EVALUATION OF A MODIFIED VARIABLE RATE GRANULAR FERTILIZER SPREADER FOR SPOT-SPECIFIC FERTILIZATION IN WILD BLUEBERRY FIELDS

by

Hassan Shafqat Chattha

Submitted in partial fulfilment of the requirements
for the degree of Master of Science

at

Dalhousie University
Halifax, Nova Scotia
October 2013

Table of Contents

List of Tables

List of Figures

ABSTRACT

The variable rate fertilizer spreader was modified to control each pair of nozzles for spot-application of fertilizer only in plant areas of wild blueberry fields. The experiments were conducted to evaluate performance accuracy of modified variable rate granular (MVRG) fertilizer spreader. The results suggested that the MVRG fertilizer spreader performed efficiently in detecting bare spots/weed patches and clay filler application only in green grass/plant areas. Two wild blueberry fields were selected to evaluate the impact of MVRG spreader on nutrient leaching through small bare spots/weed patches. Management zones were delineated on the basis of slope variability. The MVRG spreader significantly reduced the nutrient loading in subsurface water samples collected from the bare spots/weed patches. Based on the results obtained, it can be concluded that the fertilization in wild blueberry fields using MVRG fertilizer spreader can result in the protection of subsurface water quality, thus protecting the environment.

List of Abbreviations and Symbols Used

ANOVA – Analysis of Variance
ATV – All-terrain vehicle
BEEC – Bio-environmental engineering center
DAP – Diammonium phosphate
DGPS – Differential global positioning system
EC – Electrical conductivity
g – Gram
GIS – Geographical information system
GPS – Global positioning system
K – Potassium
KCL – Potassium chloride
Km hr^{-1} – Kilometer per hour
kPa – Kilo Pascal
L – Liter
LS – Least significant
LED – Light emitting diode
LSD - Least significant difference
mg L^{-1} – Milligram per liter
mL - Milliliters
MMC – Multiple means comparison
ms – Millisecond
MVRG – Modified variable rate granular fertilizer spreader
N – Nitrogen
NH_4^+ -N – Ammonium nitrogen
NH_4^+ – Ammonium
NO_3^--N – Nitrate nitrogen
NO_3^- – Nitrate
P – Phosphorus
PLC – Programmable logic controller
PPC – Pocket personal computer
RGB – Red green blue
RM ANOVA – Repeated measure analysis of variance
RTK – Real time kinematics
s – Second
SMMS – Slope measuring and mapping system
SOM – Soil organic matter
UN – Uniform
VR – Variable rate
VRC – Variable rate controller
VRF – Variable rate fertilization
VRG – Variable rate granular
VRPM - Variable rate with prescription map
VRPRD - Variable rate with prescription map and real-time detection
VRT – Variable rate technology

WAAS – Wide area augmentation system
Z1 – Zone-1
Z2 – Zone-2
Z3 – Zone-3

ACKNOWLEDGEMENTS

First of all, I am extremely thankful to Almighty ALLAH for His blessing on me to complete my M.Sc. degree successfully and for any good that comes into my life. I want to extend a special thanks to Dr. Qamar Zaman my supervisor, for his intellectual guidance, continuous support, and endless efforts to complete this project. I would like to express my heartiest gratitude to my supervisory committee members Dr. Arnold Schumann and Dr. Gordon Brewster for their support, guidance, and encouragement which made me strong and allowed me to reach my goals. Many thanks to push me, support me and guide me into this adventure!

I am thankful to Dr. Qamar Zaman and Mrs. Afshan Qamar for treating me with immense care and for helping me to acclimatize in Canada from the very first day of my arrival. I want to thank Ms. Druice Janes, Dr. David Langille, Mr. Cory Roberts, Mr. Chris Nelson and Ms. Margie Tate for providing the laboratory facilities. I am thankful to Dr. Ilhami Yildiz and Dr. Kenneth Corscadden for every possible help in the Engineering Department at Faculty of Agriculture, Dalhousie Univeristy. I would like to express my deepest gratitude to Dr. Young Ki Chang, as he was very cooperative and helping in every matter regarding my project. I would like to express my appreciation for Mr. Scott Read who always helped me in setting out my experiments and guiding me with the stuff related to fertilizer spreader, my very good friend and my teacher Mr. Aitazaz Farooque for guidance throughout this project. I owe special thanks to precision agriculture research team, Dr. Qamar Zaman, Dr. Young Ki Chang, Dr. Mumtaz Cheema, Travis Esau, Aitazaz Farooque, Scott Read, Fahad Khan, Shoaib Saleem and Asif Abbas, for helping in lab and field data collection. I would like to acknowledge the help of summer students, Riley Giffen and Brittany MacLean during the field work. I will never forget the unconditional help of two

wonderful ladies; Marie Law in Cumming hall and Mandi Wilson in Engineering department of Agricultural Campus.

I am very grateful to Oxford Frozen Foods, Nova Scotia Department of Agriculture Technology Development Program, and Wild Blueberry Producer Association of Nova Scotia for the financial assistance to complete this project. Special thanks to my course instructors, Dr. Tess Astatkie, Dr. Gordon Price, Dr. C. Walls, Dr. Q. Zaman, and Dr. Y. Chang for their excellent teaching skills.

I would like to express my appreciation for my friends back home. I would like to start from my school friends Omer Pervaiz, Waqas Latif, Moeen Ahmad and Zohaib Ahmad who always provided me courage and moral support. My college friends Bilal Niazi and Kashif Azeem stood always by me. I would like to thank Ahmad Gill, Saad Javed Cheema, Hammad Javed, Tajammal Hussain, Hafiz Mubashir, Sheraz Javed, Daniyal Mumtaz, Adeel Hameed and all others, for their continuous moral support and encouragement. Here I would like to mention the name of my cousin cum brother, Adil Majeed, who is one of my inspirations.

I like to conclude my acknowledgement with appreciation for my parents, Mr. Shafqat Javaid Chattha and Mrs. Sarwat Jahan, without your support, I would not have made it! Thank you! I also want to thank my grandmother, Jameela Ghafoor for her prayers and love and my aunt Shazia Rajab for always having an open ear for my problems. A special Thanks to my brother-in-law Mr. Khushhal Randhawa and my sister Mrs. Sadia Khushhal for their love and support throughout all my endeavors. Finally, I express my profound love and respect to my brother Mr. Usman Shafqat and my sister-in-law Mrs. Mehwish Usman, and my sweet younger brother Ali Shafqat, who always encouraged and prayed for me.

CHAPTER 1

INTRODUCTION

The wild blueberry (*Vaccinium angustifolium* Ait.), a vital horticultural crop in eastern Canada and the Maine state of USA, is a stress-tolerant calcifuge shrub normally situated in naturally acidic soils with low mineral nutrients (Grime, 1979; Chapin, 1980). The wild blueberry is compelled from its natural perennial fruit production into a biennial production system by regular pruning (mowing or burning) that eradicates most of the above-ground plant material (Hall et al., 1979). First year is for vegetative growth and fruit bud formation, followed by fruit development and harvesting in the second year (Eaton, 1988). Wild blueberry production depends on the management of native indigenous stands. Fields are promoted in areas where pre-existing wild blueberry coverage is sufficient to justify commercial field development. Fields worthy for commercial development are typically abandoned farmland or newly deforested areas and have gentle to severe topography (Zaman et al., 2010a). Field development is dependent upon the eradication of competing vegetation and may also include the removal of trees, stumps, and rocks. Newly developed fields may have significant proportion of bare spots (varies from 30% to 50% of the total field area) (Zaman et al., 2010b).

Currently, crop management practices are implemented without considering substantial variation in soil properties, topographic features and bare spots in wild blueberry fields. Wild blueberries are low input systems with a narrow optimal range of plant nutrients (Percival and Sanderson, 2004). Detrimental effects of excess nitrogen (N) occur when too much N is applied (i.e., lowers floral bud numbers and harvestable yields) (Percival and Sanderson, 2004). Fertilization of both bare spots and weed patches can deteriorate water quality, promote weed growth and reduce profit. Under-fertilization restricts yield and reduces berry quality (Zaman et al., 2010b). Site-specific fertilization can reduce fertilizer usage, improve crop production, and protect environment (Zaman et al., 2006; Saleem et al., 2011).

Site-specific fertilization, using differential global positioning system (DGPS) guided prescription maps, have been reported for several cropping systems (Miller et al., 2004; Derby et al., 2007). Saleem et al. (2011) applied fertilizer on a site-specific basis with a variable rate granular (VRG) fertilizer spreader using prescription map based on variation in slope within wild blueberry fields. They demonstrated that variable rate (VR) fertilization in wild blueberry field improved crop productivity and reduced subsurface water contamination.

Existing commercial VRG fertilizer spreaders change fertilizer rates in different management zones using DGPS-guided prescription maps without considering uneven distributed bare spots and weed patches in wild blueberry fields. Unnecessary Fertilization in both, bare spots and weed patches, can be avoided using VRG fertilizer spreader with sensing and control system for spot-application of fertilizer. Zaman et al. (2011) and Esau (2012) developed a prototype VR sprayer for spot-specific application of agrochemicals in wild blueberry cropping systems. They reduced the amount of herbicide (60% to 80%) and fungicide (20% to 30%) in wild blueberry fields. Similar technology can be used to develop/modify VRG fertilizer spreader for spot-application of fertilizer in plant areas within wild blueberry fields.

The precision agriculture team at the Faculty of Agriculture, Dalhousie University has modified the existing VRG fertilizer spreader (Valmar Airflo Inc. MB, Canada). This modified VRG fertilizer spreader can be used simultaneously with prescription mapping to change rates of fertilizer application in different management zones, and the automated sensing and control system is able to detect plants, weeds and bare spots in real-time. The detection information is then provided to VR controller to dispense fertilizer in a specific section of the boom where only plants were detected. Avoiding needless application of fertilizer, using modified VRG (MVRG) fertilizer spreader, in bare spots/weed patches can reduce cost of production and protect the environment by reducing subsurface water contamination through nutrient leaching.

The hypothesis proposed in this study is that unnecessary application of fertilizer in bare spots/weed patches still occurs with VR fertilization guided only by prescription maps. Fertilization in bare spots/weed patches can increase fertilizer usage and can deteriorate subsurface water quality. If this is true, then modifications in existing VR spreader for real-time sensing, control and spot-specific application of fertilizer will be an important management strategy for wild blueberry industry.

1.1 Objectives

The objectives of this study are to:

a) Evaluate the performance accuracy of principal components of MVRG fertilizer spreader for spot-application at exact targets.
b) Evaluate the performance of MVRG fertilizer spreader for spot-application of fertilizer in commercial wild blueberry fields.
c) Examine the impact of VR fertilization on subsurface water quality in bare spot areas with uniform, variable rate using prescription map, and spot-application using automated sensing and control systems.

CHAPTER 2
LITERATURE REVIEW

2.1 Wild Blueberry Cropping System

The wild blueberry is native to northeastern North America. The wild blueberry has a unique production system as it is not planted but developed from native existing stands. Presence of wild blueberry before land development is the prime requirement. The wild blueberry is compelled from its natural perennial fruit production system into a biennial production system by regular pruning (mowing or burning) that eradicates most of the above-ground plant material (Hall et al., 1979). This practice accelerates new growth from dormant buds on the rhizomes and consequently increases yield (Hall, 1955). After pruning the first year is for vegetative growth and flower buds initiation for the crop (second) year from August to October, followed by winter quiescence (Hall et al., 1979). During the crop year, further development of flower buds occurs during spring, and flowering is completed in May and June. The pollination of flowers is carried out by insects, and development of ovary walls occur quickly after ovule fertilisation (Bell, 1950). Fruit remains dormant during June and July, and then enlarge and ripen until harvest, which normally occurs in August and early September.

Management and environmental factors also seem to have influence on fruit production of the wild blueberry. Management practices include pruning, weed control, insect and disease control, irrigation, and fertilizer applications (Hall et al., 1979). Whereas, natural variation within stands (Hepler and Yarborough, 1991), differences in soil conditions (Trevett, 1972), climatic factors such as low winter temperatures, severe frosts and droughts are uncontrollable environmental factors (Hall et al., 1979).

Wild blueberry systems have some characteristics which are more similar to forest systems than to tilled agricultural systems (Eaton, 1988). Research to increase production of wild blueberry through the use of nitrogen (N), phosphorus (P), potassium (K) fertilizers started as early as 1928 (Chandler and Mason, 1933). Application of fertilizers is usually after pruning in vegetative year. Results of studies conducted to examine the response of berry yield to different combination of fertilizers indicated that fertilizer containing N could increase yield, but if the weed growth is accelerated excessively, production would be decreased (Jensen, 1985; Yarborough and Bhowmik, 1989; Penney and McRae, 2000). Penney and McRae (2000) found that there was little yield gain from applied P and K. One of the important features associated with N is the internal transfer of N from one plant part to the other in autumn and early spring (Chapin, 1980). Eaton and Patriquin (1990) used labelled N fertilizer and showed that N fertilizer is taken up by blueberry plants rapidly, and that the labelled N is transferred from leaves to stems, roots and rhizomes prior to leaf fall in autumn. Some of this applied N was returned to newly emerged leaves during the following spring. About 1.5% of the labelled N applied in the spring of vegetative year was exported in berry after 16 months (Eaton and Patriquin, 1990). Boron (B), magnesium (Mg) and zinc (Zn) were also used in combination with NPK and results suggested that wild blueberry responded well as the increase in berry yield was observed (Eaton, 1988). The fertilizer experiments conducted subsequently without using an effective herbicide exhibited different results, i.e., best response was from N (Trevett, 1962), complete fertilizer application gave better results than N alone (Chandler and Mason, 1938), inconsistent response of wild blueberry yield to applied fertilizer (Eaton, 1950; Trevett, 1950), and reduction in berry yield when weed growth was accelerated (Chandler, 1943). The increased weed growth was the result of fertilizer uptake by grasses and other weeds which in turn restricted the wild blueberry growth (Yarborough and Ismail, 1985). The introduction of herbicides enabled the use of fertilizers and herbicides in wild blueberry fields to increase yield and to control competing weed (Yarborough et al., 1986). Fertilizers used for wild blueberry in the past contained only N, but recent fertilizers have also incorporated P in formulation such as 13-26-5, 14-18-10, or 18-46-0 (Eaton et al., 1997). Litten et al. (1997) revealed that the use of diammonium phosphate (DAP) increased the stem length, number of floral buds, and yield, from 4900 to 6235 kg ha^{-1}.

Recently developed wild blueberry fields can have a significant proportion of bare spots (varies from 30% to 50% of the total field area) (Zaman et al., 2010b). Traditionally, fertilizers are applied uniformly with inadequate attention being given to the significant bare spots and weed patches in blueberry fields. Excess usage of fertilizer in bare spots and weed patches, using conventional methods, may result in increased cost of fertilizer input and a serious threat to the subsurface water quality. The substantial variation in soil properties, plant characteristics, topographic features along with the presence of bare spots and weed patches emphasize the need for spot-applications of fertilizer in wild blueberry fields (Farooque et al., 2012).

2.2 Nutrient Leaching

Establishing the balance between the amount of N needed and optimum plant growth while minimizing the transportation of nitrate-nitrogen (NO_3^--N) to ground water and surface water systems remains a major challenge for researchers trying to understand and improve agricultural nutrient use efficiency (Dinnes et al., 2002). Subsurface water is vital natural resource that provides drinking water supplies for about half the world population (Kaown et al., 2007). This subsurface water can be polluted by nitrate leaching beyond the soil rooting profile. According to Saffigna and Phillips (2002), leaching is defined as the downward movement of nutrients beyond the rooting profile of soil with drainage water. The leached nutrients become unavailable for plants, and therefore, can be considered out of the soil-plant system (Saleem, 2012). The leached nutrients may accumulate at the depth in the soil or may pollute the groundwater, depending on the amount of water draining out of the rooting zone.

Lehmann and Schroth (2003) stated that leached nutrients contaminate the ground water in areas of intensive agriculture. The transport of N from agricultural lands to subsurface water through leaching is a serious environmental concern and a potential risk to human health (Gaynor and Findlay, 1995; Owens et al., 2000). The majority of agricultural systems have ammonium-N and nitrate-N as the major forms of inorganic nitrogen available to plants (Keeney and Walsh, 1972). Owens et al. (2000) stated that environmental and economic sustainability associated with agricultural practices is of prime importance, therefore, the reason of giving more attention to environmental impacts of agriculture is NO_3^--N leaching as it does not adsorb to soil particles and readily leaches down to subsurface water. Therefore, the cropping systems which require high doses of nitrogenous fertilizers are a major source of N contamination of subsurface water. The major portion of the N is leached in the form of NO_3^--N (Owens et al., 2000; Zhao et al., 2001). The agricultural production can be considered as the primary nonpoint source of NO_3^--N in the subsurface water, therefore, a better understanding regarding impacts of different management practices and cropping systems on NO_3^--N leaching is important for developing agricultural practices that reduce NO_3^--N leaching (Zhu and Fox, 2003).

Nitrate pollution of subsurface water is a current global problem (Weisenburger, 1993) because the presence of excess nitrates in drinking water is a serious threat to human health (Aparicio et al., 2008). The NO_3^--N concentration in drinking water should not be greater than 10 mg L^{-1} (Health and Welfare Canada, 1996). Elevated levels of NO_3^--N (> 10 mg L^{-1}) in subsurface water cause methemoglobinemia in infants and stomach cancer in adults (Addiscott, 1996; Canter, 1997).

The amount of NO_3^--N concentrations in the subsurface water depends on the management practices being adopted, the soil class and its leaching potential, the depth of subsurface water table, rainfall, land use, slope and drainage density (Nila Rekha et al., 2011). Different factors that determine the amount of leached NO_3^--N from the plant root zone to groundwater in different agro-ecosystems may include, the amount of NO_3^--N present in the soil above the plant requirement and drainage volume, fertilizer application rates, climatic conditions, frequent cultivation, short periods for plant growth, low nutrient use efficiency and quantities of crop residues, and application of animal manures in organic farming systems (Di and Cameron, 2002). Thorn (1986) reported that nitrate leaching is affected by the amount and the number of applications of nitrogen fertilizer. However, the relationship between soil texture and the amount of nitrate leached was not significant (Thorn, 1986). Whereas, Wolkowski et al. (1995) reported that nitrogen management in sandy soils is influenced by the nitrification process which occurs when nitrogen is added to warm and moist soil and the soil bacteria convert the ammonia to nitrate. Due to the negative charge on nitrate ion it is not held by ion exchange process and is leached readily in drainage waters. Nitrates leach more rapidly in sandy soils than in fine textured soils due to the difference in rates of water transmission (Wolkowski et al., 1995).

The results of many studies on site specific application of fertilizers have shown the reduction in the amounts of nutrient leaching beyond the root zone. For instance, Ersahin (2001) reported that the variable rate application of N fertilizers reduces the NO_3^--N leaching from soil. Zaman et al. (2006) reported significant reduction of NO_3^--N concentration in leachate water from 28.5 to 1.5 and 14.0 mg L^{-1} to 4.5 mg L^{-1} under small and large size citrus trees, respectively by using site specific variable rate fertilization. Zhou et al. (2006) found that approximately 16% of total ammonium fertilizer applied, leached in sandy loam soils which they studied. They also reported that the weeds, grasses and bare soil were the major contributor towards ammonium nitrogen (NH_4^+-N) leaching.

In future, the increasing demand for food to feed the increasing population will exert more pressure on the global environment. The agricultural production will need to be enhanced to feed the growing population, and the poorly managed use of N fertilizers may accelerate the NO_3^--N leaching problem (Di and Cameron, 2002). Improved management practices are needed to optimize economic returns to farmers and minimize environmental risks associated with the nitrogen use. The relationships between subsurface water quality and management practices will eventually help to develop criteria for long term sustainability of our production systems (Nila Rekha et al., 2011).

2.3 Variable Rate Fertilization

Agriculture has undergone a large number of mechanical and biological innovations during the last several decades. The farmer's land base was confined after the settlement of the west and as a result the farmer's community started to explore new ways to increase crop productivity with a limited supply of agricultural land (Friedrichsen, 2003). Moreover, the environmental and economic problems with existing crop management practices forced developed countries of the world to manage crop nutrients and fertilizers in a more precise manner. These concerns and issues are even more pressing in developing countries, where poverty is widespread (Smaling and Braun, 1996). Bramley and Wuabba (2002) stated that precision agriculture results in better management of agricultural production by considering the variation in productivity potential of agricultural land which changes over very short distances. Precision farming techniques enable farmers to improve crop production efficiency and reduce environmental impacts by adjusting rates of seed, water, fertilizer, and pesticide application in a site-specific fashion 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). In the absence of variability, the concept of precision farming has very little meaning (Mulla and Schepers, 1997). It is correctly stated by Bell et al. (1995) that efforts towards management through precision farming must consider that the factors affecting environmental sensitivity and crop yields vary in both space and time. Precision agriculture technologies have gained popularity around the globe. The farmers with larger land holdings are more attracted by these technologies as compared to the farmers with smaller land holdings, and they rely on research institutions and extension agencies for information on adaptation of the technology (Winstead et al., 2009). Results of cotton precision farming from a survey in 2005 from 11 southern states of the USA revealed that 48% of farmers have taken benefit of precision agriculture technologies in one form or another (Roberts et al., 2006). Producers need appreciative information regarding economic returns of the adaptation costs associated with precision agriculture equipment (Mooney et al., 2009).

One of the many important applications of precision agriculture is site-specific nutrient management using variable rate technology (VRT) (Attanandana and Yost, 2003). Accurate estimation of field characteristics is very important for the successful implementation of VRT. Increased sampling allows the input application to be better tailored to the individual site characteristics. Variable rate fertilization (VRF) is a vital part of VRT for varying the fertilizer inputs based on the nutrition requirements or fertility in the soil (Lan et al., 2008). The VRF can reduce the amount of excess nutrients applied in the field (Wittry and Mallarino, 2004; Schumann et al., 2006). The VRT offers an opportunity to improve production efficiency by allowing input applications in amounts and locations where they are needed. The basic idea of VRT application is to allocate inputs more efficiently by exploiting spatial variations in soil type, topographic features, fertility levels, and other field characteristics (Miller et al., 2004). The VRT has the potential to lower the cost of production and improve farm profitability by avoiding unnecessary input use (Yang, 2001). Variable rate technology includes GPS and geographic information system (GIS) map-based, "on-the-go" sensor-based, or a combination of map and sensors (Miller et al., 2004; Schuman et al., 2006).

Robert (2002) stated that the cause of precise application is strengthened due to the development of VRT for applications of crop inputs such as fertilizers (liquid and granular), seeds, pesticides, and irrigation water in a precise manner. These newly developed precision agriculture technologies have provided many opportunities for researchers to evaluate the economics and environmental advantages of VRT (Saleem, 2012). Schumann et al. (2006) investigated the performance characteristics of a variable rate fertilizer spreader during fertilization of a commercial citrus grove using prescription mapping based on individual tree volume. Zaman et al. (2005) showed a 40% reduction in fertilizer use with VRT in a citrus orchard. Zaman et al. (2006) also reduced NO_3^--N concentration in the soil solution from 28.5 and 14.0 mg L^{-1} to 1.5 and 4.5 mg L^{-1} under small and large size citrus trees, respectively, by using variable rate precision fertilization as compared to uniform application.

Developing accurate VRF application maps is critical in implementing precision farming management. Thrikawala et al. (1999) suggested that the VRT based on proper characterization and quantification of spatial variability can result in improved yield. They also reported that deficiencies and excesses in N application can be avoided by using VRT for all fields with spatial variations and thus reducing potential leaching losses and protecting environment.

English et al. (1999) investigated the economic and environmental impacts of VR application technology. The experimental fields under study benefited economically by VRT depending upon the spatial variability within field, as well as showing a reduced risk of subsurface water contamination. Wang et al. (2003) evaluated VRT for N and lime to measure its effect on water quality in corn production. Results of their study showed that greater water quality benefits were achieved using VRT. Saleem (2012) reported that the VRF reduced the nitrate and ammonium loading in subsurface water significantly as compared to the uniform application from wild blueberry fields. Based on these results, it was strongly recommended that the slope of field must also be considered, while fertilizing. This can reduce the cost of production and nitrate and ammonium leaching beyond the root profile to avoid groundwater contamination. Lambert et al. (2007) conducted an experiment over five years in Minnesota to examine nutrient carryover–crop response dynamics from a corn-soybean rotation, variable rate N, and P applications. The site-specific management of N and P was compared with uniform management and the results suggested that when P carryover is accounted for in determining optimal P fertilizer rates, returns to the VR strategies were higher than returns to a uniform or whole-field management strategy.

2.4 Real-time Sensing and Control Systems for VR Application of Fertilizer

Camera-based, non-destructive fruit yield estimation and mapping techniques are the basis of many studies (Chinchuluun et al., 2009; Schumann et al., 2007). Chinchuluun et al. (2009) introduced a system based on citrus fruit counting for a continuous canopy shake and catch harvester. The system was developed using a three-charge-coupled device (3-CCD) camera, four halogen lamps, a laptop computer, and an encoder. The fruit identification and size measurement information was obtained using a 3-CCD camera with custom image processing software. A digital color camera mounted on a moving vehicle was used to identify and quantify the number of mature fruits. The mounted digital color camera was capable of acquiring georeferenced-overlapping images based on red-green-blue pixel ratios and thresholds. Aleixos et al. (2000) reported that the low image resolution in machine-vision based commercial sorters failed to solve problems like defect detection and correct color classification. They described a new machine vision system which was capable of real time classification of different citrus species and external features of the fruits such as color, size, and defects. A specific hardware was developed which was capable of running these algorithms in parallel making the work possible at speed of 10 fruits/s with an adequate image resolution. Annamalai et al. (2004) investigated a machine vision system based on color vision to identify citrus fruits and to estimate yield information of the citrus grove in real-time. A machine vision system consisting of a color analog camera, a DGPS receiver, and an encoder were used to acquire images in stationary mode. Moreover, a computer vision algorithm was developed for enhancement and extraction of information from the acquired images.

Management of cropping systems can be improved by replacing conventional technologies with VR technologies for precise application of fertilizer to enhance profit, reduce production cost and environmental hazards. High proportions of irregular shaped bare spots and weed patches of crops such as wild blueberry, need to be detected in real-time using sensing and control system to avoid fertilization in these specific areas.

Several techniques have been developed and evaluated for real-time detection of bare spots/weed patches and other crop requirements in different cropping systems. Hanks and Becks (1998) developed and evaluated a weed-sensing technology in row-crop production systems. They reported that real-time weed detection can be accomplished on the basis of spectral differences in green living plants and bare soils. Adsett et al. (1999) developed and tested an automated on-the-go, soil nitrate monitoring system which used a nitrate ion selective electrode, and offered a quick and convenient method for real-time in-field soil nitrate measurements. Tian et al. (1999) used a real time machine vision sensing system with an automatic herbicide sprayer to create an intelligent sensing and spraying system. In this system multiple video images were used to cover the area to be targeted. Tumbo et al. (2001) developed and tested an on-the-go system for sensing chlorophyll extent in corn using neural networks and fiber-optic spectrometry, and collected the data consisting of spectral response patterns at a travelling speed of 0.6 km hr^{-1} in five corn field plots. Hemming and Rath (2001) used digital image analysis to develop an identification system for weeds in row crops. Schumann et al. (2007) developed and tested ultrasonic and optical sensors which were able to control the placement and application rate of crop nutrients and pesticides with VR fertilizer spreaders in Florida citrus groves. Billard and Stewart (2004) quantified normalized difference vegetation index with compact airborne spectrographic imager images to differentiate weeds and wild blueberry plants. Probably due to high computing and economic cost involved in these research efforts and inherent difficulties of the methods their use has been limited.

Zhang et al. (2010) mapped bare spots in real-time, using automated machine vision system mounted on a specially designed farm motorized vehicle, within wild blueberry fields. Chang et al. (2012a) developed algorithms which were capable of discerning weeds, plants and bare spots in real-time using digital photographic techniques in wild blueberry fields. Zaman et al. (2008 and 2010b) and Chang et al. (2012b) developed an automated yield monitoring system consisting of two µEye color cameras (UI1220SE/C, IDS Imaging Development System Inc., Woburn MA, USA), real time kinematics-GPS, custom software, and a ruggedized laptop computer Latitude E6400 XFR (Dell Inc., Round Rock, TX, USA) for real-time fruit yield mapping. The digital color cameras with custom software, fast controllers and processors can be an option to differentiate weeds, bare spots and blueberry plants real-time in the field.

According to Chandler (2003) one of the major concerns regarding the use of computer vision in an outdoor condition is the variable lighting conditions due to clouds, going under trees, etc. He also reported that the texture analysis for image segmentation enables more flexibility towards changing environmental conditions in outdoor environment. Texture analysis is more resistant to changes in lighting conditions as compared to the identification of objects depending on color. Therefore, differentiating objects based on the physical property of texture is more appropriate (Chandler, 2003).

Real-time weed and bare-spot detection at the time of fertilizer application could be very valuable for reducing fertilizer costs and subsurface water contamination. Since the sensing technologies are being introduced to offer cost effective alternatives for detecting weeds and bare-spots in specific sections of variable rate fertilizer spreader boom. Many commercial controllers have been introduced to apply fertilizers on site-specific basis, e.g. DICKEY-john Land Manager II (DICKEY-john Corporation, Auburn, IL), Mid Tech Legacy 6000 controller (Midwest Technologies, Springfield, IL), Topcon X20 controller (farmer's edge), Raven 660 controller (Raven Industries, Sioux Falls, SD). Schumann and Hostler (2009) developed an 8-channel computerized variable rate controller (VRC) with the partnership of a machinery manufacturer (Chemical Containers Inc., Lake Wales, FL, USA). This controller consists of electronic hardware with internal firmware and matching Windows Mobile 6.0 software on a handheld pocket personal computer (PPC). The controller is linked with the PPC using wireless Bluetooth. This controller relies on sensors to provide real-time plant information which is used to dispense fertilizer only in plant areas.

Zaman et al. (2011) and Esau (2012) developed a prototype VR sprayer using cost-effective sensing and control system for spot-specific application of agrochemicals (fungicide and herbicide) in wild blueberry fields. Similar technology can be used with VRG fertilizer spreader for spot-specific application of fertilizer.

2.5 Global Positioning System

The possibility of locating any object on the globe is enabled by the introduction of GPS for civilian purposes (Abidine et. al., 2004). Low cost hand-held GPS receivers, are able to provide accuracy within the range of 3 to 20 m. The Wide Area Augmentation System (WAAS), a satellite-based system with free-differential correction of atmospheric and other GPS signal distortions, is the kind of hand-held GPS system which is capable of providing accuracy within about 3 m (Abidine et. al., 2004).

Agricultural producers have accepted the fact that uniform treatment of fields reflects in sub-optimal crop production due to the spatial variations of many factors within the field (Schueller, 1991). The relation of spatial yield variability with topographic features has been reported by many researchers (Jones et al., 1989; Cassel et al., 1996; Yang et al., 1998; Kravchenko and Bullock, 2000), but this relation is not exploited well by growers for improving crop management decisions (Schmidt et al., 2003). Many growers are finding ways to predict spatial yield variability by adopting site-specific management techniques in order to improve crop management decisions, but the frequency of successes to date is low. Measuring the factors which effect the within field yield variability patterns can be costly and time consuming (Schmidt et al., 2003). Earlier, it was difficult to acquire the large amounts of data required for detailed maps showing the field behaviour in crop response, salinity, soil variability, and nutrient displacement. Moreover, the lack of navigation capabilities to return and treat the agricultural field in an optimal way has been countered with advances in computer technology, intelligent sensor hardware and GPS (Gehue, 1994). The introduction of GPS and GIS in agricultural systems can be considered as the base for precision agriculture. The function of GPS is to record and store the spatially variable field data, which is then incorporated in GIS, thus generating complex view of fields and making valid agro-technical decisions (Pecze, 2001).

The GPS is a source to determine the locations anywhere on the earth. GPS allows farmers and other agriculture services providers to record the data automatically rather manually for applying variable rates inputs to smaller areas within larger fields (Pfost et al., 1998). The GPS depends on a radio navigation system which has ability to determine 3-dimensional locational/positional data (longitude, latitude, and elevation) from a constellation of orbiting satellites. A GPS receiver specifies the location of the point using pseudo random signals from at least four satellites and even higher accuracy with more satellites (Morgan and Ess, 1997). The GPS satellites broadcast signals on continuous basis allowing the GPS receiver, while moving, to specify the location of point in real-time. Any deviation can result in error since the GPS receiver depends on the time taken by the signals from a satellite to the receiver (Hurn, 1993). Timing errors, noise in the medium and electronic noises produced in the receiver can be compensated using differential GPS (DGPS) (Saunders et al., 1996). The disturbances caused by atmospheric variations, satellite location errors and other effects are compensated in DGPS using correction signals that come from different sources like ground stations or satellites. Commercial vendors or government agencies are generally responsible for providing correction factors but the horizontal positioning errors of DGPS are normally less than 1 m. The relatively low cost of the system enables the rapid expense recovery when the system is utilized for agricultural operations such as variable rate application of agro-chemicals, and in automatic guidance (Abidine et al., 2002; Gan-Mor et al., 2002).

Kasper et al. (2000) made use of kinematic GPS to measure elevation on a 16 ha field and elevation, slope, and curvature surfaces were generated using digital terrain analysis. Yang et al. (1997) measured slope and aspect during typical field operations by mounting GPS and inclinometers on agricultural vehicles. Clark and Lee (1998) successfully developed topographic maps for fields using a dual frequency GPS. They used both, stop–and–go and kinematic methods. Their major concern was development of elevation maps in real time during field operations. The GPS system provides accurate guidance for various field operations like planting, control of weeds, insect and disease infestations, cultivation and irrigation, or gathering of data for mapping purposes.

Higher accuracy of about 1 cm on-the-go can be achieved using the GPS units generally referred to as real time kinematic global positioning system (RTK-GPS). The cost associated with RTK-GPS is relatively high as it needs a dedicated base station close to the rover unit, and a radio data link to achieve this accuracy (Gan-Mor et. al., 2007). Many commercial companies are now developing and distributing automatic tractor guidance systems, based on an RTK-GPS (Gan-Mor and Clark, 2001). The position information obtained from RTK-GPS can be used for both guidance and various other applications such as seed mapping, traffic control, and tillage control (Li et al., 2009). Abidine et al. (2004) evaluated the effectiveness of an auto guidance system based on RTK-GPS with accuracy of 1 cm in agricultural production operations. They found that the system enabled the automatic steering of the tractor and implements attached to it along a path close to buried drip-tape and/or plants without damaging them, even at high ground speeds. RTK-GPS and GIS were used together to extract topographic features and relate them with the soil attributes (Iqbal et al., 2005).

2.6 Soil Sampling

The concept of increasing yield from areas within a field is attractive to farmers. However, the accomplishment of this goal requires a greater understanding of the variability in soil factors across fields (spatial variability) and effect on crop performance (Earl et al., 2003). The basic objective of site specific crop management is to identify and exploit the spatially variable information within a field to design better crop management techniques. The physical and chemical properties of the soil can be considered as the biggest variables in a field which can influence crop production directly (Shaner et al., 2008). Plant-available water, soil structure and texture, soil depth, soil organic matter (SOM), soil salinity, and topography are the examples of physical and chemical properties of the soil (Black, 1968; Hanks and Richie, 1991). Among these vital soil properties, soil texture and SOM can be considered as most important soil properties affecting crop growth. Clay content directly influences the water holding capacity of the soil, hydraulic properties, and the cation exchange capacity of the soil under consideration (Triantafilis and Lesch, 2005).

Soil is the basic component of crop production systems, and investigation of its characteristics is essential when deriving management decisions for field operations and agrochemical inputs (Lark et al., 2003). Technological advances in GPS and GIS have allowed the producers to design more effective soil sampling techniques and use the information obtained for lime and fertilizer management decisions. The major objective associated with soil sampling is to classify and characterize the nutrient status of a field accurately and inexpensively. Depending on the different field conditions among fields combined with different management practices, no single optimal soil sampling strategy for collecting soil samples in all production systems is used (Clay et al., 2000). However, a better understanding of various soil sampling techniques should help in identifying best strategy that fit the project's goals. Based on the plan developed for soil sampling, the selected field is normally divided into either zones or grids. Collection of the soil samples is performed randomly or at the intersection within marked zones or grids (Srinivasan, 2006). Grid soil sampling is one of the earliest methods for collecting soil samples and measuring soil variability. The spatial structures of soil properties within a field influence the efficacy of grid soil sampling (Flatman and Yfantis, 1996; Sadler et al., 1998). Although relatively accurate estimate of soil properties can be obtained using grid densities of 0.1 to 0.4 ha (Wollenhaupt et al., 1994; Franzen and Peck, 1995), but a coarse grid usually having the grid size of 1.5 ha or larger is used more in practice (Sawyer, 1994). Zone sampling is another method to map within field soil variability. Zone sampling is based on the assumption that the field is naturally divided into homogenous areas (i.e., zones) with differences in soil properties between these areas. An estimate of the soil properties within homogeneous zones can be obtained by sparsely spacing the soil sampling points within each zone (Shaner et al., 2008). The advantage of zone sampling is the reduction in cost, while maintaining information about soil variability (Shaner et al., 2008). Mallarino and Wittry (2004) compared more dense grid sampling (0.2 ha grid points) with less dense grid sampling (1.2–1.6 ha), elevation zones, soil series maps, and zone sampling based on P, K, pH, and SOM in eight different fields in Iowa. It was found that the most effective sampling techniques were grid sampling and zone sampling. They also reported that grid sampling approach was more effective for P, whereas zone sampling approach was better for SOM. As there were fewer sampling zones in zone sampling than the grid sampling approach, therefore zone sampling would cost less for producers but more information and judgment is required to adapt it to specific field conditions. Many methods are in practice to create sampling zones. These methods include soil survey maps, topography, yield maps, and soil color (Franzen et al., 2002; Fleming et al., 2004). One method which is most popular and receiving much attention is directed sampling (Corwin and Lesch, 2005; Bronson et al., 2006). Directed and grid samplings are soil sampling techniques commonly used for collecting soil samples. Directed sampling is more cost effective and economical than grid sampling if an accurate yield map is available (Pocknee et al., 1996). Grid sampling is performed by splitting the field into small grids and sampling at grid intersections (Chung et al., 1995). Grid soil sampling is used widely to measure soil variability (Brouder et al., 2005). Although grid sampling results in better characterization of soil variability, it is more expensive than directed sampling as closely spaced samples are required. Based on the results obtained after analyzing the soil samples collected from the field through zone or grid sampling, a single estimate for the soil test values from the entire field is drawn. The fertilizer application rates can be calculated using single estimated value. Random sampling techniques are commonly used for collecting soil samples from uniform fields. The soil sampling points should be georeferenced with GPS and same points should be considered for collecting soil samples in subsequent years to study the long term trends in soil nutrient data (Logsdon et al., 2008).

The spatial variability of soil properties can be used to develop management zones for spot-specific application of fertilizer inputs to minimize the cost of production and improve water quality. Pierce et al. (1994) stated that smaller grid size will improve the accuracy of soil variability information. Malay (2000) used a grid size of 30 m to examine spatial variability among two wild blueberry fields. Farooque et al. (2012) used a grid size of 15 m to assess the spatial variability in soil properties and fruit yield for wild blueberry field. Plant et al. (1999) collected samples using 61 m grid to characterize spatial variability in yield. In order to determine soil spatial variability; many scientists have suggested grid size greater than 60 m (Hajrasuliha et al., 1980; Morgan and Ess, 1997). The size of grid for soil sampling is not fixed, however collecting soil information using grid sampling based on geostatistical results is considered to be more reliable, efficient and accurate than other techniques (Farooque et al., 2012; Pierce et al., 1994).

2.7 Data Management

Geostatistics combined with GIS can be used to quantify the spatial variation in soil properties, topographic features and fruit yield. According to Blackmore (1994) GIS is: “A software application that is designed to process, manipulate and display the spatial data. A GIS database used for agricultural purposes consists of layers on field topography, soil types, surface and subsurface drainage, rainfall intensity, irrigation, fertilization and other chemical application rates, and crop yield. The collected information can be analyzed to understand relationships among various parameters that affect crop productivity”.

The GIS works with data in layers, each of which having its own characteristics. GIS can develop either raster based (i.e., stored as individual cells) or vector based (i.e., stored condition of boundaries) maps. The vector format explains the location of points (x-y coordinates) by utilizing a continuous coordinate system, thus allowing geo-referencing to be more precise than raster format (Morgan and Ess, 1997). Implementing the input decisions using variable and spatially precise doses of fertilizers or pesticides can be assisted by GPS guided prescription maps developed in GIS software.

The significance of slope variability cannot be ignored in site-specific nutrient management. Information about space and time variability can be used to get valuable insight of dynamic nature of soil properties within a field’s boundary (Cox et al., 2003). Management zones can be delineated based on the distribution of topographical features and these zones should be practically manageable. After delineation of management zones relationships between spatial variation in soil/crop parameters and yield can be examined (Pilesjö et al., 2005). Positive results were found by researchers after dividing the fields into management zones depending on topographic features and other soil variation in different cropping systems (Thrikawala et al., 1999; Whitley and Davenport, 2003; Goddard and Grant, 2001).

Both t-test and analysis of variance (ANOVA) can be implemented for the data analysis. The t-test is used to compare two treatments with each other. Three types of t-test are one sample t-test, paired comparison, or group comparison. It is better to use paired comparison instead of group comparison, where possible. The reason for selecting paired comparison as a priority is the positive covariance due to same experimental units and same number of replications which leads to more precision. Whereas, in case of group comparison the covariance is zero which makes it less precise as compare to paired comparison (Montgomery, 2009). If there are two or more treatments the better option is ANOVA. Analysis of variance is a statistical technique to analyze variation in a response variable measured under conditions defined by discrete factors. Analysis of variance is frequently used to test equality among several means by comparing variance among groups relative to variance within groups. Analysis of variance is basically based on the partitioning of total variability in the system. It determines whether the difference in the response variable is due to the factor of interest or due to the error terms associated with it (Montgomery, 2009). The effect due to the factor of interest is said to be significant if the variability due to factor of interest is greater than the variability due to error terms (Montgomery, 2009). The rejection of null hypothesis that all means are equal, leads to the acceptance of alternative hypothesis which suggest that at least one mean is different from the others. Therefore, the acceptance of alternative hypothesis suggests the multiple means comparison (MMC) to see which means are different. Orthogonal contrast or Scheffe's method can be used for MMC depending on the background information available, if the comparison is to be based on all means. If the comparison is to be based on pair of means least significant difference (LSD), Duncan's, SNK, or Tukey's methods can be used based on the magnitude of experimental error (Montgomery, 2009).

CHAPTER 3
MATERIALS AND METHODS

3.1 Modified VR granular (MVRG) fertilizer spreader

An existing commercial VRG fertilizer spreader was modified for spot-application of fertilizer only in plant areas. This VRG fertilizer spreader had a 7.32 m wide fertilizer boom with 12 nozzles spaced at 0.61 m and independent control on each half of the fertilizer boom. The ACCU-RATE controller (Rawson Control Systems Inc., Oelwein, Iowa, US) of this spreader is capable of reading prescription map generated in ArcGIS 10 software which is then imported into the Farmworks Site Mate VRA software (Farmworks CTN Data Service, LLC, Hamilton, IN, USA). This software enables the ACCU-RATE controller to read prescription maps and adjust the application rate. The ACCU-RATE controller uses ground speed, location, boom width and desired application rate for a specific location to calculate revolutions per minute of the hydraulic metering drive unit. This unit drives fluted metering rollers for the desired application rate. The fertilizer then drops in the venture cups due to gravity and is carried towards the nozzles through hoses by air pressure from a fan.

The modification was accomplished at the Engineering Department, Faculty of Agriculture, Dalhousie Univeristy, Truro, NS, Canada. It allowed the spreader to operate each pair of nozzles independently rather than operating one complete half boom at a time. For this purpose a diverting valve bank with 12 solenoid valves (model: V3221-08T, E.MC®, Yinzhou, Ningbo, China) along with 12 single acting pneumatic cylinders (E.MC®, Yinzhou, Ningbo, China) and an air compressor (model: CBHRFP209400RB, Campbell Hausfeld/Scott Fetzer Co., OH, USA) were used. Each pneumatic cylinder was attached with a gate which acts as one wall of each slot in valve bank. The valve bank was placed above venture cups and air manifold. Six µEye digital colour cameras (UI-1220SE/C, IDS Imaging Development System Inc., Woburn MA, USA) were incorporated on the custom made front boom of the tractor. Each camera is able to cover two sections of the boom (1.22 m each section). Cameras are attached using USB cables to a ruggedized laptop (Latitude E6400 XFR, Dell Inc., Round Rock, Texas, USA) on the tractor (Figure 3-1). The camera lenses (LM4NCL, Kowa Optimed Inc., Torrance, CA, USA) has a focal length of 3.5 mm. The lenses are set up with fixed aperture (f/4.0) and infinity focuses. Auto exposure shutter/auto gain control are able to automatically control exposure time and digital gain to adjust for variable outdoor light conditions. Picture blurring is prevented by setting auto exposure shutter to 2 milliseconds (ms) during field operation.

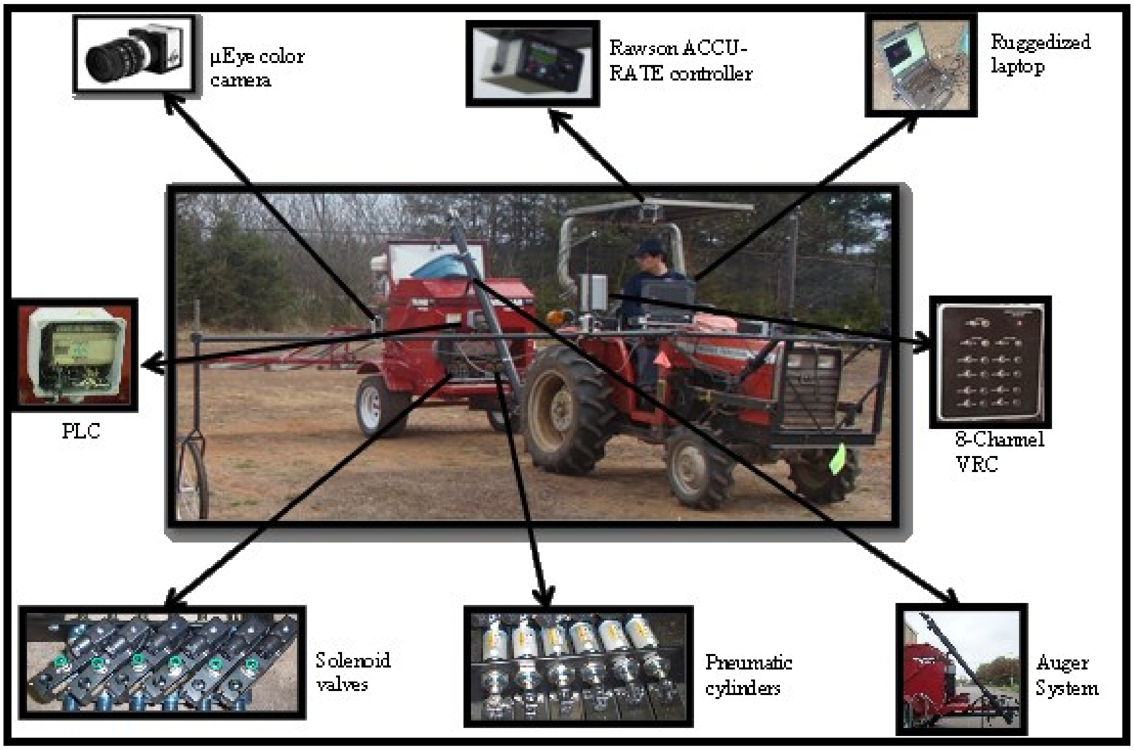


Figure 3-1. Modified variable rate granular fertilizer spreader and its components.

A custom image processing software, developed by Chang et al. (2012a) is used to process the images and to differentiate between bare spots and foliage (wild blueberry plants and weeds) in real-time and sending ON/OFF commands to a U3-HV (LabJack Corp., Lakewood, CO, USA) I/O unit. The U3-HV sends ON/OFF to the VRC. The VRC has user programmable inputs from PPC such as before and after buffer for precise overlapping, distance between front boom and fertilizer boom and response time, and was able to automatically compensate the signal delay based on vehicle ground speed from a WAAS-enabled DGPS (Garmin International Inc. Olathe, KS, USA). The VRC sends the ON/OFF signals to the programmable logic controller (PLC) (model: Omron ZEN-20C1DR-D-V2, Santa Clara Systems Inc., CA, USA) which incorporates the delay time of each nozzle to turn two or more nozzles ON/OFF at the same time when required, and sends the signal to solenoid valves. The pneumatic cylinder, attached to solenoid valve, pushes the gate from the bottom to close the venture opening for the nozzle which is needed to be turned off and the fertilizer is collected in fertilizer return system which consists of two augers. The diverted fertilizer is finally added back in the fertilizer storage tank with help of these two augers (Figure 3-2).

3.2 Laboratory Evaluation

3.2.1 Calibration of ACCU-RATE Controller

The performance of the major components of the prototype MVRG spreader including ACCU-RATE controller and digital color cameras was tested at Engineering Department and Bio-Environmental Engineering Centre (BEEC), Faculty of Agriculture, Dalhousie University, Truro, NS, Canada.

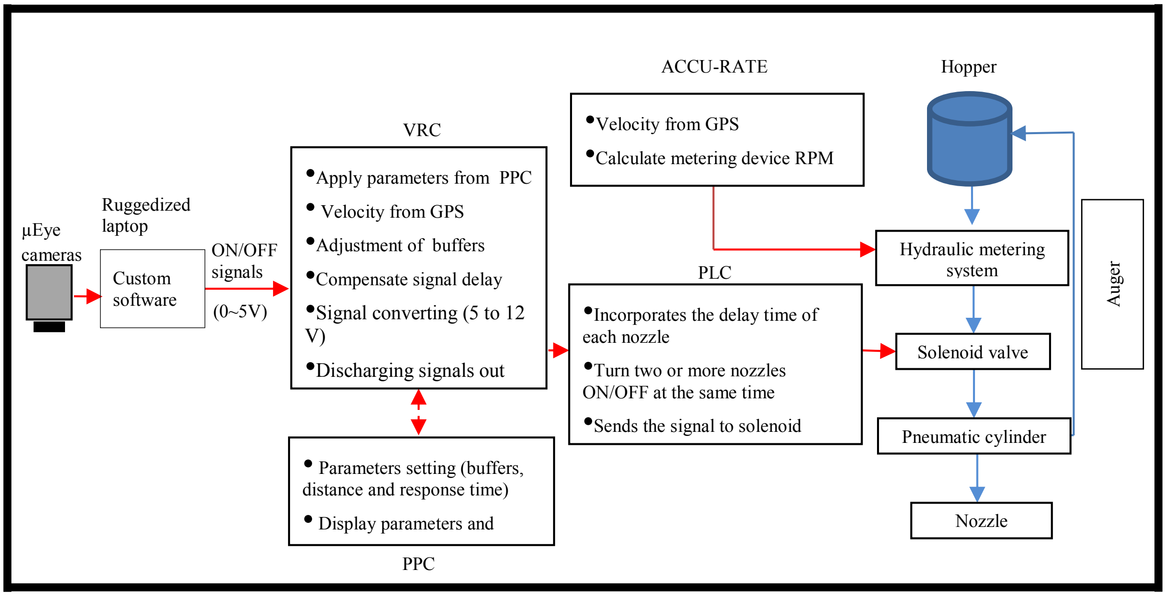


Figure 3-2. Flow chart displaying the complete process from foliage detection to fertilizer discharge.

The experiment was conducted to evaluate the performance accuracy of Rawson ACCU-RATE Controller (Figure 3-3) for fertilizer application rate (flow rate) using clay filler. The weight of clay filler from each nozzle, and using different combination of nozzles was collected and weighed manually. The delivery rate of the clay filler was also recorded from the ACCU-RATE controller. This experiment was repeated three times and weight measurement readings were averaged. The differences between ACCU-RATE controller readings and manually measured weights were used to characterize the performance accuracy of the ACCU-RATE controller.

The same experiment was repeated to calibrate ACCU-RATE controller using actual fertilizer as the bulk density and composition of the fertilizer is different from clay filler. This practice allowed for a suitable delivery rate to apply the desired amount of fertilizer across the selected wild blueberry fields.

Figure 3-3. Rawson ACCU-RATE Controller (www.google.ca)

3.2.2 Calculation of Mechanical Delay Time

The MVRG fertilizer spreader has the front boom (look-ahead camera boom) equipped with 6 µEye color cameras attached by USB cables to the computer and 8-channel computerized VR controller. The experiment, using clay filler, was conducted in the metal shop of the Engineering Department to calculate response time (i.e., lag time between look-ahead camera boom detection and fertilizer application) for 8-channel computerized VRC to open the nozzle at right target after receiving target detection information from the camera boom. The time taken by the clay filler to travel from venture cups to outlet nozzle and the time to build up the cone of clay filler from nozzle was added up in calculating response time for precise real-time fertilizer application in the areas where plants were detected. An LED bulb was wired into a switch on VRC. A µEye camera was positioned in front of the nozzle being inspected to record the video. The video was recorded with 149 frames s^{-1} when the camera boom detected the target and bulb turned on until the opening of nozzle to spread fertilizer in desired area. This test was repeated for each nozzle at different fan speeds (static pressures) and video images were analyzed with V1 HOME 2.0 software (Interactive Frontiers Inc., Plymouth, MI, USA), allowing for a frame by frame analysis of response time between target detection and fertilizer application.

The same procedure was repeated using actual fertilizer instead of clay filler and delay time was calculated again. The total response was calculated as follows:

$$T_t = T_c + T_p + T_d$$

Where:

T_t = Total response time

T_c = Time taken by camera for image acquisition

T_p = Image processing time for plant or bare spot detection and time from computer (sending signal) to VRC

T_d = Time from VRC to fertilizer application

3.2.3 Evaluation of VR Spreader

A small scale field test using clay filler was conducted at BEEC (Figure 3-4). The test was carried out to evaluate software and hardware components of MVRG fertilizer spreader for spot-application of fertilizer in plant areas. A track, which was 7.3 m wide and 57 m long, was selected for the preliminary test. The boundary of the test track was mapped with the RTK-GPS. The test was conducted by making artificial bare spots using orange colored tarps placed at random locations in the selected track. These artificial bare spots were mapped with RTK-GPS. Equal numbers (i.e., 12) of pre-weighed rat catchers (Catch Master, AP&G Co., Inc., Brooklyn, NY, USA) were placed on the artificial bare spots and green grass areas to collect applied clay filler. The spreader was operated first on modified VR mode (for detection and clay filler application only in green grass areas) and then on UN mode (clay filler application on green grass and artificial bare spots). The Visual observation for both modes of operation was made to examine the performance of MVRG spreader. The rat catchers were weighed again after the clay filler application test. The weights of rat catchers were recorded down and the weight of the applied clay filler on each rat catcher was calculated by using simple arithmetic laws. The weight of the clay filler collected by the rat catchers placed on the bare spots, when spreader was operated on VR mode, was compared using paired t-test with the collected weight of the clay filler from same bare spots when spreader was operated on UN mode. Similarly, a paired t-test was used again to compare both treatments (i.e., VR and UN) by comparing the weights of the collected clay filler by the rat catchers placed on green grass areas.

Figure 3-4. Preliminary field test experimental setup.

3.3 Field Evaluation

3.3.1 Experiment 1

3.3.1.1 Site Selection

A wild blueberry field was selected in central Nova Scotia to evaluate the performance accuracy of the MVRG fertilizer spreader for spot-specific fertilization in an actual wild blueberry field. Clay filler was used as the applied material for the test. The selected site was the Debert (45° 26' 28" N and 63° 27' 02" W).

3.3.1.2 Methodology

In this study, image texture analyses and RGB image processing software were used simultaneously to differentiate between plant areas, bare spots, and weed patches. Custom image processing software (image texture analysis and RGB image processing software) were evaluated under mainly sunny conditions and mainly cloudy conditions. A test track 7.3 m wide and 100 m long was made in the selected field. The bare spots and boundary of the test track were mapped with RTK-GPS before application of clay filler. Equal numbers of pre-weighed rat catchers (i.e., 12) were placed in the non-plant areas (bare spots and weed patches) and plant areas for collecting clay filler. The position of the rat catchers was also marked using RTK-GPS. The spreader was operated first at VR mode (detection and no application in bare patches) and then on UN mode (Uniform application throughout). This procedure, for each light condition, was repeated at three different ground speeds (1.6, 3.2 and 4.8 km h^{-1}) of the spreader (Figure 3-5). The weight of each rat catcher was recorded after clay filler application and the weight of the applied clay filler on each rat catcher was calculated. The weights of the clay filler collected by the rat catchers placed on the bare spots/weed patches in UN and VR treatments were compared using paired t-test. Similarly, a paired t-test was performed to compare both UN and VR treatments for the collected clay filler by the rat catchers placed in the plant areas. The statistical analyses were performed in Minitab 16 (Minitab Inc. NY, USA). Same procedure was repeated at the three different ground speeds (1.6, 3.2 and 4.8 km h^{-1}) of spreader using standard collection pans (*ASABE* standard, 2006).

Figure 3-5. Experimental setup for performance evaluation of modified VR spreader in actual wild blueberry field using clay filler.

3.3.2 Experiment 2

3.3.2.1 Site Selection

Two wild blueberry fields were selected in central Nova Scotia to (i) perform fertilization using MVRG fertilizer spreader and (ii) examine the nutrient losses through leaching from the bare spots or weed patches. The selected sites were Kemptown Field (45° 31' 50" N and 63° 07’ 45" W) and Cattle Market Field (45° 22' 37" N and 63° 13' 7" W), Nova Scotia. Selected fields were in vegetative sprout year in 2012 and 2013, respectively. Both fields were divided into three sections, first section received UN fertilization, second section received VR fertilization using prescription map only, and the third section received VR fertilization using prescription map and automated sensing and control system of MVRG fertilizer spreader.

3.3.2.2 Topographic Maps

Slope variability was measured and mapped with a slope measurement and mapping system (SMMS) at the start of the experiment (Figure 3-6). The system consists of a tilt sensor that determines the tilt of the vehicle in any orientation on slope. RTK-GPS was mounted on the all-terrain vehicle (ATV) to determine the location of the sampling point. A laptop computer, with the software to which data is transferred from the tilt sensor and RTK-GPS to calculate slope in real time, was also used. The detailed procedure for measurement and mapping of slope can be found in Zaman et al. (2010a).

Slope map of the selected fields were generated in Arc GIS 10 software using the kriging interpolation technique. Nugget, sill and range of influence were measured by performing geostatistical analysis using GS+ Geostatistics for the Environmental Sciences Version 9 software (Gamma Design Software, LLC, MI, USA). The variance at zero distance is nugget, semi-variance and the range can be defined as the lag distance between measurements at which one value of a variable does not affect adjacent values, and the plateau at which the variogram reaches the range is called sill. Sill is basically used to calculate the range (Oliver, 1987). The semivariogram parameters were used in the kriging interpolation technique to generate the smooth slope maps. The boundary of

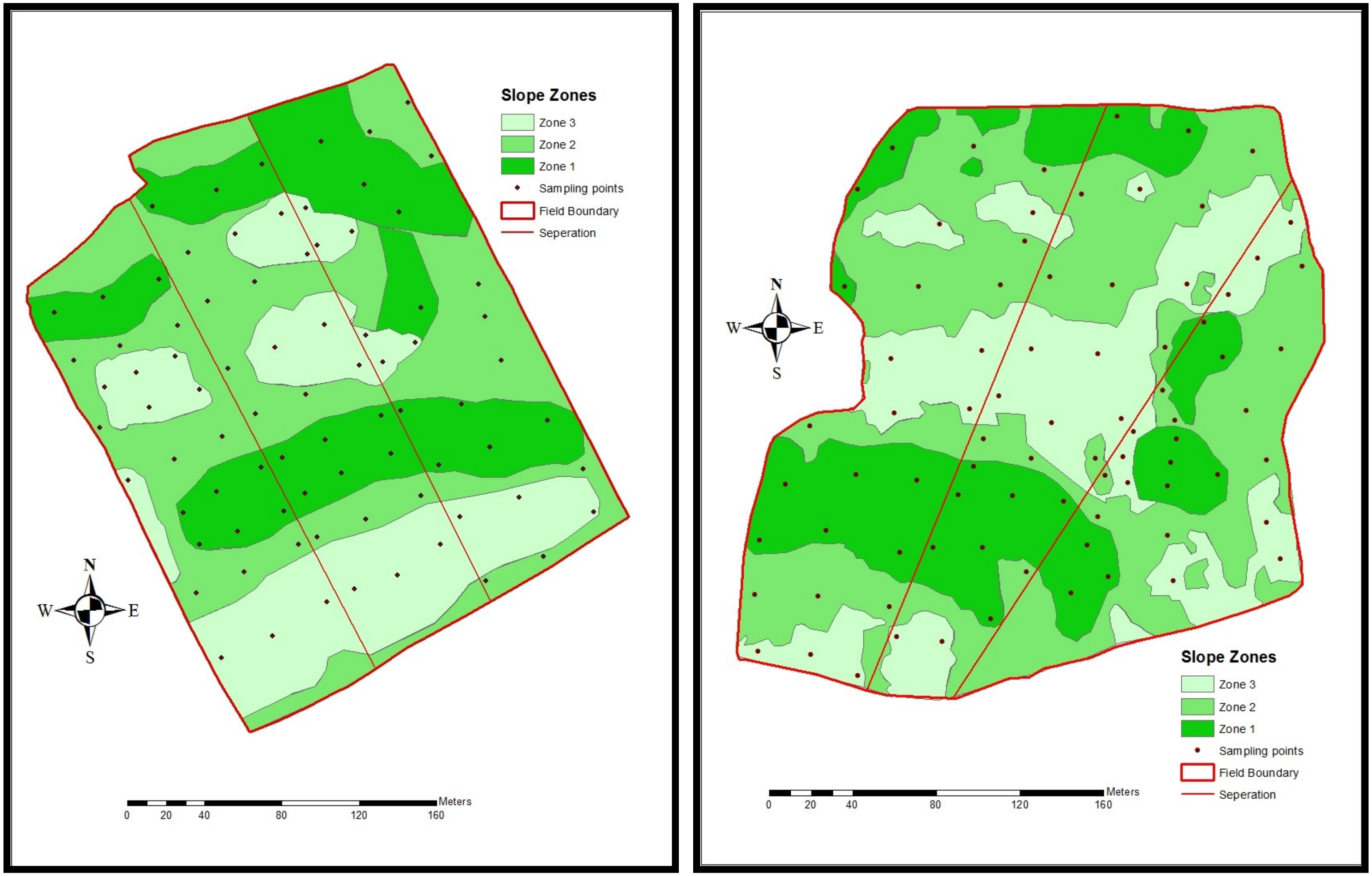
Figure 3-6. Slope Measuring and Mapping System (Zaman et al., 2010a).

the selected fields, bare spots, and weed patches were mapped using RTK-GPS. Both fields were divided into three slope categories.

3.3.2.3 Soil Sampling

Soil samples were collected from the fields to determine selected physical and chemical properties of the native soils. A sampling pattern to gather equal number of soil samples from each management zone was established on the basis of the generated slope map (Figure 3-7). Soil samples were collected before the fertilizer application in 3rd week of May 2012. The 2nd soil sampling was performed in 3rd week of July 2012. Soil samples were collected using manual auger at the depth of 0-15 cm below soil surface at each sampling point. A representative soil sample was made by collecting five cores of soil samples from each sampling point and mixing them together (Brouder et al., 2005). Each soil sample was then segregated into two sub-samples which were stored in two properly labeled sampling bags for the respective treatments. The sub-samples from the same parent sample were given the identification, and was stored immediately in the refrigerator at 4 °C for analyzing NH_4^+-N and NO_3^--N, while the other was air dried for two weeks. A soil grinding apparatus (Nasco Farm and Ranch Co, WI, USA) was used to disaggregate the air dried soil samples and then the material was passes through 2 mm sieve.

These samples were analyzed for electrical conductivity (EC), SOM, pH, and soil texture. The SOM and texture parameters were measured only once at the onset of the experiment. Other parameters including soil pH, EC, soil NH_4^+-N and NO_3^--N were measured twice (i.e., before and after the fertilizer application). The RTK-GPS was used to record the coordinates of each sampling point.



(a)

(b)

Figure 3-7. Slope zones and sampling points for (a) Kemptown Field (b) Cattle Market Field

3.3.2.3.1 Soil Analysis

3.3.2.3.1.1 Soil Organic Matter Content (SOM)

Organic matter in the soil is the material which distinguishes soil from mere geological deposits. It is essential for plant growth, water holding properties, cation exchange properties, and various other soil physical-chemical characteristics. There are many techniques used for the determination of organic materials in the soils. Some of these determine the organic matter content, others organic carbon content, and some determine total carbon content. Davies (1974) used the loss on ignition method to determine SOM. The same method was used in this study to determine SOM.

3.3.2.3.1.2 Electrical Conductivity (EC)

Mann (2009) used a conventional EC meter, Accument 50 (Fisher Scientific, NH, USA) to determine EC of soil samples. This procedure covers the determination of soluble salts in soil by measuring the EC of a 1:2 soil:water suspension. A 0.01 *N* potassium chloride (KCl) solution, with EC of 1.412 dS/m was used to calibrate EC meter. Dixie cups were used to carry prepared soil and water mixture and these cups were placed on the shaker for 40 minutes. The EC electrode (probe) attached with EC meter was then inserted in the soil water suspension. The EC readings were recorded when the EC values stabilized for a minimum of 30 seconds.

3.3.2.3.1.3 pH

The procedure for measuring the pH of the soil samples was used as outlined by McLean (1982). The pH meter, Corning 450, (Corning, Incorporated, NY, USA) was calibrated and pH of the soil samples was determined using a 1:2.5 soil: water ratio. The solution containing soil and water was placed on shaker for approximately forty minutes and pH of each sample was measured by inserting the pH electrode (probe) connected with the pH meter in the soil water suspension.

3.3.2.3.1.4 Ammonium-N and Nitrate-N

A Technicon auto-flow analyzer (Technicon Autoanalyzer-2, Terry Town, NY, USA) was used to determine (i.e., NH_4^+-N and NO_3^--N) using a 2.0 *M* KCl solution. One liter of distilled water was mixed with 150 g of KCl crystals to prepare the 2.0 *M* KCl solution. Twenty grams of the field moist soil sample was placed into the square French bottles. The weighed soil sample was then mixed with 100 mL 2.0 *M* KCl solution. The square French bottles containing the mixture were placed on a reciprocating shaker for one hour at low speed. After shaking for one hour, the solution was passed through Whatman No. 42 filter paper and the filtrate was collected in 20 mL scintillation vials. The vials were capped after filling to 3/4th level and stored in a freezer for further analysis (Voroney et al., 1993).

Technicon auto-flow analyzer uses the nitrate method (Technicon Industrial Systems, 1978) to determine NO_3^--N in the soil. The technicon auto-flow analyzer reduces the nitrate concentration of a sample to nitrite utilizing a copper/cadmium reduction column. The nitrite is then mixed with the reagents to form reddish purple azo dye which can be determined colorimetrically. NH_4^+-N in the soil was also determined by using Technicon auto-flow analyzer ammonium method (Technicon Industrial Systems, 1973).

3.3.2.3.1.5 Soil Texture

A standard hydrometer (ASTM. No. 1-152H) was used to measure the particle size distribution (Day, 1965). The hydrometer method is commonly used to estimate particle size distribution without any pretreatment, except dispersion with calgon solution (Sodium Hexameta-phosphate solution diluted with water in 1: 20 ratio). Forty grams of the oven dried soil was transferred to a 600 mL cylinder. The % sand, % silt, and % clay were determined. The detailed procedure is outlined in Day (1965).

3.3.2.4 Variable Rate Fertilization and Evaluation While Actual Fertilization

Management zones were delineated on the basis of variation in slope (Figure 3-8 a). To perform fertilization the selected fields were divided into three sections i.e., variable rate with prescription map (VRPM), variable rate with prescription map and real-time detection (VRPRD) system, and the third section of the field received grower's uniform rate (UN) for comparison (Figure 3-8 b). Each section was than divided into three sub-sections, such that each sub-section contains all three management zones (Figure 3-9). The fertilizer (N, P, K: 16.6, 34.5, 4.5) was applied in 3rd week of May during sprout year. Three fertilizer rates, 200, 150 and 100 kg ha^{-1} were allocated in steep slope, moderate, and low lying areas respectively, according to the prescription map in all three sub-sections of VRPM section.

The large size bare spots (> 13 m^2) were defined as a separate class in the prescription maps and zero rates were applied to those bare spots. The sub-sections of VRPRD section received the same rates of fertilizer based on slope variation, however, sensing and control system equipped with VR spreader detected the bare spots and weeds in real-time and turned the nozzles off in specific sections. Uniform rate of 200 kg ha^{-1} was applied in the sub-sections of UN section.

Before fertilizer application six non-plant areas (i.e., small bare spots and weed patches) and plant areas were selected in each management zone of VRPM and VRPRD sections of the Kemptown field to place rat catchers and standard collection pans for evaluation of spreader while fertilizing actually in the wild blueberry field. The data collected from non-plant areas of each management zone using VRPM and VRPRD treatments was compared using two sample t-tests. Similarly, the data collected from plant areas using both treatments was also compared to examine the performance accuracy of fertilizer spreader.

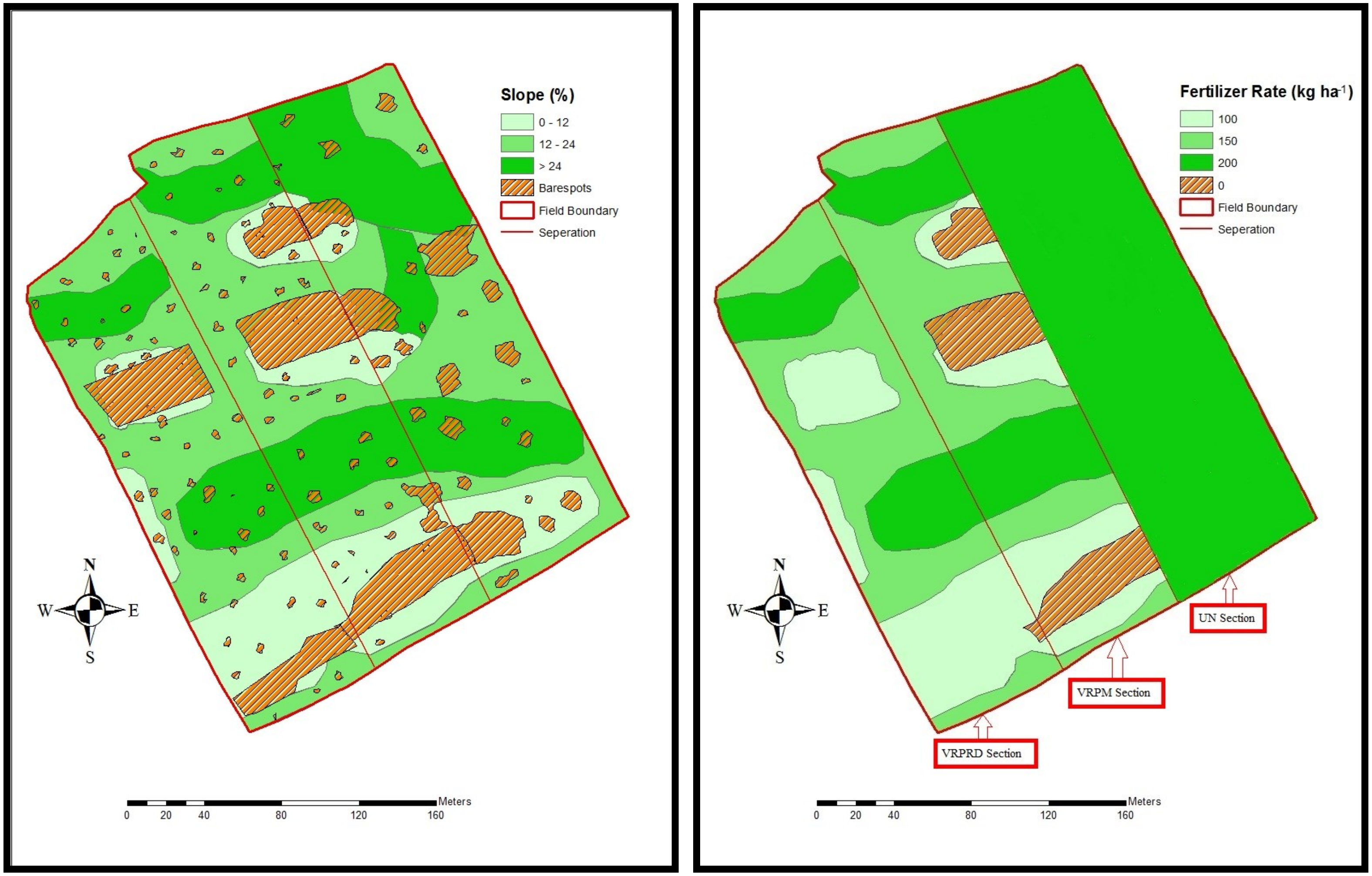
3.4 Nutrient Leaching in Bare Spots

3.4.1 Subsurface Water Collection

Eighteen lysimeters were installed in bare spots of each treatment section (6 in each management zone) to collect the leachate sample (Figure 3-10). 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 sample were extracted from each lysimeter using a vacuum pump after a heavy rainfall (>15 mm) event.

3.4.2 Statistical Design

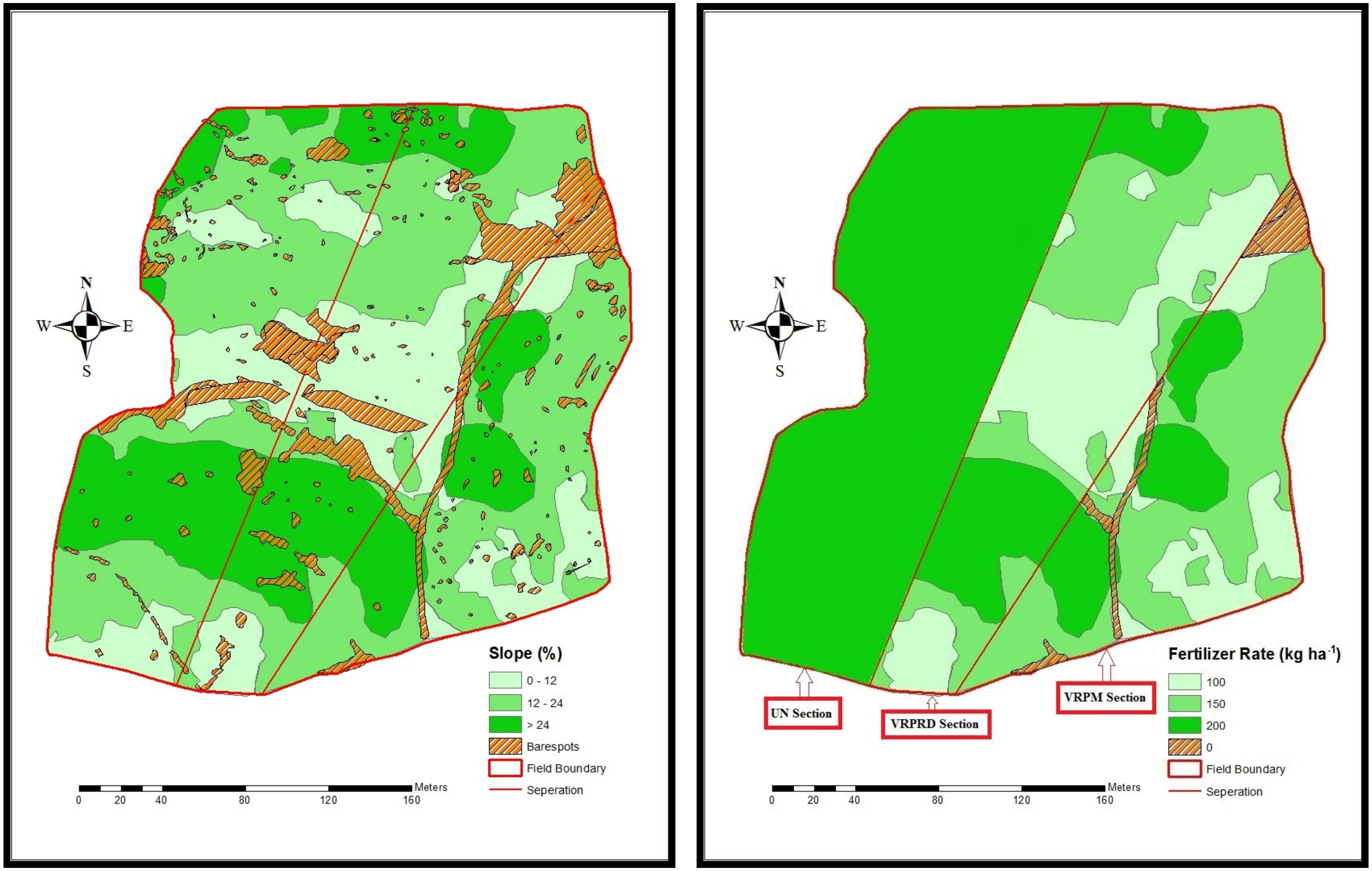
The subsurface water samples were analyzed for NH_4^+-N and NO_3^--N using a Technicon auto-flow analyzer. When sometimes in multifactor factorial experiments it is not possible to randomize the order of runs completely, generalization of the factorial



(a)

(b)

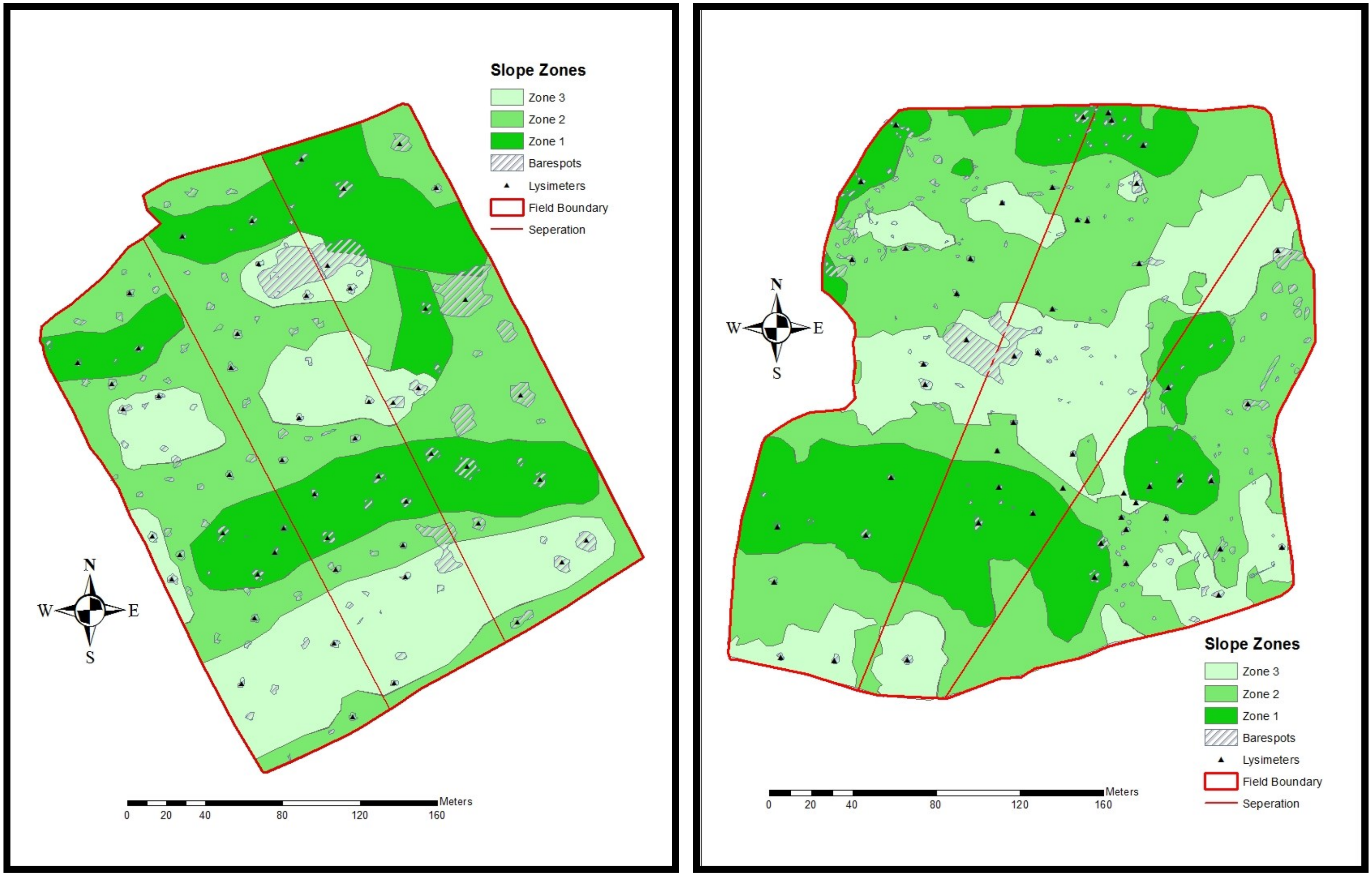
Figure 3-8. Slope maps for (a) Kemptown Field (b) Prescription map for Kemptown Field.



(a)

(b)

Figure 3-9. Slope map for (a) Cattle Market Field (b) Prescription map for Cattle Market Field



(a)

(b)

Figure 3-10. Lysimeters location for (a) Kemptown Field (b) Cattle Market Field design is used, which is termed as split-plot design (Montgomery, 2009). Therefore, the experimental design used for this particular experiment was split plot design with three replications. Each section (i.e., VRPM, VRPRD and UN) was divided into three blocks. Each block contained eighteen lysimeters such that two lysimeters installed in each management zone of all three sub-sections (VRPM sub-section, VRPRD sub-section, UN sub-section) at randomly selected points (Figure 3-10). 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) using mixed-model procedure.

CHAPTER 4

PERFORMANCE EVALUATION OF PRINCIPAL COMPONENTS OF MODIFIED VARIABLE RATE GRANULAR FERTILIZER SPREADER FOR SPOT-APPLICATION AT EXACT TARGETS

4.1 Introduction

The wild blueberry is a vital successional fruit crop of cleared woodland and deforested or abandoned farmland of northeastern North America where commercial and managed blueberry fields have been developed (Jensen and Yarborough, 2004). Different management practices (i.e., land improvements, pruning, fertility management, pollination, insect control, and disease and weed control) have been adopted over time to improve blueberry coverage and berry production (Barker et al., 1964; Blatt et al., 1989). Wild blueberry field development is based upon the eradication of competing vegetation, as well as the removal of trees, stumps, and rocks. Therefore, newly developed fields may have significant proportion of scattered bare spots throughout the field (varies from 30% to 50% of the total field area) (Zaman et al., 2010b). Traditionally, fertilizer is applied uniformly in wild blueberry fields, without considering the topography and bare spots, neither of which are distributed uniformly within fields. In such conditions, spatial information management systems are of immense potential for allowing growers to fine-tune the locations, timings, and rates of fertilizer application.

Many research efforts have been reported for the development of VR application technologies (Carrara et al., 2004; Miller et al., 2005; Zaman et al., 2005, Schumann et al., 2006; Dammer et al., 2008) but, wild blueberry production system was less considered. Michaud et al. (2008) developed a VR prototype sprayer which uses the aerial spectral scans of wild blueberry and was able to deliver pesticides based on prescription maps developed using GIS software. But, the sensitivity to positional error caused by GPS and expensive up-to-date aerial photography, variable quality, and intensive data processing for weed detection were the disadvantages associated with this VR prototype sprayer. Site-specific fertilization has also been reported using DGPS guided prescription maps for different cropping systems (Miller et al., 2004; Derby et al., 2007). Saleem (2012) used a VR fertilizer spreader for fertilizer application on site-specific basis using GPS guided prescription map based on variation in slope within wild blueberry fields. But, the existing commercial VRG fertilizer spreaders are able to change fertilizer rates in different management zones only using DGPS guided prescription maps without considering unevenly distributed bare spots and weed patches in wild blueberry fields. Fertilization in both, bare spots and weed patches, can be avoided using VRG fertilizer spreader with sensing and control system for spot-application of fertilizer.

Many researchers put their efforts in developing machine vision systems for real time detection of weeds and bare spots in various cropping systems (Sui et al., 1989; Shearer and Holmes, 1990; Zhang and Chaisattapagon, 1995; Zhang et al., 2010), because real-time detection, of weeds and bare spots, at the time of fertilizer application could be very useful in lowering fertilizer usage and reducing environmental contamination. Gillis et al. (2001) developed and evaluated a system that was able to detect and spray herbicides on weeds in real time along highways. This system was composed of vision sensors and spraying nozzles without boom.

Brown et al. (1994) stated that the different weed species can be detected using spectral analysis in green, red, and near-infrared. Tian et al. (1999) controlled solenoid valves on a spraying boom using real time image processing of spatial and frequency parameters which enabled the on-the-go application of agrochemicals. The system performed efficiently at a speed of 4.2 km h^{-1}. Hanks and Becks (1998) developed and evaluated a real-time weed detection system for row-crop production systems, which was able to detect weeds in real time on the basis of spectral differences in green living plants and bare soils.

Since sensing technologies are being introduced to offer cost effective alternatives for detecting weeds and bare spots in specific sections of VR fertilizer spreader boom, many commercial controllers have been introduced to apply fertilizers on site-specific basis (e.g. DICKEY-john Land Manager II (DICKEY-john Corporation, Auburn, IL), Mid Tech Legacy 6000 controller (Midwest Technologies, Springfield, IL), and Raven 660 controller (Raven Industries, Sioux Falls, SD)). Schumann and Hostler (2009) were able to develop an 8-channel computerized VRC with the partnership of a machinery manufacturer (Chemical Containers Inc., Lake Wales, FL, USA). This controller consists of electronic hardware with internal firmware and matching Windows Mobile 6.0 software on a handheld PPC which is linked with controller through wireless Bluetooth. This controller relies on sensors to provide real-time plant information which is used to dispense fertilizer only in plant areas.

A newly established wild blueberry field can have a significant proportion of bare spots (varies from 30% to 50% of the total field area) (Zaman et al., 2010b). Fertilization in bare spots/weed patches may result in increased cost of fertilizer input and a serious threat to the subsurface water quality. Therefore, modifications in the existing spreader are needed for real-time sensing and application of fertilizer in plant areas only. In this present study, a VR prototype granular fertilizer spreader consisting of digital color cameras, 8-channel computerized VRC, solenoid valves, PPC with operating software was evaluated for real time detection of bare spots and weed patches for site-specific fertilization.

4.2. Materials and methods

4.2.1. Modified variable rate granular fertilizer spreader

The existing commercial VR granular fertilizer spreader, used for this study had a 7.32 m wide fertilizer boom with 12 nozzles spaced at 0.61 m and independent control on each half of the fertilizer boom. A GPS guided prescription map generated in ArcGIS 10 (ESRI, Redlands, CA, USA) is imported into Farmworks Site Mate VRA (Farmworks CTN Data Service, LLC, Hamilton, IN, USA) software. The ACCU-RATE controller (Rawson Control Systems Inc., Oelwein, Iowa, USA) of existing spreader is capable of reading prescription maps to adjust the fertilizer application rates as prescribed in the map. The ACCU-RATE controller uses the ground speed, location, boom width and desired application rate for a specific location to calculate revolutions per minute of the hydraulic metering drive unit for the desired application rate. The fertilizer then drops in venture cups due to gravity and is carried by air pressure through hoses to the output nozzles.

The modifications in this VR granular spreader were made to control each pair of nozzles independently rather than operating half boom section at a time. In order to control each pair of nozzles a diverting valve bank with 12 solenoid valves (Model: V3221-08T, E.MC®, Yinzhou, Ningbo, China) along with single acting pneumatic cylinders (E.MC®, Yinzhou, Ningbo, China) and an air compressor (Model: CBHRFP209400RB, Campbell Hausfeld/Scott Fetzer Co., OH, USA) were incorporated into the commercial VR granular spreader. Each pneumatic cylinder was attached with a gate. The valve bank was placed above venture cups and air manifold. The pneumatic cylinder, attached to solenoid valve, pushes the gate from the bottom to close the venture opening for the nozzle which is needed to be turned off and the fertilizer is collected in the hopper using return auger system (Figure 3-1).

4.2.1.1. Hardware and software development

Six µEye color cameras (UI-1220SE/C, IDS Imaging Development System Inc., Woburn, MA, USA) were incorporated on the boom in front of the tractor at a height of 1.2 m (Figure 3-1). Each camera covered two sections of the boom (1.22 m each section). Cameras were connected using USB cables to the ruggedized laptop (Latitude E6400 XFR, Dell Inc., Round Rock, TX, USA) on the spreader. The camera lenses (LM4NCL, Kowa Optimed Inc., Torrance, CA, USA) had a 3.5 mm focal length and were set up with fixed aperture (f/4.0) and infinity focus. Exposure time and digital gain were automatically controlled by auto exposure shutter and auto gain control to adjust for variable outdoor light conditions. However, maximum auto exposure shutter was set to 2 milliseconds to prevent picture blurring during field operation.

Custom software installed in the ruggedized laptop was capable of processing images to differentiate between bare spots and foliage in real-time and sends on/off commands to U3-HV (LabJack Corp., Lakewood, CO, USA) I/O unit. The U3-HV send on/off signals (5/0 VDC) to the VRC. The VRC has user programmable inputs from PPC such as before and after buffer for precise overlapping, distance between front boom and spreader boom and response time, and is able to automatically compensate the signal delay based on vehicle ground speed from a WAAS-enabled DGPS (Garmin

International Inc. Olathe, KS, USA). The VRC converts on/off signals from 5/0 VDC to 12/0 VDC and sends to the PLC (Model: Omron ZEN-20C1DR-D-V2, Santa Clara Systems Inc., CA, USA) which incorporates the delay time of each nozzle and sends the signal to solenoid valves to turn two or more nozzles on at the same time in the areas where targets have been detected (Fig. 3-2).

Custom image processing software was developed in C++ using Visual Studio 2010 (Microsoft®, Redmond, WA, USA) for real-time green foliage detection in wild blueberry cropping system. The digital color images taken by the cameras were transferred onto the ruggedized laptop. The image processing software installed in the ruggedized laptop acquired a 752 × 128 pixel image (24-bit RGB) corresponding to 1.83 m × 0.31 m area of interest from each camera for processing in real-time to differentiate bare spots and green foliage. The ratio used was (G×255)/(R+G+B), and a manually obtained threshold (> 85) adequately discriminated the apparent foliage green pixels from the remaining pixels in all images. The final result of the foliage detection process converted 0 or 5 VDC signal, in each image and sent it to the VRC for fertilization in the specific section of the boom where the foliage had been detected (Figure 4-1).

4.2.2. Laboratory tests

The experiments were performed at Faculty of Agriculture, Dalhousie University to calibrate the ACCU-RATE controller for proper application rate and calculation of response time using clay filler. The growers normally operate the fertilizer spreader at ground speeds of 3.2 km hr^{-1} or 4.8 km hr^{-1} for fertilizer applications in wild blueberry fields. Therefore, MVRG fertilizer spreader was operated at ground speeds of 3.2 km hr^{-1} and 4.8 km hr^{-1} for calibrating ACCU-RATE controller. The fertilizer application rate of

200 kg ha^{-1} (grower's application rate) was fixed in ACCU-RATE controller and the clay filler from each nozzle and using different combination of nozzles was collected and

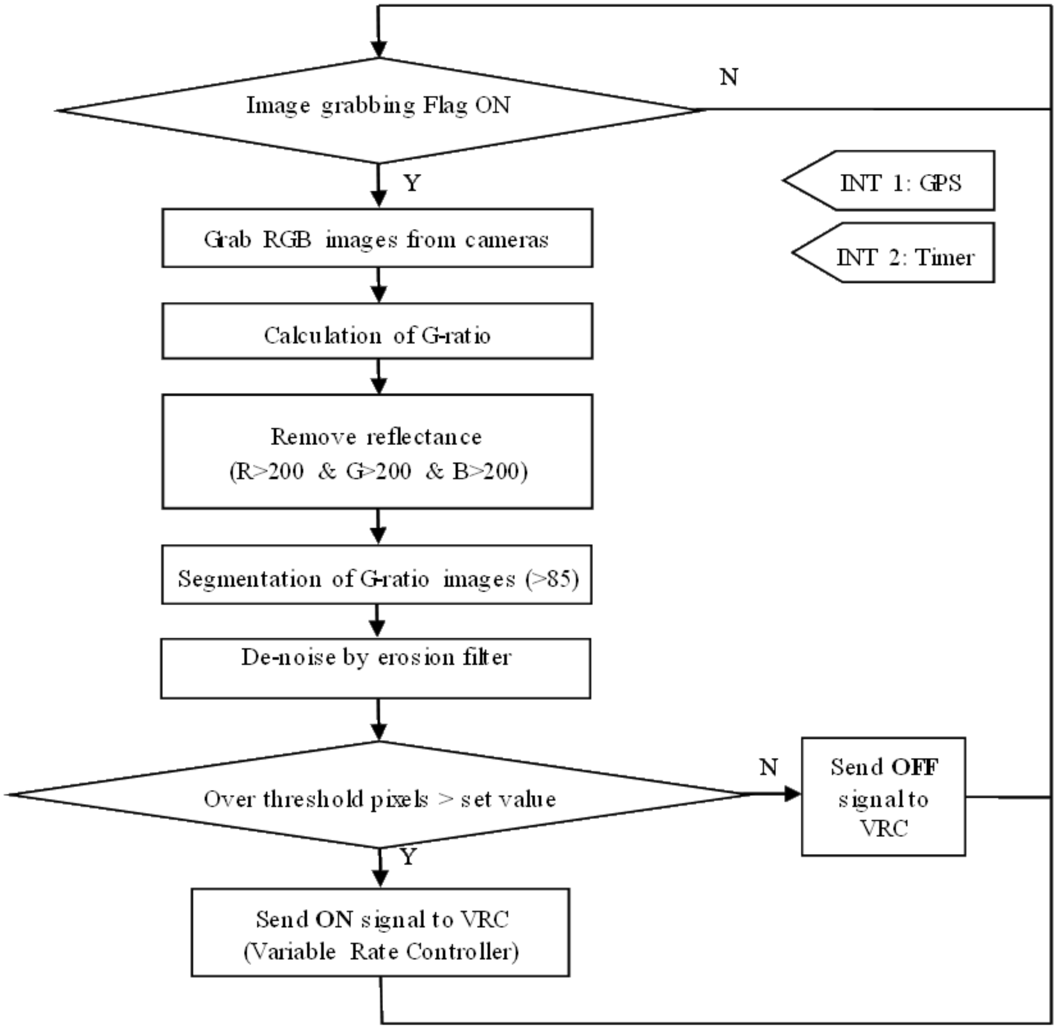


Figure 4-1. Flowchart displaying the complete process from foliage detection to fertilizer discharge using digital color cameras.

weighed manually. This experiment was repeated three times and the manual weight measurements were averaged. The average weight readings were converted to application rate (kg ha^{-1}) and the ACCU-RATE controller readings were compared with manually measured application rate to examine the performance accuracy of the controller. The experiment was repeated to calibrate ACCU-RATE controller using actual fertilizer.

The MVRG fertilizer spreader equipped with a 7.32 m look-ahead camera boom consisting of six µEye color cameras connected with computer and 8-channel computerized VRC via USB cables (Figure 3-1). The experiment, using clay filler was conducted at the Engineering Department, Faculty of Agriculture, Dalhousie University to calculate response time (i.e., lag time between look-ahead camera boom detection and fertilizer application) for 8-channel computerized VRC to open the nozzle at right target after receiving target detection information from the front look-ahead camera boom. The time taken by the clay filler to travel from venture cups to outlet nozzle and the time to build up the cone of clay filler from nozzle was added up in calculating response time for precise real-time fertilizer application in the areas where the targets have been detected. A light emitting diode (LED) bulb was wired into a switch on the VRC. An image recording camera was positioned in front of the nozzle being inspected to record the video. The video was recorded with 149 frames per second when the camera boom detected the target and LED bulb turned on until the opening of nozzle to spread fertilizer in the desired location. The response time calculation test was repeated for each nozzle at different static pressures (4.98, 6.23 and 7.47 kPa) attained by varying the fan speed of blower and the recorded videos were analyzed using V1 HOME 2.0 software (Interactive Frontiers Inc., Plymouth, MI, USA), allowing for a frame by frame analysis of response time between target detection and fertilizer application.

4.2.3. Field test

The use of actual fertilizer for extensive testing of MVRG fertilizer spreader in the field was not feasible as it can adversely affect the field soil conditions and environment. For this reason, clay filler was used for evaluating software and hardware components of MVRG fertilizer spreader in the field. A small scale field test was conducted using clay filler at BEEC, Faculty of Agriculture, Dalhousie University. A test track (7.3 m x 57 m) was made in the selected field (45° 23' 17" N, 63° 14' 13" W) to examine the accuracy of MVRG fertilizer spreader to apply fertilizer in the areas where the targets were detected. The artificial bare spots were made using orange colored tarps placed at random locations in the selected track. The track boundary and artificial bare spots were mapped with the real-time kinematics global positioning system (RTK-GPS). Twelve pre-weighed rat catchers (Catch Master, AP&G Co., Inc., Brooklyn, NY, USA) were placed on the artificial bare spots and green grass areas to collect applied clay filler. The spreader was operated on modified VR mode to testify the application of clay filler only in green grass areas and no application on artificial bare spots (orange tarps). The pre-weighted rat catchers were replaced with the new ones and the spreader was then operated at UN mode to apply clay filler, both in grass areas and artificial bare spots. Rat catchers were weighed again after the test and the weights of the clay filler collected by the rat catchers were calculated and recorded.

The weights of the clay filler collected by the rat catchers placed on the artificial bare spots in UN and VR treatments were compared using paired t-test. Similarly, a paired t-test was performed to compare both UN and VR treatments for the collected clay filler by the rat catchers placed in the green grass areas. The statistical analysis were performed in Minitab 16 (Minitab Inc. NY, USA)

4.3. Results and discussion

The principle components of MVRG fertilizer spreader (μEye cameras and controllers) were tested and calibrated at Faculty of Agriculture, Dalhousie University for target detection and fertilizer application through a specific section of the fertilizer boom where the target has been detected. Results of calibration indicated that the ACCU-RATE controller performed reliably and accurately to control the application rate for clay filler and fertilizer from combination of different pairs of nozzles at the ground speed of 3.2 km h^{-1} and 4.8 km h^{-1}. The difference between the ACCU-RATE controller reading and manually measured readings was found to be < 5%. The ACCU-RATE controller at the ground speed of 3.2 km h^{-1} was found to have a deviation of 3.19% in application rate when nozzles 1 and 2 were operated using clay filler as the applied material. However, the maximum deviation in the ACCU-RATE controller reading was observed to be 2.02% at the ground speed of 4.8 km h^{-1} when nozzles 1 to 4 were opened (Table 4-1). Similar results were obtained when the controller was calibrated using fertilizer as the applied material at 3.2 km hr^{-1} and 4.8 km hr^{-1} (Table 4-2). Overall, the results of calibration reported that the ACCU-RATE controller was accurate enough to dispense the correct amount of fertilizer based on the prescribed rate for different combinations of nozzles.

In order to assess the accuracy of the ACCU-RATE controller for the individual pair of nozzles the fertilizer spreader was operated at the ground speed of 3.2 km h^{-1} and 4.8 km h^{-1}, using clay filler and fertilizer as an applied material. The difference between

Table 4-1. Comparison of ACCU-RATE controller reading with manually measured clay filler application rate from different combination of nozzles at 3.2 km hr^{-1} and 4.8 km hr^{-1}ground speeds.

3.2 km hr^{-1}ground speed						
Number of Nozzles	1, 2	1 to 4	1 to 6	1 to 8	1 to 10	All 12
ACCU-RATE Controller (kg ha^{-1})	200.00	200.00	200.00	200.00	200.00	200.00
Manually Measured (kg ha^{-1})	206.38	204.62	202.67	201.22	200.05	200.55
Difference (%)	+3.19	+2.31	+1.34	+0.84	+0.03	+0.28
4.8 km hr^{-1}ground speed						
Number of Nozzles	1, 2	1 to 4	1 to 6	1 to 8	1 to 10	All 12
ACCU-RATE Controller (kg ha^{-1})	200.00	200.00	200.00	200.00	200.00	200.00
Manually Measured (kg ha^{-1})	202.60	204.04	201.84	197.82	197.07	198.38
Difference (%)	+1.30	+2.02	+0.92	-1.10	-1.47	-0.81

Table 4-2. Comparison of ACCU-RATE controller reading with manually measured fertilizer application rate from different combination of nozzles at 3.2 km hr^{-1} and 4.8 km hr^{-1}ground speeds.

3.2 km hr^{-1}ground speed						
Number of Nozzles	1, 2	1 to 4	1 to 6	1 to 8	1 to 10	All 12
ACCU-RATE Controller (kg ha^{-1})	200.00	200.00	200.00	200.00	200.00	200.00
Manually Measured (kg ha^{-1})	206.32	204.80	203.41	201.12	199.61	200.60
Difference (%)	+3.16	+2.40	+1.71	+0.56	-0.20	+0.30
4.8 km hr^{-1}ground speed						
Number of Nozzles	1, 2	1 to 4	1 to 6	1 to 8	1 to 10	All 12
ACCU-RATE Controller (kg ha^{-1})	200.00	200.00	200.00	200.00	200.00	200.00
Manually Measured (kg ha^{-1})	205.49	206.28	202.07	201.04	200.73	202.30
Difference (%)	+2.75	+3.14	+1.04	+0.52	+0.37	+1.15

the observed reading from the ACCU-RATE controller and manually measured readings from each pair of nozzles was found to be < 5% using both clay filler and fertilizer (Tables 4-3 and 4-4).

The maximum deviation from the ACCU-RATE controller at the ground speed of 3.2 km h^{-1} was observed when nozzles 7 and 8 were operated for clay filler. The actual application rate from this pair of nozzles was 3.76% less than the theoretical application rate (i.e., the application rate fed in ACCU-RATE controller). The least deviation (0.28%) was observed when nozzles 9 and 10 were operated at 3.2 km h^{-1}. The maximum deviation from the ACCU-RATE controller at the ground speed of 4.8 km h^{-1} was found to be 4.92% when nozzles 7 and 8 were operated. The second last pair of nozzles (i.e., nozzles 9 and 10) at the ground speed of 4.8 km h^{-1} was found to have least deviation (i.e., 1.73%) when compared with manually measured application rate (Table 4-3). Similar results were obtained when each pair of nozzles were calibrated separately using fertilizer as the applied material (Table 4-4).

The C++ calculation was performed to measure the image acquisition and processing time with a C++ millisecond timer function using a ruggedized laptop (2.5 GHz Intel® Core™2 Duo CPU) (Chang et al., 2012b). Image processing time for foliage/artificial bare spot detection for six images plus time required for sending the signal from computer to VRC was found to be 0.21 s (Table 4-5). The fan speed was varied to get static pressures of 4.98, 6.23 and 7.47 kPa. The time taken by the VRC to clay filler discharge from the spreader nozzles was calculated at these static pressures. The results of the response time calculation indicated that the time required from VRC to clay filler discharge was higher at a static pressure of 4.98 kPa when compared with 6.23

Table 4-3. Comparison of ACCU-RATE controller reading with manually measured clay filler application rate from individual pair of nozzles at 3.2 km hr^{-1} and 4.8 km h^{-1}ground speeds.

3.2 km hr^{-1}ground speed						
Number of Nozzles	1, 2	3, 4	5, 6	7, 8	9, 10	11, 12
ACCU-RATE Controller (kg ha^{-1})	200.00	200.00	200.00	200.00	200.00	200.00
Manually Measured (kg ha^{-1})	206.52	206.39	196.98	192.76	200.55	203.46
Difference (%)	+3.26	+3.20	-1.53	-3.76	+0.28	+1.02
4.8 km hr^{-1}ground speed						
Number of Nozzles	1, 2	3, 4	5, 6	7, 8	9, 10	11, 12
ACCU-RATE Controller (kg ha^{-1})	200.00	200.00	200.00	200.00	200.00	200.00
Manually Measured (kg ha^{-1})	204.18	206.81	195.83	190.15	196.59	204.03
Difference (%)	+2.09	+3.41	-2.13	-4.92	-1.73	+2.02

Table 4-4. Comparison of ACCU-RATE controller reading with manually measured fertilizer application rate from individual pair of nozzles at 3.2 km hr^{-1} and 4.8 km h^{-1}ground speeds.

3.2 km hr^{-1}ground speed						
Number of Nozzles	1, 2	3, 4	5, 6	7, 8	9, 10	11, 12
ACCU-RATE Controller (kg ha^{-1})	200.00	200.00	200.00	200.00	200.00	200.00
Manually Measured (kg ha^{-1})	206.52	206.10	195.07	191.93	200.51	203.41
Difference (%)	+3.27	+3.05	-2.53	-4.20	+0.26	+1.71
4.8 km hr^{-1}ground speed						
Number of Nozzles	1, 2	3, 4	5, 6	7, 8	9, 10	11, 12
ACCU-RATE Controller (kg ha^{-1})	200.00	200.00	200.00	200.00	200.00	200.00
Manually Measured (kg ha^{-1})	204.77	206.34	195.45	190.91	198.11	204.45
Difference (%)	+2.39	+3.17	-2.33	-4.76	-0.95	+2.23

and 7.47 kPa. Moreover, it was also found that the least time was taken by the clay filler to come out of the nozzles at a static pressure of 7.47 kPa (Table 4-5). The reason for the lower delay time when fan was operating faster (i.e., at static pressure of 7.47 kPa) was due to direct relationship of fan speed and air velocity. The faster the airstream is the more force it applies on the material to be conveyed (Baker et al., 1994). The results of the tests at the static pressures of 4.98 and 6.23 kPa are presented in appendix A (Table A1 and A2, Appendix 'A'). The results of the VRC response time indicated that the time taken by the clay filler to come out of the nozzles kept on reducing on moving from outer nozzles to inner nozzles. The maximum time taken by the nozzle 1 was 2.38 s, while the minimum time consumed by nozzle 6 was 1.57 s to dispense the clay filler (Table 4-5). This reduction in response time was due to the reduced distance of nozzles from the hopper and metering rollers.

Table 4-5. Response time using clay filler for 8-channel computerized VRC to open nozzle in the specific section of the boom where the target detected at static pressure of 7.47 kPa.

Nozzle No.	Image taken/processing time (from camera to VRC) (s)	LED bulb start time (s)	Clay filler dispense time (s)	Response time (s)
1	0.21	5.01	7.39	2.38
2		3.66	5.90	2.24
3		3.25	5.31	2.06
4		3.07	4.92	1.85
5		3.53	5.25	1.72
6		3.59	5.16	1.57
7		3.55	5.13	1.58
8		4.23	5.95	1.72
9		3.92	5.77	1.85
10		3.27	5.30	2.03
11		3.45	5.67	2.22
12		3.64	6.01	2.37

Similarly, the time taken by the VRC to discharge fertilizer from each nozzle of the spreader was calculated by varying the fan speed (i.e., to give static pressures of 4.98, 6.23 and 7.47 kPa). The results of response time for fertilizer were in agreement with our findings for clay filler suggesting lower response time at the static pressure of 7.47 kPa (Table 4-6). The results of the tests at the static pressures of 4.98 and 6.23 kPa are presented in appendix A (Table A3 and A4, Appendix 'A'). These results showed that the response time using fertilizer was less as compared to clay filler. The possible reason of different response time at same fan speed (7.47 kPa) can be due to the nature of the material being conveyed. Rizk (1986) reported that the clay filler having greater bulk density requires more time to reach the outlet as compared to fertilizer. These results were in agreement with the findings of Baker et al. (1994).

Table 4-6. Response time using fertilizer for 8-channel computerized VRC to open nozzle in the specific section of the boom where the target detected at static pressure of 7.47 kPa.

Nozzle No.	Image taken/processing time (from camera to VRC) (s)	LED bulb start time (s)	Fertilizer dispense time (s)	Reponse time (s)
1	0.21	4.16	6.41	2.25
2		3.59	5.67	2.08
3		3.79	5.51	1.72
4		4.07	5.70	1.63
5		3.40	4.92	1.52
6		2.96	4.42	1.46
7		2.64	4.10	1.46
8		3.29	4.82	1.53
9		3.52	5.15	1.63
10		3.11	4.85	1.74
11		3.22	5.28	2.06
12		5.07	7.32	2.25

After successful calibrations of the ACCU-RATE controller and calculation of response time, the MVRG fertilizer spreader was tested at BEEC for real-time performance evaluation using clay filler. The application rate was fixed at 200 kg ha^{-1} and the fan speed was set to give static pressure of 7.47 kPa. The MVRG fertilizer spreader was operated at the tractor ground speed of 3.2 km hr^{-1} with the response time of 2.59 s programmed into the VRC. The front boom was spaced far enough ahead of the rear spreader boom to compensate for the time lag needed to process the images and dispense clay filler. The MVRG fertilizer spreader was operated at VR mode to detect the foliage/artificial bare spots using sensing and control system to apply clay filler only on foliage. The grasses were treated as foliage to dispense clay filler at VR mode. The MVRG fertilizer spreader was also operated at UN mode to apply clay filler at both artificial bare spots and grasses for comparison.

The results of the paired t-test indicated that there was significant difference (P-value < 0.0001) in both treatments (i.e., UN and VR) when weights of the clay filler collected from artificial bare spots were compared, suggesting that the MVRG fertilizer spreader performed accurately to detect and leave artificial bare spots un-fertilized (Table 4-7). These results also reported that there was non-significant difference (P-value = 0.58) in UN and VR treatments when weights collected from foliage (grass) areas were compared (Table 4-7). This non-significant difference between both treatments suggested that there was no difference in applying clay filler in grass areas of the selected track using either mode of operation.

Table 4-7. Paired comparison of the data collected at VR and UN mode for MVRG fertilizer spreader using clay filler in grass field.

Comparison of VR and UN treatments in terms of clay filler applied on artificial bare spots

Treatment (n)	Minimum ($g\ m^{-2}$)	Maximum ($g\ m^{-2}$)	Mean ($g\ m^{-2}$)	Standard Deviation ($g\ m^{-2}$)	P-value
VRB (12)	0.0	9.3	3.0	3.0	<0.0001
UNB (12)	10.3	33.0	20.3	6.7	

Comparison of VR and UN treatments in terms of clay filler applied on green grass areas

Treatment (n)	Minimum ($g\ m^{-2}$)	Maximum ($g\ m^{-2}$)	Mean ($g\ m^{-2}$)	Standard Deviation ($g\ m^{-2}$)	P-value
VRG (12)	7.0	43.3	20.7	10.7	0.58
UNG (12)	10.3	32.7	19.0	6.3	

4.4. Summary and conclusions

The µEye cameras and controller were tested and calibrated for target detection and fertilizer application through a specific section of the fertilizer boom. The ACCU-RATE controller performed reliably and efficiently to control the fertilizer application rate through each pair of nozzles and different combinations of nozzles with < 5% difference from manual measurements. Image processing time for foliage/bare spot detection for six images plus time required for sending the signal from computer to VRC was 0.21 s. The response time of 2.38 s was programmed into the VRC using clay filler and the front boom was spaced far enough ahead of the rear spreader boom to compensate for the time lag needed to process and spread clay filler in the areas where target have been detected. The performance accuracy test suggested that the MVRG fertilizer spreader performed efficiently and rapidly while conducting field operations, as it detected the artificial bare spots in real-time and applied clay filler only on the target areas. Therefore, the MVRG fertilizer spreader could be used to further expand the fertilization capabilities and allow for spot-application of fertilizer only on as needed basis. The spot-application of fertilizer using MVRG fertilizer spreader can result in increased input use efficiency and reduce cost of production while minimizing the environmental risks.

CHAPTER 5

PERFORMANCE EVALUATION OF MODIFIED VARIABLE RATE GRANULAR FERTILIZER SPREADER FOR SPOT-APPLICATION OF FERTILIZER IN COMMERCIAL WILD BLUEBERRY FIELDS

5.1 Introduction

The wild blueberry is an endogenous plant which is an important horticultural crop in northeastern North America (Percival and Privé, 2002). Wild blueberry crops are usually fertilized by the growers with 30-50 kg N ha^{-1} as ammonium nitrate or urea (Trevett, 1962; Hall et al., 1967). Most agricultural systems utilize ammonium and nitrate as the major forms of inorganic nitrogen available to plants (Keeney and Walsh, 1972). Despite the fact that these inorganic forms of nitrogen are less effective on most calciphile plants, but they are effective on calcifuge plants significantly, including wild blueberries (Korcak, 1988). Townsend (1966) examined the response of wild blueberry towards the use of ammonia- and nitrate-based forms of nitrogen. He found wild blueberry responded better when ammonia-based forms of nitrogen were used.

Research efforts to determine the impact of fertilization in wild blueberry fields has shown improved nutrient uptake by plants, however, yield varied inconsistently in response to fertilizer applications (Eaton et al., 2009). Eaton (1994) found that repeated NPK fertilizer applications combined with herbicides resulted in increased stem lengths and fruit bud numbers, whereas, yield response was not consistent. A study conducted in Newfoundland indicated that the use of herbicide and nitrogen fertilizers significantly increased yield over 8 years, whereas the effect of fertilizer containing P only had no effect on yield (Penney and McRae, 2000). Moreover, a 12 year study on second cropping demonstrated that the plant growth and yields were elevated in both first and second crops with the application of NPK fertilizer (Eaton and Nams 2006). Percival and Privé (2002) conducted an experiment to assess the impact of fertilizer application on wild blueberry yield at three different sites in Nova Scotia. They found that the yield increased by 23, 27, and 25% as compared to control (no fertilizer application) at the selected sites. They also reported that nitrogen formulation influenced the wild blueberry yield and must be considered while developing management strategies.

Most agricultural systems have the objective of precise application of crop inputs like fertilizer applications (Al-Gaadi and Ayers, 1999). According to Schueller (1991) varying the crop inputs in relation to the variations within the field is called precision farming. Precision agriculture is the way of combining different technologies together to make agriculture economically and environmentally more viable (Al-Gaadi and Ayers, 1999; Castro et al., 2011). Variable rate fertilization is a precision agriculture technology which is achieved by using fast controllers and computers, accurate GPS receivers, GIS, remote sensing techniques, actuators, and sensors (Schumann, 2010). One of the recent innovations in precision agriculture is real-time fertilizer applications. Real-time management strategy normally does not need GPS data as the decisions about agrochemical rates and crop targets are made “on-the-go” at the time of fertilization. This type of system is widely used for fertilizing agronomic and horticultural crops (Schumann, 2010). Although research efforts throughout North America have been extended for the development of VR technologies for various crops to date, minor attention has been paid to wild blueberry production systems. In this present study, performance accuracy of MVRG fertilizer spreader for spot-application of fertilizer was evaluated in selected wild blueberry fields in central Nova Scotia.

5.2 Methodology

After successful evaluation of principle components and preliminary field test conducted at the BEEC, Faculty of Agriculture, Dalhousie University, a wild blueberry field was selected near Debert (45° 26' 28" N and 63° 27' 02" W) in central Nova Scotia. The performance of software and hardware components of the MVRG fertilizer spreader for spot-application of fertilizer was evaluated in the selected field. A test track 7.3 m in width and 100 m in length was made. Equal number (12) of bare spots/weed patches and plant areas were randomly selected in the field. Pre-weighed rat catchers and standard collection pans were placed on the selected bare spots/weed patches and plant areas to collect the applied clay filler. The software and hardware components of the spreader were performance tested for spot-application at three different ground speeds; 1.6, 3.2 and 4.8 km h^{-1} and two different light conditions; mainly cloudy and mainly sunny. The spreader was operated at VR and UN modes for each ground speed and light condition. The clay filler collected by each rat catcher and standard collection pan was weighed and recorded.

The weights of the clay filler collected by the rat catchers and standard collection pans placed on the bare spots/weed patches in UN and VR treatments were compared using paired t-test. Paired t-test was also performed to compare both UN and VR treatments for the collected clay filler by the rat catchers and standard pans placed in the plant areas using Minitab 16.

After testing the hardware and software components of MVRG fertilizer spreader in wild blueberry field using clay filler, another wild blueberry field, Kemptown (45° 31' 50" N and 63° 07' 45" W) was selected for actual fertilization. The field was divided into three sections (i.e., VRPM, VRPRD, and UN) and the management zones were delineated on the basis of slope variation within the field. Prior to the fertilizer application, six bare spots/weed patches and plant areas were selected in each management zone of VRPM and VRPRD sections of the field to place rat catchers and standard collection pans for evaluation of spreader. The small bare spots/weed patches of VRPRD section were expected to receive no fertilizer, unlike small bare spots/weed patches of VRPM section. The weight data collected using VRPM and VRPRD treatments were compared using two sample t-tests. Detailed procedure can be seen in Chapter 3 (Materials and Methods).

5.3 Results and Discussion

Results of this study indicated that automated identification of irregularly shaped and spaced bare spots/weed patches in real-time and spot-application of clay filler using sensing and control system would help in avoiding useless fertilization in non-plant areas.

5.3.1 Evaluation with Clay Filler Application

5.3.1.1 Mainly Sunny Condition

The experiment was conducted in Debert, on May 08, 2012 to test the performance of software and hardware components of MVRG fertilizer spreader in actual wild blueberry field at three different ground speeds (1.6, 3.2, 4.8 km hr^{-1}). The day was mainly sunny. The temperature ranged from -2 to 18 °C, average humidity was noted as 58.5 %, and wind speed was 10.5 km hr^{-1} from the West (National Climate Data and Information Archive, 2011).

The weights of the clay filler collected by the rat catchers placed on plant areas in UN and VR treatments were compared using paired t-test. Results indicated non-significant difference between UN and VR treatments in applying clay filler in plant areas at ground speed of 1.6 km hr^{-1} (Table 5-1). The weight of the clay filler collected by the rat catchers at UN and VR modes of operation ranged from 0.38 to 0.60 g and from 0.39 to 0.64 g, respectively. Similar results were obtained at the ground speeds of 3.2 km hr^{-1} and 4.8 km hr^{-1}, indicating no difference between UN and VR treatments in applying clay filler in plant areas of the wild blueberry field (Table 5-1).

Paired t-test was performed to compare both UN and VR treatments for the collected clay filler by the rat catchers placed on the bare spots/weed patches. The MVRG fertilizer spreader was operated at a ground speed of 1.6 km hr^{-1} and the results indicated a significant difference between UN and VR treatments (Table 5-1). The results suggested that the bare spots/weed patches were avoided during fertilization using VR treatment. Similar results were obtained at the ground speed of 3.2 km hr^{-1}, suggesting that the fertilization can be avoided in bare spots/weed patches of the field using VR treatment (Table 5-1). The test was repeated at the ground speed of 4.8 km hr^{-1}. The weight of the clay filler collected by the rat catchers at UN and VR modes at this speed of operation ranged from 0.37 to 0.88 g and from 0 to 0.76 g, respectively. Despite the significant difference between UN and VR treatments, few bare spots received clay filler using VR treatment at 4.8 km hr^{-1} (Table 5-1). The potential reason could be the insufficient distance between the front camera boom and rear spreader boom reducing the time for image processing at speed of 4.8 km hr^{-1}. The visual observation while setting out experiments suggested that the custom made image texture analysis algorithm was

Table 5-1. Comparison of UN and VR treatments using rat catchers at ground speeds of 1.6, 3.2 and 4.8 km h^{-1}.

Comparison of VR and UN treatments in terms of clay filler applied on plant areas at all speeds

Ground Speeds (km hr^{-1})	Treatment (n)	Minimum (g m^{-2})	Maximum (g m^{-2})	Mean (g m^{-2})	Standard Deviation (g m^{-2})	P-value
1.6	VRP (12)	13.0	21.3	16.7	2.7	0.55
	UNP (12)	12.7	20.0	16.0	2.3	
3.2	VRP (12)	14.3	26.7	21.0	4.0	0.96
	UNP (12)	13.0	29.0	20.7	4.7	
4.8	VRP (12)	12.7	27.3	18.7	4.3	0.27
	UNP (12)	14.0	26.3	20.0	4.0	

Comparison of VR and UN treatments in terms of clay filler applied on bare spots at all speeds

Ground Speeds (km hr^{-1})	Treatment (n)	Minimum (g m^{-2})	Maximum (g m^{-2})	Mean (g m^{-2})	Standard Deviation (g m^{-2})	P-value
1.6	VRP (12)	0.0	2.7	1.0	1.0	<0.0001
	UNP (12)	12.3	20.7	16.0	2.7	
3.2	VRP (12)	0.0	2.3	1.0	0.7	<0.0001
	UNP (12)	13.0	27.0	18.7	4.3	
4.8	VRP (12)	0.0	25.3	15.7	8.7	0.03
	UNP (12)	12.3	29.3	21.0	5.0	

Significant at $P < 0.05$

unable to perform efficiently due to minor changes in camera focus. The intensive jerks and vibrations felt by the front camera boom might cause minor alteration in the focus of the μEye color cameras resulting in the acquisition of blurry images. Therefore, the developed image texture analysis algorithm could not differentiate plants and bare spots effectively at 4.8 km hr^{-1} ground speed of MVRG fertilizer spreader.

The developed software and hardware components were tested again by using standard collection pans for collecting applied clay filler. The MVRG fertilizer spreader was first operated at ground speed of 1.6 km hr^{-1}. The weights of the clay filler collected by standard pans placed on plant areas in UN and VR treatments were compared using paired t-test. Results obtained were similar to those obtained for rat catchers, suggesting non-significant difference between UN and VR treatments in applying clay filler in plant areas (Table 5-2). Similar results were obtained at the ground speeds of 3.2 km hr^{-1} and 4.8 km hr^{-1}, indicating non-significant difference between UN and VR treatments in applying clay filler in plant areas of wild blueberry field (Table 5-2).

Paired t-test was performed to compare UN and VR treatments for the collected clay filler by the standard collection pans placed on the bare spots/weed patches. The results obtained at the ground speeds of 1.6 and 3.2 km hr^{-1} were found to be satisfactory. The results indicated significant difference between UN and VR treatments (Table 5-2), suggesting that the bare spots/weed patches received no clay filler during VR treatment. The test was repeated at the ground speed of 4.8 km hr^{-1}. The results indicated significant difference between UN and VR treatments (Table 5-2). The results also suggested under-performance of MVRG fertilizer spreader at the ground speed of 4.8 km hr^{-1}, as the real-time sensing system failed to detect few bare spots during VR treatment. The insufficient

Table 5-2. Comparison of UN and VR treatments using standard collection pans at ground speeds of 1.6, 3.2 and 4.8 km h^{-1}.

Comparison of VR and UN treatments in terms of clay filler applied on plant areas at all speeds

Ground Speeds (km hr^{-1})	Treatment (n)	Minimum (g m^{-2})	Maximum (g m^{-2})	Mean (g m^{-2})	Standard Deviation (g m^{-2})	P-value
1.6	VRP (12)	15.5	21.0	18.0	1.8	0.23
	UNP (12)	13.0	21.5	16.8	2.5	
3.2	VRP (12)	15.5	20.1	17.8	1.5	0.12
	UNP (12)	12.6	18.8	16.5	1.8	
4.8	VRP (12)	13.0	19.5	16.6	2.0	0.85
	UNP (12)	13.1	20.1	16.5	2.1	

Comparison of VR and UN treatments in terms of clay filler applied on bare spots at all speeds

Ground Speeds (km hr^{-1})	Treatment (n)	Minimum (g m^{-2})	Maximum (g m^{-2})	Mean (g m^{-2})	Standard Deviation (g m^{-2})	P-value
1.6	VRP (12)	0.0	3.3	1.2	1.0	<0.0001
	UNP (12)	14.8	19.7	17.2	1.7	
3.2	VRP (12)	0.0	3.2	1.2	1.2	<0.0001
	UNP (12)	14.0	19.5	17.0	1.7	
4.8	VRP (12)	0.0	18.3	10.2	7.2	0.02
	UNP (12)	12.3	20.0	16.7	2.2	

Significant at $P < 0.05$

distance between front and rear boom and the intensive jerks felt by the front camera boom while moving on undulating surface could be the reasons for under-performance of spreader. Therefore, the developed software could not differentiate plants and weed patches at 4.8 km hr^{-1} ground speed of MVRG fertilizer spreader.

5.3.1.2 Mainly Cloudy Condition

The experiment was conducted in Debert, on May 07, 2012 to test the performance of software and hardware components of MVRG fertilizer spreader for spot-application in actual wild blueberry field at three different ground speeds (1.6, 3.2, 4.8 km hr^{-1}). The day was mainly cloudy. The temperature ranged from 1 to 11 °C, average humidity was noted as 78 %, and wind speed was 16 km hr^{-1} from the South (National Climate Data and Information Archive, 2011).

The experiment was designed for the paired comparison of the weights of the clay filler collected by the rat catchers placed on plant areas in UN and VR treatments. Results indicated a non-significant difference between UN and VR treatments in applying clay filler in plant areas at ground speed of 1.6 km hr^{-1} (Table 5-3). The weight of the clay filler collected by the rat catchers at UN and VR modes of operation ranged from 0.36 to 0.67 g and from 0.39 to 0.67 g, respectively. Similar results were obtained at the ground speeds of 3.2 km hr^{-1} and 4.8 km hr^{-1}, suggesting non-significant difference between UN and VR treatments in applying clay filler in plant areas of wild blueberry field (Table 5-3).

Paired t-test was performed to compare UN and VR treatments for the collected clay filler by the rat catchers placed on the bare spots/weed patches. The ground speed of

Table 5-3. Comparison of UN and VR treatments using rat catchers at ground speeds of 1.6, 3.2 and 4.8 km h^{-1}.

Comparison of VR and UN treatments in terms of clay filler applied on plant areas at all speeds

Ground Speeds (km hr^{-1})	Treatment (n)	Minimum (g m^{-2})	Maximum (g m^{-2})	Mean (g m^{-2})	Standard Deviation (g m^{-2})	P-value
1.6	VRP (12)	13.0	22.3	17.7	2.7	0.63
	UNP (12)	12.0	22.3	17.0	3.0	
3.2	VRP (12)	12.3	21.3	16.7	3.3	0.38
	UNP (12)	15.3	19.7	17.7	2.0	
4.8	VRP (12)	12.0	20.7	16.0	3.0	0.20
	UNP (12)	14.0	24.0	18.7	2.3	

Comparison of VR and UN treatments in terms of clay filler applied on bare spots at all speeds

Ground Speeds (km hr^{-1})	Treatment (n)	Minimum (g m^{-2})	Maximum (g m^{-2})	Mean (g m^{-2})	Standard Deviation (g m^{-2})	P-value
1.6	VRP (12)	0.0	5.7	2.3	2.0	<0.0001
	UNP (12)	12.7	21.3	17.7	3.0	
3.2	VRP (12)	0.0	2.0	0.7	0.7	<0.0001
	UNP (12)	9.7	19.7	15.7	2.7	
4.8	VRP (12)	0.0	20.7	12.3	7.0	0.08
	UNP (12)	12.0	22.3	16.7	2.7	

Significant at $P < 0.05$

MVRG fertilizer spreader was first maintained at 1.6 km hr^{-1}. Results indicating significant difference between UN and VR treatments suggested no clay filler application in bare spots/weed patches during VR treatment. Similar results were obtained by operating MVRG fertilizer spreader at the ground speed of 3.2 km hr^{-1} (Table 5-3). The test was repeated at the ground speed of 4.8 km hr^{-1} to characterize the performance accuracy of real-time detection system for spot-application at high ground speed. Results indicated non-significant difference between UN and VR treatments, suggesting that bare spots/weed patches received clay filler during VR treatment (Table 5-3). The weight of the clay filler collected by the rat catchers at UN and VR modes of operation ranged from 0.36 to 0.67 g and from 0 to 0.62 g, respectively (Table 5-3). In addition to the intensive jerks on undulating ground surface, cloudy conditions resulted in the under-performance of real-time detection system of MVRG fertilizer spreader. Other potential reason could be the insufficient distance between the front camera boom and rear spreader boom reducing the time for image processing at speed of 4.8 km hr^{-1}.

The procedure under mainly cloudy conditions was repeated using standard collection pans for collecting applied clay filler. The MVRG fertilizer spreader was operated at three different ground speeds (1.6, 3.2 and 4.8 km hr^{-1}). Visual observation indicated that the MVRG fertilizer spreader performed efficiently in applying clay filler in plant areas at ground speeds of 1.6, 3.2 and 4.8 km hr^{-1}. The weights of the clay filler collected by standard pans placed on plant areas in UN and VR treatments were compared using paired t-test. Results showed similar trend as shown by the rat catchers, suggesting non-significant difference between UN and VR treatments in applying clay filler in plant areas (Table 5-4).

Table 5-4. Comparison of UN and VR treatments using standard collection pans at ground speeds of 1.6, 3.2 and 4.8 km h^{-1}.

Comparison of VR and UN treatments in terms of clay filler applied on plant areas at all speeds

Ground Speeds (km hr^{-1})	Treatment (n)	Minimum (g m^{-2})	Maximum (g m^{-2})	Mean (g m^{-2})	Standard Deviation (g m^{-2})	P-value
1.6	VRP (12)	15.7	21.0	18.5	1.7	0.20
	UNP (12)	13.7	19.8	17.2	2.0	
3.2	VRP (12)	14.8	20.3	17.8	1.5	0.73
	UNP (12)	13.2	21.0	17.5	1.8	
4.8	VRP (12)	13.8	18.7	17.2	1.8	0.90
	UNP (12)	13.2	20.0	17.2	2.2	

Comparison of VR and UN treatments in terms of clay filler applied on bare spots at all speeds

Ground Speeds (km hr^{-1})	Treatment (n)	Minimum (g m^{-2})	Maximum (g m^{-2})	Mean (g m^{-2})	Standard Deviation (g m^{-2})	P-value
1.6	VRP (12)	0.0	2.7	1.2	1.0	<0.0001
	UNP (12)	15.0	20.8	17.8	1.8	
3.2	VRP (12)	0.0	2.3	1.0	0.8	<0.0001
	UNP (12)	14.3	19.3	17.3	1.5	
4.8	VRP (12)	0.0	19.5	13.2	5.2	0.02
	UNP (12)	14.0	20.0	17.0	2.0	

Significant at $P < 0.05$

The experiment for paired comparison was designed to compare UN and VR treatments using standard collection pans for collecting applied clay filler. The standard pans were placed on the bare spots/weed patches of the selected track in the wild blueberry field. The results obtained at the ground speeds of 1.6 and 3.2 km hr^{-1} showed efficient results. The results indicated significant difference between UN and VR treatments (Table 5-4), suggesting that the bare spots/weed patches were avoided during clay filler application in VR treatment. The test was repeated at the ground speed of 4.8 km hr^{-1}. Although the results indicated significant difference between UN and VR treatments, the visual observation and P-value (0.02) indicated under-performance of MVRG fertilizer spreader (Table 5-4). The results suggested that the real-time detection system of MVRG fertilizer spreader failed to detect few bare spots at the ground speed of 4.8 km hr^{-1}. The reason could be the insufficient spacing between the front camera boom and rear spreader boom limiting the time for image processing at speed of 4.8 km hr^{-1}. The visual observation suggested that the minor changes in camera focus affect the performance of custom made image texture analysis algorithm. The intensive jerks and vibrations felt by the front camera boom might cause minor changes in the focus of the µEye color cameras resulting in the acquisition of blurry images. Therefore, the developed image texture analysis algorithm could not differentiate plants and bare spots effectively at 4.8 km hr^{-1} ground speed of MVRG fertilizer spreader.

5.3.2 Evaluation with Actual Fertilizer Application

The evaluation results suggested that the MVRG fertilizer spreader can be used for fertilization in wild blueberry fields. A test was devised in order to assess the performance of MVRG fertilizer spreader in a wild blueberry field at Kemptown site.

Equal number (i.e., 6) of non-plant areas (i.e., small bare spots and weed patches) and plant areas were selected in each management zone of VRPM and VRPRD sections of the field to place rat catchers and standard collection pans for evaluating MVRG fertilizer spreader during fertilization in the wild blueberry field. The MVRG fertilizer spreader was operated at the ground speed of 3.2 km hr^{-1}. A two sample t-test was performed to compare VRPM and VRPRD treatments. The rat catchers placed in the steep slope plant areas (fertilizer application rate of 200 kg ha^{-1}) of the field were compared. The results indicated non-significant difference between VRPM and VRPRD treatments (Table 5-5). The results also suggested that both treatments were identical in applying fertilizer in plant areas. Similar results were obtained for moderate slope (fertilizer application rate of 150 kg ha^{-1}) and low slope plant areas (fertilizer application rate of 100 kg ha^{-1}) of the field (Table 5-5).

The weights of the fertilizer collected by the rat catchers placed on the bare spots/weed patches of VRPM and VRPRD treatment sections were also compared using two sample t-test. The results indicated significant difference between VRPM and VRPRD treatments (Table 5-5), suggesting that the MVRG fertilizer spreader performed efficiently in applying fertilizer only in plant areas. The standard collection pans were placed beside the rat catchers in the selected bare spots/weed patches and plant areas of VRPM and VRPRD sections of the field. The results indicated non-significant difference between VRPM and VRPRD treatments (Table 5-6), suggesting no difference in applying fertilizer in plant areas. Whereas, significant difference between both treatments (Table 5-6) suggested that the MVRG fertilizer spreader can be used to avoid fertilization in bare spots/weed patches of the fields.

Table 5-5. Comparison of VRPM and VRPRD treatments using rat catchers at different slope zones.

***Comparison of VRPRD and VRPM treatments in terms of fertilizer applied on plant areas**

Slope Zones	Treatment (n)	Minimum ($g\ m^{-2}$)	Maximum ($g\ m^{-2}$)	Mean ($g\ m^{-2}$)	Standard Deviation ($g\ m^{-2}$)	P-value
Steep slope	VRPRD (6)	15.3	20.0	18.0	2.0	0.71
	VRPM (6)	14.3	21.0	17.3	2.7	
Moderate slope	VRPRD (6)	9.7	15.3	12.3	2.0	0.36
	VRPM (6)	11.3	15.7	13.3	1.7	
Low slope	VRPRD (6)	6.3	10.3	8.0	1.7	0.42
	VRPM (6)	6.0	11.0	8.7	2.0	

***Comparison of VRPRD and VRPM treatments in terms of fertilizer applied on bare spots/weed patches**

Slope Zones	Treatment (n)	Minimum ($g\ m^{-2}$)	Maximum ($g\ m^{-2}$)	Mean ($g\ m^{-2}$)	Standard Deviation ($g\ m^{-2}$)	P-value
Steep slope	VRPRD (6)	0.0	1.0	0.3	0.3	<0.0001
	VRPM (6)	16.3	20.7	18.7	1.7	
Moderate slope	VRPRD (6)	0.0	1.0	0.3	0.3	<0.0001
	VRPM (6)	9.3	13.3	11.7	1.3	
Low slope	VRPRD (6)	0.0	0.7	0.3	0.3	<0.0001
	VRPM (6)	6.7	11.3	9.0	1.7	

Significant at $P < 0.05$

*Test was conducted at the ground speed of 3.2 km hr^{-1}

Table 5-6. Comparison of VRPM and VRPRD treatments using standard collection pans at different slope zones.

***Comparison of VRPRD and VRPM treatments in terms of clay filler applied on plant areas**

Slope Zones	**Treatment (n)**	**Minimum (g m^{-2})**	**Maximum (g m^{-2})**	**Mean (g m^{-2})**	**Standard Deviation (g m^{-2})**	**P-value**
Steep slope	VRPRD (6)	15.8	19.0	17.7	1.2	0.51
	VRPM (6)	14.7	19.0	17.0	1.5	
Moderate slope	VRPRD (6)	11.7	15.2	14.5	1.2	0.10
	VRPM (6)	12.8	15.5	13.8	1.0	
Low slope	VRPRD (6)	6.3	10.5	8.7	1.7	0.71
	VRPM (6)	7.3	11.3	9.0	1.3	

***Comparison of VRPRD and VRPM treatments in terms of clay filler applied on bare spots**

Slope Zones	**Treatment (n)**	**Minimum (g m^{-2})**	**Maximum (g m^{-2})**	**Mean (g m^{-2})**	**Standard Deviation (g m^{-2})**	**P-value**
Steep slope	VRPRD (6)	0.0	1.3	0.5	0.5	<0.0001
	VRPM (6)	15.0	20.7	17.7	2.0	
Moderate slope	VRPRD (6)	0.0	0.5	0.2	0.2	<0.0001
	VRPM (6)	11.5	14.0	13.0	1.7	
Low slope	VRPRD (6)	0.0	0.5	0.2	0.2	<0.0001
	VRPM (6)	6.3	10.3	8.5	1.5	

Significant at $P < 0.05$

*Test was conducted at the ground speed of 3.2 km hr^{-1}

5.4 Summary and Conclusions

The MVRG fertilizer spreader performed efficiently and reliably for spot-application of fertilizer (applying fertilizer only in plant areas) under different light conditions and at different ground speeds. The ground speeds of 1.6 and 3.2 km hr^{-1} were found to be most suitable for real-time detection and fertilizer application under sunny or cloudy conditions. The under-performance of MVRG fertilizer spreader was also observed at ground speed of 4.8 km hr^{-1} under sunny and cloudy conditions. The insufficient spacing between the front camera boom and rear spreader boom could be the potential reason. Moreover, the custom made image texture analysis algorithm found to have performance issues due to minor changes in camera focus. The vibrations in the front camera boom might cause minor changes in the focus of the μEye color cameras resulting in the acquisition of blurry images. Therefore, the developed image texture analysis algorithm could not differentiate plants and bare spots effectively at 4.8 km hr^{-1} ground speed of MVRG fertilizer spreader. The MVRG fertilizer spreader was operated at the ground speed of 3.2 km hr^{-1} for actual fertilization in wild blueberry fields.

This MVRG fertilizer spreader could be considered as the vital precision agriculture machine which can be used for spot-application of fertilizer in wild blueberry fields. Further research and experimentation are needed to make it rigorous to apply the fertilizer at higher speeds in commercial wild blueberry fields. The knowledge of agricultural engineers, agricultural economists, and agrochemical experts must be combined to develop the high performance expert system required for a VR spreader with real-time detection system.

CHAPTER 6

QUANTIFYING THE IMPACT OF FERTILIZER APPLICATION ON NITROGEN LEACHING THROUGH NON-VEGETATED AREAS OF FIELD USING A MODIFIED VARIABLE RATE FERTILIZER SPREADER

6.1 Introduction

Nitrogen fertilizer is one of the main sources of increased agricultural production over the past few years (Di and Cameron, 2002). Increased N application to soil beyond the plant requirement can result in adverse environmental impacts (Zhao et al., 2003). A large proportion of applied N is either incorporated into the soil organic matter, is lost through volatilization to atmosphere, or lost through leaching to ground water (Di and Cameron, 2002). In general, most soils have lower concentrations of ammonium (NH_4^+) compared to nitrate (NO_3^-) due to the fact that NH_4^+ is converted readily to NO_3^- (Di and Cameron, 2002). The intensive agricultural activities using economically viable agricultural production systems to meet the world food requirements have increased the chances of groundwater contamination with NO_3^--N leaching, especially in developed countries (Addiscott, 1996; Cameron et al., 1997). Drinking water containing high concentrations of NO_3^--N are considered harmful to infant's health having age of 1 year or less as it can cause methemoglobinemia (blue-baby syndrome) (Di and Cameron, 2002). The world and national health organizations have set the standards for drinking water, allowing maximum of 10 - 11.3 mg NO_3^--N L^{-1} (World Health Organization, 1984). The two basic factors which determine the amount of NO_3^--N leached from the plant root zone to groundwater are the accumulation of NO_3^--N in the soil beyond the plant requirement and drainage volume. The presence of high concentration of NO_3^- in the soil profile accompanied with heavy rainfall event can cause high NO_3^--N leaching

(Di and Cameron, 2002). The NO_3^--N present in the soil may be the result of either applied N in form of fertilizers, or mineralization of soil organic N (Addiscott, 1996).

Wild blueberry is a heath plant which likes strongly acidic and low fertility soils. Under such circumstances the microbial production of NO_3^--N is restricted, whereas NH_4^+-N is likely to be a major part of inorganic N in wild blueberry fields (Colgrove and Roberts, 1956). However, some nitrification of NH_4^+-N in acidic soils cannot be ignored (Vitousek and Melillo, 1979). If the NO_3^--N production is greater, it can result in higher losses of N through leaching and denitrification, because wild blueberries are reported to be inefficient users of nitrate (Townsend, 1969). Also, the shallow rooting depth of the wild blueberry (i.e., 15 cm below the soil surface) (Trevett, 1962), and intensive rainfall may result in high NO_3^--N and NH_4^+-N leaching risk in wild blueberry production system (Thyssen and Percival, 2006).

The improved site-specific management practices considering the within field variability can reduce the risk associated with groundwater pollution. Dampney et al. (1999) compared uniform and variable rate application of fertilizer to see the impact of both treatments on winter wheat. They found significant reduction in NO_3^--N leaching using variable rate treatment. Kitchen et al. (1995) reported lower amounts of N in the soil profile with variable rate application of N in corn. Variable rate fertilization based on slope variations in wild blueberry fields also reduced nutrient leaching (Saleem et al., 2013). Wild blueberry fields are developed on deforested farmlands that have gentle to severe topography and have significant proportion of bare spots and weed patches that vary from 30% to 50% of the total field area (Zaman et al., 2010b). Fertilizer application in bare spots/weed patches can result in increased cost of production and environmental contamination through NO_3^--N and NH_4^+-N leaching.

In this present study, existing VRG fertilizer spreader was modified for real-time detection and application of fertilizer only in plant areas of wild blueberry field. The automated sensing and control system of MVRG fertilizer spreader was used in conjunction with the GPS guided prescription map based on slope variation. The function of the automated sensing and control system was to detect bare spots and weed patches in real-time and no application of fertilizer in these specific areas, whereas, the prescription map was used to vary the fertilizer rate based on slope variation. It was hypothesized that VR fertilization using MVRG fertilizer spreader could reduce leaching losses from bare spots and weed patches of the field as compared to VR fertilization using existing VRG fertilizer spreader. Therefore, the objective of this research was to quantify the impact of variable rate fertilization on subsurface water quality using MVRG fertilizer spreader.

6.2 Materials and Methods

Management zones were delineated on the basis of slope variation (Figure 3-8 a, Chapter 3). Fertilization was performed by dividing the selected fields into three sections VRPM, VRPRD system, and the UN for comparison (Figure 3-8 b, Chapter 3). Two lysimeters were installed in each slope zone of a sub-section (Figure 3-10, Chapter 3). The lysimeters were installed such that each slope zone of a sub-section contains 2 lysimeters (Figure 3-10, Chapter 3). Subsurface water samples were collected in the sampling bottles from suction lysimeters after every heavy rainfall event during vegetative year. Vacuum was created in suction lysimeters before, or soon after heavy rainfall event using manual vacuum pump. Nalgene sampling containers were used for collecting leachates. The collected samples were immediately placed in a freezer to avoid volatilization of analytes. Samples were analyzed for NH_4^+-N and NO_3^--N at the Water Quality Research Laboratory, Faculty of Agriculture, Dalhousie University. The samples collected were analyzed for NH_4^+-N and NO_3^--N. The experimental design was a split-plot with three fertilizer treatments and three slope zones. The design was modeled with fertilizer treatment as a main plot and slope as sub plot, and sampling date was considered as repeated measure factor. Response variables for the statistical analysis were the concentrations of NH_4^+-N and NO_3^--N in soil leachates. The SAS (SAS Institute Inc., NC, USA) was used to perform repeated measures analysis of variance to find any treatment effect. The mixed-model procedure at 5 % level of significance was used. Least significant (LS) means was used as the multiple means comparison for comparing significantly different treatments.

6.3 Results and Discussion

6.3.1 Nitrate Nitrogen Leaching

6.3.1.1 Kemptown Field

The results of repeated measure (RM) ANOVA indicated that mean NO_3^--N concentrations in the bare spots/weed patches of uniform treatment were significantly higher than the NO_3^--N concentrations in the bare spots/weed patches of VRPM and VRPRD treatment sections of the field. The mean NO_3^--N concentrations in soil leachate samples collected from the lysimeters installed in VRPRD treatment section ranged from 1.84 to 2.06 mg L^{-1}, while mean values for VRPM and UN treatment sections ranged from 2.57 to 3.80 mg L^{-1} and 3.84 to 7.40 mg L^{-1}, respectively (Table 6-1). The mean

Table 6-1. Effects of UN, VRPM and VRPRD fertilization techniques on mean NO_3^--N concentrations in soil leachates through bare spots of Kemptown Field.

Slope Zone	Fertilization Method	June 26 (mg L^{-1})	July 24 (mg L^{-1})	August 16 (mg L^{-1})	August 28 (mg L^{-1})	Mean (mg L^{-1})
Zone 1	VRPM	2.50^{ab}	2.98^{cd}	4.84^{b}	4.88^{c}	3.80^{b}
	UN	2.36^{b}	3.21^{bc}	4.87^{b}	4.94^{c}	3.84^{b}
	VRPRD	2.25^{bc}	2.24^{ef}	2.00^{d}	1.74^{d}	2.06^{c}
Zone 2	VRPM	2.73^{ab}	3.75^{b}	3.90^{c}	4.36^{c}	3.68^{b}
	UN	3.13^{a}	5.57^{a}	7.69^{a}	8.01^{b}	6.10^{a}
	VRPRD	2.27^{bc}	2.19^{ef}	2.11^{d}	1.56^{d}	2.04^{c}
Zone 3	VRPM	2.33^{b}	2.46^{de}	2.71^{d}	2.78^{cd}	2.57^{c}
	UN	3.15^{a}	5.84^{a}	7.93^{a}	12.68^{a}	7.40^{a}
	VRPRD	1.62^{c}	1.84^{f}	1.91^{b}	1.98^{d}	1.84^{c}
Mean	VRPM	2.52^{ab}	3.06^{ab}	3.82^{a}	4.01^{a}	3.35^{a}
	UN	2.88^{a}	4.87^{a}	6.83^{b}	8.54^{b}	5.78^{b}
	VRPRD	2.05^{b}	2.09^{b}	2.01^{a}	1.76^{c}	1.98^{a}

RM ANOVA

Effect	DF	F-value	P-value
Fertilization Method (F)	2	171.55	<0.0001
Slope Zone (S)	2	20.78	<0.0001
Time (T)	3	63.20	<0.0001
F × S	4	44.07	<0.0001
F × T	6	33.38	<0.0001
F × S × T	12	5.13	<0.0001

Significantly different means contain different letters at a significance level of 0.05.

Significant at $P < 0.05$

NO_3^--N concentration in leachates collected from the bare spots/weed patches of VRPRD section was lower than the mean NO_3^--N concentration of VRPM section. The higher NO_3^--N concentrations in the leachate samples collected from lysimeters might continue percolating downwards through the porous soil until they reach the groundwater. Thus, there is the possibility of potential impact of NO_3^--N pollutants on groundwater. The NO_3^--N concentrations obtained from bare spots/weed patches of zone 1 (Z1) indicated non-significant difference between VRPM and UN treatments with mean values of 3.80 and 3.84 mg L^{-1}, respectively. The mean NO_3^--N concentration (i.e., 2.06 mg L^{-1}) in bare spots/weed patches of VRPRD section was significantly lower than that of VRPM and UN sections (Table 6-1). Similar result for NO_3^--N concentrations in bare spots/weed patches of VRPM and UN sections was due to the application of identical fertilizer rate in Z1 (Figure 3-3 b, Chapter 3). The reason for significantly low NO_3^--N in VRPRD section might be due to no fertilizer application in bare spots/weed patches of this section. The results also indicated significant difference between all three treatments in terms of NO_3^--N concentration in leachates collected from zone 2 (Z2) of treatment sections. The VRPRD section was found to have significantly lower NO_3^--N concentration (i.e., 2.04 mg L^{-1}) in this area of the field. The possible reason for the lower mean value of NO_3^--N in Z2 of VRPRD section could be due to the fact that there was no fertilizer application in bare spots/weed patches of this section (Figure 3-3 b, Chapter 3). The results also indicated that some NO_3^--N concentration was found in the leachates collected from VRPRD section which could be due to the nutrients accumulated through runoff in bare spots/weed patches of this section. Similar trend was observed for zone 3 (Z3) indicating significant difference between VRPM and UN treatments with mean NO_3^--N concentration of 2.57 and 7.40 mg L^{-1}, respectively. The NO_3^--N concentrations in leachates collected from bare spots/weed patches of VRPRD and VRPM sections were found to be non-significantly different from each other with mean values of 1.84 and 2.57 mg L^{-1}, respectively. Nevertheless, the mean NO_3^--N concentration in leachates collected from of VRPRD section was lower than that of VRPM section because of no fertilizer application in bare spots/weed patches of this VRPRD section (Table 6-1). The higher fertilizer application rate (200 kg ha^{-1}) in UN section as compared to VRPM section (100 kg ha^{-1}) in Z3 could be one of the reasons for more concentration of NO_3^--N in soil leachates for UN treatment section of the field. The other possible reason for higher mean values of NO_3^--N in Z3 for UN treatment section could be the accumulation of nutrients in low slope areas. On the other hand, no discrimination of bare spots/weed patches in Z3 of VRPM section might be one of the reasons for more concentration of NO_3^--N in the bare spots/weed patches of VRPM section as compared to VRPRD section of the field. The results obtained were found in agreement with the findings of Farooque et al. (2012) and Saleem et al. (2013), who reported higher values for NO_3^--N in low slope areas and vice versa for wild blueberry fields. The variation in NO_3^--N for soil leachate samples from bare spots/weed patches present in wild blueberry fields indicated significance of modifications in the existing VRG fertilizer spreader. Therefore, the results suggested the use of MVRG fertilizer spreader for spot-specific fertilizer application in wild blueberry fields is better option to avoid nutrient leaching in bare spots/weed patches to subsurface water (Table 6-1).

The results showed that NO_3^--N concentrations in soil leachates increased with time indicating the occurrence of nitrification process in wild blueberry fields. Thyssen and Percival (2006) also reported that nitrate concentrations in blueberry soils increases with time. Although, the acidic nature of wild blueberry fields hinders the nitrification process, however in general, nitrification proceeds slowly. Wide spread presence of wild blueberry plants and low pH conditions in wild blueberry fields can be considered as the favorable conditions for autotrophic nitrifying bacteria which are the main contributors to nitrate production. On the basis of these results, it can be concluded that the apparent acidity was not been able to restrict nitrifying activities in wild blueberry fields.

In general, NO_3^--N leaching losses from the bare spots/weed patches of VRPM treatment section were significantly lower than UN treatment section of the field. Previous studies carried out on different cropping systems also supported the findings of this study (Shahandeh et al., 2005; Zaman et al., 2006). The NO_3^--N leaching losses from VRPRD treatment section was low but not significantly different when compared with VRPM section. The reason of less NO_3^--N leaching losses from the bare spots/weed patches of VRPRD section could be due to real-time detection and no fertilizer application in these specific areas of the field. Some NO_3^--N losses in leachates could be due to accumulation of nitrates in the bare spots/weed patches due to runoff after heavy rainfall event.

6.3.1.2 Cattle Market Field

The results of the experiment indicated that mean NO_3^--N concentrations in the bare spots/weed patches of UN and VRPM sections were significantly higher than the NO_3^--N concentrations in the bare spots/weed patches of VRPRD treatment section. The mean NO_3^--N concentrations in soil leachates collected from the lysimeters installed in VRPRD treatment section ranged from 1.31 to 1.87 mg L^{-1}. The mean values for VRPM and UN treatment sections ranged from 2.32 to 3.01 mg L^{-1} and 2.87 to 8.85 mg L^{-1}, respectively (Table 6-2). The higher concentrations of NO_3^--N leaching through the bare spots/weed patches of UN and VRPM treatment sections can deteriorate the ground water quality. Results indicated significantly lower NO_3^--N concentration (1.87 mg L^{-1}) in the leachates collected from the bare spots/weed patches of zone 1 (Z1) of VRPRD treatment section as compared to VRPM and UN sections (Table 6-2). The reason of significantly lower NO_3^--N concentration in VRPRD section might be due to no fertilizer application in bare spots/weed patches of this section. The results also suggested significant difference in NO_3^--N concentrations in leachates collected from zone 2 (Z2) of all three treatment sections (Table 6-2). The VRPRD section found to have significantly lower NO_3^--N concentration (1.75 mg L^{-1}) in Z2 as compared to VRPM and UN sections (Table 6-2). The possible reason for the lower mean value of NO_3^--N in Z2 of VRPRD section could be no fertilizer application in bare spots/weed patches of this section (Figure 3-3 b, Chapter 3). The concentration of NO_3^--N found in the leachates collected from VRPRD section could be due to the nutrients accumulated through runoff from plant areas to bare spots/weed patches of this section (Table 6-2). Similar results were observed for zone 3 (Z3) indicating significant difference between VRPRD, VRPM and UN treatments with mean NO_3^--N concentration of 1.31, 2.32 and 8.85 mg L^{-1}, respectively (Table 6-2). The difference of fertilizer application rate (200 kg ha^{-1}) in Z3 of UN and VRPM section (100 kg ha^{-1}) could be one of the reasons for higher concentration of NO_3^--N leaching through Z3 of UN treatment section. The other possible reason for higher mean values of NO_3^--N in Z3 for UN treatment section could be the accumulation of nutrients in low slope areas. Whereas, no fertilizer application in bare spots/weed patches of Z3 of the VRPRD section

Table 6-2. Effects of UN, VRPM and VRPRD fertilization techniques on mean NO_3^--N concentrations in soil leachates through bare spots of Cattle Market Field.

Slope Zone	Fertilization Method	May 25 (mg L^{-1})	June 08 (mg L^{-1})	July 26 (mg L^{-1})	August 10 (mg L^{-1})	Mean (mg L^{-1})
Zone 1	VRPM	1.68^{cd}	2.18^{de}	3.58^{cd}	3.80^{c}	2.81^{c}
	UN	1.77^{c}	2.25^{d}	3.71^{c}	3.76^{c}	2.87^{c}
	VRPRD	1.36^{def}	1.76^{ef}	2.12^{e}	2.23^{e}	1.87^{e}
Zone 2	VRPM	1.41^{cde}	3.09^{c}	3.81^{c}	3.73^{c}	3.01^{c}
	UN	3.13^{b}	7.06^{b}	9.96^{b}	10.37^{b}	7.63^{b}
	VRPRD	1.24^{ef}	1.57^{fg}	2.03^{ef}	2.15^{e}	1.75^{e}
Zone 3	VRPM	1.09^{ef}	2.20^{de}	2.96^{d}	3.02^{d}	2.32^{d}
	UN	3.82^{a}	8.14^{a}	11.78^{a}	11.64^{a}	8.85^{a}
	VRPRD	1.02^{f}	1.19^{g}	1.42^{f}	1.63^{e}	1.31^{f}
Mean	VRPM	1.39^{ac}	2.49^{a}	3.45^{a}	3.52^{a}	2.71^{a}
	UN	2.91^{c}	5.82^{b}	8.48^{b}	8.59^{b}	6.45^{b}
	VRPRD	1.21^{b}	1.51^{c}	1.86^{c}	2.00^{c}	1.64^{c}

RM ANOVA

Effect	DF	F-value	P-value
Fertilization Method (F)	2	254.61	<0.0001
Slope Zone (S)	2	33.47	<0.0001
Time (T)	3	79.18	<0.0001
F × S	4	49.21	<0.0001
F × T	6	40.16	<0.0001
F × S × T	12	18.31	<0.0001

Significantly different means contain different letters at a significance level of 0.05.

Significant at $P < 0.05$

might be one of the reasons for less concentration of NO_3^--N in the bare spots/weed patches of VRPRD section as compared to VRPM section. The results of this study were found in agreement with Shahandeh et al. (2005), Zaman et al. (2006), and Saleem et al. (2013). They reported that NO_3^--N leaching losses in a VRPM section were significantly lower as compared to NO_3^--N leaching concentrations in UN treatment sections under different cropping systems.

Similar to Kemptown field the results, suggesting the higher concentrations of NO_3^--N in leachates collected from the bare spots/weed patches of VRPM and UN sections as compared to VRPRD section, were found in agreement with the findings of Saleem et al. (2013). Overall results suggested the delineation of management zones based on the slope variation along with the modifications in existing VRG fertilizer spreader for real-time detection and fertilizer application only in plant areas. The modifications in the existing VRG fertilizer spreader can reduce NO_3^--N concentrations in the leachate water through the small and irregularly shaped bare spots/weed patches of the field. These improved management practices using MVRG fertilizer spreader can result in increased profit margin and environmental protection.

6.3.2 Ammonium Nitrogen Leaching

6.3.2.1 Kemptown Field

The NH_4^+-N concentration in the leachates collected from the bare spots at the start of the growing season was found to be very high which could be due to the use of ammonium based fertilizer. The results indicated non-significant difference ($P\text{-value} > 0.05$) in NH_4^+-N leaching from bare spots of VRPM and UN sections, when the samples collected from Z1 were compared. Whereas, the concentration of NH_4^+-N in the subsurface water samples collected from the bare spots that exists in the Z1 of VRPRD section was found to be significantly lower (P-value < 0.05) as compared to VRPM and UN sections. The application of same fertilizer rate (i.e., 200 kg ha^{-1}) without discriminating bare spots and plants in Z1 of both treatment sections (i.e., VRPM and UN) could be the reason of similar NH_4^+-N concentrations in leachates. The reason of significantly lower loss of NH_4^+-N in subsurface water samples could be no fertilizer application in the bare spots of the VRPRD section using real-time sensing and control system of MVRG fertilizer spreader. Comparison of the NH_4^+-N concentrations in the subsurface water samples collected from the bare spots existing in Z2 of VRPM, UN and VRPRD treatment sections indicated significant difference among treatments (Table 6-3). Lower fertilizer application rate (i.e., 150 kg ha^{-1}) in Z2 of VRPM section as compared to UN section might be the reason for less NH_4^+-N concentrations in soil leachates collected from bare spots of VRPM section (Figure 3-3 b, Chapter 3). Again, no fertilizer application in the bare spots of VRPRD section might be the reason for low NH_4^+-N concentrations in the leachates collected from Z2 of this section. Similar results were obtained from the subsurface water samples collected from the lysimeters installed in the Z3 of VRPM, UN and VRPRD sections, with mean NH_4^+-N of 1.49 mg L^{-1}, 4.70 mg L^{-1} and 0.51 mg L^{-1}, respectively (Table 6-3). The difference in NH_4^+-N concentrations from the bare spots of VRPM and UN sections could be due to the difference in fertilizer application rates in Z3 of both sections. Although, the NH_4^+-N concentration in all three slope zones of VRPRD section was significantly lower due to the no fertilizer application in bare spots/weed patches of this section, however, small amounts of NH_4^+-N in the leachates could be due

Table 6-3. Effects of UN, VRPM and VRPRD fertilization techniques on mean NH_4^+-N concentrations in soil leachates through bare spots of Kemptown Field.

Slope Zone	Fertilization Method	June 26 (mg L^{-1})	July 24 (mg L^{-1})	August 16 (mg L^{-1})	August 28 (mg L^{-1})	Mean (mg L^{-1})
Zone 1	VRPM	5.05^{c}	3.76^{ab}	3.17^{a}	1.94^{b}	3.48^{c}
	UN	5.13^{c}	3.90^{b}	3.35^{ab}	1.99^{b}	3.59^{bc}
	VRPRD	0.94^{f}	0.78^{d}	0.67^{cd}	0.62^{d}	0.75^{f}
Zone 2	VRPM	3.64^{d}	3.34^{b}	2.45^{b}	1.67^{b}	2.77^{d}
	UN	5.73^{b}	4.79^{b}	3.45^{ab}	2.58^{a}	4.14^{ab}
	VRPRD	0.75^{f}	0.66^{d}	0.58^{d}	0.56^{d}	0.64^{f}
Zone 3	VRPM	1.92^{e}	1.71^{c}	1.21^{c}	1.15^{c}	1.49^{e}
	UN	6.72^{a}	5.18^{a}	4.02^{a}	2.87^{a}	4.70^{a}
	VRPRD	0.59^{f}	0.47^{d}	0.56^{d}	0.40^{d}	0.51^{f}
Mean	VRPM	3.54^{a}	2.94^{a}	2.28^{a}	1.59^{a}	2.58^{a}
	UN	5.86^{b}	4.62^{b}	3.61^{b}	2.48^{b}	4.14^{b}
	VRPRD	0.76^{c}	0.64^{c}	0.60^{c}	0.53^{c}	0.63^{c}

RM ANOVA

Effect	DF	F-value	P-value
Fertilization Method (F)	2	727.59	<0.0001
Slope Zone (S)	2	15.52	<0.0001
Time (T)	3	170.25	<0.0001
F × S	4	72.99	<0.0001
F × T	6	40.53	<0.0001
F × S × T	12	3.32	0.0008

Significantly different means contain different letters at a significance level of 0.05.

Significant at $P < 0.05$

to nutrient runoff from plant areas and accumulation of nutrients in the bare spots/weed patches.

The results of this study were found in consensus with the findings of Hong et al. (2006). They reported significantly lower NH_4^+-N concentration in subsurface water samples for VRPM treatment section as compared to UN treatment section. The results obtained were also supported by the findings of Saleem et al. (2013). They found significantly high NH_4^+-N leaching losses from the bare spots of the wild blueberry field after site-specific fertilization. Zaman et al. (2009) also suggested that fertilization in the bare spots should be avoided for wild blueberry fields. According to them no fertilization in bare spots will lower input costs and reduce NH_4^+-N leaching. Overall, the NH_4^+-N concentration collected from the bare spots in all three slope zones was significantly different for VRPM, UN and VRPRD sections.

The decreasing trend in NH_4^+-N concentrations after every rainfall event is due to nutrients uptake by plants, ammonium loss through runoff and leaching, and nitrification (Saleem et al., 2013). These results were also supported by the findings of Thyssen and Percival (2006). They reported that decrease in ammonium level increases nitrate concentration in leachates with time. Farooque (2010) also reported increase in soil pH below root zone in the wild blueberry fields. The elevated pH can accelerate the nitrification process in the wild blueberry fields.

6.3.2.2 Cattle Market Field

The mean values for NH_4^+-N concentration in subsurface water samples collected from the bare spots/weed patches of VRPRD treatment section were significantly lower as compared to VRPM and UN treatment sections with mean values of 0.73, 2.75, and

4.26 mg L^{-1}, respectively (Table 6-4). The mean NH_4^+-N concentration in leachate samples for VRPM and UN treatment sections were similar in Z1. Whereas, the NH_4^+-N concentration through the bare spots/weed patches of Z2 and Z3 of VRPM treatment section was significantly lower than UN treatment section throughout the study period (Table 6-4). Higher fertilizer application rate in Z2 and Z3 of UN treatment section as compared to VRPM section could be the reason for significant differences (Figure 3-3 b, Chapter 3). The mean NH_4^+-N concentration in the samples collected from the small bare spots/weed patches of VRPRD section were significantly lower for all three slope zones with mean values of 0.86 (Z1), 0.74 (Z2), and 0.60 (Z3) mg L^{-1} as compared to VRPM and UN sections (Table 6-4). Real-time detection and no fertilizer application in the bare spots/weed patches of the VRPRD section could be the reason for lower NH_4^+-N concentrations. Overall a decreasing trend was observed for VRPRD, VRPM and UN treatments during the study period (Table 6-4).

The mean concentrations of NH_4^+-N for VRPM treatment section at the start of the experiment were found to be 5.12, 4.07, and 2.47 mg L^{-1} for Z1, Z2, and Z3, respectively (Table 6-4). The results suggested the decrease in NH_4^+-N concentration with decrease in fertilizer application rates. These results were found in agreement with the findings of Burwell et al. (1976) and Saleem et al. (2013). They reported lower NH_4^+-N concentrations in subsurface water samples for low fertilizer inputs in various cropping systems. Similarly, the mean NH_4^+-N concentrations for VRPRD treatment section were found to be 1.06, 0.93, and 0.72 mg L^{-1} for Z1, Z2, and Z3, respectively, at the start of the study (Table 6-4). These results suggested significantly lower NH_4^+-N concentrations in the leachate samples collected from the bare spots/weed patches of the VRPRD section as

Table 6-4. Effects of UN, VRPM and VRPRD fertilization techniques on mean NH$_4^+$-N concentrations in soil leachates through bare spots of Cattle Market Field.

Slope Zone	Fertilization Method	May 25 (mg L^{-1})	June 08 (mg L^{-1})	July 26 (mg L^{-1})	August 10 (mg L^{-1})	Mean (mg L^{-1})
Zone 1	VRPM	5.12^{b}	4.04^{b}	3.05b^{c}	2.11^{b}	3.58^{c}
	UN	5.02^{b}	4.18^{b}	2.96b^{c}	2.47^{ab}	3.66^{c}
	VRPRD	1.06^{e}	0.91^{e}	0.80^{e}	0.69^{c}	0.86^{f}
Zone 2	VRPM	4.07^{c}	3.32^{c}	2.51^{c}	1.92^{b}	2.96^{d}
	UN	5.47^{b}	4.51^{b}	3.49^{ab}	2.86^{a}	4.08^{b}
	VRPRD	0.93^{e}	0.84^{e}	0.64^{e}	0.54^{c}	0.74^{f}
Zone 3	VRPM	2.47^{d}	2.02^{d}	1.45^{d}	0.88^{c}	1.70^{e}
	UN	7.04^{a}	6.09^{a}	3.99^{a}	3.01^{a}	5.03^{a}
	VRPRD	0.72^{e}	0.68e	0.54^{e}	0.47^{c}	0.60^{f}
Mean	VRPM	3.87^{a}	3.13^{a}	2.34^{ab}	1.64^{abc}	2.75^{a}
	UN	5.84^{b}	4.93^{b}	3.48^{b}	2.78^{b}	4.26^{b}
	VRPRD	0.90^{c}	0.81^{c}	0.66^{c}	0.57^{c}	0.73^{c}

RM ANOVA

Effect	DF	F-value	P-value
Fertilization Method (F)	2	486.23	<0.0001
Slope Zone (S)	2	4.13	0.0204
Time (T)	3	131.55	<0.0001
F × S	4	57.80	<0.0001
F × T	6	25.07	<0.0001
F × S × T	12	2.63	0.0062

Significantly different means contain different letters at a significance level of 0.05.

Significant at $P < 0.05$

compared to VRPM section of the field (Table 6-4). The results of the study were found in agreement with Saleem et al. (2013). They reported that useless fertilization in bare spots/weed patches can increase the risk of NH_4^+-N leaching.

6.3.3 Impact of Soil Properties on Nutrient Leaching

6.3.3.1 Kemptown Field

The results suggested that the sand content in Z3 of VRPM section was significantly lower as compared to Z2, with mean values of 51.14% and 56.85%, respectively. Whereas, non-significant difference was found between sand contents of Z1 and Z3 of VRPM section (Table B1, Appendix B). The sand contents in all three slope zones of UN section were found to be non-significantly different from each other, with Z3 containing lowest sand content (i.e., 52.07%) (Table B1, Appendix B). The results also reported that the sand contents in Z1 and Z3 of VRPRD section were significantly different from each other, with mean values of 59.79% and 49.88%, respectively. Although, the sand content in Z2 and Z3 of VRPRD section were non-significantly different from each other, but Z3 contained lower sand contents as compared to 52.86% of sand in Z2.

The comparison of mean values of clay content in all three slope zones of VRPM and VRPRD sections indicated that the Z3 of both sections contained significantly higher clay content with mean values of 11.77% and 10.60%, respectively. Whereas, the clay contents in Z1, Z2 and Z3 of UN section were found to be non-significantly different from each other with mean values of 10.21%, 9.89% and 10.48%, respectively (Table B1, Appendix B).

The comparison of SOM content in all three slope zones of VRPM, UN and VRPRD section indicated that the Z3 contained significantly higher values of SOM with mean values of 9.52%, 9.61% and 9.54%, respectively (Table B1, Appendix B). The results found were in agreement with Beckie et al. (1997), Zaman et al. (2009), and Saleem et al. (2013). They reported lower sand and higher clay and SOM contents in the low slope areas of the field, which can result in accumulation of more soil nutrients in these specific areas of the field. It was also reported that the soil EC in Z1 of VRPM and VRPRD sections was significantly lower as compared to Z3 of these sections, before fertilization. However, the soil EC in Z1, Z2 and Z3 of UN section was significantly different from each other with mean values of 46.12, 51.96 and 59.34 μS cm^{-1}, respectively. Similar results were obtained for soil EC after fertilization. However, the soil EC in Z2 and Z3 of UN and VRPRD sections were non-significantly different from each other after fertilization (Table B1, Appendix B). The silt content in all three slope zones of VRPM, UN and VRPRD sections were non-significantly different from each other, except for Z1 of VRPRD section which was significantly lower as compared to Z2 and Z3 of the same section with mean values of 30.95%, 37.42% and 39.52%, respectively (Table B1, Appendix B). The results suggesting non-significant difference in pH of all three slope zones of each section were found in agreement with Farooque et al. (2011). They reported no effect of fertilization in pH of the soil.

The comparison of soil NO_3^--N in all three slope zones of each section before and after fertilization reported significantly higher soil NO_3^--N in Z3 of each section (Table 6-5). However, the soil NO_3^{-1}-N in Z2 and Z3 of VRPRD section was found to be non-significantly different from each other after fertilization. Higher values of soil NO_3^{-1}-N in

Table 6-5. 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	VRPM	2.77^{a}	4.13^{a}	3.80^{b}	4.01^{a}	5.44^{a}	3.48^{c}
	UN	3.23^{ab}	4.22^{a}	3.84^{b}	3.63^{a}	5.22^{a}	3.59^{bc}
	VRPRD	2.87^{ab}	4.48^{b}	2.06^{c}	3.91^{a}	5.25^{a}	0.75^{f}
Zone 2	VRPM	3.27^{ab}	4.59^{a}	3.68^{b}	4.29^{a}	5.67^{a}	2.77^{d}
	UN	3.49^{b}	5.12^{ab}	6.82^{a}	4.04^{a}	5.97^{a}	4.14^{ab}
	VRPRD	3.13^{ab}	4.78^{b}	2.04^{c}	4.34^{a}	5.84^{a}	0.64^{f}
Zone 3	VRPM	4.43^{c}	6.25^{c}	2.57^{c}	5.58^{b}	8.01^{b}	1.49^{e}
	UN	4.38^{c}	7.55^{d}	7.40^{a}	5.54^{b}	9.99^{c}	4.70^{a}
	VRPRD	4.70^{c}	6.04^{bc}	1.84^{c}	5.28^{b}	7.84^{b}	0.51^{f}
Treatment Factor				Mixed ANOVA			
Fertilization Method (F)		NS	NS	***	NS	*	***
Slope Zone(S)		***	***	**	***	***	NS
F x S		NS	NS	***	NS	**	**

Significantly different means contain different letters 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

Z3 could be due to the surface runoff from steep and moderate slope areas and accumulation of nutrients in low slope areas of the field (Frank et al., 1994; Farooque, 2010; Tsui and Chen, 2010; Saleem et al., 2013). Similar trends were observed for soil NH_4^+-N before and after fertilization. In general an increase in soil NO_3^--N and NH_4^+-N was observed after fertilization.

6.3.3.2 Cattle Market Field

The results of ANOVA indicated significantly different values for soil properties in different slope zones for Cattle Market Field (Table B2, Appendix B). The sand contents in Z1 of VRPM, UN and VRPRD section were found to be 60.28, 60.42, and 62.07 %, respectively. The results also indicated decrease in sand contents as moved from Z1 to Z3 of the field with mean sand content values of 51.39, 50.71, and 52.14 % in Z3 of VRPM, UN, and VRPRD treatment sections, respectively (Table B2, Appendix B). The soil in the Z3 of the field for each section found to have significantly higher clay contents as compared to Z1 and Z2. The silt content in Z1 and Z3 of VRPM and UN sections were significantly different from each other. The silt content in all three slope zones of VRPRD section was found to be similar (Table B2, Appendix B).

The results suggested significantly higher SOM in Z3 of VRPM, UN and VRPRD treatment sections with mean values of 9.88, 9.57 and 9.16 %, respectively as compared to Z1 and Z2 (Table B2, Appendix B). The soil EC was found to be significantly lower in Z1 of all treatment sections as compared to Z2 and Z3, before fertilization. An increase in soil EC was observed after fertilization in all three slope zones of each section. The fertilization found to have non-significant effect on soil pH in all three slope zones of treatment sections (Table B2, Appendix B). The presence of higher clay content and

SOM in low lying areas of the field can result in higher nutrient retention in these specific areas of the field (Saleem et al., 2013).

The mean values for soil NH_4^+-N before fertilization in Z1 were 3.63, 3.46, and 3.73 mg kg^{-1} for VRPM, UN and VRPRD treatment sections, respectively. The results indicated significantly higher concentrations of soil NH_4^+-N in Z3 of VRPM, UN and VRPRD treatment sections with mean values of 5.23, 5.37, and 5.21 mg kg^{-1}, respectively as compared to Z1 and Z2 (Table B2, Appendix B). The results also indicated an increase in soil NH_4^+-N after fertilization in all three slope zones of each section. Significant difference in soil NH_4^+-N among all three slope zones were observed for VRPM and UN sections, with Z3 having the highest and Z1 having the lowest soil NH_4^+-N. Whereas, non-significant difference was found in soil NH_4^+-N retained by Z1 and Z2 of VRPRD sections (Table B2, Appendix B).

The mean soil NO_3^--N before fertilization in Z1 of VRPM, UN and VRPRD sections was found to be 2.46, 3.04, and 2.24 mg kg^{-1}, respectively (Table B2, Appendix B). Whereas, the Z3 found to have significantly higher values of soil NO_3^--N as compared to Z1 with mean values of 4.12, 3.78 and 3.92 mg kg^{-1} for VRPM, UN and VRPRD treatment sections, respectively (Table B2, Appendix B). The post-fertilization effects on soil NO_3^--N were found to have similarity with soil NH_4^+-N. Overall the results suggested an increase in soil NH_4^+-N and NO_3^--N after fertilization in wild blueberry fields (Table B2, Appendix B).

The comparison of soil NO_3^--N and NH_4^+-N in all three slope zones of each section before and after fertilization indicated significantly higher soil NO_3^--N and NH_4^+-N in Z3 of each section (Table 6-6). The relatively higher values of soil NO_3^{-1}-N and

Table 6-6. 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	VRPM	2.46^{de}	3.39^{e}	2.81^{c}	3.63^{c}	4.93^{e}	3.58^{c}
	UN	3.04^{cd}	4.05^{d}	2.87^{c}	3.46^{c}	5.31^{de}	3.66^{c}
	VRPRD	2.24^{e}	3.67^{de}	1.87^{e}	3.73^{c}	4.98^{e}	0.86^{f}
Zone 2	VRPM	3.01^{cd}	4.92^{c}	3.01^{c}	4.18^{b}	5.68^{d}	2.96^{d}
	UN	3.36^{bc}	5.13^{c}	7.63^{b}	4.14^{b}	6.20^{c}	4.08^{b}
	VRPRD	2.71^{de}	4.05^{d}	1.75^{e}	4.16^{b}	5.12^{e}	0.74^{f}
Zone 3	VRPM	4.12^{a}	5.98^{b}	2.32^{d}	5.23^{a}	7.82^{a}	1.70^{e}
	UN	3.78^{ab}	7.36^{a}	8.85^{a}	5.37^{a}	7.98^{a}	5.03^{a}
	VRPRD	3.92^{ab}	5.32^{c}	1.31^{f}	5.21^{a}	7.26^{b}	0.60^{f}

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

Significantly different means contain different letters 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

NH_4^+-N in Z3 could be due to the runoff load from steep and moderate slope areas and accumulation of nutrients in low slope areas of the field (Frank et al., 1994; Farooque, 2010; Tsui and Chen, 2010; Saleem et al., 2013). Overall the results indicated an increase in soil NO_3^--N and NH_4^+-N after fertilization (Table 6-6).

The higher values of soil NO_3^--N and NH_4^+-N in low slope areas of the field can enhance subsurface water contamination through leaching of NO_3^--N and NH_4^+-N (Saleem et al., 2013). Therefore, VR fertilization in conjunction with real-time sensing for spot-application of fertilizer only in plant areas can reduce subsurface water contamination through nutrient leaching.

6.4 Summary and Conclusions

The MVRG fertilizer spreader equipped with real-time sensing and control system applied fertilizer only in plant areas of the wild blueberry field. Therefore, the NO_3^--N and NH_4^+-N leaching through the bare spots/weed patches of the VRPRD section was decreased significantly as compared to the VRPM and UN sections of the field. The bare spots/weed patches in the low slope areas of VRPM and UN sections indicated higher concentrations of NO_3^--N and NH_4^+-N as compared to VRPRD section in Kemptown and Cattle Market Fields.

On the basis of the results obtained, it can be concluded that the real-time sensing and control system in the MVRG fertilizer spreader helped in avoiding the bare spots/weed patches during fertilization. Therefore, the use of real-time sensing and control system along with the prescription maps can result in reduced nitrate and ammonium leaching through the bare spots/ weed patches of the wild blueberry fields.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The main objective of this project was to evaluate MVRG fertilizer spreader for spot-application of fertilizer only in plant areas. Results of this study indicated that the ACCU-RATE controller performed efficiently with < 5% difference from manual application rate to control the fertilizer application rate through each pair of nozzles and different combinations of nozzles. The overall response time of 2.59 s was programmed into the VRC to apply clay filler accurately in the areas where target have been detected. The results of the field tests suggested that the MVRG fertilizer spreader performed reliably, as it detected the artificial bare spots in real-time and applied clay filler only on the target areas.

The MVRG fertilizer spreader was also tested for spot-application of fertilizer (applying fertilizer only in plant areas) under different light conditions and at different ground speeds. The ground speeds of 1.6 and 3.2 km hr^{-1} were found to be most suitable for fertilizer application using real-time sensing and control system under sunny or cloudy conditions. The MVRG fertilizer spreader was found less efficient in detecting bare spots/weed patches at ground speed of 4.8 km hr^{-1} under sunny and cloudy conditions. The reason for the under-performance could be the insufficient distance between the front camera boom and rear spreader boom reducing the time for image processing at speed of 4.8 km hr^{-1}. The visual observation while setting out experiments suggested that the custom made image texture analysis algorithm was unable to perform efficiently due to minor changes in camera focus. The intensive jerks and vibrations felt by the front camera boom might cause minor alteration in the focus of the µEye color cameras resulting in the acquisition of blurry images. Therefore, the developed image texture analysis algorithm could not differentiate plants and bare spots effectively at 4.8 km hr^{-1} ground speed of MVRG fertilizer spreader. The ground speed of 3.2 km hr^{-1} was selected for actual fertilization in wild blueberry fields using MVRG fertilizer spreader.

An experiment was conducted in a commercial wild blueberry field to examine the impact of nutrient leaching on subsurface water quality. Small bare spots/weed patches were selected to install lysimeter within the fields. The selected fields were divided into three sections (VRPRD, VRPM, and UN) for fertilization. Each section was further divided into three sub-sections, such that each sub-section contains all three management zones. The lysimeters were installed in a way that each slope zone of a sub-section contains 2 lysimeters. Subsurface water samples were collected in the sampling bottles from suction lysimeters after every heavy rainfall event. The MVRG fertilizer spreader was used to apply fertilizer only in plant areas of the wild blueberry field. The results suggested significant decrease in NO_3^--N and NH_4^+-N leaching through the bare spots/weed patches of the VRPRD section as compared to VRPM and UN sections of the field. The higher concentrations of NO_3^--N and NH_4^+-N were found in the bare spots/weed patches located in the low slope areas of VRPM and UN sections as compared to VRPRD section in Kemptown and Cattle Market Fields. Based on the results of this study, it can be concluded that the real-time sensing and control system of the MVRG fertilizer spreader helped to avoid fertilization in small bare spots/weed patches within the field.

This MVRG fertilizer spreader could be considered as the vital inclusion in the precision agriculture technologies which can apply fertilizer on spot-specific basis in wild blueberry fields. Fertilization using real-time sensing and control system along with the prescription maps can result in reduced nitrate and ammonium leaching load in bare spots/ weed patches of the wild blueberry fields. Therefore, the use of MVRG fertilizer spreader can expand the fertilization capabilities by allowing for spot-application of fertilizer only on as needed basis. This would result in economic benefit and environment protection.

REFERENCES

Abidine, A. Z., B. C. Heidman, S. K. Upadhyaya, and D. J. Hills. 2002. Application of RTK-GPS Based Auto-Guidance System in Agricultural Production. ASAE Paper No. 021152. St. Joseph, Mich.: ASAE.

Abidine, A. Z., B. C. Heidman, S. K. Upadhyaya, and D. J. Hills. 2004. Autoguidance system operated at high speed causes almost no tomato damage. Calif. Agri. 58(1): 44-47.

Addiscott, T. M. 1996. Fertilizers and nitrate leaching. Issues in Environ. Sci. Tech. 5: 1-26.

Adsett, J., J. Thottan, and K. Sibley. 1999. Development of an automated on-the-go soil nitrate monitoring system. Appl. Engg. Agri. 15(4): 351-356.

Ahmadi, H. and K. Mollazade. 2009. Determination and investigation of information technology parameters effective to precision agricultural development. Agri. Tech. J. 5(2): 213-224.

Aleixos, N., J. Blasco, E. Molto, and F. Navarron. 2000. Assessment of Citrus Fruit Quality Using a Real-Time Machine Vision System. *In*: Proc. of the 15th Int. Conf. on Pattern Recognition, Vol. 1, pp. 482–485. IEEE. Barcelona, Spain.

Al-Gaadi, K. and P. Ayers. 1999. Integrating GIS and GPS into a spatially variable rate herbicide application system. Appl. Engg. Agri. 15(4): 255-262.

Annamalai, P., W. S. Lee, and T. Burks. 2004. Color Vision System for Estimating Citrus Yield in Real-Time. ASAE Paper No. 043054.

Aparicio, V., J. L. Costa, and M. Zamora. 2008. Nitrate leaching assessment in a long-term experiment under supplementary irrigation in humid Argentina. Agri. Water Mgt. 95: 1361-1372.

ASABE Standards. 2006. S341.3: Procedure for Measuring Distribution Uniformity and Calibrating Broadcast Spreaders. St. Joseph, MI.

Attanandana, T. and R. S. Yost. 2003. A Site Specific Nutrient Management Approach for Maize: Thailand's Experience. Better Crops Int. 17: 3-7.

Baker, R. V., E. P. Columbus, R. C. Eckley, and B. J. Stanley. 1994. Pneumatic and mechanical handling systems. *In*: W. S. Anthony and W. D. Mayfield (eds.), Cotton Ginners Handbook, pp. 143-171. ARS, USDA. Washington, D.C.

Barker, W. G., I. V. Hall, and G. W. Wood. 1964. The lowbush blueberry industry in eastern Canada. Econ. Bot. 18: 357-365.

Beckie, H. J., A. P. Moulin, and D. J. Pennock. 1997. Strategies for variable rate nitrogen fertilization in hummocky terrain. Can. J. Soil Sci. 77: 589-595.

Bell, H. P. 1950. Determinate growth in the blueberry. Can. J. Res. Com. 28: 637-644.

Bell, J. C., C. A. Butler, and J. A. Thompson. 1995. Soil-Terrain Modeling for Site-Specific Management. *In:* P. C. Robert, R. H. Rust, and W. E. Larson (eds.), Proc. of the 2nd Int. Conf. on Site Specific Management for Agricultural Systems, pp. 209-227. ASA, CSSA, and SSSA. Madison, WI.

Billard, D. and H. Stewart. 2004. Precision agriculture for wild blueberry classification. Annual Progress Report: Environmental Technologies and Precision Agriculture Initiatives, NSAC, Truro, NS, Canada.

Blackmore, S. 1994. Precision Farming: An Introduction. Outlook Agri. 23: 275-280.

Black, C. A. 1968. Soil-Plant Relationships. 2nd ed. John Wiley and Sons, NY.

Blatt, C. R., I. V. Hall, K. I. N. Jensen, W. T. A. Neilsen, P. D. Hildebrand, N .L. Nickerson, R. K. Prange, P. D. Lidster, L. Crozier, and J. D. Sibley. 1989. Lowbush Blueberry Production. Publ.1477/E. Agri. Ottawa, Canada.

Bramley, R. and R. Quabba. 2002. Opportunities for improving management of sugarcane production through the adoption of precision agriculture-an Australian perspective. Int. Sugar J. 104: 152-161.

Bronson, K., W. Keeling, R. Lascano, and R. Boman. 2006. Management zone soil sampling on the Texas high plains. Retrieved from: http://precisionagriculture.tamu.edu/brochures/zonemanage.pdf. Accessed on 14 Oct. 2012.

Brouder, S., B. Hofmann, and D. Morris. 2005. Mapping soil pH accuracy of common soil sampling strategies and estimation techniques. Soil Sci. Soc. Amer. J. 69: 427-442.

Brown, R. B., J. P. G. A. Steckler, and G. W. Anderson. 1994. Remote sensing for identification of weeds in no-till corn. Trans. of the ASAE. 37(1): 297-302.

Burwell, R. E., G. E. Schumann, K. E. Saxton, and H. G. Heinemann. 1976. Nitrogen in subsurface discharge from agricultural watersheds. Environ. Qual. J. 5(3): 325-329.

Cameron, K. C., H. J. Di and R. G. McLaren. 1997. Is soil an appropriate dumping ground for our wastes? Austr. J. Soil Res. 35: 995-1035.

Canter, L. W. 1997. Nitrates in Groundwater. Lewis publishers. Boca Raton, Fla.Carrara, M., A. Comparetti, P. Febo, and S. Orlando. 2004. Spatially variable herbicide application on durum wheat in Sicily. Biosys. Engg. 87(4): 387-392.

Cassel, D. K., E. J. Kamprath, and F. W. Simmons. 1996. Nitrogen–sulfur relationships in corn as affected by landscape attributes and tillage. Soil Sci. Soc. Amer. J. 88(2): 133-140.

Castro, M., A. Jara, A. Guillen, J. Fuster, M. Zamora, and A. Skarmeta. 2011. Digitally and electronically programmable fertilizer spreader based on geographical information system and fertilization intelligent system for precision agriculture optimization. Sensors. doi: 10.3390/s110x0000x.

Chang, Y., Q. U. Zaman, A. W. Schumann, D. C. Percival, T. J. Esau, and G. Ayalew. 2012a. Development of color co-occurrence matrix based machine vision algorithms for wild blueberry fields. Appl. Engg. Agri. 28(3): 315–323.

Chang, Y., Q. U. Zaman, A. W. Schumann, and D. C. Percival. 2012b. Automated yield monitoring system II for commercial wild blueberry double-head harvester. Comp. Electron. Agri. 81: 97-103.

Chandler, F. B. and I. C. Mason. 1933. Effects of fertilizer on the native Maine blueberry. Proc. Amer. Soc. Hort. Sci. Sci. 30: 297-298.

Chandler, F. B. and I. C. Mason, 1938. Blueberry Investigations. Maine Agri. Exp. Sta. Ann. Bull 391, pp. 306-309. Orono, ME.

Chandler, F. B. 1943. Lowbush Blueberries. Maine Agri. Exp. Sta. Bull 423, pp. 105-131. Orono, ME.

Chandler, R. C. 2003. Autonomous Agent Navigation Based On Textural Analysis. Ph.D. Dissertation, Univeristy of Florida, Gainesville, FL.

Chapin, F. S. 1980. The mineral nutrition of wild plants. Ann. Rec. Ecol. Syst. 11: 233-260.

Chinchuluun, R., W. S. Lee, and R. Ehsani. 2009. Machine vision system for determining citrus count and size on a canopy shake and catch harvester. Appl. Engg. Agri. 25(4): 451-458.

Chung, C. K., S. Chong, and E. C. Varsa. 1995. Sampling strategies for fertility on a stoy silt loam soil. Commun. Soil Sci. Plant Anal. 26: 741-763.

Clark, R. L. and R. Lee. 1998. Development of topographic maps for precision farming with kinematic GPS. Trans. of the ASAE. 41(4): 909-916.

Clay, D. E., J. Chang, C. G. Carlson, D. Malo, S. A. Clay, and M. Ellsbury. 2000. Precision farming protocols. Part 2. Comparison of sampling approaches for precision phosphorus management. Commun. Soil Sci. Plant Anal. 31: 2969-2985.

Colgrove, M. S. Jr. and A. N. Roberts. 1956. Growth of the azalea as influenced by ammonium and nitrate nitrogen. Proc. Amer. Soc. Hort. Sci. 68: 522-536.

Corwin, D. L. and S. M. Lesch. 2005. Characterizing soil spatial variability with apparent soil electrical conductivity I. Survey protocols. Comp. Electron. Agri. 46: 103-133.

Cox, M. S., P. D. Gerard, M. C. Wardlaw, and M. J. Abshire. 2003. Variability of selected soil properties and their relationships with soybean yield. Soil Sci. Soc. Amer. J. 67: 1296-1302.

Dammer, K. H., J. Wollny, and A. Giebel. 2008. Estimation of the leaf area index in cereal crops for variable rate fungicide. Eur. J. Agron. 28: 351-360.

Dampney, P. M. R., G. Goodlass, M. A. Froment, and J. V. Stafford. 1999. Environmental and Production Effects from Variable-Rate Nitrogen Fertilizer to Winter Wheat in England. *In:* R. H. Rust, P. C. Robert, and W. E. Larson (eds.), Proc. of the 4th Int. Conf. on Precision Agriculture, pp. 697-708. ASA, CSSA, and SSSA. Madison, WI.

Davies, B. E. 1974. Loss-on-ignition as an estimate of soil organic matter. Soil Sci. Soc. Amer. Proc. 38: 150-151.

Day, P. R. 1965. Particle Fractionation and Particle-Size Analysis.. *In:* C. A. Black (ed.), Methods of Soil Analysis Part I, Agron, Vol. 9, pp. 545-567. ASA, CSSA, and SSSA. Madison, WI.

Derby, N. E., F. X. M. Casey, and D. E. Franzen. 2007. Comparison of nitrogen management zone delineation methods for corn grain yield. Agron. J. 99: 405-414.

Di, H. J. and K. C. Cameron. 2002. Nitrate leaching in temperature agro ecosystems: Sources, factors and mitigating strategies. Nutr. Cycl. Agroecosyst. 46: 237-256.

Dinnes, D. L., D. L. Karlen, D. B. Jaynes, T. C. Kaspar, J. L. Hatfield, T. S. Colvin, and C. A. Cambardella. 2002. Nitrogen management strategies to reduce nitrate leaching in tile-drained midwestern soils. Agron. J. 94: 153-171.

Earl, R. J., C. Taylor, G. A. Wood, I. Bradley, I. T. James, T. Waine, J. P. Welsh, R. J. Godwin, and S. M. Knight. 2003. Soil factors and their influence on within-field crop variability, part I: field observation of soil variation. Biosys. Engg. 84(4): 425-440.

Eaton, E. L. 1950. Blueberry Culture and Propagation. Pages 1-25 *In:* The Blueberry. Publ. 754. Canadian Department of Agriculture, Ottawa, ON.

Eaton, L. J. 1988. Nitrogen Cycling in Lowbush Blueberry Stands. Ph.D. Dissertation. Dalhousie University, Halifax, NS.

Eaton, L. J. and D. G. Patriquin. 1990. Fate of labelled fertilizer nitrogen in commercial lowbush blueberry stands. Can. J. Soil Sci. 70: 727-730.

Eaton, L. J. 1994. Long-term effects of herbicides and fertilizers on lowbush blueberry growth and production. Can. J. Plant Sci. 74: 341345.

Eaton, L. J., G. W. Stratton, and K. R. Sanderson. 1997. Fertilizer phosphorus in lowbush blueberries: effects and fate. Acta. Hort. 446: 447-486.

Eaton, L. J. and V. O. Nams. 2006. Second cropping of wild blueberries: Effects of management practices. Can. J. Plant Sci. 86: 1189-1195.

Eaton, L. J., K. Sanderson, and S. Filmore. 2009. Nova Scotia wild blueberry soil and leaf nutrient ranges. Int. J. Fruit Sci. 9: 46-53.

English, C. B., S. B. Mahajanashetti, and R. K. Roberts. 1999. Economics and environmental benefit of variable rate application of nitrogen to corn fields: role of variability and weather. Retrieved from: http://riley.nal.usda.gov/wqic/cgi-bin/retrieve_wq_record.pl?rec_id=451. Accessed on 29 Jan. 2013.

Ersahin, S. 2001. Assessment of spatial variability in nitrate leaching to reduce nitrogen fertilizers impact on water quality. Agri. Water Manage. 48: 179-189.

Esau, T. 2012. Development and Evaluation of a Prototype Variable Rate Sprayer for Spot-application of Agrochemicals in Wild Blueberry Fields. Master's thesis. Nova Scotia Agricultural College/Dalhousie University, Halifax, NS.

Farooque, A. 2010. Effect of Soil Variability on Wild Blueberry Fruit Yield. Master's thesis. Nova Scotia Agricultural College /Dalhousie University, Halifax, NS.

Farooque, A., Q. Zaman, A. Madani, D. C. Percival, and A. Schumann. 2011. Delineating management zones for site-specific fertilization in wild blueberry fields. Appl. Engg. Agri. 28(1): 57-70.

Farooque, A., Q. U. Zaman, A. W. Schumann, A. Madani, and D. C. Percival. 2012. Response of wild blueberry yield to spatial variability of soil properties. Soil Sci. 177(1): 56-68.

Flatman, G. T. and A. A. Yfantis. 1996. Geostatistical Sampling Designs for Hazardous Waste Sites. *In*: L. H. Keith (ed.), Proc. of Int. Conf. on Principles of Environmental Sampling, 2nd edition, pp. 779–801. Washington, D.C.

Fleming, K. L., D. F. Heermann, and D. G. Westfall. 2004. Evaluating soil color with farmer input and apparent soil electrical conductivity for management zone delineation. Agron. J. 96: 1581-1587.

Frank, D. A., R. S. Inouye, N. Huntly, G. W. Marshall, and J. E. Anderson. 1994. The biogeochemistry of a north-temperate grassland with native ungulates: Nitrogen dynamics in Yellowstone National Park. Biochem. 26: 163-188.

Franzen, D. W. and T. R. Peck. 1995. Field soil sampling density for variable rate fertilization. J. Prod. Agric. 8: 568-574.

Franzen, D. W., D. H. Hopkins, M. D. Sweeney, M. K. Ulmer, and A. D. Halvorson. 2002. Evaluation of soil survey scale for zone development of site-specific nitrogen management. Agron. J. 94: 381-389.

Friedrichsen, M. 2003. Marginal Impact of Education, Financial Performance, and Government Programs on the Adoption of Precision Agriculture Technology. Master's Thesis, North Dakota State University, Fargo, ND.

Gan-Mor, S. and R. L. Clark. 2001. DGPS-Based Automatic Guidance-Implementation and Economical Analysis. ASAE Paper No. 011192.

Gan-Mor, S., B. L. Upchurch, R. L. Clark, and D. Hardage. 2002. Implement Guidance Error as Affected by Feld Conditions Using Automatic DGPS Tractor Guidance. ASAE Paper No. 021153.

Gan-Mor, S., R. L. Clark, and B. L. Upchurch. 2007. Implement lateral position accuracy under RTK-GPS tractor guidance. Comp. Electron. Agri. 59: 31-38.

Gaynor, J. D. and W. I. Findlay. 1995. Soil and phosphorus loss from conservation and conventional tillage in corn production. Environ. Qual. J. 24: 734-741.

Gehue, H. L. 1994. GPS Integrated System for Precision Farming. Ph.D. Dissertation. University of Calgary, Calgary, AB.

Gillis K. P., D. K. Giles, D. C. Slaughter, and D. Downey. 2001. Injection and Fluid Handling System for Machine-Vision Controlled Spraying. ASAE Paper 01-1114.

Goddard, T. and R. Grant. 2001. Landscape management of agronomic processes for site-specific farming. Retrieved from: http://www.ppipic.org/far/farguide.nsf/$webindex/article_860FC17685256A1000521799506AEE1C!opendocument. Accessed on 07 Mar. 2013.

Grime, J. P. 1979. Plant Strategies and Vegetational Processes. John Wiley and Sons, NY.

Grossman, R. B. and T. G. Reinsch. 2002. Bulk Density and Linear Extensibility. *In:* J. H. Dane and G. C. Topp (eds.), Proc. of Int. Conf. on methods of soil analysis, Part 4, pp. 201-228. ASA, CSSA, and SSSA. Madison, WI.

Hajrasuliha, S., N. Baniabbassi, J. Metthey, and D. R. Nielson. 1980. Spatial variability in soil sampling for salinity studies in southwest Iran. Irrig. Sci. 1: 197-208.

Hall, I. V. 1955. Floristic changes following the cutting and burning of a woodlot for blueberry production. Can. J. Agri. Sci. 35: 143-152.

Hall, I. V., L. E. Aalders, L. P. Jackson, G. W. Wood, and C. L. Lockhart. 1967. Lowbush Blueberry Production in Canada, Publ. 1278, pp. 39. Canadian Department of Agriculture. Ottawa, ON.

Hall, I. V., L. E. Aalders, N. L. Nickerson, and S. V. Kloet . 1979. The biological flora of Canada. I. *Vaccinium angustifolium Ait*., sweet lowbush blueberry. Can. Field Nat. 93: 415-430.

Ritchie, J. T. 1991. Wheat phasic development. *In*: J. E. Hanks and J. T. Richie (eds.), Modeling Plant and Soil systems, Agron. Monogr. 31., pp.31-54. ASA, CSSA, and SSSA. Madison, WI.

Hanks, J. E. and J. L. Becks. 1998. Sensor-controlled hooded sprayer for row crops. Weed Tech. 12: 308-314.

Health and Welfare Canada. 1996. Guidelines for Canadian Drinking Water Quality. 6th ed. Canada Communications, ON, Canada.

Hepler, P. R. and D. E. Yarborough 1991. Natural variability in yield of Iowbush blueberries. Hort. Sci. 26: 245-246.

Hemming, J. and T. Rath. 2001. Computer-vision-based weed identification under field conditions using controlled lighting. J. Agri. Engg. Res. 78(3): 233–243.

Hong, N., J. G. White, R. Weisz, C. R. Crozier, M. L. Gumpertz, and D. K. Cassel. 2006. Remote sensing-informed variable-rate nitrogen management of wheat and corn: agronomic and groundwater outcomes. Agron. J. 98: 327-338.

Hurn, J. 1993. Differential GPS Explained. Trimble Navigation, pp 55. CA, USA.

Iqbal, J., J. B. Read, A. J. Thomasson, and J. N. Jenkins. 2005. Relationship between soil landscape and dryland cotton lint yield. Soil Sci. Soc. Amer. J. 69: 1872-1882.

Jensen, K. I. N. 1985. Weed control in lowbush blueberries in eastern Canada. Acta Hort. 165: 259-265.

Jensen, K. I. N. and D. E. Yarborough. 2004. An overview of weed management in the wild lowbush blueberry-past and present. Small Fruits Rev. 3: 229-255.

Jones, A. J., L. N. Mielke, C. A. Bartles, and C. A. Miller. 1989. Relationship of landscape position and properties to crop production. J. Soil and Water Cons. 44(4): 328-332.

Kaown, D., Y. Hyun, G. O. Bae, and K. Lee. 2007. Factors affecting the spatial pattern of nitrate contamination in shallow groundwater. J. Environ. Qual. 36(5): 1479-1487.

Kaspar, T. C., T. S. Colvin, D. B. Jaynes, D. L. Karlen, D. E. James, D. W. Meek, D. Pulido, and H. Butler. 2000. Estimating Corn Yield Using Six Years of Yield Data and Terrain Attributes. *In:* P. C. Robert, R. H. Rust, and W. E. Larson (eds.), Proc. of 5th Int. Conf. on Precision Agriculture. ASA, CSSA, and SSSA. Madison, WI.

Keeney, P. R. and L. M. Walsh. 1972. Available nitrogen in rural ecosystems: sources and fate. Hort. Sci. 7: 219-223.

Khosla, R., K. Fleming, J. A. Delgado, T. M. Shaver, and D. G. Westfall. 2002. Use of site specific management zones to improve nitrogen management for precision agriculture. Soil Water Conserv. J. 57: 513-518.

Kitchen, N. R., D. F. Hughes, K. A. Sudduth, and S. J. Birrell. 1995. Comparison of Variable Rate to Single Rate Nitrogen Fertilizer Application: Corn Production and Residual Soil NO_3^--N. *In*: R. H. Rust, P. C. Robert, and W. E. Larson (eds.), Proc. of 4th Int. Conf. on Precision Agriculture, pp. 427-439. ASA, CSSA, and SSSA. Madison, WI.

Korcak, R. F. 1988. Nutrition of blueberries and other calcifuges. Hort. Rev. 10: 183-227.

Kravchenko, A. N. and D. G. Bullock. 2000. Correlation of corn and soybean grain yield with topography and soil properties. Agron. J. 92(1): 75-83.

Lambert, D. M., J. Lowenberg-DeBoer, and G. Malzer. 2007. Managing phosphorous soil dynamics over space and time. Agri. Econ. 37: 43-53.

Lan, Y., S. Zhang, W. Li, W. C. Hoffmann, and C. Ma. 2008. Variable rate fertilization for maize and its effects based on the site-specific soil fertility and yield. Int. Agri. Engg. J. X:IT-08002.

Lark, R. M., H. C. Wheeler, R. I. Bradley, T. R. Mayr, and P. M. R. Dampney. 2003. Developing a Cost-Effective Procedure for Investigating Within-Field Variation of Soil Conditions. Project Report No. 296, Home-Grown Cereals Authority, London, UK.

Lehmann, J. and G. Schroth. 2003. Nutrient Leaching. *In*: G. Schroth and F. L. Sinclair (eds.), Proc. of Int. Conf. on Trees, Crops and Soil Fertility, pp. 151–166. Wallingford, UK. CAB.

Litten, W. J., J. Smagula, and S. Durham. 1997. Blueberry Surprise from Phosphorus. Maine Agri. Exp. Sta. Ann., Report 401. Orono, ME.

Li, Y., D. Dusha, W. Kellar, and A. G. Dempster. 2009. Calibrated MEMS Inertial Sensors with GPS for a Precise Attitude Heading Reference System on Autonomous Farming Tractors. *In*: Proc. of IONGNSS, pp. 2138-2145. Savannah, GA.

Logsdon, S. D., O. S. Mbuya, and T. Tsegaye. 2008. Bulk Density and Soil Moisture Sensors. *In:* S. Logsdon, D. Clay, D. Moore, and T. Tsegaye (eds.), Proc. of Int. Conf. on step-by-Step Field Methods, Soil Sci. Soc. of Amer, pp. 211-220. ASA, CSSA, and SSSA. Madison, WI.

Malay, W. J. 2000. Spatial Variability and Yield Monitor Evaluation for Carrots and Wild Blueberries. Master's Thesis. Nova Scotia Agricultural College/Dalhousie University, Halifax, NS.

Mallarino, A. P., and D. J. Wittry. 2004. Efficacy of grid and zone soil sampling approaches for site-specific assessment of phosphorus potassium, pH and organic matter. Prec. Agri. 5: 131-144.

Mann, K. K. 2009. Characterization and Amelioration of Yield Limiting Soil Variability in Florida Citrus Production. Ph.D. Dissertation. University of Florida, Gainesville, FL.

McLean, E. O. 1982. Soil pH and Lime Requirement. *In:* A. L. Page, R. H. Miller, and D. R. Keeney (eds.), Proc. of Int. Conf. on Methods of Soil Analysis, Part II, pp. 199-223. ASA, CSSA, and SSSA. Madison, WI.

Michaud, M., K. C. Watts, D. C. Percival, and K. I. Wilkie. 2008. Precision pesticide delivery based on aerial spectral imaging. Can. J. Biosys. Engg. 50(2): 9-15

Miller, W. M., A. W. Schumann, and J. D. Whitney. 2004. Evaluating variable rate granular fertilizer technologies in Florida citrus. Proc. Fla. State Hort. Soc. 117: 161-166.

Miller, W. M., A. W. Schumann, J. D. Whitney, and S. Buchanon. 2005. Variable rate application of granular fertilizer for citrus test plots. Appl. Engg. Agri. 21(5): 795-801.

Montgomery, D. C. 2009. Design and Analysis of Experiments. 7th ed. John Wiley and Sons, NY.

Mooney, D., J. Larson, R. Roberts, and B. English. 2009. Economics of the variable rate technology investment decision for agricultural sprayers. Southern Agricultural Economics Association. Retrieved from: http://ideas.repec.org/p/ags/saeana/46860.html. Accessed on 16 Jan. 2013.

Morgan, M. and D. Ess. 1997. The Precision Farming Guide for Agriculturists. pp. 117. John Deer Publishing. Moline, IL.

Mulla, D. J. and J. S. Schepers. 1997. Key Processes and Properties for Site-Specific Management. *In*: F. J. Pierce and E. J. Sadler (eds.), Proc. of Int. Conf. on the state of site-specific management for agriculture, ASA Miscellaneous Publication, pp. 1-18. ASA, CSSA, and SSSA. Madison, WI.

National Climate Data and Information Archive. 2011. Environment Canada. Retrieved from: http://www.climate.weatheroffice.gc.ca. Accessed on 30 August. 2013.

Nila Rekha, P., R. S. Kanwar, A. K. Nayak, C. K. Hoang, and C. H. Pederson. 2011. Nitrate leaching to shallow groundwater systems from agricultural fields with different management practices. J. Environ. Mon. 13: 2550-2558.

Oliver, M. A. 1987. Geostatistics and its applications to soil science. Soil Use Manage. 3: 8-20.

Owens, L. B., R. W. Malone, M. J. Shipitalo, W. M. Edwards, and J. V. Bonta. 2000. Lysimeter study of nitrate leaching from a corn-soy bean rotation. Environ. Qual. J. 29: 467-474.

Patzold, S., F. M. Mertens, L. Bornemann, B. Koleczek, H. Feilhauer, and G. Welp. 2008. Soil heterogeneity at the field scale: a challenge for precision crop protection. Prec. Agri. 9: 367-390.

Pecze, Z. 2001. The Engineering Background of Precision Farming. Ph.D. Dissertation. Institute of Agricultural, Food and Environmental Engineering, University of West-Hungary, Mosonmagyaróvár, Hungary.

Penney, B. G. and K. B. McRae. 2000. Herbicidal weed control and crop-year NPK fertilization improves lowbush blueberry (*Vaccinium angustifolium Ait.*) production. Can. J. Plant Sci. 80: 351-361.

Percival, D. C and J. P. Privé. 2002. Nitrogen formulation influences Plant nutrition and yield components of lowbush blueberry (*Vaccinium angustifolium*) Acta Hort. 574: 347-353.

Percival, D. C. and K. R. Sanderson. 2004. Main and interactive effects of vegetative-year applications of nitrogen, phosphorus, and potassium fertilizers on the wild blueberry. Small Fruits Rev. 3(1-2): 105-121.

Pfost, D., W. Casady, and K. Shanon. 1998. Precision Agriculture; Global Positioning System (GPS). Water Quality, University Extension, University of Missouri.
Retrieved from at: http://extension.missouri.edu/ explore/envqual/wq0452.htm. Assessed on 22 Mar. 2013.

Pierce, F. J., D. D. Warncke, and M. W. Everett. 1994. Yield and Nutrient Variability in Glacial Soils of Michigon. *In*: P. C. Robert, R. H. Rust, and W. E. Larson (eds.), Proc. of the 2nd International Conference on Precision Agriculture, pp. 133-152. ASA, CSSA, and SSSA. Madison, WI.

Pilesjö, P., L. Thylén, and A. Persson. 2005. Topographical Data for Delineation of Agricultural Management Zones. *In:* J. V. Stafford, (ed.), Proc. of the 5th Eur. Conf. on Precision Agriculture, pp. 819-826. Wageningen, The Netherlands.

Plant, R. E., A. Mermer, G. S. Pettygrove, M. P. Vayssieres, and J. A. Young. 1999. Factors underlying grain yield spatial variability in three irrigated wheat fields. Trans. of the ASAE. 42(5): 1187-1202.

Pocknee, S., B. C. Boydell, H. M. Green, D. J. Waters, and C. K. Kvien. 1996. Directed Soil Sampling. *In*: P. C. Robert, R. H. Rust and W. E. Larson (eds.), Proc. of the 3rd Int. Conf., Amer. Soc. Agron, pp. 159-168. ASA, CSSA, and SSSA. Madison, WI.

Reynolds, W. D., D. E. Elrick, and B. E. Clothier. 1985. The constant head well perrmeameter. Soil Sci. 139: 172-180.

Rizk, F. 1986. Pneumatic transport in dilute and dense phase.. The Best of bulk solids handling 1981-1985 D/86, pp. 9-15. Clausthak-Zellerfeld.

Robert, P. C. 2002. Precision agriculture: a challenge for crop nutrition management. J. Plant Soil. 247: 143-149.

Roberts, R., B. English, J. Larson, R. Cochran, W. Goodman, S. Larkin, M. Marra, S. Martin, K. Paxton, W. Shurley, and J. Reeves. 2006. Use of Precision Farming Technologies by Cotton Farms in Eleven States. Proc. of the Beltwide Cotton Conferences, pp. 288-294. NCCA. Memphis, Tenne.

Sadler, E. J., W. J. Bussceher, P. J. Bauer, and D. L. Karlen. 1998. Spatial scale requirements for precision farming: A case study in southeastern USA. Agron. J. 90: 191-197.

Saffigna, P. G. and I. R. Phillips. 2002. Fertilizers Leaching Losses. *In:* R. Lal, (ed.), Encyclopedia of Soil Science, pp. 557-559. CRC series. Boca Raton, Fla.

Saleem, S. R., Q. U. Zaman, A. W. Shumann, A. Madani, D. C. Percivel, A. A. Farooque, F. S. Khan, and S. Read. 2011. Impact of Variable Rate Fertilization on Groundwater Contamination in Wild Blueberry Cropping System. ASABE Paper No. 1110631.

Saleem, S. R. 2012. Variable Rate Fertilization in Wild Blueberry Fields to Improve Crop Productivity and Reduce Environmental Impacts. Master's Thesis. Nova Scotia Agricultural college/Dalhousie University, Halifax, NS.

Saleem S. R., Q. U. Zaman, A. W. Schumann, A. Madani, A. A. Farooque, and D. C. Percival. 2013. Impact of variable rate fertilization on subsurface water contamination in wild blueberry cropping system. Appl. Engg. Agric. 29 (2): 225-232.

Saunders, S. P., G. Larschied, and B. S. Blackmore. 1996. A Method for Direct Comparison of Differential Global Positioning Systems Suitable for Precision Farming. *In*: P. C. Robert, R. S. Rust, and W. E. Larson (eds.), Proc. of the 3rd Int. Conf. on Precision Agriculture, pp. 663-671. ASA, CSSA, and SSSA. Madison, WI.

Sawyer, J. E. 1994. Concepts of variable rate technology with considerations for fertilizer application. J. Prod. Agric. 7: 195-201.

Schueller, J. K. 1991. In Field Site-Specific Crop Production. Automated Agriculture for the 21st Century, 291-292. ASAE Paper No. 1191.

Scheuller, J. K. 1992. A review and integrating analysis of spatially-variable control of crop production. Fertilizer Res. 33: 1-34.

Schmidt, J. P., R. K. Taylor, and R. J. Gehl. 2003. Developing topographic maps using a sub-meter accuracy global positioning receiver. Appl. Engg. Agri. 19: 291-300.

Schumann, A. W., W. M. Miller, Q. U. Zaman, K. Hostler, S. Buchanon, and S. Cugati. 2006. Variable rate granular fertilization of citrus groves: Spreader performance with single-tree prescription zones. Appl. Engg. Agri. 22(1): 19-24.

Schumann, A. W., H. K. Hostler, J. C. Melgar, and J. Syvertsen. 2007. Georeferenced ground photography of citrus orchards to estimate yield and plant stress for variable-rate technology. Proc. Flor. State Hort. Soc. 120: 56-63.

Schumann, A. W. and H. K. Hostler. 2009. Computerized Automatic Variable Rate Controller for Application of Agrochemicals in Orchards. Submitted for U.S.A. Patent as "Managing Applications Agrochemicals to Plants".

Schumann, A. W. 2010. Precise placement and variable rate fertilizer application technologies for horticultural crops. Hort. Tech. 20: 34-40.

Shahandeh, H., A. L. Wright, F. M. Hons, and R. J. Lascano. 2005. Spatial and temporal variation of soil nitrogen parameters related to soil texture and corn yield. Agron. J. 97: 772-782.

Shaner, D. L., R. Khosla, M. K. Brodahl, G. W. Buchleiter, and H. J. Farahani. 2008. How well does zone sampling based in soil electrical conductivity maps represent soil variability? Agron. J. 100: 1472-1480.

Shearer, S. A. and R. G. Holmes. 1990. Plant identification using color co-occurrence matrices. Trans. of the ASAE. 33(6): 2037-2044.

Smaling E. M. A. and A. R. Braun. 1996. Soil fertility research in Sub-Saharan Africa: New dimensions, new challenges. Commun. Soil Sci. Plan. 27: 365-386.

Solie, J. B., R. W. Whitney, and M. F. Broder. 1994. Dynamic pattern analysis of two pneumatic granular fertilizer applicators. Appl. Engg. Agri. 10(3): 335-340.

Srinivasan, A. 2006. Handbook of Precision Agriculture: Principles and Applications, pp. 100-105. The Haworth Press, NY.

Sui, R., J. B. Wilkerson, L. R. Wilhelm, and F. D. Tompkins. 1989. A Microcomputer based morphometer for bush-type plants. Comp. Electron. Agri. 4(1): 43-58.

Technicon Industrial Systems. 1973. Ammonia in Water and Wastewater. Industrial Method No. 98-70W. Technicon Industrial Systems, NY.

Technicon Industrial Systems. 1978. Nitrate and Nitrite in Water and Wastewater. Industrial Method No. 100-70W. Technicon Industrial Systems, NY.

Thorn, R. H. 1986. Factors affecting the leaching of nitrate to groundwater in the Republic of Ireland. Ir. Geogr. 19: 23-32.

Thrikawala, S., A. Weersink, K. Gary, and G. Fox. 1999. Economic feasibility of variable-rate technology for nitrogen on corn. Amer. J. Agri. Eco. 81: 914-927.

Thyssen, G. and D. Percival. 2006. Environmental Losses of Soil Applied Nitrogen in Wild Blueberry Production. *In:* D. S. NeSmith, (ed.), Proc. of 10th North American blueberry research and extension workers Conf., pp. 55-63. Athens, Ga.

Tian, L., J. F. Reid, and J. W. Hummel. 1999. Development of a precision sprayer for site-specific weed management. Trans. of the ASABE. 42(4): 893-900.

Townsend, L. R. 1966. Effect of ammonium and nitrate nitrogen on the growth of the lowbush blueberry. Can. J. Plant Sci. 46: 209-210.

Townsend. L. R. 1969. lnfluence of form of nitrogen and pH on growth and nutrient levels in the leaves and roots of the lowbush blueberry. Can. J. Plant Sci. 49: 333-338.

Trevett, M. F. 1950. Weed control. *In:* Producing Blueberries in Maine, Agri. Exp. Sta. Bull 479, pp. 32-42. Orono, ME.

Trevett, M. F. 1962. Nutrition and Growth of the Lowbush Blueberry. Maine, Agri. Exp. Sta. Bull 605. Orono, ME.

Trevett, M. F. 1972. A Second Approximation of Leaf Analysis Standards for Lowbush Blueberry. Maine Agr. Extp. Sta. 19(15): 15-16.

Triantafilis, J. and S. M. Lesch. 2005. Mapping clay content variation using electromagnetic induction techniques. Comp. Electron. Agri. 46: 203-237.

Tsui, C. C. and Z. S. Chen. 2010. Net nitrogen mineralization and nitrification of different landscape positions in a lowland subtropical rainforest in Taiwan. Soil Sci. Plant Nutr. 56: 319-331.

Tumbo, S., D. Wagner, and P. Heinemann. 2001. On-the-go sensing of chlorophyll status in corn. ASAE Paper No. 01-1175. St. Joseph, Mich.: ASAE.

Van Bergeijk, J., D. Goense, L. G. van Willigenburg, and L. Speelman. 2001. Dynamic weighing for accurate fertilizer application and monitoring. J. Agri. Engg. Res. 80(1): 25-35.

Vitousek, P. M. and J. M. Mellilo. 1979. Nitrate losses from disturbed forests: patterns and mechanisms. For. Sci. 25: 605-619.

Voroney, R. P., J. P. Winter, and R. P. Beyaert. 1993. Soil Microbial Biomass C and N. *In:* M. R. Carter (ed.), Soil Sampling and Methods of Analysis, pp. 277-286. Lewis publishers. Boca Raton, Fla.

Wang, D., T. Prato, Z. Qiu, N. R. Kitchen, and K. A. Sudduth. 2003. Economic and environmental evaluation of variable rate nitrogen and lime application for claypan soil fields. Prec. Agri. 4: 35-52.

Webb, K. T., R. L. Thompson, G. J. Beke, and J. L. Nowland. 1991. Soils of Colchester County, Nova Scotia. Report No. 19. Nova Scotia Soil Survey. Research Branch, Agriculture Canada, ON, Canada.

Weisenburger, D. D. 1993. Potential health consequences of ground-water contamination of nitrates in Nebraska. Nebraska Med. J. 78: 7-12

Whitley, K. M. and J. R. Davenport. 2003. Nitrate leaching potential under variable and uniform nitrogen fertilizer management in irrigated potato systems. HortTech. 13: 605-609.

Winstead, A., S. Norwood, T. Griffin, M. Runge, A. Adrian, J. Fulton, and J. Kelton. 2009. Adoption and use of precision agriculture technologies by practitioners. Alabama Precision Ag Extension. Retrieved from: http://www.aces.edu/anr/precisionag/documents/ICPAAdoptionandUseofPA.pdf. Accessed on 22 Mar. 2013.

Wittry, D. J. and A. P. Mallarino. 2004. Comparison of uniform and variable rate phosphorus fertilization for corn-soybean rotations. Agron. J. 96: 26-33.

Wollenhaupt, N. C., R. P. Wolkowski, and M. K. Clayton. 1994. Mapping soil test phosphorus and potassium for variable-rate fertilizer applications. J. Prod. Agri. 7: 441-448.

Wolkowski, R. P., K. A. Kelling, and L. G. Bundy. 1995. Nitrogen Management on Sandy Soils. UWEX Bulletin A3634. Univ. of Wisconsin-Extension, Madison, WI.

World Health Organization. 1984. Guidelines of Drinking Water Quality. Recommendations, Vol. 1. WHO, Geneva, Switzerland.

Yang, C., C. L. Peterson, G. J. Shropshire, and T. Otawa. 1998. Spatial variability of field topography and wheat yield in the Palouse region of the Pacific Northwest. Trans. of the ASAE. 41(1): 17-27.

Yang, C., G. J. Shropshire, and C. L. Peterson. 1997. Measurement of ground slope and aspect using two inclinometers and GPS. Trans. of the ASAE. 40(6): 1769-1776.

Yang, C. 2001. A variable rate applicator for controlling rates of two liquid fertilizers. Appl. Engg. Agri. 17(3): 409-417.

Yarborough, D. E. and A. A. Ismail. 1985. Hexazinone on weeds and on lowbush blueberry growth and yield. HortSci. 20: 406-407.

Yarborough, D. E., J. J. Hanchar, S. P. Skinner, and A. A. Ismail. 1986. Weed response, yield, and economics of hexazinone and nitrogen use in lowbush blueberry production. Weed Sci. 34: 723-729.

Yarborough, D. E. and P.C. Bhowmik. 1989. Effect of hexazinone on weed populations and on lowbush blueberries in Maine. Acta Hort. 241: 344-349.

Zaman, Q. U., A. W. Schumann, and W. M. Miller. 2005. Variable rate nitrogen application in Florida citrus based on ultrasonically-sensed tree size. Appl. Engg. Agri. 21(3): 331-335.

Zaman, Q. U., A. W. Schumann, and S. Shibusawa. 2006. Impact of Variable Rate Fertilization on Nitrate Leaching in Citrus Orchards. *In*: D. J. Mulla, (ed.), Proc. of the 8th Int. Conf. on Precision Agriculture, pp. 15-20. ASA, CSSA, and SSSA. Madison, WI.

Zaman, Q. U., A. W. Schumann, D. C. Percival, and R. J. Gordon. 2008. Estimation of wild blueberry fruit yield using digital color photography. Trans. of the ASABE. 51(5): 1539-1544.

Zaman, Q. U., A. W. Schumann, D. C. Percival, K. C. Swain, M. Arshad, and T. Esau. 2009. Evaluation of Low- Cost Automated System for Real-Time Slope Measurement and Mapping. *In:* E. J. Henten, D. Goense, and C. Lokhorst (eds.), Proc. of 7th Eur. Conf. on Precision Agriculture, pp. 221-227. Wageningen, The Netherlands.

Zaman, Q. U., A. W. Schumann, and D. C. Percival. 2010a. An automated cost-effective system for real-time slope mapping in commercial wild blueberry fields. HortTech. 20(2): 431-437.

Zaman, Q. U., K. C. Swain, A. W. Schumann, and D. C. Percival. 2010b. Automated, low-cost yield mapping of wild blueberry fruit. Appl. Engg. Agri. 26 (2): 225-232.

Zaman, Q. U., T. Esau, A. W. Schumann, D. Percival, Y. Chang, S. Read, and A. Farooque. 2011. Development of a prototype automated variable rate sprayer for real-time spot-application of agrochemicals in wild blueberry fields. Comp. Electron. Agri. 76(2): 175-182.

Zhang, F., Q. U. Zaman, A. W. Schumann, and D. C. Percival. 2010. Detecting bare spot in wild blueberry fields using digital color photography. Appl. Engg. Agri. 26(5): 723-728.

Zhang, N. and C. Chaisattapagon. 1995. Effective criteria for weed identification in wheat fields using machine vision. Trans. of the ASAE. 38(3): 965-975.

Zhao, S. L., S. C. Gupta, D. R. Huggins, and J. F. Moncrief. 2001. Tillage and nutrient source effects on surface and subsurface water quality at corn planting. Environ. Qual. J. 30: 998-1008.

Zhao, L. Y., F. R. Li, and X. Z. Wang. 2003. The characteristics of soil seed bank and standing vegetation changes in sandy grasslands along a desertification gradient. Acta Ecol. Sin. 23: 1745-1756.

Zhou, J. B., J. G. Xi, Z. J. Chen, and S. X. Li. 2006. Leaching and transformation of nitrogen fertilizers in soil after application of N with irrigation: A soil column method. Pedosphere. 16 (2): 245-252.

Zhu, Y. and R. H. Fox. 2003. Corn-soybean rotation effects on nitrate leaching. Agron. J. 95: 1028-1033.

APPENDIX ‘A’

Table A1: Response time using clay filler for 8-channel computerized VRC to open nozzle in the specific section of the boom where the target detected at static pressure of 4.98 kPa.

Nozzle No.	Image taken/processing time (from camera to VRC) (s)	LED bulb start time (s)	Clay filler dispense time (s)	Response time (s)
1	0.21	2.96	5.58	2.62
2		3.67	6.26	2.59
3		3.68	6.17	2.49
4		3.35	5.60	2.25
5		4.00	6.12	2.12
6		3.30	5.24	1.94
7		4.27	6.20	1.93
8		3.86	5.97	2.11
9		3.40	5.65	2.25
10		2.98	5.47	2.49
11		3.96	6.56	2.60
12		4.51	7.12	2.61

Table A2: Response time using clay filler for 8-channel computerized VRC to open nozzle in the specific section of the boom where the target detected at static pressure of 6.23 kPa.

Nozzle No.	Image taken/processing time (from camera to VRC) (s)	LED bulb start time (s)	Clay filler dispense time (s)	Response time (s)
1	0.21	2.96	5.47	2.51
2		4.59	6.99	2.40
3		4.82	7.09	2.27
4		3.54	5.63	2.09
5		4.24	6.16	1.92
6		3.36	5.10	1.74
7		3.77	5.51	1.74
8		3.65	5.58	1.93
9		3.91	6.00	2.09
10		4.24	6.52	2.28
11		3.78	6.17	2.39
12		4.52	7.03	2.51

Table A3: Response time using fertilizer for 8-channel computerized VRC to open nozzle in the specific section of the boom where the target detected at static pressure of 4.98 kPa.

Nozzle No.	Image taken/processing time (from camera to VRC) (s)	LED bulb start time (s)	Clay filler dispense time (s)	Response time (s)
1	0.21	1.14	3.74	2.60
2		3.54	5.95	2.41
3		2.85	4.97	2.12
4		3.51	5.51	2.00
5		3.51	5.42	1.91
6		2.73	4.55	1.82
7		3.42	5.25	1.84
8		2.01	3.91	1.90
9		3.49	5.48	2.00
10		2.55	4.66	2.11
11		3.30	5.71	2.41
12		4.39	6.98	2.59

Table A4: Response time using fertilizer for 8-channel computerized VRC to open nozzle in the specific section of the boom where the target detected at static pressure of 6.23 kPa.

Nozzle No.	Image taken/processing time (from camera to VRC) (s)	LED bulb start time (s)	Clay filler dispense time (s)	Response time (s)
1	0.21	2.86	5.20	2.34
2		3.74	6.02	2.28
3		3.98	5.89	1.91
4		2.48	4.25	1.77
5		3.84	5.48	1.64
6		3.96	5.54	1.58
7		3.58	5.16	1.58
8		3.19	4.84	1.65
9		4.09	5.87	1.77
10		3.44	5.35	1.91
11		4.08	6.35	2.27
12		3.71	6.05	2.34

APPENDIX ‘B’

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

Soil properties	VRPM			UN			VRPRD		
	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 (%)	55.48^{abc}	56.85^{ab}	51.14^{cd}	54.42^{bcd}	56.71^{ab}	52.07^{bcd}	59.79^{a}	52.86^{bcd}	49.88^{d}
Clay (%)	10.27^{bcd}	9.18^{d}	11.77^{a}	10.21^{bcd}	9.89^{bcd}	10.48^{bc}	9.26^{cd}	9.72^{bcd}	10.60^{ab}
Silt (%)	34.25^{bc}	33.97^{bc}	37.09^{ab}	35.37^{abc}	33.40^{bc}	37.45^{ab}	30.95^{c}	37.42^{ab}	39.52^{a}
SOM (%)	8.26^{b}	8.65^{ab}	9.11^{ab}	8.84^{ab}	8.95^{ab}	9.61^{a}	8.23^{b}	8.39^{b}	9.04^{ab}
EC (BF) (µS cm^{-1})	52.15^{cd}	54.28^{bc}	59.45^{a}	46.12^{e}	51.96^{cd}	59.34^{a}	49.06^{de}	52.39^{cd}	57.53^{ab}
EC (AF) (µS cm^{-1})	65.84^{bc}	71.96^{ab}	76.15^{a}	59.02^{d}	70.22^{ab}	75.76^{a}	59.46^{cd}	68.38^{b}	72.47^{ab}
Soil pH (BF)	5.07^{a}	5.02^{ab}	4.91^{ab}	5.01^{ab}	4.89^{b}	4.91^{ab}	5.00^{ab}	5.05^{ab}	4.96^{ab}
Soil pH (AF)	4.94^{ab}	5.03^{a}	5.02^{a}	5.06^{a}	5.07^{a}	5.08^{a}	4.98^{ab}	4.95^{ab}	4.87^{b}
	Soil Nutrients (Before Fertilization)								
NH$_4^+$-N (mg kg^{-1})	4.01^{a}	4.29^{a}	5.58^{b}	3.63^{a}	4.04^{a}	5.54^{b}	3.91^{a}	4.34^{a}	5.28^{b}
NO$_3^-$-N (mg kg^{-1})	2.77^{a}	3.27^{ab}	4.43^{c}	3.23^{ab}	3.49^{b}	4.38^{c}	2.87^{ab}	3.13^{ab}	4.70^{c}
	Soil Nutrients (After Fertilization)								
NH$_4^+$-N (mg kg^{-1})	5.44^{a}	5.67^{a}	8.01^{b}	5.22^{a}	5.97^{a}	9.99^{c}	5.25^{a}	5.84^{a}	7.84^{b}
NO$_3^-$-N (mg kg^{-1})	4.13^{a}	4.59^{a}	6.25^{c}	4.22^{a}	5.12^{ab}	7.55^{d}	4.48^{b}	4.78^{b}	6.04^{bc}

Significantly different means contain different letters 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	VRPM			UN			VRPRD		
	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 (%)	60.28^{ab}	59.16^{ab}	51.39^{c}	60.42^{ab}	57.14^{b}	50.71^{c}	62.07^{a}	57.74^{b}	52.14^{c}
Clay (%)	7.96^{d}	7.66^{d}	12.28^{abc}	8.18^{cd}	8.63^{bcd}	12.48^{ab}	5.81^{d}	8.58^{bcd}	15.72^{a}
Silt (%)	31.7^{6c}	33.18^{bc}	36.33^{ab}	31.39^{c}	34.23^{abc}	36.80^{a}	32.12^{c}	33.68^{abc}	32.14^{c}
SOM (%)	8.01^{c}	7.95^{c}	9.88^{a}	7.72^{c}	8.05^{c}	9.57^{ab}	7.84^{c}	8.02^{c}	9.16^{b}
EC (BF) ($\mu S\ cm^{-1}$)	55.29^{e}	58.14^{cde}	62.69^{abc}	57.12^{de}	63.29^{ab}	67.05^{a}	55.30^{e}	60.67^{bcd}	61.72^{bcd}
EC (AF) ($\mu S\ cm^{-1}$)	$66.34b^{c}$	69.48^{abc}	72.83^{ab}	70.96^{ab}	73.62^{a}	75.05^{a}	63.25^{c}	70.17^{ab}	73.64^{a}
Soil pH (BF)	4.66^{d}	4.85^{a}	4.75^{abcd}	4.79^{abc}	4.67^{d}	4.83^{ab}	4.68^{d}	4.70^{cd}	4.74^{bcd}
Soil pH (AF)	4.58^{c}	4.76^{ab}	4.79^{a}	4.81^{a}	4.60^{bc}	4.74^{ab}	4.57^{c}	4.74^{ab}	4.69^{abc}
				Soil Nutrients (Before Fertilization)					
NH_4^+-N (mg kg^{-1})	3.63^{c}	4.18^{b}	5.23^{a}	3.46^{c}	4.14^{b}	5.37^{a}	3.73^{c}	4.16^{b}	5.21^{a}
NO_3^--N (mg kg^{-1})	$2.46d^{e}$	3.01^{cd}	4.12^{a}	3.04^{cd}	3.36^{bc}	3.78^{ab}	2.24^{e}	2.71^{de}	3.92^{ab}
				Soil Nutrients (After Fertilization)					
NH_4^+-N (mg kg^{-1})	4.93^{e}	5.68^{d}	7.82^{a}	5.31^{de}	6.20^{c}	7.98^{a}	4.98^{e}	5.12^{e}	7.26^{b}
NO_3^--N (mg kg^{-1})	3.39^{e}	4.92^{c}	5.98^{b}	4.05^{d}	5.13^{c}	7.36^{a}	3.67^{de}	4.05^{d}	5.32^{c}

Significantly different means contain different letters at a significance level of 0.05.
BF= Before Fertilization
AF= After Fertilization