff plot in the Cattle Market Field.

Rainfall Date	**Rainfall (mm)**	**Plot Name**	**Slope (%)**	**VMC (%)**
6/15/2011	29.1	CTL	8.7	29
		CTM	20.9	27.6
		CTO	29.7	26.3
		CTS	26.2	28.7
		UNL	7.9	29.3
		UNM	22.7	27.8
		UNO	31.4	26.1
		UNS	27.1	28.9
		VRL	8.7	28.3
		VRM	22.7	27.2
		VRO	31.4	26.5
		VRS	26.2	28.6
7/12/2011	30.5	CTL	8.7	29.6
		CTM	20.9	27.9
		CTO	29.7	26.1
		CTS	26.2	28.5
		UNL	7.9	30.0
		UNM	22.7	28.5
		UNO	31.4	28.0
		UNS	27.1	28.5
		VRL	8.7	29.5
		VRM	22.7	28.5
		VRO	31.4	27.5
		VRS	26.2	28.5
7/30/2011	41.9	CTL	8.7	27
		CTM	20.9	26.1
		CTO	29.7	25.2
		CTS	26.2	26.3
		UNL	7.9	30.5
		UNM	22.7	29.5
		UNO	31.4	29.0
		UNS	27.1	30.0
		VRL	8.7	30.0
		VRM	22.7	29.0
		VRO	31.4	29.0
		VRS	26.2	29.5
8/2/2011	37.6	CTL	8.7	31
		CTM	20.9	28
		CTO	29.7	26
		CTS	26.2	28.5
		UNL	7.9	31.0
		UNM	22.7	30.0
		UNO	31.4	28.5
		UNS	27.1	29.0
		VRL	8.7	30.5
		VRM	22.7	30.5
		VRO	31.4	28.5
		VRS	26.2	29.5

Table A2. Continued……

Rainfall Date	Rainfall (mm)	Plot Name	Slope (%)	VMC (%)
8/10/2011	34.8	CTL	8.7	28.2
		CTM	20.9	26.8
		CTO	29.7	25.9
		CTS	26.2	27.7
		UNL	7.9	28.1
		UNM	22.7	26.3
		UNO	31.4	25.6
		UNS	27.1	27.3
		VRL	8.7	28.6
		VRM	22.7	27.2
		VRO	31.4	25.9
		VRS	26.2	27.9
9/15/2011	38.2	CTL	8.7	27.9
		CTM	20.9	26.1
		CTO	29.7	25.9
		CTS	26.2	27
		UNL	7.9	27.9
		UNM	22.7	26.1
		UNO	31.4	25.9
		UNS	27.1	27
		VRL	8.7	27.9
		VRM	22.7	26.1
		VRO	31.4	25.9
		VRS	26.2	27
10/02/2011	40	CTL	8.7	27
		CTM	20.9	25.8
		CTO	29.7	24
		CTS	26.2	26.7
		UNL	7.9	27
		UNM	22.7	25.8
		UNO	31.4	24
		UNS	27.1	26.7
		VRL	8.7	27
		VRM	22.7	25.8
		VRO	31.4	24
		VRS	26.2	26.7

Table A3. Runoff volumes for runoff collectors from July 12, 2011 rainfall event in the Cattle Market Field.

Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)
VR-1	0.088	2.07	UN-1	0.107	2.52	CT-1	0.014	0.32
VR-2	0.027	0.64	UN -2	0.081	1.90	CT-2	0.022	0.51
VR-3	0.038	0.89	UN -3	0.021	0.50	CT-3	0.044	1.04
VR-4	0.066	1.56	UN -4	0.093	2.20	CT-4	0.012	0.28
VR-5	0.058	1.36	UN -5	0.030	0.70	CT-5	0.058	1.36
VR-6	0.041	0.96	UN -6	0.065	1.53	CT-6	0.019	0.45
VR-7	0.117	2.22	UN -7	0.057	1.03	CT-7	0.018	0.33
VR-8	0.026	0.49	UN -8	0.080	1.44	CT-8	0.032	0.60
VR-9	0.037	0.71	UN -9	0.046	0.84	CT-9	0.022	0.42
VR-10	0.054	1.02	UN -10	0.036	0.66	CT-10	0.067	1.26
VR-11	0.019	0.35	UN -11	0.083	1.49	CT-11	0.037	0.70
VR-12	0.020	0.39	UN -12	0.059	1.07	CT-12	0.058	1.09

VR= Variable, UN= Uniform, CT= Control

Table A4. Runoff volumes for runoff collectors from July 30, 2011 rainfall event in the Cattle Market Field.

Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)
VR-1	0.088	3.26	UN-1	0.107	3.97	CT-1	0.014	0.51
VR-2	0.027	1.02	UN -2	0.081	3.00	CT-2	0.022	0.81
VR-3	0.038	1.40	UN -3	0.021	0.79	CT-3	0.044	1.64
VR-4	0.066	2.45	UN -4	0.093	3.46	CT-4	0.012	0.44
VR-5	0.058	2.15	UN -5	0.030	1.11	CT-5	0.058	2.15
VR-6	0.041	1.52	UN -6	0.065	2.40	CT-6	0.019	0.71
VR-7	0.117	2.93	UN -7	0.057	1.36	CT-7	0.018	0.44
VR-8	0.026	0.64	UN -8	0.080	1.90	CT-8	0.032	0.79
VR-9	0.037	0.94	UN -9	0.046	1.10	CT-9	0.022	0.56
VR-10	0.054	1.34	UN -10	0.036	0.87	CT-10	0.067	1.67
VR-11	0.019	0.47	UN -11	0.083	1.97	CT-11	0.037	0.92
VR-12	0.020	0.51	UN -12	0.059	1.42	CT-12	0.058	1.44

VR= Variable, UN= Uniform, CT= Control

Table A5. Runoff volumes for runoff collectors from August 2, 2011 rainfall event in the Cattle Market Field.

Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)
VR-1	0.088	4.29	UN-1	0.107	7.03	CT-1	0.014	0.91
VR-2	0.027	1.34	UN -2	0.081	5.31	CT-2	0.022	1.44
VR-3	0.038	1.85	UN -3	0.021	1.40	CT-3	0.044	2.91
VR-4	0.066	3.22	UN -4	0.093	6.13	CT-4	0.012	0.77
VR-5	0.058	2.83	UN -5	0.030	1.96	CT-5	0.058	3.81
VR-6	0.041	2.00	UN -6	0.065	4.26	CT-6	0.019	1.26
VR-7	0.117	4.24	UN -7	0.057	3.74	CT-7	0.018	1.19
VR-8	0.026	0.93	UN -8	0.080	5.23	CT-8	0.032	2.13
VR-9	0.037	1.35	UN -9	0.046	3.05	CT-9	0.022	1.51
VR-10	0.054	1.95	UN -10	0.036	2.39	CT-10	0.067	4.50
VR-11	0.019	0.67	UN -11	0.083	5.43	CT-11	0.037	2.48
VR-12	0.020	0.74	UN -12	0.059	3.90	CT-12	0.058	3.89

VR= Variable, UN= Uniform, CT= Control

Table A6. Runoff volumes for runoff collectors from August 10, 2011 rainfall event in the Cattle Market Field.

Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)
VR-1	0.088	2.83	UN-1	0.107	3.16	CT-1	0.014	0.41
VR-2	0.027	0.88	UN -2	0.081	2.38	CT-2	0.022	0.64
VR-3	0.038	1.22	UN -3	0.021	0.63	CT-3	0.044	1.31
VR-4	0.066	2.13	UN -4	0.093	2.75	CT-4	0.012	0.35
VR-5	0.058	1.87	UN -5	0.030	0.88	CT-5	0.058	1.71
VR-6	0.041	1.32	UN -6	0.065	1.91	CT-6	0.019	0.56
VR-7	0.117	4.09	UN -7	0.057	1.01	CT-7	0.018	0.33
VR-8	0.026	0.90	UN -8	0.080	1.42	CT-8	0.032	0.59
VR-9	0.037	1.31	UN -9	0.046	0.82	CT-9	0.022	0.42
VR-10	0.054	1.88	UN -10	0.036	0.65	CT-10	0.067	1.25
VR-11	0.019	0.65	UN -11	0.083	1.47	CT-11	0.037	0.69
VR-12	0.020	0.71	UN -12	0.059	1.06	CT-12	0.058	1.08

VR= Variable, UN= Uniform, CT= Control

Table A7. Runoff volumes for runoff collectors from September 15, 2011 rainfall event in the Cattle Market Field.

Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)
VR-1	0.088	3.36	UN-1	0.107	3.72	CT-1	0.014	0.48
VR-2	0.027	1.05	UN -2	0.081	2.81	CT-2	0.022	0.76
VR-3	0.038	1.45	UN -3	0.021	0.74	CT-3	0.044	1.54
VR-4	0.066	2.52	UN -4	0.093	3.24	CT-4	0.012	0.41
VR-5	0.058	2.22	UN -5	0.030	1.04	CT-5	0.058	2.01
VR-6	0.041	1.56	UN -6	0.065	2.25	CT-6	0.019	0.66
VR-7	0.117	2.96	UN -7	0.057	1.16	CT-7	0.018	0.38
VR-8	0.026	0.65	UN -8	0.080	1.63	CT-8	0.032	0.68
VR-9	0.037	0.94	UN -9	0.046	0.95	CT-9	0.022	0.48
VR-10	0.054	1.36	UN -10	0.036	0.74	CT-10	0.067	1.43
VR-11	0.019	0.47	UN -11	0.083	1.69	CT-11	0.037	0.79
VR-12	0.020	0.51	UN -12	0.059	1.21	CT-12	0.058	1.24

VR= Variable, UN= Uniform, CT= Control

Table A8. Runoff volumes for runoff collectors from October 2, 2011 rainfall event in the Cattle Market Field.

Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)
VR-1	0.088	10.45	UN-1	0.107	10.65	CT-1	0.014	1.38
VR-2	0.027	3.26	UN -2	0.081	8.05	CT-2	0.022	2.18
VR-3	0.038	4.50	UN -3	0.021	2.12	CT-3	0.044	4.41
VR-4	0.066	7.86	UN -4	0.093	9.29	CT-4	0.012	1.17
VR-5	0.058	6.89	UN -5	0.030	2.97	CT-5	0.058	5.78
VR-6	0.041	4.86	UN -6	0.065	6.45	CT-6	0.019	1.90
VR-7	0.117	10.70	UN -7	0.057	5.06	CT-7	0.018	1.45
VR-8	0.026	2.34	UN -8	0.080	7.07	CT-8	0.032	2.59
VR-9	0.037	3.41	UN -9	0.046	4.12	CT-9	0.022	1.84
VR-10	0.054	4.91	UN -10	0.036	3.23	CT-10	0.067	5.48
VR-11	0.019	1.70	UN -11	0.083	7.34	CT-11	0.037	3.02
VR-12	0.020	1.86	UN -12	0.059	5.28	CT-12	0.058	4.73

Table A9. Runoff volumes for runoff collectors from June 6, 2010 rainfall in the Kemptown Field.

Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)
VR-1	0.007	0.54	UN-1	0.020	0.68
VR-2	0.045	3.42	UN -2	0.132	4.36
VR-3	0.017	1.26	UN -3	0.118	3.91
VR-4	0.017	1.26	UN -4	0.067	2.20
VR-5	0.077	5.83	UN -5	0.013	0.42
VR-6	0.030	2.24	UN -6	0.030	1.00
VR-7	0.016	0.99	UN -7	0.023	0.86
VR-8	0.090	5.76	UN -8	0.105	3.86
VR-9	0.008	0.54	UN -9	0.020	0.73
VR-10	0.121	7.76	UN -10	0.020	0.72
VR-11	0.861	55.22	UN -11	0.695	25.67
VR-12	0.007	0.46	UN -12	0.072	2.65

VR= Variable, UN= Uniform

Table A10. Runoff volumes for runoff collectors from July 14, 2010 rainfall in the Kemptown Field.

Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)
VR-1	0.007	1.04	UN-1	0.020	0.96
VR-2	0.045	6.58	UN -2	0.132	6.19
VR-3	0.017	2.43	UN -3	0.118	5.55
VR-4	0.017	2.44	UN -4	0.067	3.13
VR-5	0.077	11.24	UN -5	0.013	0.59
VR-6	0.030	4.31	UN -6	0.030	1.42
VR-7	0.016	2.10	UN -7	0.023	1.20
VR-8	0.090	12.17	UN -8	0.105	5.42
VR-9	0.008	1.15	UN -9	0.020	1.03
VR-10	0.121	16.39	UN -10	0.020	1.02
VR-11	0.861	116.72	UN -11	0.695	36.05
VR-12	0.007	0.97	UN -12	0.072	3.72

VR= Variable, UN= Uniform

Table A11. Runoff volumes for runoff collectors from August 5, 2010 rainfall in the Kemptown Field.

Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)
VR-1	0.007	0.08	UN-1	0.020	0.23
VR-2	0.045	0.54	UN -2	0.132	1.49
VR-3	0.017	0.20	UN -3	0.118	1.34
VR-4	0.017	0.20	UN -4	0.067	0.76
VR-5	0.077	0.92	UN -5	0.013	0.14
VR-6	0.030	0.35	UN -6	0.030	0.34
VR-7	0.016	0.17	UN -7	0.023	0.42
VR-8	0.090	0.96	UN -8	0.105	1.90
VR-9	0.008	0.09	UN -9	0.020	0.36
VR-10	0.121	1.29	UN -10	0.020	0.35
VR-11	0.861	9.21	UN -11	0.695	12.60
VR-12	0.007	0.08	UN -12	0.072	1.30

VR= Variable, UN= Uniform

Table A12. Runoff volumes for runoff collectors from September 17, 2010 rainfall in the Kemptown Field.

Runoff Collector	Area (ha)	Runoff (m^3)	Runoff Collector	Area (ha)	Runoff (m^3)
VR-1	0.007	0.42	UN-1	0.020	1.01
VR-2	0.045	2.68	UN -2	0.132	6.50
VR-3	0.017	0.99	UN -3	0.118	5.83
VR-4	0.017	0.99	UN -4	0.067	3.29
VR-5	0.077	4.57	UN -5	0.013	0.62
VR-6	0.030	1.75	UN -6	0.030	1.49
VR-7	0.016	0.76	UN -7	0.023	1.53
VR-8	0.090	4.38	UN -8	0.105	6.92
VR-9	0.008	0.41	UN -9	0.020	1.31
VR-10	0.121	5.90	UN -10	0.020	1.30
VR-11	0.861	41.98	UN -11	0.695	46.02
VR-12	0.007	0.35	UN -12	0.072	4.74

VR= Variable, UN= Uniform

Appendix ‘B’

Table B1. Comparisons of soil properties between different slope zones for the Kemptown Field.

Soil properties	VR			Uniform		
	Slope Zones			Slope Zones		
	Zone-1	Zone-2	Zone-3	Zone-1	Zone-2	Zone-3
	Soil Properties					
Sand (%)	57.04^{a}	55.93^{a}	48.52^{b}	57.54^{a}	55.35^{a}	47.77^{b}
Clay (%)	9.18^{a}	9.43^{a}	11.85^{b}	9.01^{a}	9.25^{a}	12.28^{b}
Silt (%)	33.77^{a}	34.63^{a}	39.62^{a}	33.45^{a}	35.40^{a}	39.95^{a}
SOM (%)	7.30^{a}	8.10^{a}	9.42^{b}	7.35^{a}	8.54^{b}	9.71^{c}
EC (BF) ($\mu S\ cm^{-1}$)	49.08^{a}	53.77^{b}	56.93^{b}	49.21^{a}	52.70^{ab}	57.20^{b}
EC (AF) ($\mu S\ cm^{-1}$)	60.20^{a}	67.27^{a}	71.38^{a}	59.67^{a}	67.44^{ab}	75.90^{b}
Soil pH (BF)	5.01^{a}	5.05^{a}	5.14^{a}	5.08^{a}	5.12^{a}	5.16^{a}
Soil pH (AF)	4.88^{a}	4.89^{a}	4.96^{a}	4.90^{a}	4.91^{a}	4.96^{a}
	Soil Nutrients (Before Fertilization)					
NH_4^+-N (mg kg^{-1})	3.79^{a}	3.92^{a}	5.41^{b}	3.78^{a}	3.95^{a}	5.43^{b}
NO_3^--N (mg kg^{-1})	2.89^{a}	3.19^{a}	4.27^{b}	2.91^{a}	3.22^{ab}	4.22^{b}
	Soil Nutrients (After Fertilization)					
NH_4^+-N (mg kg^{-1})	5.11^{a}	5.28^{a}	7.74^{b}	5.15^{a}	6.03^{b}	9.27^{c}
NO_3^--N (mg kg^{-1})	4.22^{a}	4.32^{a}	5.97^{b}	4.32^{a}	5.09^{a}	7.45^{b}

Means followed by different letters are significantly different at a significance level of 0.05.

BF= Before Fertilization

AF= After Fertilization

Table B2. Comparisons of soil properties between different slope zones for the Cattle Market Field.

Soil properties	VR			Uniform			Control		
	Slope Zones			Slope Zones			Slope Zones		
	Zone-1	Zone-2	Zone-3	Zone-1	Zone-2	Zone-3	Zone-1	Zone-2	Zone-3
Soil Properties									
Sand (%)	61.83^{a}	58.05^{a}	51.12^{b}	60.18^{a}	57.31^{a}	51.34^{b}	61.81^{a}	58.30^{a}	50.35^{b}
Clay (%)	7.38^{a}	8.41^{a}	12.87^{b}	7.98^{a}	8.16^{a}	12.36^{b}	7.11^{a}	8.56^{a}	13.00^{b}
Silt (%)	30.79^{a}	33.54^{a}	36.01^{a}	31.84^{a}	34.53^{a}	36.30^{a}	31.09^{a}	33.14^{a}	36.65^{a}
SOM (%)	7.89^{a}	8.11^{b}	9.51^{b}	7.70^{a}	8.15^{b}	9.63^{b}	7.92^{a}	8.02^{a}	9.90^{b}
EC (BF) (µS cm^{-1})	51.97^{a}	59.10^{b}	63.34^{b}	51.20^{a}	60.58^{b}	63.79^{b}	50.36^{a}	59.95^{b}	62.89^{b}
EC (AF) (µS cm^{-1})	65.10^{a}	68.50^{a}	72.43^{a}	66.24^{a}	71.70^{ab}	79.14^{b}	49.99^{a}	51.93^{a}	55.01^{a}
Soil pH (BF)	4.72^{a}	4.77^{a}	4.85^{a}	4.69^{a}	4.74^{a}	4.82^{a}	4.63^{a}	4.73^{a}	4.76^{a}
Soil pH (AF)	4.50^{a}	4.56^{a}	4.64^{a}	4.52^{a}	4.54^{a}	4.66^{a}	4.66^{a}	4.78^{a}	4.86^{a}
Soil Nutrients (Before Fertilization)									
NH_4^+-N (mg kg^{-1})	3.47^{a}	4.11^{a}	5.43^{b}	3.45^{a}	4.10^{a}	5.40^{b}	3.43^{a}	4.13^{b}	5.45^{b}
NO_3^--N (mg kg^{-1})	2.43^{a}	2.84^{a}	3.71^{b}	2.48^{a}	2.87^{ab}	3.75^{b}	2.46^{a}	2.89^{a}	3.76^{b}
Soil Nutrients (After Fertilization)									
NH_4^+-N (mg kg^{-1})	5.05^{a}	5.17^{a}	7.50^{b}	5.09^{a}	6.05^{b}	8.22^{c}	2.79^{a}	3.17^{a}	4.67^{b}
NO_3^--N (mg kg^{-1})	3.79^{a}	3.92^{a}	5.02^{b}	3.76^{a}	4.03^{a}	6.26^{b}	2.14^{a}	2.31^{a}	3.36^{b}

Means followed by different letters are significantly different at a significance level of 0.05.
BF= Before Fertilization
AF= After Fertilization

Table B3. Total phosphorus losses in the surface runoff from the Cattle Market Field for USDA-NRCS runoff plots in 2011.

Slope Zone	USDA Plot	June 15 (g ha^{-1})	July 12 (g ha^{-1})	July 30 (g ha^{-1})	August 02 (g ha^{-1})	August 10 (g ha^{-1})	September 15 (g ha^{-1})	October 02 (g ha^{-1})	Cumulative (g ha^{-1})
Zone 1	VRS	218.2	205.3	160.7	125.2	87.7	28.7	36.3	862.1
	UNS	237.3	216.4	171.1	139.9	91.6	32.9	39.4	928.6
	CTS	8.4	7.1	6.8	5.6	4.5	3.6	3.5	39.5
Zone 2	VRM	173.3	150.6	126.5	103.8	69.3	18.7	12.9	655.1
	UNM	240.1	220.3	168.6	137.1	89.5	28.8	35.6	920
	CTM	9.5	7.1	6.2	5.9	4.9	4.2	3.7	41.5
Zone 3	VRL	145.7	136.1	113.9	82.4	42.1	11.1	7.6	538.9
	UNL	249.1	216.4	182.1	129.6	93.1	35.1	33.6	939
	CTL	9.7	8.5	6.5	6.2	5.6	4.5	3.8	44.8
Combine	VRO	239.1	213.7	173.4	131.0	99.1	39.8	32.4	928.5
	UNO	405.8	352.1	258.8	195.1	148.6	85.2	64.1	1509.7
	CTO	10.7	8.9	6.9	6.1	5.9	4.6	4.2	47.3

RM ANOVA

Effect	DF	F-value	P-value
Fertilization Method (F)	2	40.97	0.0003
Sampling Date	6	145.70	<0.0001
Sampling Date × Fertilization Method (F)	12	36.63	<0.0001

Significant at $P < 0.05$

Table B4. Dissolved reactive phosphorus losses in the surface runoff from the Cattle Market Field for USDA-NRCS runoff plots in 2011.

Slope Zone	USDA Plot	June 15 (g ha^{-1})	July 12 (g ha^{-1})	July 30 (g ha^{-1})	August 02 (g ha^{-1})	August 10 (g ha^{-1})	September 15 (g ha^{-1})	October 02 (g ha^{-1})	Cumulative (g ha^{-1})
Zone 1	VRS	142.3	110.6	83.4	54.6	36.5	10.8	11.3	449.5
	UNS	157.9	126.4	93.3	60.8	43.3	14.6	10.9	507.2
	CTS	4.1	3.8	2.9	2.6	2.5	1.3	2.5	19.7
Zone 2	VRM	102.7	89.3	65.3	39.5	24.9	7.6	5.9	335.2
	UNM	151.9	130.2	89.4	61.2	37.5	12.1	12.4	494.7
	CTM	4.8	3.7	3.6	2.7	2.6	2.5	2.9	22.8
Zone 3	VRL	95.2	80.3	43.4	35.9	18.6	5.1	3.2	286.1
	UNL	159.6	115.4	96.2	57.8	42.5	15.3	13.4	500.2
	CTL	4.3	3.5	3.4	3.1	2.3	2.1	2.6	21.3
Combine	VRO	140.8	112.3	81.6	55.6	35.6	16.4	12.3	454.6
	UNO	295.3	213.8	130.2	91.3	60.5	30.8	21.6	843.5
	CTO	4.8	3.8	3.4	2.8	3.1	2.6	3.5	24

RM ANOVA

Effect	DF	F-value	P-value
Fertilization Method (F)	2	35.25	0.0005
Sampling Date	6	75.96	<0.0001
Sampling Date × Fertilization Method (F)	12	20.80	<0.0001

Significant at $P < 0.05$

Table B5. Particulate phosphorus losses in the surface runoff from the Cattle Market Field for USDA runoff plots in 2011.

Slope Zone	USDA Plot	June 15 (g ha^{-1})	July 12 (g ha^{-1})	July 30 (g ha^{-1})	August 02 (g ha^{-1})	August 10 (g ha^{-1})	September 15 (g ha^{-1})	October 02 (g ha^{-1})	Cumulative (g ha^{-1})
Zone 1	VRS	75.9	94.7	77.3	70.6	51.2	17.9	25	412.6
	UNS	79.4	90.0	77.8	79.1	48.3	18.3	28.5	421.4
	CTS	4.3	3.3	3.9	3.0	2.0	2.3	1.0	19.8
Zone 2	VRM	70.6	61.3	61.2	64.3	44.4	11.1	7.0	319.9
	UNM	88.2	90.1	79.2	75.9	52.0	16.7	23.2	425.3
	CTM	4.7	3.4	2.6	3.2	2.3	1.7	0.8	18.7
Zone 3	VRL	50.5	55.8	70.5	46.5	23.5	6.0	4.4	252.8
	UNL	89.5	101.0	85.9	71.8	50.6	19.8	20.2	438.8
	CTL	5.4	5.0	3.1	3.1	3.3	2.4	1.2	23.5
Combine	VRO	98.3	101.4	91.8	75.4	63.5	23.4	20.1	473.9
	UNO	110.5	138.3	128.6	103.8	88.1	54.4	42.5	666.2
	CTO	5.9	5.1	3.5	3.3	2.8	2.0	0.7	23.3

RM ANOVA

Effect	DF	F-value	P-value
Fertilization Method (F)	2	46.40	0.0002
Sampling Date	6	146.63	<0.0001
Sampling Date × Fertilization Method (F)	12	33.15	<0.0001

Significant at P < 0.05

Table B6. Inorganic nitrogen losses in the surface runoff for the USDA Runoff plots from the Cattle Market Field in 2011.

Slope Zone	USDA Plot	June 15 (kg ha^{-1})	July 12 (kg ha^{-1})	July 30 (kg ha^{-1})	August 02 (kg ha^{-1})	August 10 (kg ha^{-1})	September 15 (kg ha^{-1})	October 02 (kg ha^{-1})	Cumulative (kg ha^{-1})
Zone 1	VRS	0.61	0.48	0.41	0.30	0.17	0.12	0.07	2.16
	UNS	0.66	0.55	0.43	0.31	0.16	0.14	0.08	2.33
	CTS	0.07	0.05	0.04	0.05	0.04	0.04	0.02	0.31
Zone 2	VRM	0.48	0.41	0.32	0.27	0.13	0.09	0.05	1.75
	UNM	0.69	0.53	0.46	0.31	0.18	0.15	0.09	2.41
	CTM	0.08	0.05	0.05	0.04	0.04	0.03	0.03	0.32
Zone 3	VRL	0.37	0.33	0.26	0.21	0.09	0.06	0.03	1.35
	UNL	0.73	0.56	0.49	0.32	0.19	0.16	0.10	2.55
	CTL	0.09	0.06	0.05	0.04	0.05	0.04	0.03	0.36
Combine	VRO	0.61	0.51	0.41	0.29	0.16	0.11	0.08	2.17
	UNO	1.02	0.87	0.77	0.58	0.34	0.26	0.18	4.02
	CTO	0.08	0.07	0.09	0.05	0.05	0.04	0.03	0.41

RM ANOVA

Effect	DF	F-value	P-value
Fertilization Method (F)	2	46.40	0.0002
Sampling Date	6	146.63	<0.0001
Sampling Date × Fertilization Method (F)	12	33.15	<0.0001

Significant at $P < 0.05$