EFFECT OF SOIL VARIABILITY ON WILD BLUEBERRY FRUIT YIELD

by

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ABSTRACT

Two wild blueberry fields were selected in central Nova Scotia, to characterize and quantify the spatial pattern of variability in soil properties, leaf nutrients and fruit yield, identification of yield influencing soil properties, and to develop management zones for site-specific fertilization. A combination of classical statistics, geostatistical analysis and mapping in Arc GIS 9.3 indicated substantial variation within field. The stepwise regression suggested that the soil EC, horizontal co-planar geometry (HCP), inorganic nitrogen and moisture content were major yield influencing factors. The cluster analysis of the soil variables with the fruit yield also indicated that HCP, inorganic nitrogen, EC, SOM, and θv were closely grouped with the fruit yield at a similarity level greater than 70%. Based on the results of this study the wild blueberry fields can be divided into different management zones for variable rate fertilization to improve crop production, increase revenue, and reduce potential environmental contamination.

LIST OF ABBREVIATIONS AND SYMBOLS USED

ANOVA – Analysis of Variance

B – Boron

Ca – Calcium

cm – Centimeter

Cu – Copper

C. V. – Coefficient of variation

CVs – Coefficient of variations

DGPS – Differential global positioning system

EC – Electrical conductivity

Fe – Iron

GIS – Geographical information system

GPS – Global positioning system

ha – Hectare

HCP – Horizontal co-planar geometry

IDW – Inverse weighted distance

K – Potassium

Kg – Kilogram

LSD – Least significant difference

L – Liter

m – Meter

Max - Maximum

Min - Minimum

Mg – Magnesium

mg – Milligram

mS – Milli Simons

Mn – Manganese

MZs – Management zones

N – Nitrogen

NH_4^+ -N – Ammonium nitrogen

NO_3^--N – Nitrate nitrogen

NS – non-significant

n/a – Not applicable

PRP – Perpendicular co-planar geometry

P – Phosphorus

θ_v – Volumetric water content

r – Coefficient of correlation

R^2 – Coefficient of determination

S. D – Standard deviation

SOM – Soil organic matter

TDR – Time domain reflectometry

VRT – Variable rate technology

Zn – Zinc

~ – Ranges from

μS – Micro Simons

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CHAPTER 1

INTRODUCTION

Northeastern North America is the world's leading producer of wild blueberries with over 86,000 ha under management, producing 112 million kg of fruit valued at $470 million annually (Yarborough, 2009). Blueberry fields are developed from native stands on deforested farmland by removing competing vegetation (Eaton, 1988). The majority of fields are situated in naturally acidic soils that are low in nutrients, have high proportions of bare spots and weed patches, and on gentle to severe topography (Trevett, 1962). Currently, crop management practices are implemented uniformly with inadequate attention being given to substantial variation in soil/plant characteristics, topographic features and fruit yield (Zaman et al., 2008). These variations within wild blueberry fields emphasize the need for precise site-specific crop management.

The variability of soil properties results from complex interactions between topography, and climate as well as cultivation, land use, and soil erosion (Quine and Zhang, 2002). The dynamic nature of these interactions results in substantial variability in the physical, chemical, biological and hydrologic properties of soils within the field (Gupta et al., 1997). Other spatially variable factors causing variation in crop yield include man-related (irrigation management, and compaction), biological (disease, and pests), meteorological (humidity, rainfall, wind, solar radiation and temperature), and topographical (slope, and ground features) influences (Corwin, 2005). Topography has been found to be among the important causes of nutrient and fruit yield variability, thus better understanding of topographic features is important, especially for site-specific soil management (Si and Farrell, 2004). Precision agriculture (PA) technologies are utilized to "identify, analyze, and manage site-soil spatial variability within fields for optimum profitability, sustainability and protection of the environment using less agrochemicals and apply them only where and when they are necessary" (Duffera et al., 2007).

Yield, fertility and topographic maps can be used to generate prescription maps for site-specific fertilization. This practice has the potential to increase the crop productivity along with economic profitability. Development of maps for soil properties, plant characteristics, topographic features and yield by using grid sampling, satellite imagery and aerial photography is an important aspect of precision agriculture (Yasrebi et al., 2008).

The **hypothesis** proposed in this study was that the spatial variability in plant growth development and wild blueberry fruit yield is caused by variability in soil conditions. If these patterns of variability can be characterized and quantified using PA techniques, it will then allow for more efficient management strategies for site-specific fertilization by improving profitability and water quality of wild blueberry fields having large spatial variation in soil and plant characteristics.

1.1 Goal and Objectives

The objectives of this study were to:

(i) Characterization and quantification of spatial variability in soil properties, leaf nutrients and fruit yield,

(ii) Identification of soil properties significantly affecting wild blueberry fruit yield, and

(iii) Delineation of management zones for site-specific fertilization.

CHAPTER 2

LITERATURE REVIEW

2.1 Soil and Crop Variability

Spatial variation is the change in soil and crop properties over a distance (Morgan and Ess, 1997). Crop yield varies spatially among the fields, and within fields on a farm. There are many factors, including climatic conditions, crop management, soil properties and site characteristics, which can affect crop yield and quality (Patzold et al., 2008). Spatial variations in yield are primarily caused by heterogeneity in weather and the physical and chemical properties of soil (Wong and Asseng, 2006). With the increasing need to protect the ground water contamination, more attention is being given to manage the fields according to yield variability by varying the agricultural inputs based on the soil properties and crop requirements (Frogbrook et al., 2002).

Soil variability plays a significant role in crop performance; precision agriculture is concerned with variability in soil properties on a small scale. Spatial variability of several nutrient supplies may cause low fertilizer efficiency, low productivity, and high losses to the environment (Haefele and Wopereis, 2005). The chemical properties of interest normally include pH, electrical conductivity (EC), nutrients, and organic matter. The physical properties such as texture and structure are also important as they influence soil moisture and strength (McBratney and Pringle, 1999).

Work in quantifying and managing soil variability in order to identify and rectify the soil limitations, to maximize profit and reduce environmental impacts in different cropping systems has been previously completed (Ovalles and Collins. 1988; Malay, 2000; Schumann and Zaman, 2003; Patzold et al., 2008; Ping et al., 2008). However, limited research has been performed in wild blueberry to investigate soil spatial variability and its impact on yield. The adoption of site-specific crop management (SSCM), also known as precision agriculture (PA), can be a successful management tool for identifying within field soil variability (Mann, 2009). With the PA, areas of land or crops within a field are managed with different levels of input according to their specific requirements. The PA technology includes the global positioning system (GPS) and geographic information system (GIS) coupled with sensors, controllers, data loggers, yield monitors, remote sensing, and variable rate application equipment. Each crop production unit can be managed with inputs on a site-specific basis to reduce waste, increase profits, and maintain the quality of the environment (Morgan and Ess, 2003). Various soil physical and chemical properties can have independent or combined effects on the plant growth and yield variability. Therefore, detailed characterization of soil variability is required to evaluate and quantify spatial variation in crop productivity.

Soil chemical properties have significant influence on yield variability. Soil pH is an important soil property that affects nutrient availability. Hence, it is a critical factor that contributes to the variation of soil nutrient status (Earl et al., 2003). Low pH values reduce the uptake of phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) and cause the toxicity of hydrogen (H), manganese (Mn) and aluminum (Al) impairing root growth and negatively affecting crop growth and fruit production. Conversely, high soil pH reduces micronutrient availability (Marschner et al., 1990). High pH soils show deficiency symptoms such as yellowing of crop leaves and dieback of branches related to deficiencies of iron (Fe), manganese (Mn) or zinc (Zn). The majority of the wild blueberry fields are situated in naturally acidic soils that are low in nutrients and high proportion of bare spots and weed patches, and having gentle to severe topography

(Zaman et al., 2008). The optimum pH range for wild blueberry production ranges from 4.5 to 5.5 (Percival and Prive, 2002).

Fertilization is a routine procedure in wild blueberry production system. The fertilizer used is usually urea, ammonium nitrate or ammonium nitrogen in combination with phosphorous and potassium (Eaton, 1988). In most of agricultural soils the major forms of nitrogen available to the plants is either ammonium nitrogen (NH_4^+-N) or nitrate nitrogen (NO_3^--N). In acidic soils the ammonium and nitrate form of nitrogen were found to have significant effect on calcifuges plants including blueberries (Korcak, 1988). Eaton and Patriquin (1988) and Korcak (1988) indicated that due to the acidic nature of blueberry soil, the process of nitrification is hindered, and the inorganic nitrogen available to the plants is in the NH_4^+-N form. The NO_3^--N is also available in the soil, but it has tendency to leach down easily from root zone which not only decrease soil fertility, but it may also cause a serious threat to ground water pollution (Addiscott, 1991). The severity of these problems is spatially variable. Variation of available nitrogen to the plants has been recorded at different landscape positions, and this variation is mainly controlled by topographic features and net N mineralization (Qian and Schoenau, 1995).

The availability of nitrogen to the plants is influenced by soil organic matter content, texture, water content, soil structure, temperature, pH, and the C/N ratio of added organic materials (Qian and Schoenau, 1995). Plant available nitrogen (PAN) also varies with management practices such as tillage and the use of leguminous crops (Addiscott, 1991). Characterization of spatial variability of nitrogen availability across the landscape, and quantification of factors influencing this variability is, therefore, essential to assess maximum benefits that could be obtained from different management practices on variable landscapes. The goal of site-specific nutrient management is to minimize the wastage of fertilizer by varying the application rates in response to the spatial variation of PAN in the soil **(**Bronson et al., 2006)**.**

Measurement of apparent electrical conductivity (EC_a) using electromagnetic induction (EMI) methods is another alternate approach for describing soil and yield variability (Ping et al., 2005). EMI can be used as an indirect measure of soil physical and chemical properties. Commercially available EC_a sensors can efficiently and inexpensively develop the spatially dense datasets required for describing soil variability (Sudduth et al., 2005). EC_a sensors can also be used to investigate yield variability caused by variations in soil properties including salinity, nutrient concentration, moisture content and clay content (Corwin et al., 2003; Li et al., 2008). Schumann and Zaman (2003) used electromagnetic induction to predict and map water table depth in flatwood soils of Florida and found that 81% of the variation in the water table depth could be explained with vertical dipole electrical conductivity (EMv). Banton et al. (1997) determined that EC_a was significantly correlated with clay and organic matter of soil, and was non-significantly correlated with porosity, bulk density, and hydraulic conductivity. Sudduth et al. (2005) confirms the finding that the relationship of EC_a to clay content of soils was surprisingly high, bearing in mind that the data was collected on different fields at different times of the year. Due to its interaction with major soil properties, EC_a can be easily correlated with yield to predict future production (Corwin et al., 2003; Kitchen et al., 2003). It provides information about subsoil properties at a range of depths that are important to plant growth, which makes EC_a unique for site-specific management because remote sensing and topographical information cannot directly assess subsoil properties (Kravchenko et al., 2003).

Soil moisture content refers to the amount of water retained by the soil. Soil is a porous medium having various sizes of pores and the water that enters the soil either remains in the pores, percolates through them, transpires or evaporates (Havlin, 1999). The presence of organic matter in the soil helps to conserve the moisture content in the soil by protecting the soil from direct exposure of sun, avoiding evaporation; it also improves the soil quality and productivity (Havlin, 1999). During periods of active growth, lack of water may cause a decrease in subsequent growth or may result in reduced yield (Black, 1957). Plant growth is basically an increase in volume resulting from the formation and development of cells and if there is lack of water the growth of plants is restricted. Marschner (1995) indicated that water-logging can also affect plant growth and yield, given that water displaces air from the pore spaces, inducing a cease in growth of roots resulting in a significant drop in the crop uptake. Marschner (1995) and Havlin (1999) indicated that sudden water-logging of soils high in organic matter and nitrate, might lead to an accumulation of nitrite (NO_2) in the soil solution, through denitrification (NO_3^- to NO_2^-), to concentrations that are toxic to the roots of sensitive plant species.

Soil organic matter is an important indicator of soil quality and productivity, but organic matter varies greatly within agricultural lands. These variations of organic matter content are strongly correlated to yield variability (Ayoubi et al., 2007). In most cases, the variation of organic matter is the single most important indicator of soil quality and productivity (Mulla and Bhatti, 1997). Organic matter is of particular interest in productivity because of its role in improving soil structure and as a precursor for biochemical transformations that occur in soil (Baldock and Nelson, 2000). The role of organic matter in explaining soil and yield variability is well documented (Mapa and Kumaragamage, 1996; Rawls et al., 2003). Nutritional status of a soil has a direct effect on nutrient availability and uptake by plants, and hence on its productivity. The deficiency of macronutrients and micronutrients in the root zone has a significant effect on yield and quality (Obreza and Rouse, 1993; Obreza, 1994).

In addition, soil physical properties have numerous sources of variability. Soil texture can have a profound effect on many soil properties and is the most important physical property. Soil particle size distribution affects nutrient retention and water holding capacity (WHC) of a soil. The soil texture can also be responsible for variation of productivity, as fine soil particles can support greater nutrient and water retention owing to their large surface area as compared with coarse size fractions (Hwang and Choi, 2006). The vital role of soil texture in affecting soil water retention is responsible for the variations in productivity (Kvaerno et al., 2007). Jiang et al. (2008) research on a landscape of clay pan soils found a good correlation between plant available water (PAW) and yield in water stressed years. They demonstrated significant yield loss due to depletion in PAW.

Variation in soil properties is considered to be the most important factor responsible for yield variability (Ping et al., 2005). Malay (2000) investigated the spatial variability of soil physical and chemical properties, leaf nutrients and plant growth parameters using 30 m grid sampling for two wild blueberry fields. They found low variability in soil and leaf nutrients and suggested that smaller grid size or directed sampling would be more appropriate to cover all variability. Variations in soil properties and processes may strongly reflect variations in soil fertility and crop productivity (Schepers et al., 2004). Hence, understanding the variability of intrinsic soil fertility is the key factor for variable rate fertilizer and soil amendment application. This understanding can be achieved by carefully planning soil sampling and characterizing soil variability spanning the entire range of differential productivity.

Topography influences the redistribution of soil particles, organic matter, and nutrients due to erosion, causing large spatial variability of soil properties (Ovalles and Collins, 1988). The distribution of organic matter, nutrients, and water in the landscape is more prominent in low lying areas (Balasundram et al., 2006). The differences in elevation also affect water availability to crops and hence the productivity (Kaleita et al., 2007). Due to their role in influencing soil and yield variability, topographic attributes are generally used to map areas of high and low productivity within a field.

The size of field used to describe variability is also an important consideration, especially in fields where spatial variability of crop yield and soil properties exists (Bhatti, 2004). Wild blueberry producers typically manage their fields uniformly on a block basis, with block size varying from one or two to several hectares, hence ignoring within-field variability (Schueller et al., 1999). Uniform management of large fields could result in under-fertilization of high yielding areas, thus lowering yield, and over-fertilization of low-yielding areas which may lead to nutrient leaching and environmental contamination (Schumann et al., 2003). Furthermore, uniform fertilization leads to decreased net economic returns. Hence, there is an emerging need for increased crop production efficiency, profitability, and environmental protection; however, these cannot be achieved if a field is managed as a single unit. One solution to this problem is to introduce spatially variable fertilizer application, a relatively new practice that is more favorable economically compared with uniform rate application (Zaman et al., 2005; Robertson et al., 2007). The utility of spatially variable fertilizer application depends on understanding and accurately identifying the underlying factors responsible for yield variation.

Several researchers have investigated the relationship between soil variability and fruit yield. Haefele and Wopereis (2005) determined the N, P and K from a field using grid sampling to develop the fertilizer strategies for rice. Bourennane et al. (2004) assessed the spatial correlations between wheat yields and some physical and chemical properties of soil using multivariate geostatistical techniques.

GopalaPillai and Tian (1999) acquired high-resolution color infrared (CIR) images with an airborne digital camera to detect in-field spatial variability in soil type, and crop nutrient stress, and analyzed spatial variability in yield. The potential of remote sensing to identify soil properties and problems that affect crops were recognized by the scientific community as early as in the 1930s (Curran, 1985). These techniques are expensive, the quality is variable, and data processing is intensive and complicated. The spatial variability of soil properties can be characterized using soil sampling methods.

2.2 Soil Sampling

Soil is the primary resource in crop production, and investigation about its characteristics is necessary when making decisions about operations and inputs (Lark et al., 2003). Two soil sampling techniques, directed and grid, are normally used for collecting soil samples. Direct sampling is cheaper and more effective than grid sampling if an accurate yield map is available (Pocknee et al., 1996). Directed sampling can also be performed by sampling low and high yield areas. Grid sampling is normally performed, when accurate field maps are not available. Grid sampling involves dividing the field into small areas and sampling at grid intersections (Chung et al., 1995). Grid soil sampling is widely used to characterize soil variability (Brouder et al., 2005). Spatial variability in wild blueberry crop can be described using grid sampling that allows a field to be divided into different management zones.

Physical and chemical properties of soil can be determined by collecting soil samples using sampling methods for precision agriculture, especially when combined with good scouting. The spatial variability of soil properties can be used to develop management zones for site- specific application of agricultural inputs to reduce the cost of production and improve water quality. Generally, it is concluded that smaller grid size will increase the accuracy of variability information (Pierce et al., 1994). Plant et al. (1999) used point samples on a regular 61 m grid to assess spatial variability in grain. Pierce et al. (1994) used 30.5 m grid size while Wollenhaupt et al. (1994) used two grid sizes of 35.5 m and 106 m. Some scientists have suggested a grid size greater than 60 m (Morgan and Ess, 1997). The size of the grid for soil sampling is arbitrary; however, obtaining soil information using grid sampling based on geostatistical results is considered as more reliable and accurate than the other techniques (Kerry and Oliver, 2003; Ping et al., 2008).

Collecting soil information by sampling manually and laboratory analysis to assess variability is also expensive; however, by using geostatistics, the range of soil variability can be assessed on the basis of which sampling strategy should be established to reduce the number of samples and cost of analysis (McBratney and Pringle, 1999). It is estimated that more than 60% yield variability is caused by soil properties and topographic features (Yang et al., 1998; Kravchenko and Bullock, 2000). Adoption of computer and differential global positioning system (DGPS) technologies allows the producers to investigate spatial variability within fields for more benefits (Weiss, 1996).

2.3 Global Positioning System (GPS)

The site-specific management of agricultural inputs has been made possible by combining the global positioning system (GPS) and geographic information systems (GIS). These technologies enable the coupling of real-time data collection with accurate position information, leading to the efficient manipulation and analysis of large amounts of geospatial data (Saunders et al., 1996). GPS based applications in agriculture are being used for field mapping, soil sampling, tractor guidance, crop scouting, variable rate applications, and yield mapping.

The GPS provides opportunities for agricultural producers to map their land and crop production more precisely. The GPS is based on radio navigation system capable of determining 3-dimensional location data (longitude, latitude, and elevation). A GPS receiver determines the location of the point using pseudo random signals from at least four satellites; more satellite signals give higher accuracy (Morgan and Ess, 1997). The GPS satellite continuously broadcast signals, allowing the GPS receiver, while in motion, to determine the location of the point real-time. Since the GPS locations are determined from the time taken by the signal from the satellite to reach the receiver, any deviation can cause error in the calculated location (Hurn, 1993).

The DGPS is used to compensate timing errors, to reduce noise in the medium, and the electronic noise in the receiver (Saunders et al., 1996; Morgan and Ess, 1997).

Differential correlation utilizes a stationary GPS at a benchmark location. The benchmark determines the difference between apparent GPS reading and actual surveyed position, and this error is transmitted to DGPS to correct it real time. Differential correlation can be utilized for the processing of raw GPS data later on (Hurn, 1993).

2.4 Yield Monitoring

Yield monitoring, the process of determining the harvested product over a given area, is the most important cornerstone of PA**.** Instantaneous yield monitors were developed in 1980 having a system to measure the yield and location in the field (Graham and Dawe, 1995). Yield monitors allow producers to assess the effects of soil variability, and management practices on the crop yield (Calvin and Vellidis, 2005). The yield monitors are intended to provide the user an accurate assessment of how yields vary within a field. Growers constantly strive to increase the profitability of their operations by minimizing costs of production or increasing crop yield. Precision agriculture is a knowledge-based management system that can empower producers to apply accurate management practices.

The yield monitoring system comprises of DGPS, data-loggers and sensors installed on a harvester, which can be used to measure spatial fruit yield variability. A GPS receiver provides location data to enable creation of yield maps, providing variability of yield across a field. Yield maps are helpful in implementing management decisions in the field (Calvin and Vellidis, 2005; Schuellaer et al., 1999).

Yield mapping is a logical starting point for site specific nutrient management and it is very effective for potential management zone identification (Boydell and McBratney, 2002). Site-specific yield monitoring and mapping systems have been developed and are used in wild blueberry production (Zaman et al., 2008 and 2010a). These systems provide a direct feedback to the producer by quantifying yield variability within a field, producing yield maps, and raising questions regarding management practices. It is important to map the yield potential of each field for fertilizer application to match the requirement of individual fields.

Malay (2000) developed a yield monitoring system for blueberries using optical sensors. The limitations of this system were that the debris common to blueberry harvest, including sticks, grass, and rocks, affected the accuracy of the yield monitor. Schumann et al. (2007) estimated the citrus fruit yield and tree characteristics by using ground-based digital photography and an ultrasonic ranging system that allowed real-time imaging, monitoring, calculation, storage and mapping of yield. Dunn et al. (2006) used cameras, a GPS unit, and ground speed radar to create a yield map for macadamia nuts. They obtained 80% accuracy in tree trunk identification in some cases, but observed that GPS location accuracy at the start of the row was vital to the success of their algorithm.

A more precise yield mapping system may be possible with the addition of photographic yield sensors on blueberry harvesters, estimating fruit yield on the ground just ahead of harvesting. Zaman et al. (2008 and 2010a) accurately estimated and mapped the wild blueberry fruit yield using a digital color photography technique by calculating the blue pixels in the image taken with the digital color camera, using image processing software.

2.5 Data Management

The characterization of factors causing spatial variability of crop yield is a necessary prerequisite for a better management of soil moisture content, soil organic matter, and other nutrients within field. By better understanding how features within the field interact, decision makers can optimize operational efficiency and improve economic returns (Kravchenko et al., 2003).

The coefficient of variation (C. V) is normally used to demonstrate the variability; however, it does not provide the information about spatial pattern of variability. Geostatistics provide an eloquent method for interpolation of data from sampled points to unsampled locations. Therefore, precision soil sampling schemes improve the analysis of field soil properties by quantifying and mapping the spatial variation of the measured properties within fields. Geostatistics quantifies the spatial relationship among samples and employs this relationship to allow a wide variety of analyses to be conducted and therefore, it provides a linear optimization technique for estimation and mapping of unsampled points (James and Charles, 1988). Geostatistics incorporates the spatial properties of data by calculating the accuracy of the resulting estimates and the range of influence of the neighboring location (Zirschy et al., 1986). The neighboring locations are called regionalized variables, having specific location in space. (Matheron, 1963).

Semivariograms are used to quantitatively assess spatial correlation in observations measured at sample locations (Di et al., 1989). Semivarigram is commonly represented as a graph which shows the variance in measure with distance between all pairs of sampled points (Oliver, 1987). Such a graph is helpful to build a mathematical model that describes the variability of the measure with location. Modeling of relationship among sample points to indicate the variability of the measure with distance of separation is called semivariogram modeling (Zirschy et al., 1986). There are three components of a semivariogram. Nugget semivariance is the variance at zero distance;

sill is the lag distance between measurements at which one value for a variable does not influence the neighboring values; and range is the distance at which the values of one variable become spatially independent of another (Oliver, 1987).

Interpolation procedures calculates regular array of values from irregular spaced raw data points having no particular pattern (Moore, 1997). Common interpolation techniques are bilinear, inverse distance weighting, fault and Kriging (Weiss, 1996). The advantage of using semivariograms and kriging is to describe variability that a user can specify (Moore, 1997). Once a semivariogram of the attributes is developed, kriging must be supplied with suitable variogram model for effective interpolation (Mohammad et al. 1996). The interpolation method and parameters may have a great effect on the appearance of variability (Birrel et al., 1996).

The data collected from the field are incorporated into a GIS usually in point form (having different attributes); GIS is then utilized for analyzing, processing, and displaying spatial geographical information, as well as for marking specific soil sampling locations or crop monitoring before the work is started in the field (Halverson et al., 1995; Blackmore, 1994). It is a method of making computerized maps, organize, statistically analyze and display the diverse types of data that are digitally referenced to a common co-ordinate system.

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

Both the DGPS and GIS are key technologies that enable the emergence of variable rate technology (VRT). The GPS allows producers to identify field locations with their productivity status, so that inputs can be applied appropriately according the variability of soil nutrients. The GIS technology allows producers to store field input and output data as separate layers in a digital map and to retrieve and utilize these data for future input allocation decisions (Morgan and Ess, 1997). With the availability of supporting precision agriculture technologies, VRT allows producers to capture detailed field spatial data, interpret and analyze that data, and implement an appropriate management response based on the information.

2.6 Variable Rate Technology (VRT)

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 variable rate fertilizer 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 application includes GPS and GIS map-based, "on-the-go" sensor-based, or a combination of map and sensors (Miller et al., 2004; Schuman et al., 2006).

Precision farming techniques enable farmers to improve crop production efficiency and reduce environmental impacts by adjusting rates of seeds, fertilizers, and pesticides 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). Accurate estimation of field characteristics is very important for the successful implementation of VRT. Increased sampling density allows the input application to be better tailored to the individual site characteristics. The VRT can reduce the amount of nutrients applied in the field and also controls the variability of the nutrient with in the field (Wittry and Mallarino, 2004; Schuman et al., 2006).

Schumann et al. (2006) investigated the performance characteristics of a VRT spreader during fertilization of a commercial citrus grove to improve profitability and reduce nitrate contamination of groundwater. Zaman et al. (2005) showed a 40% reduction in fertilizer use with VRT in a citrus orchard. Zaman et al. (2006) also reduced nitrate-N concentration in soil solution from 28.5 and 14.0 mg L^{-1} to 1.5 and 4.5 mg L^{-1} under small and large size citrus trees, respectively, by using VR precision fertilization as compared to uniform application. Developing accurate variable rate fertilizer application maps is critical in implementing precision farming management. Management zones can be useful for variable rate application of crop inputs using the spatial analysis tools of precision agriculture for improved crop management (Ferguson et al., 2003). The VRT has also been developed for seed, chemical fertilizers and pesticides, animal manure, and water applications (King et al., 1995; Schuman et al., 2006). Crop scouting using DGPS can also be useful for site specific application of agrochemicals.

2.7 Management Zones

Currently, management practices are implemented uniformly with inadequate attention being given to substantial variation in soil and plant characteristics, topographic features and fruit yield, which not only increase the cost of production but also deteriorate water quality. Precision agriculture seeks to identify, analyze, and manage spatial variability within fields in order to optimize profitability, sustainability, and environmental protection. The site-specific management of agricultural inputs, rather than the traditional uniform application in the whole field, will be a popular approach for farm managers to manage field variability on a site-specific basis (Duffera et al., 2007).

One approach to apply precision agriculture to optimize crop production and environmental quality is identifying management zones. Management zones play an important role for characterizing spatial soil variability. A management zone is defined as a sub-region of a field with homogeneous yield-limiting factors (Schepers et al., 2004). A specific application of management zones is the identification of areas with similar productivity and yield potential, to characterize soil variability (Khosla et al., 2002; Kitchen et al., 2005).

Development of management zones rely on spatial information sources that are stable or predictable over time and are related to crop yield (Doerge, 1999). Soil properties, soil survey maps, aerial photographs, topography, and yield maps have all been suggested as logical and appealing to divide variable fields into management zones (Schepers et al., 2004). Temporally stable soil data such as topography and depth-weighted average of EC_a can also be used to estimate patterns of yield and soil variability (Fraisse et al., 2001). These attributes can either be used individually or in combination with each other. For example, EC_a (Li et al., 2008), elevation plus EC_a (Kravchenko et al., 2003; Kitchen et al., 2005) and soil color plus topography and EC_a (Schepers et al., 2004) are suggested as combined approaches for delineating management zones.

Several researchers used one or multiple information sources to delineate homogeneous management zones. Fraisse et al. (2001) used a combination of topographic attributes and EC_a to delineate management zones. Schepers et al. (2004) aggregated the landscape attributes into management zones to characterize spatial variability in soil chemical properties and corn yield. The variability in soil EC_a reflects the cumulative variability in multiple soil properties; it is one criterion for defining management zones (Sudduth et al., 1995). Johnson et al. (2001) found that management zones, based on EC_a mapping, provided a useful framework for soil sampling to reflect spatial heterogeneity and could potentially be applied to assess temporal impacts of management on soil conditions. Ferguson et al. (2003) compared management zones based on slope and surface soil texture with those based on soil EC_a and concluded that the management zones based soil EC_a measurements, are preferable and have the potential for use in the site-specific management of nitrification inhibitors. Stafford et al. (1998) used yield maps to identify generalized management zones of low, medium and high yield productivities. Blackmore (2000) used a series of yield maps to classify the management zones with different relative yield and yield stability within a field. Long et al. (1994) concluded that aerial photographs of growing crops were the most accurate for classifying a field into management units to predict grain yield.

One promising statistical approach for identifying management zones, on the basis of a number of different sources, is called cluster analysis. This can be used to identify areas that have similar landscape attributes, soil properties and plant parameters, to quantify patterns of variability and to reduce the empirical nature of defined management zones (Fraisse et al., 2001). Stafford et al. (1998) used fuzzy clustering of combine yield monitor data to divide a field into potential management zones. Similarly, Boydell and McBratney (2002) divided a field into management zones using cotton yield estimates from satellite imagery.

2.8 Wild Blueberries

The lowbush blueberry (*Vaccinium angustifolium* Ait.) is an endogenous plant that has developed into an important horticultural crop in northeastern North America. Currently, wild blueberry is commercially grown on 86,000 ha in Atlantic Provinces of Canada, Quebec and State of Maine (Yarbrough, 2009). Wild blueberry fields originate when competing vegetation is removed from native plant stands found in the forest clearings. The soil environment for wild blueberries is more similar to that of forest ecosystem than the cultivated fields (Eaton, 1988). The wild blueberry soils are infertile, acidic and usually have well developed organic layer (Trevett, 1962). The plants spread slowly by underground rahizomes.

Wild blueberries having the characteristics of slow growth rate, adaptation to low nitrogen levels in soils, tolerance to high concentrations of H^+, Al^{+++}, and Mn^{++}, and mechanism for uptake of nutrients during temporarily favorable conditions (Trevett, 1962; Grime, 1979). The wild blueberry fields are commercially managed on a two year cycle with the perennial shoots being pruned in alternate years to maximize floral bud initiation, yield and ease of mechanical harvest (Percival and Prive, 2002). The commercial blueberry stands are maintained through regular pruning which allows the blueberry to remain dominant by controlling some competitors (Trevett 1959). Pruning forces the blueberry into biennial production cycle, with vigorous vegetative growth and floral bud formation during the first season, followed by flowering and fruit production in the second year (Barker et al. 1964). Following pruning the wild blueberries are routinely treated with selective herbicides to control competing species including grasses and goldenrods (Ismail et al., 1981). Approximately, half of the wild blueberry fields are harvested each year because of biennial management of the crop. (Yarbrough, 2007).

Production of the wild blueberry crop has increased in last 15 years. Most of these gains are from improved management practices within fields. Pre-emergence weed control, improved fertility management, introduction of bees and adoption of irrigation, have all contributed to this increase in production (Yarbrough, 2004). Maine has 31% of the wild blueberry area and produces 37% of the total yield (Yarbrough, 2007). With the production on over 16000 ha and yield as high as 18 million kg, the wild blueberry has become the most important commodity in Nova Scotia in terms of total area (Yarbrough, 2009).

The fertilization of the wild blueberry fields after pruning is common practice despite of little evidence of consistent increase in yield when combined with weed control. The fertilizer used is usually urea, ammonium nitrate or ammonium nitrogen in combination with phosphorous and potassium (Eaton, 1988). The wild blueberries are harvested in August or September. The quality of the fruit is deteriorated due to frost, which emphasize the need of rapid harvesting (Kinsman, 1993). Wild blueberries have been harvested using hand rakes for many years (Kinsman, 1993). Currently, mechanical harvesters are used to decrease the labor cost, and harvesting efficiency.

2.9 Summary

Soil properties are spatially variable, from region to region, between fields, and within fields. The within-field variability in soil properties influences water and nutrient movement and their redistribution and supply to plants and root growth. This variability also influences crop response to management and the susceptibility of soil to degradation and reduction in the yield. Currently, the management practices are implemented uniformly without considering the soil variability. Detailed characterization of soil variability is required to evaluate and quantify spatial variation in wild blueberry yield. Precision agriculture practices can be implemented to manage soil spatial variability within fields for optimum profitability and protection of the environment. Yield maps along with fertility and topographic maps can be used to generate prescription maps/management zones for site-specific fertilization to increase the input use efficiency by reducing the cost of production.

Wild blueberry producers are generally well aware of soil variability within fields, but they have not had tools to manage soils based on spatial variability. However, this variability can now be managed with the application of precision agriculture technologies. For the application of precision agriculture variable rate application, it is essential to comprehensively characterize soil spatial variability and to recommend appropriate management practices to increase crop yield. The optimum productivity cannot be achieved if a field is managed as a single production unit irrespective of variations in soil characteristics. The proper characterization of soil variability and identifying the factors responsible for within-field variability are therefore, necessary for the implementation of variable rate technology.

CHAPTER 3

MATERIALS AND METHODS

3.1 Evaluation of Sites

Two wild blueberry (*Vaccinium angustifolium* Ait.) fields in central Nova Scotia were selected to evaluate the effect of soil variability on the wild blueberry fruit yield. The selected fields were the Carmal site (Field1; 1.2 ha; 45°.44' N, 63°.54' W) and the North River site (Field2; 1.6 ha; 45°.27' N, 63°.12' W). Both fields were in their vegetative sprout year of the biennial crop production cycle in 2009, and crop year in 2010. The fields had been under commercial management over the past decade and received biennial pruning by mowing along with inorganic fertilizer, weed, and disease management practices.

3.2 Soil Sampling

Soil sampling was carried out under uniform application of inorganic fertilizers and other agricultural inputs such as pesticides and insecticides. In order to develop a sampling strategy, soil samples were initially collected at a spacing of 3-4 m from both fields by using two perpendicular transect lines. The sampling coordinates for transect line were recorded using a ProMark3 mobile mapper GPS (Thales Navigation, Santa Clara, Cal.). These samples were analyzed for soil organic matter content and pH using standard methods (Davies, 1974; Mann, 2009). The EC_a survey data collected by ground conductivity meter (DualEM, Milton, Ontario, Canada) was also used to optimize the soil sampling strategy. Geostatistical analysis was performed using GS+ Geostatistics for the Environmental Sciences Version 9 software (Gamma Design Software, LLC, Woodhams St, Plainwell, MI) to produce a semivariogram. Based on the geostatistical range of influence, a grid sampling strategy was established to collect soil, leaf and fruit yield samples for this research.

Soil samples were collected using sampling auger from 0-15 cm depth at each grid point. Five samples were collected from each grid point to obtain a representative pooled soil sample. The collected pooled soil samples were placed into two separate bags for each grid point. The samples were labeled, one of the sample bags for each sampling location was placed in the refrigerator, and the other sample bag was placed in the green house for two weeks for air drying. The air dried soil samples from the green house were grinded using a soil grinding machine (Nasco Farm & Ranch Co, Wisconsin, USA), and passed through 2 mm sieve.

The soil samples from the refrigerator were analyzed for soil ammonium-nitrogen (NH_4^+-N) and nitrate-nitrogen (NO_3^--N). The air dried samples were analyzed for soil organic matter (SOM) content, texture, pH, and electrical conductivity (EC) using standard methods. The soil samples were collected from each grid point immediately after the application of nitrogen fertilizer (3rd week of May, 2009), and were analyzed for all soil parameters mentioned above. The 2nd soil sampling was performed in 3rd week of July, 2009 during sprout year, and soil samples were analyzed for all soil properties except texture, pH and SOM. In 2010, the soil samples were collected once in 1st week of June, 2010 and were analyzed for inorganic nitrogen, EC, and SOM. Soil texture and pH was measured only once (at the beginning of the experiment) because these parameters do not tend to change in the two monitoring years. Other soil parameters except volumetric water content (θ_v) were determined twice in sprout year (2009) and once in crop year (2010). The θ_v was recorded twice in sprout year and on biweekly basis (May – August, 2010) in fruit year using time domain reflectometry (TDR). The ground conductivity measurements including horizontal co-planar geometry (HCP) and perpendicular co-planar geometry (PRP) were also recorded at each grid point along with θ_v.

Additionally, twelve soil samples (6 from bare spot and 6 from crop) were also collected from each field at three depths (0-15, 15-30, and 30-50 cm). These samples were analyzed for NH_4^+-N, NO_3^--N, pH, EC, θ_v and SOM. A t-test was used to determine if there are significant differences among deeper soil properties influencing the variation in yield. The coordinates of each sampling point were recorded with a ProMark3 mobile mapper GPS (Thales Navigation, Santa Clara, Cal). The boundary and bare spots were also mapped using a mobile mapper.

3.3 Soil Analysis

3.3.1 Soil Organic Matter Content (SOM)

The SOM was measured using loss on ignition method (Davies, 1974). Ten grams of soil sample was placed in a crucible, and the oven temperature was set at 100° C for 24 hours to evaporate the moisture present in the soil. The samples were reweighed and placed in muffle furnace at 450° C for 8 hours. The % SOM was calculated by:

$$\text{SOM (\%)} = \frac{\text{Oven dry weight of soil} - \text{Muffle furnace weight of soil}}{\text{Oven dry weight of soil}} \text{ X } 100$$

3.3.2 Electrical Conductivity (EC)

The electrical conductivity meter was calibrated with the standards for determination of soil's EC. A ratio of 1:2 (soil: water suspension) was prepared and EC was measured by inserting the Accument 50 (Fisher Scientific, Hampton, NH, USA) EC meter in soil water suspension (Mann, 2009; Rhoades, 1982).

3.3.3 pH

The pH meter was calibrated with standards for determination of soil's pH. A ratio of 1:2.5 (soil: water suspension) was prepared and pH was measured by inserting the Corning 450 (Corning, Incorporated, NY, USA) pH meter in soil water suspension (Mann, 2009; Mclean, 1982).

3.3.4 Ammonium-N and Nitrate-N

Soil extracts were prepared with 2.0 M potassium chloride (KCl), and were analyzed for NH_4^+-N and NO_3^--N using Technicon auto- flow analyzer (Technicon Autoanalyzer-2, Terry Town, NY, USA) (Voroney et al., 1993). The 2.0 M KCl solution was prepared by dissolving 150 g of KCl crystals in one liter distilled water. Twenty grams of wet soil was weighed into the square French bottles, and mixed with 100 ml KCl extract. The bottles were placed on a reciprocating shaker for one hour at low speed. After shaking, suspension was passed through Whatman No. 42 filter paper to get the extract for analysis. The filtrate was collected in 20 ml scintillation vials. When the vial was ¾ full of extract, the vial was capped and placed in the freezer for the further analysis (Voroney et al., 1993).

These extracts were then analyzed for available forms of nitrogen in soil. Nitrate-nitrogen in the soil was determined by using Technicon auto-flow analyzer nitrate method (Technicon Industrial Systems, 1978). In this method the nitrate concentration of the sample is reduced to nitrite by using copper/cadmium reduction chamber. The extract is then mixed with the reagents to form reddish purple color, which is determined colorimetrically to find the concentration of NO_3^--N in the sample. Ammonium-nitrogen in the soil was determined by using Technicon auto-flow analyzer ammonium method (Technicon Industrial Systems, 1973). In this method the ammonium ions are heated with reagents to produce blue color which is proportional to the ammonia concentration in the solution. This colorimetric technique is then utilized to determine the amount of NH_4^+-N in the sample.

3.3.5 Volumetric Water Content (Θ_v)

Time-domain reflectometry (TDR) is a proven technology for quickly and accurately determining volumetric water content (θ_v) in soil (Roberto and Guida, 2006). TDR-300 (Spectrum Technologies, Inc, Plainfield, IL) probes were inserted 15 cm below the soil surface and θ_v was recorded. Three TDR readings were made at each sampling point to get an average value. The θ_v was determined twice in vegetative sprout year and bi-weekly in crop year.

3.3.5.1 Principle of TDR

The underlying principle of TDR for measurement of θ_v is based on the strong correlation observed between relative dielectric permittivity of wet soil and its volumetric water content. The dielectric permittivity of a material is a measure of the extent to which the charge distribution within the material is polarized in an external electric field. It consists of measuring travel time (Tp) of an electromagnetic pulse along a metallic waveguide of known probe length (Lp) inserted into the soil. The speed of the wave along the probes in the soil is dependent on the bulk dielectric permittivity (ε) of the soil matrix (Roberto and Guida, 2006).

Electronics in the TDR 300 probes generate and sense the return of a high energy signal that travels down and back, through the soil, along the waveguide composed of the two replaceable, stainless steel rods. The sampling volume is an elliptical cylinder that extends approximately 3 cm out from the rods. The high frequency signal information is then converted to volumetric water content (Campbell et al., 1990).

TDR 300 probes were calibrated and installed to measure soil moisture content in both selected fields. To calibrate the TDR probes, ten samples with the known volume of the soil were collected from the field and the θ_v was determined from the gravimetric method (wet-dry weight method). The θ_v was also determined from the same sampling points using TDR probes. The moisture content determined by the both method was analyzed using regression analysis to check the accuracy of the TDR, before using for the experiment.

3.3.6 Soil Texture

The standard hydrometer method, ASTM. No. 1-152H was utilized to measure the particle size distribution (Day, 1965). A hydrometer was calibrated by adding 100 gram of calgon (sodium hexameta-phosphate) dispersion solution to a cylinder and distilled water was added to make the volume one liter. The hydrometer was lowered into the solution and the calibration reading (R_L) at the upper edge of meniscus surrounding the stem was recorded (Day, 1965).

Forty grams of soil were weighed and placed in the crucible. This crucible was placed in the oven at a temperature of 100^0 C for 24 hours. Soil was then inserted into a 600 mL cylinder, 300 mL of distilled water and 100 mL of calgon solution was added to the cylinder. The sample was allowed to soak overnight. This sample solution was transferred to shaker jar, and shaker jar was placed in the shaker for 5-10 minutes to mix the soil with the solution. After mixing the solution was transferred to a graduated cylinder, and distilled water was added to make the volume one liter. The rubber plunger was put to the top of the cylinder, gripped properly with hands, and was moved up and down 6-12 times to mix the contents properly. The hydrometer was then inserted to the cylinder, and the first reading was recorded after 40 seconds. The second reading for the hydrometer was recorded after 7 hours. This method is used to estimate texture without any pretreatment, except dispersion with calgon solution (Day, 1965). The percent sand, silt and clay were calculated by:

$$\text{Sand \%} = 100 - [(R_{40} - R_L) \times 100/\text{oven dry weight of soil})]$$

$$\text{Clay \%} = [(R_{7h} - R_L) \times 100/\text{oven dry weight of soil})]$$

$$\text{Silt \%} = 100 - [(\text{sand\%} + \text{clay\%})]$$

Where

R_L = Calibration value with the standard solution.

R_{40} = Reading of the hydrometer after 40 seconds in the soil solution.

R_{7h} = Reading of the hydrometer after 7 hours in the soil solution.

3.3.7 Ground Conductivity

The ground conductivity meter (DualEM, Milton, Ontario, Canada) was used to determine EC_a in horizontal co-planar geometry (HCP) and perpendicular co-planar geometry (PRP). Measurements of ground conductivity were geo-referenced with an AgGPS 132 DGPS receiver (Fig. 3-1). The DualEM geo-conductivity meter simultaneously measured terrain conductivity at two exploration depths expressed as HCP and PRP, which corresponded with the vertical-dipole and horizontal-dipole modes of the EM38 instrument (Geonics Limited, Mississauga, Ontario, Canada), respectively (Abdu et al., 2007). The maximum depth of exploration (DOE) for PRP is 1.3 m and for HCP it is 3 m.

Figure 3-1. Measurement of ground conductivity using DualEM.

3.3.8 Slope

Slope variability was measured and mapped with automated slope measurement and mapping system (ASMMS) at the start of the experiment. ASMMS consists of a tilt sensor that determines the tilt of the vehicle in any orientation on slope. The configuration uses two accelerometers mounted with their X-Y planes perpendicular to each other in a custom plastic enclosure. The tilt sensor was mounted on an all terrain vehicle (ATV) 0.3 m above ground level (Fig. 3-2). The ATV was driven at an average speed of about 2 ms^{-1} following 10 meter spaced grid lines on a ProMark3 mobile mapper (Thales Navigation, Santa Clara, Calif., USA). The grid lines within the boundary of each field were created in Arc GIS 9.3 (ESRI, Redland, Calif), and imported into the

ProMark3 mobile mapper. The reason for using the mobile mapper was to follow the grid lines as the wild blueberry fields have no rows or tramline for guiding the vehicle.

The accelerometer's pulse width modulation (PWM) outputs for their X and Y axis were processed by a BasicX-24 microcontroller (Netmedia Inc., Tucson, Ariz.) which uses software algorithms to convert the force vectors to angles of tilt. Thus the microcontroller - accelerometer assembly was configured to continuously measure tilt of the vehicle and slope of the terrain at any orientation in the X-Y plane. The tilt data from the microcontroller was continuously transmitted through a serial RS-232 port to a laptop computer. The sample locations were determined by a Trimble AgGPS-332 DGPS antenna (Trimble Navigation Limited, Sunnyvale, CA) mounted on the ATV above the tilt sensor. A laptop computer also collected DGPS position (X, Y coordinates) and ground speed data in a MS-Access database (Microsoft Corp., Redmond, WA). The ground speed (in knots) was parsed from the DGPS string and converted to metric units, using speed (ms^{-1}) = 0.51444 x speed (knots). Detailed procedure for measurement and mapping of slope will be adapted from Zaman et al. (2010b).

3.4 Leaf Sampling

Leaf samples were collected in 3rd week of July, 2009 at tip-dieback stage during sprout year. The leaf samples were analyzed for nitrogen (N), phosphorus (P), potassium (K), Calcium (Ca), Magnesium (Mg), Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn) and Boron (B) using inductivity coupled plasma emission spectrometry (ICPES) (Percival and Prive, 2002). In 2010, the leaf samples were collected again in 1st week of June, 2010 and were analyzed for same leaf nutrients.

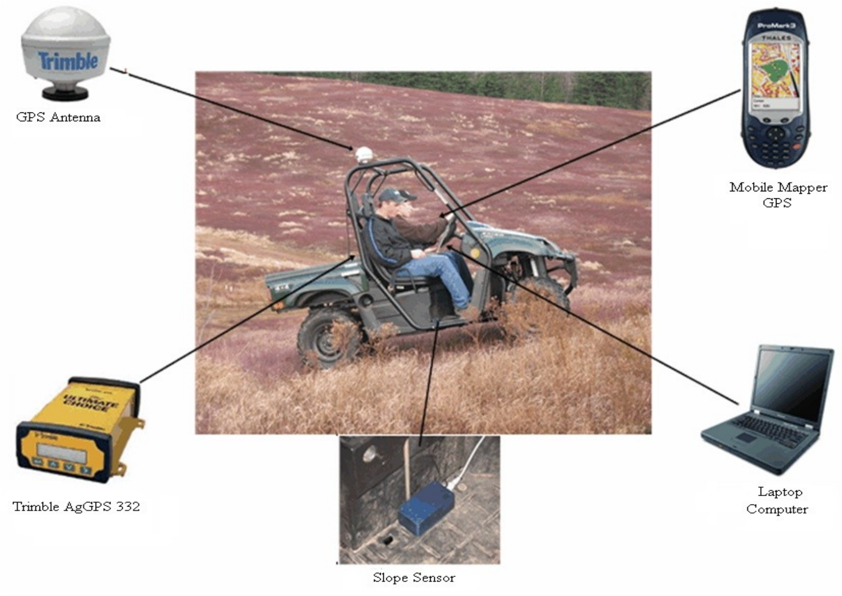


Figure 3-2. Automated slope measurement and mapping system (ASMMS)

3.4.1 Leaf Collection

The leaves were collected from 20 random blueberry stems at four to six locations zigzagged within each grid node to cover variability. The stem was grasped from its base, and pulled gently to collect the leaves. The leaves were placed in the labeled paper bag, and collection of the leaves was continued until the bag was ¾ full. The bags were labeled for each grid point. The leaf bags were opened and placed in the green house for 7-10 days to make the leaves dry. In order to complete the drying process the leaves were placed in the oven at 65 ^{0} C for 8-10 hours (Percival and Prive, 2002).

3.4.2 Leaf Grinding

Wiley Mill (Arthur H. Thomas Co, Philadelphia, PA, USA) was used to grind the leaf samples. The front panel of the grinder was opened and 2mm sieve was fixed to get the grinded material in the bottom bin. The leaf sample was placed in the top funnel and grinder was turned on. The grinded material was collected from the bottom bin, and put into a labeled paper bag for further analysis.

3.4.3 Digestion of the Leaves with Nitric Acid

Two grams of the ground leaf sample was placed in pre-conditioned digestion tube (250 mL), 10 mL of concentrated nitric acid (HNO_3) was added, and swirled gently to ensure the sample is completely wet. The sample was put in the digestion block at 100^{o} C for 45 minutes. The temperature was increased to 140^{o} C and the cooking was continued until the digestate became clear of particulate matter. The digestion continued until the volume is reduced to 1 mL. Five mL of 1% HNO_3 was added to the digestate. Whatman No. 42 filter paper was used to get the filtrate for further analysis (Percival and Prive, 2002).

3.4.4 Analysis of Leaf Samples

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

3.5 Plant Growth Parameters

The plant growth parameters were measured at the end of the November 2009 to assess the effect of plant density, plant height, branches and number of flower buds on the wild blueberry yield. A steel quadrant of 15 X 15 cm was utilized to measure the plant growth parameters at each grid point for both fields. Six plants from the steel quadrant were randomly cut using a knife and the height of the plants from the ground surface was measured to get an average height of the plants within the grid. The number of flower buds and branches of those six plants were also counted.

3.6 Yield Estimation

The fruit yield was mapped using calibrated digital color photography technique (Zaman et al., 2008 and 2010a) at the selected grid points in both fields to estimate the variability in the yield. The sampling points were marked with a ProMark3 mobile mapper GPS (Thales Navigation, Santa Clara, Cal.).

A 10-megapixel 24-bit digital color camera (Canon Canada, Inc., Mississauga, Ont.) was mounted on a tripod, pointing downwards to take photographs of the blueberry crop from a height of about 1 m. A steel frame of 0.5 × 0.5 m was placed on the ground to take wild blueberry fruit images within the frame (Fig. 3-3). The image exposure and other camera settings were on automatic for the experiment. The images were imported into a laptop computer for further processing. Custom image processing software developed with the Pascal programming language using the Delphi 5.0 compiler (Borland, Austin, Tex.) was utilized to determine the blue pixels, representing the fruit in the image (Zaman et al., 2008 and 2010a). The final result of percentage fruit pixels in the quadrant region of each image was calculated automatically by running the software in batch mode, and the results were added to a Microsoft Access (Microsoft Corp., Seattle, Wash.) database. The fruit yield was also harvested manually using hand rakes from the same quadrant at each grid point. Two more photographs along with GPS positions in each grid were taken to cover all within field variability. A pre-determined calibration equation was used to convert the blue pixels into fruit yield for both fields.

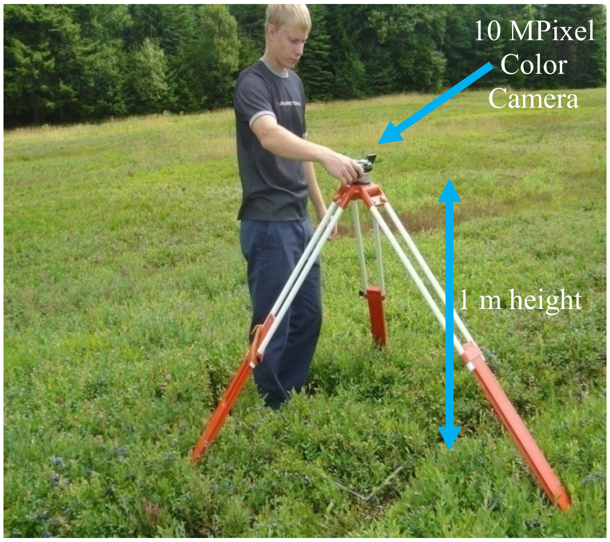


Figure 3-3. Fruit yield mapping using digital color photography.

CHAPTER 4

CHARACTERIZATION AND QUANTIFICATION OF SPATIAL VARIABILITY IN SOIL PROPERTIES, LEAF NUTRIENTS AND FRUIT YIELD

4.1 Introduction

Soil properties and crop yield vary spatially within field, among fields, and from year to year on a farm. There are many factors including soil properties, site characteristics, crop management and climate which can affect crop yield and quality (Patzold et al., 2008; Wong and Asseng, 2006). The characterization of the spatial variability of soil properties is essential to achieve better understanding of complex interactions between soil and environmental factors and to determine appropriate management practice. Site-specific management is aimed at managing soil spatial variability by applying inputs in accordance with the specific requirements of soil and crop (Wong and Asseng, 2006). Variation in soil physical, chemical, and biological properties is considered to be the most important factor responsible for soil fertility and crop productivity (Ping et al., 2005). However, determining such factors requires consideration of multiple soil properties indicator such as soil organic matter, nutrient status, texture, water holding capacity and clay mineralogy.

Grid soil sampling is widely used to characterize and quantify spatial soil variability and to determine different fertilizer application rates for each sampled location. With the introduction of geostatistics a sampling strategy can be established to collect soil, leaf and fruit yield samples, which not only reduces the number of samples but also the cost of analysis (McBratney and Pringle, 1999; Brouder et al., 2005). The characterization of soil variability using color infrared images, remote sensing, soil survey maps and arial photographs is more expensive, the quality may be inadequate, and data processing is normally intensive and complicated (Zaman et al., 2008). Therefore, within field spatial variability can be described using grid sampling that allows a field to be divided into different management zones.

The coefficient of variation (CV) is normally used to characterize the soil variability which assumes that the variation is randomly distributed within field; however, it does not provide the information about spatial pattern of variability. Geostatistics provide an eloquent method for interpolation of data from sampled points to unsampled locations. The geostatistical range of influence from semivariogram confirms the existence of the spatial variability. Lower range of influence is an indication of large spatial variation within field (James and Charles, 1988). Geostatistics provide the spatial dependency of the soil properties both isotropically and anisotropically (Burgess and Webster, 1980).

Wild blueberry producers are generally well aware of soil variability within fields (Zaman et al., 2008 and 2010a); however, they had not have adequate tools to characterize, quantify and manage their fields based on spatial variability. The PA technologies could be used to manage soil variability within fields. For variable rate application, it is essential to comprehensively characterize soil variability and to recommend appropriate management practices to increase crop yield.

Many researchers have attempted to characterize and quantify the spatial variation of soil properties, leaf nutrients and fruit yield for different crops (McBratney and Pringle, 1999; Brouder et al., 2005; Wong & Asseng, 2006; Mann, 2009). However, to date little attention has been paid to wild blueberry production system. Little effort has been made on characterizing soil variability and identifying the major factors responsible for within-field variability in wild blueberry field. It is hypothesized that optimum productivity cannot be achieved if a field is managed as a single production unit irrespective of variations in soil and plant characteristics within field. The proper characterization of these soils can be ameliorated on the basis of site-specific factors responsible for limiting crop growth and yield. Therefore, the objective of this research was to characterize and quantify the spatial patterns of variability in soil properties, leaf nutrients and wild blueberry fruit yield in central Nova Scotia.

4.2 Material and Methods

Two wild blueberry (*Vaccinium angustifolium* Ait.) fields in central Nova Scotia were selected to characterize and quantify the spatial pattern of soil properties, leaf nutrients and fruit yield variability. A grid pattern of sampling points was established at each experimental site based on the geoststistical results to collect soil, leaf and fruit yield samples. The soil samples were analyzed for NH_4^+-N, NO_3^--N, SOM, texture, θ_v, pH, and EC using standard methods. Soil texture and pH were measured once at the onset of the experiment since these parameters do not tend to change significantly in two monitoring years. Other soil properties were determined twice in sprout year and once in crop year. The ground conductivity values (HCP and PRP) using Dual EM were also recorded at each grid point along with soil samples. The coordinates of each sampling point were recorded with a ProMark3 mobile mapper GPS (Thales Navigation, Santa Clara, Cal). The boundary of the field was also marked using a mobile mapper. Twelve soil samples were collected from the each field up to the depth of 0.5 m to assess if there are significant differences among shallow and deep soil samples.

Slope variability was measured and mapped with ASMMS once at the beginning of experiment. Leaf samples were collected at tip-dieback stage during the sprout year, and 1st week of June, 2010 in crop year. The leaf samples were analyzed for leaf N, P, K, Ca, Mg, Fe, Cu, Mn, Zn and B using ICPES. The plant growth parameters were measured in late November 2009 (Sprout year) to determine the effect of plant density, plant height, number of branches and number of flower buds on the wild blueberry yield. The fruit yield was measured and mapped using calibrated digital color photography. The fruit yield was also harvested manually using hand rakes from the same quadrant at each grid point. Detailed material and method were discussed in chapter 3 (Material and Methods).

4.3 Statistical Analysis

A combination of classical statistics and geostatistical techniques was used to determine spatial variability of soil properties, leaf nutrients and fruit yield. The frequency distribution was analyzed and normality was tested using Kolmogorov-Smironv test at a significance level of 5%. Classical statistics were utilized to calculate minimum, maximum, mean, standard deviation, coefficient of variance and skewness using Minitab 15 statistical software (Minitab Inc. NY, USA) Classical statistics provides variability of the soil properties; however, it does not provide the spatial trend. Geostatistical analysis was performed using GS+ Geostatistics for the Environmental Sciences Version 9 software (Gamma Design Software, LLC, Plainwell, MI). The semivariograms for soil properties, leaf nutrients, plant growth parameters and fruit yield were developed in order to determine the range of variability and spatial dependence. The semivariogram indicates the nature of spatial variability exhibited by the samples of a variable. The advantage of using semivariograms is to plan optimal grid soil sampling schemes. Zonal statistics function of the Arc GIS 9.3 (ESRI, Redlands, CA) software was utilized to assess the variation of the soil properties and fruit yield with respect to slope.

The correlation matrix for all the soil properties was developed to assess the relationships among the soil properties within field. A two sample t-test was used to determine if there were significant differences among the shallower and deeper soil properties. The maps for soil properties, leaf nutrients and fruit yield were created in Arc GIS 9.3 to view and examine the pattern of within field variability visually.

4.4 Results and Discussion

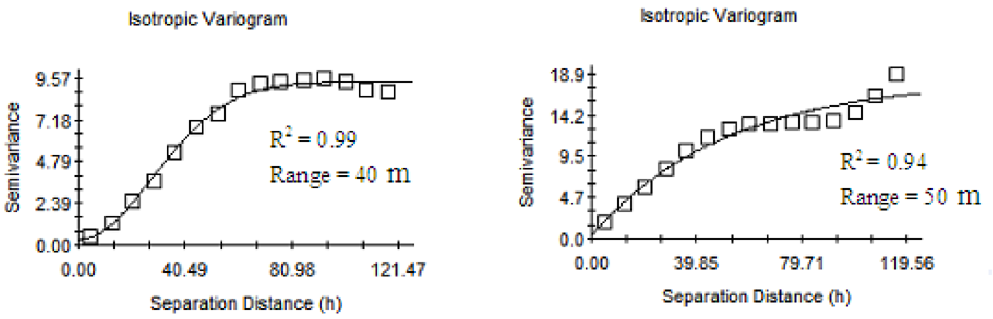
4.4.1 Sampling Strategy

The ground conductivity survey data (HCP and PRP) collected by ground conductivity meter (DualEM, Milton, Ontario, Canada) were utilized to develop a sampling strategy to collect soil, leaf and fruit yield samples from both fields. The semivariograms for HCP and PRP data were developed and exponential and gaussian models of semivariogram were found to best fit the data set. The grid size to collect soil, leaf, and fruit yield samples was then established based on the range of the influence from semivariogram which was found to be around 50 m for both monitoring fields (Fig. 4-1 a and b). Kerry and Oliver (2003) suggested that the grid pattern for sampling is one third or half of the range of variability. Based on the range of the variability, a grid size of 15 x 15 m was selected for sampling at both sites.

4.4.2 Descriptive Statistics of Soil Properties

4.4.2.1 Carmal Site

The Kolmogrov-Smironov normality test of soil properties data suggested that all parameters were normally distributed ($p > 0.05$) except HCP, $\theta_{v,}$ EC, SOM and inorganic



(a) (b)

Figure 4-1. Semivarigram of ground conductivity (a) Carmal Site, (b) N. River Site.

nitrogen. Summary statistics (Table 4-1) showed a large variation in soil properties as indicated by their high CVs. The CV is a first approximation of field heterogeneity and according to Wilding (1985); soil properties are least variable if the CVs< 15%, moderate with CVs ranging from 15 to 35% and most with CVs > 35%. All soil properties for the top soil layer (0 - 15 cm) at the first sampling date (May, 2009) had high CVs showing moderate to high variability except soil pH, sand and clay content with the CVs less than 11% showing less variability (Table 4-1).

The pH of soil was in acidic range with the mean value of 5.52, and CV of 3.43% indicating less variability (Table 4-1). The mean clay content was 41.88% with the CV of 10.58% showing less variability. The inorganic forms of nitrogen had a highly skewed distribution with high CVs. Other studies evaluating spatial variation also found moderate to high CVs for these soil properties except pH (Cox et al., 2003; Brye, 2006; Souza et al., 2006), which may be due in part to the logarithmic scale of pH measurement.

The soil properties for the 2nd and 3rd soil sampling also exhibited moderate to high variation as the CVs ranging from 17% to 74% (Table 4-1). The pattern of variation for soil properties including NH_4^+-N, NO_3^--N, HCP, PRP, EC, and θ_v was similar to the

Table 4-1. Summary statistics of soil properties for Carmal Site.

First Sampling, May, 2009 (0 - 15 cm)

Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
HCP (mS m^{-1})	1.60	10.90	5.81	2.01	34.52	0.07
PRP (mS m^{-1})	0.20	8.40	3.98	1.89	47.47	0.10
θ_v	16.25	36.42	27.77	4.64	16.72	-0.49
pH	5.05	6.03	5.52	0.19	3.43	-0.20
EC (µS cm^{-1})	22.65	67.57	41.06	11.04	26.89	0.57
SOM (%)	5.02	17.67	11.36	2.62	23.12	-0.44
Sand (%)	35.98	58.31	49.52	4.46	9.01	-0.86
Silt (%)	0.99	14.04	8.24	2.85	34.71	-0.52
Clay (%)	35.53	52.63	41.88	4.43	10.58	0.74
NH_4^+ -N (mg Kg^{-1})	1.07	24.85	8.57	4.60	53.70	1.16
NO_3^--N (mg Kg^{-1})	0.82	8.07	4.05	1.69	41.75	0.08

2nd Sampling, July, 2009 (0 - 15 cm)

Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
HCP (mS m^{-1})	1.2	11.0	5.82	2.06	35.52	0.08
PRP (mS m^{-1})	0.90	9.3	4.97	1.86	37.40	-0.12
θ_v	17.60	38.15	28.01	5.03	17.97	-0.35
EC (µS cm^{-1})	18.26	56.45	38.37	9.01	23.47	0.08
NH_4^+ -N (mg Kg^{-1})	0.13	23.64	5.53	4.06	74.01	1.63
NO_3^--N (mg Kg^{-1})	1.39	9.50	3.59	2.16	47.09	0.35

3rd Sampling, June, 2010 (0 - 15 cm)

Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
HCP (mS m^{-1})	2.76	12.06	6.93	2.26	38.77	0.07
PRP (mS m^{-1})	1.35	9.43	5.14	1.89	36.76	0.10
EC (µS cm^{-1})	27.88	55.70	28.14	7.18	22.35	0.35
SOM (%)	5.10	16.67	11.40	2.47	24.71	-0.57
NH_4^+ -N (mg Kg^{-1})	0.13	18.42	4.39	3.89	55.26	1.06
NO_3^--N (mg Kg^{-1})	1.40	7.89	3.10	1.17	49.42	0.29

Deep Sampling (0-50 cm depth)

Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
HCP (mS m^{-1})	2.50	7.10	4.70	1.54	32.80	-0.17
PRP (mS m^{-1})	2.90	6.80	4.51	1.24	27.61	0.51
θ_v	22.46	36.83	31.07	3.65	11.70	-0.51
pH	4.89	5.59	5.41	0.18	3.48	-1.86
EC (µS cm^{-1})	21.77	35.07	29.14	3.93	13.50	-0.30
SOM (%)	3.28	10.91	7.34	1.84	25.16	-0.44
Sand (%)	36.02	53.11	45.61	4.40	9.64	-0.44
Silt (%)	37.54	51.91	44.58	4.25	9.54	0.11
Clay (%)	3.49	15.88	9.81	3.21	32.67	-0.12
NH_4^+ -N (mg Kg^{-1})	0.25	3.22	1.08	0.88	80.91	1.33
NO_3^--N (mg Kg^{-1})	0.19	0.64	0.31	0.12	37.93	1.93

1st soil sampling. The mean values for available forms of nitrogen and EC were lower in the 2nd and 3rd soil sampling as compare to 1st sampling. This may due to the uptake of nitrogen by plants and leaching of nutrients to the ground water. The variation in the SOM was small as suggested by its CVs and mean values, indicating the tendency of SOM not to change much in two monitoring years (Table 4-1).

The summery statistic of soil moisture content recorded on bi-weekly basis during the crop year (Table 4-3) showed the moderate variability with the CVs ranging from 16.39% to 20.63%. The θ_v exhibited the similar pattern of variation as sprout year, which was also indicated by the range of CVs. The crop year was wet, higher mean θ_v was observed during the season as compare to vegetative sprout year. The purpose of recording θ_v on bi-weekly basis was to assess the effect of moisture content on the fruit yield.

The soil properties for deep soil samples (Table 4-1) showed that the θ_v, pH, sand, silt and EC were less variable with CVs less than 15%. The SOM, HCP, and PRP were found to be moderately variable, and the inorganic nitrogen was found to be highly variable with the CVs 80.91 % and 37.93% for NH_4^+-N and NO_3^--N, respectively. Lower mean values for inorganic nitrogen, and higher θ_v was observed for deeper soil samples as compare to 1st sampling. The mean values of SOM and EC for deep soil samples were 7.34% and 29.14 μS cm^{-1} while in the 1st soil sampling (upper 15 cm) the mean values were 11.36% and 41.06 μS cm^{-1} indicating higher productivity potential in upper 15 cm sampling (Table 4-1).

4.4.2.2 North River Site

The HCP, PRP, clay, EC, NH_4^+-N, and NO_3^--N for 1st sampling (0 - 15 cm) were

Table 4-3. Summary statistics of volumetric soil water content during 2010 for Carmal Site.

Sampling Depth (0 - 15 cm)							
Parameters	Sampling Time	Min	Max	Mean	S.D	C.V (%)	Skewness
θ_v	June 01	18.48	38.65	30.01	4.64	19.48	-0.49
θ_v	June 15	16.25	36.42	27.73	4.37	18.25	-0.39
θ_v	July 01	16.14	37.21	27.91	4.57	16.39	-0.44
θ_v	July 15	19.72	39.89	31.38	4.57	19.72	-0.46
θ_v	July 30	18.63	38.80	30.29	5.06	20.63	-0.44

found to be highly variable with the CVs greater than 35% (Table 4-2). The percent sand, silt, SOM and θ_v were moderately variable with the CVs ranging from 15% to 35%. The soil pH was in acidic range and found to be least variable as indicated by its lower coefficient of variation. The North River Field had lower mean clay content (9.64%), but more silt and sand indicating the textural variation across the field.

The CVs of soil properties for the 2nd and 3rd sampling indicated the large variation in soil properties except soil EC during the crop year, and θ_v for 2nd soil sampling with CVs less than 25% showing moderate variability (Table 4-2). The pattern of the variation for most of the soil properties was similar to the 1st soil sampling. The mean values for available forms of nitrogen and EC were lower in the 2nd and 3rd sampling which was similar to the Carmal Site. This may due to the uptake of nitrogen by plants and/or more leaching effect due to sandy nature of North River Site. The mean values of HCP, PRP and EC were observed higher for North River Site, this may be due to more variation in texture. The mean SOM remained relatively constant for 1st and 3rd sampling indicating the less temporal variation of SOM during two monitoring years. Summary statistic of soil moisture content during crop year (Table 4-4) showed the

Table 4-2. Summary statistics of soil properties for North River Site.

First Sampling, May, 2009 (0 -15 cm)

Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
HCP (mS m^{-1})	-0.70	16.00	6.83	3.56	52.12	0.25
PRP (mS m^{-1})	1.20	11.10	5.84	2.36	40.56	0.26
θ_v	11.25	36.97	25.58	5.51	21.56	-0.20
pH	4.58	6.37	5.52	0.30	5.60	-0.20
EC (µS cm^{-1})	15.25	89.42	47.99	9.14	39.87	0.43
SOM (%)	4.89	14.31	8.50	2.23	26.15	0.56
Sand (%)	8.63	74.10	48.71	12.48	25.61	-0.23
Silt (%)	19.90	66.83	41.20	9.06	21.99	-0.27
Clay (%)	2.39	24.08	9.64	4.04	41.91	1.21
NH_4^+ -N (mg Kg^{-1})	0.30	26.12	6.72	5.17	77.00	1.70
NO_3^--N (mg Kg^{-1})	1.64	10.86	5.71	2.32	40.62	0.23

2nd Sampling, July, 2009 (0 -15 cm)

Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
HCP (mS m^{-1})	-0.80	18.70	6.81	3.84	56.26	0.47
PRP (mS m^{-1})	1.00	22.50	5.53	4.02	72.68	1.66
θ_v	12.33	37.40	25.91	5.77	22.27	0.02
EC (µS cm^{-1})	17.20	95.99	46.97	6.98	36.14	0.45
NH_4^+ -N (mg Kg^{-1})	0.14	22.86	4.66	4.19	89.39	1.84
NO_3^--N (mg Kg^{-1})	0.69	13.78	3.84	2.61	67.97	1.12

3rd Sampling, June, 2010 (0 -15 cm)

Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
HCP (mS m^{-1})	-0.70	16.05	7.85	3.47	51.19	0.23
PRP (mS m^{-1})	1.2	11.5	5.88	2.33	39.74	0.20
EC (µS cm^{-1})	12.88	98.13	8.42	2.24	25.63	0.55
SOM (%)	4.50	14.50	41.25	9.85	43.27	1.16
NH_4^+ -N (mg Kg^{-1})	0.16	18.32	4.22	3.56	85.13	1.18
NO_3^--N (mg Kg^{-1})	0.50	11.20	3.43	2.53	63.54	1.10

Deep Sampling (0-25 cm depth)

Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
HCP (mS m^{-1})	0.30	11.10	4.87	3.59	73.75	0.67
PRP (mS m^{-1})	1.00	7.20	3.43	1.87	54.62	0.97
θ_v	10.77	32.63	24.89	6.57	26.42	-0.82
pH	5.07	5.72	5.32	0.17	3.23	0.94
EC (µS cm^{-1})	52.00	86.38	68.67	8.96	13.05	-0.04
SOM (%)	5.32	9.56	7.67	1.37	17.90	-0.25
Sand (%)	40.08	77.51	56.08	10.23	18.24	0.55
Silt (%)	22.00	43.81	37.37	7.60	20.35	-1.48
Clay (%)	1.50	17.51	7.96	5.14	64.62	0.78
NH_4^+ -N (mg Kg^{-1})	1.11	9.74	5.03	2.66	52.94	0.51
NO_3^--N (mg Kg^{-1})	1.64	8.04	4.83	2.03	42.02	0.04

moderate variability as indicated by its CVs ranging from 18.38% to 22.22%. The soil moisture content exhibited the similar pattern of variation as vegetative sprout year.

The classical statistics of deep soil properties (Table 4-2) indicated a large variation of HCP, PRP, NH_4^+-N, NO_3^--N and percent clay as suggested by their higher CVs, all the other soil properties were moderately variable. The North River Site was found to be more variable as indicated by higher coefficient of variation and range of values (min. and max.) than Carmal Site. The deeper soil samples were found to have less inorganic nitrogen and clay content as compare to shallower soil samples. The mean values for θ_v were similar for both sampling depths because this site was very stoney and deeper samples were collected from 25 cm below the soil surface (Tables 4-2 and 4-4). The soil pH was found to be least variable for deep soil samples with the coefficient of variation of 3.23%. The mean SOM was observed higher in upper 15 cm as compare to deeper soil samples while the mean value of EC was observed higher for deep soil samples for North River Site.

4.4.3 Descriptive Statistics of Leaf Nutrients, Plant Growth Parameters and Yield

4.4.3.1 Carmal Site

The Kolmogrov-Smironov normality test of leaf nutrients, plant growth parameters and fruit yield data suggested that all parameters were normally distributed ($p > 0.05$) except tissue N, P, K and Fe. Summary statistics for tissue nutrients (Table 4-5) showed that tissue P and Fe were highly variable with CVs of 60.29% and 43.96%, respectively. Tissue Ca, Mg and Zn were found to be least variable with the CVs less than 15%, all the other tissue nutrients were moderately variable with CVs ranging from 15% to 30% (Table 4-5).The leaf nutrients were found to be moderately variable during the crop year with the CVs ranging from 10% to 30%. The pattern of variation for the

Table 4-4. Summary statistics of volumetric soil moisture content during 2010 for North River Site.

Sampling Depth (0 - 15 cm)							
Parameters	Sampling Time	Min	Max	Mean	S.D	C.V (%)	Skewness
θ_v	June 01	17.30	42.01	29.59	5.62	18.38	0.11
θ_v	June 15	12.33	38.13	25.99	5.39	22.22	0.03
θ_v	July 01	13.53	38.46	26.93	5.17	21.33	0.02
θ_v	July 15	17.42	42.15	30.68	5.66	18.46	0.01
θ_v	July 30	16.65	41.52	30.12	5.61	18.78	-0.06

leaf nutrients was similar to sprout year (Table 4-5). The lower mean values of leaf nutrients were observed in the crop year as compare to the sprout year. The leaf N was found to approximately 18% lower in fruit year. The reduction in the leaf N in the crop year was in agreement with the findings of Penney and McRae (2000). They found the 20% decrease in leaf N in the fruit year as compare to vegetative sprout year. The mean leaf P and K were also decreased, by approximately 25% and 10% respectively, in the fruit year. The lower leaf nutrients in the crop year may be due to transport of nutrients in flowers during fruit development process.

The descriptive statistics for plant growth parameters (Table 4-7) showed that the plant density (number of plants in a grid), height, number of buds, and number of branches were moderately variable with the CVs ranging from 18 to 32%. The height of the plants from the ground surface was 14-31 cm with the mean plant density of 13 plants in a 225cm^2 area. The summary statistics suggested the more flower buds at Carmal Site than the North River Site (Tables 4-7 and 4-8). This may be due to more fertility at Carmal Site as indicated by summary statistics. The mean value for the number of plants in the grid and the number of branches were approximately same for both fields.

Table 4-5. Summary statistics of leaf nutrients for Carmal Site.

1st Sampling (July, 2009)

Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
Nitrogen (%)	1.03	3.68	1.89	0.51	27.24	1.21
Phosphorous (%)	0.10	0.53	0.20	0.12	60.29	1.39
Potassium (%)	0.14	0.53	0.45	0.08	20.86	-1.60
Calcium (%)	0.41	0.66	0.53	0.06	11.13	-0.16
Magnesium (%)	0.15	0.25	0.18	0.02	11.58	0.76
Iron (mg L^{-1})	30.03	127.47	45.96	20.20	43.96	2.71
Manganese (mg L^{-1})	1175.60	2237.30	1712.50	288.1	16.82	-0.29
Copper (mg L^{-1})	4.58	11.60	7.62	1.75	23.02	0.18
Zinc (mg L^{-1})	14.07	22.02	17.62	1.99	11.30	0.12
Boron (mg L^{-1})	13.32	29.14	19.88	3.55	17.90	0.67

2nd Sampling (June, 2010)

Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
Nitrogen (%)	1.12	2.46	1.58	0.16	19.12	1.57
Phosphorous (%)	0.11	0.18	0.15	0.01	30.41	0.02
Potassium (%)	0.30	0.53	0.41	0.05	17.05	-0.98
Calcium (%)	0.33	0.50	0.43	0.04	10.63	-0.42
Magnesium (%)	0.13	0.21	0.17	0.01	10.97	-0.11
Iron (mg L^{-1})	32.25	76.95	42.68	9.99	31.05	2.17
Manganese (mg L^{-1})	624.7	2458.60	1465.60	381.42	26.02	0.43
Copper (mg L^{-1})	3.99	7.93	5.75	0.83	24.50	0.33
Zinc (mg L^{-1})	13.42	21.01	16.45	1.67	10.20	0.61
Boron (mg L^{-1})	7.79	17.70	12.78	1.94	15.18	-0.07

Gebre-Mariam and Larter (1979) reported the lower plant density resulted in higher yield and higher plant density resulted in lower crop yield for wheat crop. The classical statistics of the fruit yield and blue pixel (Table 4-7) suggested that fruit yield was highly variable with the CVs of 49.52%. The mean fruit yield and blue pixel were higher for the Carmal Site as compare to North River Site. This may be due to more nutrients and number of flower buds during the sprout year as suggested by the descriptive statistics of the plant growth parameters (Table 4-7).

4.4.3.2 North River Site

Descriptive statistics (Table 4-6) showed that tissue Fe and N were highly

Table 4-7. Summary statistics of plant growth parameters and yield for Carmal Site.

Plant Growth Parameters and Yield						
Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
Plant Density	7.00	25.00	12.89	3.86	29.94	0.95
Height	14.00	31.00	19.55	3.67	18.79	0.83
Buds	114.00	274.00	179.82	33.24	18.48	0.41
Branches	10.00	38.00	20	6.53	32.63	1.14
Yield (Kg ha^{-1})	800.00	6344.00	2689.00	1332.00	49.52	0.86
Blue Pixel (%)	0.30	9.98	2.67	1.22	43.02	1.43

variable with CVs of 55.37% and 35.24%, respectively. Tissue Mg and Cu were found to be least variable with the CVs less than 15%, all other tissue nutrients were moderately variable with CVs ranging from 15% to 30% (Table 4-6). The mean values for tissue nutrients were approximately similar to the standards set by Eaton et al. (2009) for wild blueberry crop of Nova Scotia. The leaf nutrients exhibited the moderate to high variability during the crop year with the CVs ranging from 12% to 41% (Table 4-6). The pattern of variation for the leaf nutrients during crop year was similar to sprout year, with lower mean values of leaf nutrients as compare to the sprout year.

The leaf N, P and K were found to be lower 17%, 2% and 5%, respectively, in fruit year. Because of low soil pH and mycorrhizal relationship, it is commonly believed that leaf nutrition may be useful when compared to soil fertility to determine wild blueberry crop health and make fertilizer management decisions (McIsaac and Eaton 1995). Zaman and Schumann (2006) reported that the leaf nutrients exhibited low to moderate variation except for B and Mn where % CVs were relatively high in citrus grove.

The classical statistics for plant growth parameters (Table 4-8) showed that the plant density, height, number of buds and number of branches were moderately variable with the CVs ranging from 20% to 32%. The height of the plants from the ground surface

Table 4-6. Summary statistics of leaf nutrients for North River Site.

1st Sampling (July, 2009)

Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
Nitrogen (%)	1.22	3.86	1.88	0.66	35.24	0.59
Phosphorous (%)	0.11	0.37	0.18	0.06	33.86	1.51
Potassium (%)	0.39	0.87	0.60	0.11	19.20	0.26
Calcium (%)	0.32	0.79	0.51	0.08	16.93	1.04
Magnesium (%)	0.13	0.24	0.19	0.02	13.05	0.28
Iron (mg L^{-1})	29.33	222.84	59.93	27.64	55.37	4.91
Manganese (mg L^{-1})	643.0	2788.90	1699.90	499.70	29.40	0.19
Copper (mg L^{-1})	3.85	7.70	5.87	0.83	14.26	-0.29
Zinc (mg L^{-1})	14.25	31.59	20.18	3.37	16.70	1.26
Boron (mg L^{-1})	19.86	69.43	41.60	11.02	26.48	0.45

2nd Sampling (June, 2010)

Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
Nitrogen (%)	1.18	3.03	1.60	0.29	27.45	0.46
Phosphorous (%)	0.11	0.35	0.17	0.03	30.96	1.31
Potassium (%)	0.41	0.71	0.56	0.04	16.95	0.16
Calcium (%)	0.24	0.46	0.33	0.05	16.96	0.63
Magnesium (%)	0.10	0.17	0.13	0.01	13.06	0.33
Iron (mg L^{-1})	26.31	151.64	49.78	24.88	41.62	2.31
Manganese (mg L^{-1})	6.3.80	2183.60	1418.70	364.80	25.71	0.27
Copper (mg L^{-1})	5.49	10.71	5.03	1.12	14.04	0.42
Zinc (mg L^{-1})	13.23	27.26	17.82	3.38	12.94	0.19
Boron (mg L^{-1})	7.52	23.66	16.38	3.35	2049	0.23

was 10-23 cm with average plant density of 12 plants in a 225cm^2 area. The lower number of flower buds were observed for North River Site as compare to Carmal Site (Tables 4-7 and 4-8). The fruit yield was also found to be highly variable within field as suggested by its CVs of 55.36% (Table 4-8). The mean fruit yield was lower for North River Site as compare to Carmal Site; this may be due to more coverage by bare spots and grasses, rocky nature of soil, and lower number of flower buds during sprout year.

4.4.4 Comparison of the Soil Properties

Twelve soil samples (6 near blueberry crop and 6 from bare spots) were randomly collected from each field to assess the differences among soil properties for deeper and

Table 4-8. Summary statistics of plant growth parameters and yield for North River Site.

Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
Plants Density (Plants/0.0225m^2)	6.00	20.00	11.24	3.17	28.23	0.48
Height	10.00	23.00	15.16	3.10	20.44	0.50
Buds	95.00	232.00	154.24	33.29	21.58	-0.07
Branches	12.00	52.00	21.48	6.86	31.97	1.80
Yield (Kg ha^{-1})	68.00	5600.00	2583.00	1430.00	55.36	0.13
Blue Pixel (%)	0.12	7.00	2.48	1.89	56.17	0.11

shallower soil samples. The North River Field was very stoney and the soil samples were collected only up to the depth of 25 cm, while at Carmal Site the deep sampling was performed up to the depth of 50 cm. The results of a two sample t-test (Table 4-9) indicated that the soil EC, SOM, NH_4^+-N and NO_3^--N were significantly higher in upper 15 cm than the deep samples for Carmal Field ($p < 0.05$).

The θ_v and silt content were higher in the deep samples than upper 15 cm sampling ($p < 0.001$) for Carmal Site. The results of two sample t-test for North River Site (Table 4-9) indicated that the θ_v, SOM, silt, clay and inorganic nitrogen were similar at both sampling depths ($p > 0.05$). These results also indicated that % sand and EC were greater for the deeper than the shallower samples ($p < 0.05$) for North River Site. There was a non-significant difference in soil pH for both sampling depths ($p > 0.05$) for both fields. Most of soil properties were similar for North River site at both sampling depths, which may due to the rocky nature of the soil and shallower deep samples.

Mann (2009) showed that soil EC and SOM were higher at 0-15 cm than deeper soil samples for citrus grove. EC may represent the variations in soil nutrient concentration, clay content (Corwin et al., 2003) or soil water content (Jiang et al., 2007). Due to EC's influence on major soil chemical and physical properties it may lead to

Table 4-9. Two sample t-test for shallow and deep soil samples for both fields.

	Carmal Site			North River Site		
Parameters	Mean 0 - 15cm	Mean Deep	p-value	Mean 0 - 15cm	Mean Deep	p-value
θ_v	27.77	31.07	0.007	25.58	24.89	0.730
pH	5.52	5.41	0.062	5.52	5.32	0.073
EC (µS cm^{-1})	41.06	29.14	0.000	47.99	68.67	0.040
SOM (%)	11.36	7.34	0.000	8.50	7.67	0.090
Sand (%)	49.52	45.61	0.006	48.71	56.08	0.038
Silt (%)	8.24	44.58	0.000	41.20	37.37	0.130
Clay (%)	41.88	9.81	0.000	9.64	7.96	0.290
NH_4^+ -N (mg Kg^{-1})	8.57	1.08	0.000	6.72	5.03	0.088
NO_3^--N (mg Kg^{-1})	4.05	0.31	0.000	5.71	4.83	0.188

spatial variability in yield and is used to predict yield variability (Kitchen et al., 2003; Li et al., 2008). Overall the mean values of soil parameters for deep samples was observed lower as compare to shallow samples (upper 15cm).

4.4.5 Correlation Matrix of Soil Properties

4.4.5.1 Carmal Site

The correlation analysis of the soil properties used to describe the soil variability (Table 4-10) revealed significant relationships among the soil properties. In general, the soil parameters such as SOM, θ_v, clay, EC, HCP, PRP and inorganic forms of nitrogen were significantly correlated with each other. The relationships of HCP and PRP with soil pH were significant, indicating the increase in ground conductivity values as the soil pH increases (Table 4-10). The correlation of HCP with sand content were negatively significant indicating lower values of HCP and PRP in the areas with more sand content, while the relationship of PRP with sand content was non-significant. The significant positive correlation (r ~ 0.56 to 0.89) between ground conductivity and θ_v suggested a linear trend, indicating that the values HCP and PRP are influenced greatly with the moisture level in the soil. The positive correlation among HCP, PRP and SOM suggested higher ground conductivity values in the areas, enriched with SOM and vice versa (Table 4-10). The HCP and PRP were found to be significantly correlated with EC and clay content (r ~ 0.40 to 0.74). The significant correlations of ground conductivity with SOM, EC, and θ_v suggested that ground conductivity can be used to assess the fertility status of the soil, and to predict soil properties within wild blueberry fields. The relationship of the ground conductivity with the silt content was non-significant.

The θ_v was significantly correlated with SOM (r = 0.73), clay (r = 0.62), EC (r = 0.67) and inorganic nitrogen (r ~ 0.57 to 0.61). These relationships suggested that θ_v was higher where there was more clay and organic matter in the soil. The available forms of nitrogen were significantly correlated with HCP (r ~ 0.66 to 0.98), PRP (r ~ 0.43 to 0.50), clay (r = 0.38 to 0.50), SOM (r ~0.58 to 0.74), θ_v (r ~ 0.57 to 0.71) and EC (r ~ 0.47 to 0.59) (Table 4-10) indicating the more retention of inorganic nitrogen by clay particles and SOM. The soil θ_v, inorganic nitrogen, clay, and EC were negatively correlated (r ~ -0.14 to -0.69) with the sand content indicating lower fertility, less moisture and inorganic nitrogen availability for plant uptake, and more exposure of leaching which may cause an impact on the yield. Soil pH was found to be significantly correlated with θ_v (r = 0.43). The relationships of the moisture content with silt were non-significant (Table 4-10). The soil pH having significant positive correlation (r = 0.33, 0.42, 0.33 and 0.48) with EC, SOM, clay and NH_4^+-N. The relationship of the pH with sand and silt were found to be non-significant (Table 4-10). The soil EC having significant positive correlations with all

Table 4-10. Correlation matrix of soil properties for Carmal Site.

	HCP	PRP	θ_v	pH	EC	SOM	Sand	Silt	Clay	NH4-N	NO3-N	HCP	PRP	θ_v	EC	NH4-N
PRP	0.71***															
θ_v	0.85***	0.56***														
pH	0.41**	0.37*	0.43**													
EC	0.74***	0.51**	0.67***	0.35*												
SOM	0.87***	0.60***	0.73***	0.42**	0.64***											
Sand	-0.35*	-0.22^{NS}	-0.43**	-.20 ^{NS}	-0.26 ^{NS}	-0.22 ^{NS}										
Silt	-0.15 ^{NS}	0.03 ^{NS}	-0.21 ^{NS}	-.19 ^{NS}	-0.11 ^{NS}	-0.19 ^{NS}	-0.38*									
Clay	0.61***	0.40*	0.62***	0.23 ^{NS}	0.56***	0.56***	-.69***	-.22 ^{NS}								
NH4-N	0.71***	0.43**	0.58***	0.36*	0.59***	0.64***	-0.33 ^{NS}	-.04 ^{NS}	0.50**							
NO3-N	0.82***	0.50**	0.71***	0.41**	0.59***	0.74***	-0.19 ^{NS}	-.20 ^{NS}	0.49**	0.59***						
HCP	0.98***	0.75***	0.81***	0.37*	0.74***	0.84***	-0.25 ^{NS}	-.12 ^{NS}	0.56***	0.67***	0.78***					
PRP	0.95***	0.79***	0.78***	0.44**	0.70***	0.83***	-0.24 ^{NS}	-.14 ^{NS}	0.55***	0.64***	0.75***	0.96***				
θ_v	0.89***	0.69***	0.73***	0.44**	0.65***	0.74***	-0.28 ^{NS}	-.06 ^{NS}	0.53**	0.52**	0.73***	0.90***	0.89***			
EC	0.73***	0.49**	0.65***	0.31 ^{NS}	0.93***	0.60***	-0.23 ^{NS}	-.22 ^{NS}	0.55***	0.53**	0.54***	0.71***	0.67***	0.62***		
NH4-N	0.66***	0.49**	0.61***	0.45**	0.47**	0.59***	-0.25 ^{NS}	0.07 ^{NS}	0.39*	0.42**	0.49**	0.65***	0.67***	0.59***	0.42**	
NO3-N	0.74***	0.47**	0.57***	0.22 ^{NS}	0.52**	0.58***	-0.14 ^{NS}	-.08 ^{NS}	0.38*	0.52**	0.53**	0.74***	0.72***	0.76***	0.51**	0.54***

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

soil properties except sand and silt with negative and non-significant correlations. Overall the positive correlations of soil properties including SOM, EC, θ_v, NH_4^+-N, NO_3^--N and clay content with HCP and PRP suggested that ground conductivity can be used to assess the fertility status, to ameliorate productive and unproductive area within field and to visualize its impact on the yield. The negative correlations of the soil properties with sand content suggested less nutrient and moisture holding capacity which may cause a threat to water quality.

4.4.5.2 North River Site

The correlation matrix (Table 4-11) revealed the significant correlations of HCP and PRP with all soil properties except silt content (Table 4-11). The ground conductivity was negatively correlated with sand content indicating lower values of HCP and PRP in the areas enriched with more sand content. The θ_v was significantly correlated with pH (r = 0.41), EC (r = 0.67), SOM (r = 0.78), clay (r = 0.59), NH_4^+-N (r ~ 0.46 to 0.65) and NO_3^--N (r ~ 0.62 to 0.75). These positive relationships suggested the higher values of θ_v, inorganic nitrogen, EC and ground conductivity in the areas having more clay and SOM. This may be due to more retention of moisture, available nitrogen and soluble salts by fine clay particles and SOM. The soil pH was significantly correlated with EC (r = 0.33), while the relationships of pH with other soil properties were non-significant except a significant correlation with PRP (r = 0.32).

The soil EC and SOM were significantly correlated with all soil properties except negative correlation with sand content (Table 4-11) indicating less fertility due to lower SOM. The correlation of SOM with sand, silt and pH was found to be non-significant. The clay content was found to have significant correlations with HCP (r = 0.49), PRP (r = 0.55), θ_v (r = 0.59), EC (r = 0.42), SOM (r = 0.68), NH_4^+-N (r ~ 0.27 to 0.49), and NO_3^--N (r ~ 0.45 to 0.49). The clay content was negatively correlated with the sand (r = - 0.47), while the relationship of clay with the silt was non-significant (r = 0.18). The positive correlations of the clay with other soil properties indicated the high productivity potential in the areas enriched with clay. The sand content was found to have significant negative correlations with θ_v, HCP, PRP, silt and clay. The correlations of sand with other soil properties including EC, SOM, NH_4^+-N and NO_3^--N were also negative but non-significant. The silt content of the soil having non-significant correlations with soil properties (Table 4-11). The significant correlations among the soil properties are in agreement with the findings of Ristolainen et al. (2009) who predicted the selected soil properties at the depth of 0-20 cm using geo-electrical probes.

The significant positive correlations among the soil properties excluding sand and silt content suggested the spatial variation of the soil properties with respect to each other. The positive correlations of HCP and PRP with other soil properties showed that the ground conductivity could be used to predict soil properties within wild blueberry fields. Due to its ease of measurement, rapid data collection and significant relationships with other soil properties indicated that the ground conductivity could be used develop management zones for variable rate application of fertilizer to increase farm profitability and reducing environmental contamination.

4.4.6 Geostatistical Analysis of Soil Properties

Geostatistics provides an advanced methodology which facilitates characterization and quantification of the spatial features of soil parameters and enables spatial interpolation (Brouder et al., 2005). The soil properties do not vary randomly in

Table 4-11. Correlation matrix of soil properties for North River Site.

	HCP	PRP	θ_v	pH	EC	SOM	Sand	Silt	Clay	NH4-N	NO3-N	HCP	PRP	θ_v	EC	NH4-N
PRP	0.70***															
θ_v	0.86***	0.57***														
pH	0.39**	0.34*	0.41**													
EC	0.77***	0.50***	0.67***	0.33*												
SOM	0.72***	0.73***	0.78***	0.03^{NS}	0.71***											
Sand	-0.22 ^{NS}	-0.30 ^{NS}	-0.31*	-.04 ^{NS}	-0.15 ^{NS}	-0.17 ^{NS}										
Silt	0.12 ^{NS}	0.14 ^{NS}	0.13 ^{NS}	-.05 ^{NS}	0.02 ^{NS}	0.03 ^{NS}	-0.89***									
Clay	0.49***	0.55***	0.59***	0.13 ^{NS}	0.42**	0.68***	-0.47***	0.18 ^{NS}								
NH4-N	0.72***	0.63***	0.65***	0.12 ^{NS}	0.60***	0.61***	-0.18 ^{NS}	0.03 ^{NS}	0.49***							
NO3-N	0.77***	0.75***	0.73***	0.04 ^{NS}	0.68***	0.70***	-0.17 ^{NS}	0.01 ^{NS}	0.49***	0.63***						
HCP	0.95***	0.82***	0.75***	0.18 ^{NS}	0.81***	0.68***	-0.25 ^{NS}	0.12 ^{NS}	0.43***	0.70***	0.73***					
PRP	0.64***	0.65***	0.52***	0.32*	0.46***	0.36*	-0.31*	0.22 ^{NS}	0.31*	0.51***	0.46***	0.75***				
θ_v	0.69***	0.76***	0.92***	0.06 ^{NS}	0.60***	0.66***	-0.43***	0.27*	0.55***	0.56***	0.58***	0.68***	0.55***			
EC	0.80***	0.63***	0.61***	0.11 ^{NS}	0.91***	0.66***	-0.15 ^{NS}	0.02 ^{NS}	0.38**	0.49***	0.65***	0.75***	0.49***	0.51***		
NH4-N	0.61***	0.53***	0.46***	0.15 ^{NS}	0.41**	0.47***	-0.20 ^{NS}	0.15 ^{NS}	0.27*	0.69***	0.46***	0.66***	0.56***	0.42**	0.38**	
NO3-N	0.75***	0.62***	0.54***	0.19 ^{NS}	0.62***	0.53***	-0.31*	0.18 ^{NS}	0.45***	0.62***	0.63***	0.80***	0.66***	0.49***	0.59***	0.61***

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

space; such a variation is gradual and follows a pattern that can be quantified using spatial correlation structure (Kerry and Oliver, 2003). The spatial correlation is expressed in terms of variogram or co-variance function which is the measure of the dissimilarity between two points in space separated by some distance (Deutsch et al., 2002).

The semivariogram parameters with the best fitted model (Tables 4-12 and 4-13 for Carmal and North River Sites, respectively) for each soil property were calculated using GS+ Geostatistics for the Environmental Sciences Version 9 software (Gamma Design Software, LLC, Woodhams St, Plainwell, MI). Semivariograms are modeled using several authorized models that can be fitted to the data, and the one with minimum nugget and high coefficient of determination (R^2) is selected (Oliver, 1987). In Carmal Site, gaussian, spherical, exponential and linear models were found to best fit the data of soil properties. The best fitted semivariogram models for North River Site were exponential, spherical and gaussian.

Semivariogram has three parameters nugget, sill, and range (Brouder et al., 2005). Nugget to sill ratio is the indicator of spatial dependence of a parameter; low nugget to sill ratio represents high spatial dependence of the parameters. A variable has strong spatial dependency if the ratio is less than 25%, moderate spatial dependency if the ratio is between 25 and 75%, and weak spatial dependency for a ratio greater than 75% (Cambardella et al., 1994; Chien et al., 1997).

4.4.6.1 Carmal Site

The geostatistical parameters of soil properties for 1st sampling (0 - 15 cm) showed that all soil properties had lower nugget to sill ratio, indicating large spatial dependence, and large within field variation of soil properties due to their lower range of influence (Table 4-12). However, sand and silt showed weak spatial dependence with nugget to sill ratio 100% and range of influence greater than 80 m. The results indicated that NH_4^+-N, NO_3^--N, EC, θ_v, HCP, and clay content were highly variable with the range of influence less than 30 m (Table 4-12). The soil properties including SOM, PRP, pH, sand and silt content were moderately variable within field with range of variability ranging from 65 to 87 m. Geostatistical results of soil properties including θ_v, EC, inorganic nitrogen, and HCP for 2nd soil sampling also showed large spatial variability in soil properties within field as indicated by their lower range of influence and moderate to high spatial dependency. Similar pattern of variation for these soil properties was observed for 3rd soil sampling during the crop year (Table 4-12). The PRP was moderately variable with the range of influence 65.60 m and 45.93 m for 2nd and 3rd sampling, respectively (Table 4-12). The SOM was moderately variable with the range of influence 70.23 m which was almost similar to the sprout year. The θ_v recorded on bi-weekly basis during the crop year was moderate to highly variable within field with the range of variability ranging from 15 to 49 m (Table 4-14). The pattern of variation for θ_v during the crop year was similar to the sprout year, which was suggested by its lower range of influence and moderate to high spatial dependence (Table 4-14).

4.4.6.2 North River Site

The geostatistical analysis of soil properties (Table 4-13) indicated that SOM, available forms of nitrogen, pH, EC, HCP, and PRP were highly variable with the range of influence less than 30 m and sill to nugget ratio less than 15% indicating high spatial dependence (Table 4-13). The θ_v, sand, silt and clay were found to be moderately variable within field with the range of influence less than 70 m and having high to

Table 4-12. Semivarigram parameters of soil properties for Carmal Site.

First Sampling (May, 2009)						
Parameters	Nugget	Sill	Range (m)	Nugget Sill ratio (%)	R^2	Model
HCP (mS m^{-1})	1.77	3.95	28.30	44.86	0.63	Gaussian
PRP (mS m^{-1})	0.07	3.93	70.80	1.78	0.74	Spherical
θ_v	1.03	21.42	12.60	4.80	0.31	Exponential
pH	0.02	0.06	76.40	33.33	0.57	Exponential
EC (µS cm^{-1})	9.80	125.10	24.90	7.8	0.23	Exponential
SOM (%)	3.37	6.74	76.10	50	0.65	Spherical
Sand (%)	18.75	18.75	85.86	100	0.37	Linear
Silt (%)	7.62	7.62	81.66	100	0.10	Linear
Clay (%)	0.01	19.16	23.70	0.05	0.30	Linear
NH_4^+ -N (mg Kg^{-1})	0.01	17.36	20.30	0.05	0.50	Spherical
NO_3^--N (mg Kg^{-1})	0.84	2.87	19.00	29.26	0.44	Exponential
2nd Sampling (July, 2009)						
Parameters	Nugget	Sill	Range (m)	Nugget Sill ratio (%)	R^2	Model
HCP (mS m^{-1})	1.35	4.15	28.10	32.53	0.70	Gaussian
PRP (mS m^{-1})	0.68	3.51	65.60	19.37	0.68	Spherical
θ_v	8.97	26.96	16.70	33.27	0.77	Spherical
EC (µS cm^{-1})	4.00	80.70	26.50	4.95	0.93	Exponential
NH_4^+ -N (mg Kg^{-1})	12.10	43.86	31.90	27.58	0.54	Exponential
NO_3^--N (mg Kg^{-1})	0.52	4.89	16.30	10.63	0.40	Gaussian
3rd Sampling (June, 2010)						
Parameters	Nugget	Sill	Range (m)	Nugget Sill ratio (%)	R^2	Model
HCP (mS m^{-1})	0.10	3.95	20.50	2.50	0.88	Gaussian
PRP (mS m^{-1})	0.23	3.92	45.93	5.86	0.95	Gaussian
EC (µS cm^{-1})	27.80	96.60	28.56	28.77	0.92	Gaussian
SOM (%)	3.27	6.32	70.23	51.74	0.72	Spherical
NH_4^+ -N (mg Kg^{-1})	3.23	16.25	27.80	19.87	0.62	Spherical
NO_3^--N (mg Kg^{-1})	0.79	4.28	18.30	18.45	0.54	Gaussian

moderate spatial dependence. The lower range of influence suggested the high variability of the soil properties across the field. The large spatial dependency and lower range of soil properties in field caused fruit yield variability within field. Similar results have been reported for different crops (Zaman and Schumann, 2006; Li et al., 2008).

Geostatistical results of soil properties for 2nd soil sampling also showed large spatial variability of soil properties within field with the range of influence less than 30 m except for HCP and θ_v which were moderately variable with the range of influence 58.70 m and 48.23 m, respectively (Table 4-13). A large range of influence indicates that the observed values of soil variable are influenced by the other values of this variable over greater distances than soil variables which have smaller ranges (Lepez-Granados et al., 2002). The soil EC, NH_4^+-N, NO_3^--N, SOM and HCP for 3rd sampling (crop year) were highly variable with the range of influence less than 27 m (Table 4-13). The PRP was moderately variable with the range of influence 61.70 m for 3rd soil sampling. The spatial pattern of the variability for soil properties during crop year was similar to 1st and 2nd soil sampling during the sprout year. The θ_v during the crop year was moderate to highly variable within field with the range of influence ranging from 14 to 51 m (Table 4-14). The pattern of variation for θ_v during the crop year was similar to the sprout year (Tables 4-13 and 4-14).

Overall the results of geostatistical analysis showed that the soil properties were moderate to highly variable within field for both sites. The lower ranges of influence and higher coefficient of variation suggested the large spatial variation of soil properties for North River Field as compare to the Carmal Field. The semivarigrams for soil properties were shown (Figs 4-2 and 4-3, Appendix A for Carmal and North River Fields, respectively).

The scale of spatial correlation varied in distance from 12 m to 86.86 m, for selected soil properties (Table 4-12 and 4-13). The most of the soil properties were found to have the range of influence ranging from 20 to 50m. At distances shorter than this range, variability is non-random (Oliver, 1987). These results showed that selected soil

Table 4-13. Semivarigram parameters of soil properties for North River Site.

First Sampling (May, 2009)

Parameters	Nugget	Sill	Range (m)	Nugget Sill ratio (%)	R^2	Model
HCP (mS m^{-1})	0.83	12.86	27.40	6.40	0.97	Exponential
PRP (mS m^{-1})	0.70	6.09	21.60	11.49	0.96	Exponential
θ_v	9.21	32.29	46.20	28.52	0.77	Spherical
pH	0.008	0.09	15.80	8.88	0.31	Exponential
EC (μS cm^{-1})	41.00	387.40	12.80	10.58	0.70	Exponential
SOM (%)	0.66	5.39	14.60	12.24	0.74	Exponential
Sand (%)	68.80	106.40	67.90	41.34	0.82	Spherical
Silt (%)	25.00	84.94	44.20	29.43	0.78	Spherical
Clay (%)	8.08	17.91	65.50	45.11	0.77	Spherical
NH_4^+ -N (mg Kg^{-1})	0.01	25.24	26.20	0.04	0.78	Spherical
NO_3^--N (mg Kg^{-1})	0.48	5.57	13.10	8.61	0.87	Exponential

2nd Sampling (July, 2009)

Parameters	Nugget	Sill	Range (m)	Nugget Sill ratio (%)	R^2	Model
HCP (mS m^{-1})	5.29	14.99	58.70	35.29	0.73	Spherical
PRP (mS m^{-1})	6.51	19.35	30.49	33.64	0.78	Linear
θ_v	1.70	35.01	48.23	4.85	0.86	Spherical
EC (μS cm^{-1})	32.50	306.40	12.20	10.60	0.71	Exponential
NH_4^+ -N (mg Kg^{-1})	0.01	16.12	25.80	0.06	0.60	Spherical
NO_3^--N (mg Kg^{-1})	4.52	9.24	23.00	48.91	0.96	Gaussian

3rd Sampling (June, 2010)

Parameters	Nugget	Sill	Range (m)	Nugget Sill ratio (%)	R^2	Model
HCP (mS m^{-1})	0.63	11.89	25.50	5.29	0.65	Exponential
PRP (mS m^{-1})	2.12	5.43	61.70	39.04	0.98	Spherical
EC (μS cm^{-1})	32.40	331.00	13.30	9.78	0.66	Exponential
SOM (%)	0.75	5.51	13.70	13.61	0.70	Exponential
NH_4^+ -N (mg Kg^{-1})	1.03	13.24	26.89	7.79	0.73	Spherical
NO_3^--N (mg Kg^{-1})	3.36	15.63	22.11	21.49	0.94	Gaussian

characteristics vary at large spatial scales, and there are correlations between several soil properties (Tables 4-10 and 4-11). Kerry and Oliver (2003) suggested that the sample spacing should be from one third or less than half the range of semivariogram. The results of this study suggest that a sampling interval ~15 to 20 m, would provide reliable

Table 4-14. Semivarigram parameters of volumetric moisture content during crop year for both sites.

Carmal Site							
Parameters	Sampling Time	Nugget	Sill	Range (m)	Nugget Sill ratio (%)	R^2	Model
θ_v	June 01	10.46	21.39	48.90	48.90	0.74	Spherical
θ_v	June 15	9.76	19.53	45.23	49.97	0.57	Spherical
θ_v	July 01	2.92	20.44	15.86	14.42	0.84	Gaussian
θ_v	July 15	4.69	25.46	18.56	18.42	0.80	Gaussian
θ_v	July 30	6.29	26.58	16.50	23.66	0.81	Gaussian
North River Site							
Parameters	Sampling Time	Nugget	Sill	Range (m)	Nugget Sill ratio (%)	R^2	Model
θ_v	June 01	11.60	33.34	47.40	34.79	0.99	Spherical
θ_v	June 15	10.81	35.76	27.90	30.22	0.90	Gaussian
θ_v	July 01	10.88	35.22	33.21	30.89	0.96	Gaussian
θ_v	July 15	2.40	29.50	50.50	8.13	0.88	Spherical
θ_v	July 30	6.53	35.40	14.78	15.62	0.86	Spherical

predictions for managing the within field variation in wild blueberry fields. This emphasizes the need to adjust sampling intensity according to the range of spatial dependence, to avoid unnecessary sampling and analytical cost.

4.4.7 Geostatistical Analysis of Leaf Nutrients, Plant Growth Parameters and Yield

4.4.7.1 Carmal Site

The semivariograms were developed for leaf nutrients to assess the spatial variation of the leaf nutrients within field. The geostatistical parameters of leaf nutrients (Table 4-15) showed that all the leaf nutrients had moderate to high spatial dependence, and large within field variation due to their lower range of influence (less than 30 m), except leaf N, K, Mg, Mn and Zn that showed moderate variability with the range of

Table 4-15. Geostatistical parameters of leaf nutrients for Carmal Site.

July, 2009

Parameters	Nugget	Sill	Range (m)	Nugget Sill ratio (%)	R^2	Model
N (%)	0.01	0.02	60.21	50.00	0.47	Linear
P (%)	0.007	0.09	21.10	7.77	0.28	Exponential
K (%)	0.006	0.006	67.10	100.00	0.37	Linear
Ca (%)	0.001	0.004	23.70	25.00	0.49	Spherical
Mg (%)	0.003	0.006	70.40	50.00	0.58	Spherical
Fe (mg L^{-1})	235.00	803.00	63.40	29.26	0.81	Gaussian
Mn (mg L^{-1})	57.00	1587.36	77.10	3.59	0.93	Gaussian
Cu (mg L^{-1})	0.18	3.05	14.90	5.91	0.30	Gaussian
Zn (mg L^{-1})	3.02	7.75	74.20	38.96	0.45	Exponential
B (mg L^{-1})	4.01	12.25	27.80	32.65	0.35	Spherical

June, 2010

Parameters	Nugget	Sill	Range (m)	Nugget Sill ratio (%)	R^2	Model
N (%)	0.02	0.04	62.34	5000	0.65	Linear
P (%)	0.01	0.02	19.70	50.00	0.29	Exponential
K (%)	0.02	0.03	65.89	66.66	0.41	Linear
Ca (%)	0.001	0.06	23.52	5.00	0.48	Exponential
Mg (%)	0.001	0.002	49.40	50.00	0.51	Spherical
Fe (mg L^{-1})	67.02	219.06	59.21	30.59	0.75	Linear
Mn (mg L^{-1})	217.05	1615.05	85.40	13.43	0.78	Spherical
Cu (mg L^{-1})	0.32	0.81	14.60	39.50	0.37	Exponential
Zn (mg L^{-1})	2.76	6.56	70.12	42.07	0.55	Linear
B (mg L^{-1})	2.85	6.67	25.10	42.72	0.40	Spherical

influence ranging from 60 to 80 m during sprout year. The geostatistical analysis of the leaf nutrients during the fruit year also suggested the similar pattern of variation as sprout year with the range of influence ranging from 14 to 86 m (Table 4-15).

The geostatisitical analysis of plant growth parameters and fruit yield (Table 4-17) suggested that the plant density was moderately variable with the range of influence 60.21 m. The height of plants, number of buds and branches were highly variable with the range of variability ranging from 15 to 37 m. Geostatistical results showed large spatial variability in fruit yield with the range of influence less than 30m. Variations in soil properties, leaf nutrients and plant growth parameters corresponding with the variability in fruit yield, provided strong evidence that soil variability is a major factor affecting localized yield reduction. Overall the results showed the substantial variability of leaf nutrients, plant growth parameters, and fruit yield within field.

4.4.7.2 North River Site

The geostatistical parameters of leaf nutrients (Table 4-16) showed that all the leaf nutrients had higher to moderate spatial dependence, and large within field variation of leaf nutrients as indicated by their lower range of variability, except leaf N, Mg, Mn and Cu showing moderate variability with the range of influence ranging from 45 to 62 m. The semivariogram analysis showed that the leaf P, K, Ca, Fe and Zn, were highly variable within field with the range of variability less than 30 m (Table 4-16). The geostatistical analysis of the leaf nutrients during the crop year suggested the similar pattern of variation as sprout year. The leaf nutrients N, Mg and Mn with the range of influence of 58.23 m, 65.60 m and 60.58 m, respectively were found to be moderately variable during the fruit year (Table 4-16). The remaining leaf nutrients were highly variable with the range of influence less than 31 m during crop year.

The geostatistical analysis of plant growth parameters and fruit yield (Table 4-17) indicated that the plant density and number of branches were moderately variable with the range of influence ranging from 60 to 70 m. The height of plants and number of buds were highly variable with the range of variability less than 25 m. The geostatistical range influence from semivariogram (Table 4-17) suggested the large spatial variation of fruit yield within field, which was similar to Carmal Site. These results indicated that the large

Table 4-16. Geostatistical parameters of leaf nutrients for North River Site.

July, 2009						
Parameters	Nugget	Sill	Range (m)	Nugget Sill ratio (%)	R^2	Model
N (%)	0.41	0.85	60.39	48.23	0.39	Linear
P (%)	0.01	0.35	22.50	1.35	0.31	Spherical
K (%)	0.02	0.13	20.25	15.38	0.36	Spherical
Ca (%)	0.01	0.71	12.10	14.38	0.64	Exponential
Mg (%)	0.57	0.87	70.39	65.51	0.47	Linear
Fe (mg L^{-1})	10.00	771.90	24.10	1.29	0.50	Spherical
Mn (mg L^{-1})	0.80	3.90	61.80	20.51	0.96	Gaussian
Cu (mg L^{-1})	0.04	0.79	45.10	5.06	0.85	Spherical
Zn (mg L^{-1})	4.10	11.09	26.10	36.97	0.43	Spherical
B (mg L^{-1})	3.10	14.60	10.40	21.98	0.75	Exponential
June, 2010						
Parameters	Nugget	Sill	Range (m)	Nugget Sill ratio (%)	R^2	Model
N (%)	0.02	0.04	58.23	50.00	0.31	Linear
P (%)	0.01	0.25	19.60	4.00	0.33	Spherical
K (%)	0.02	0.20	13.30	10.00	0.46	Exponential
Ca (%)	0.01	0.03	16.20	33.33	0.65	Spherical
Mg (%)	0.01	0.03	65.60	33.33	0.58	Exponential
Fe (mg L^{-1})	18.00	641.50	31.25	2.80	0.88	Exponential
Mn (mg L^{-1})	153.00	1397.00	60.58	10.95	0.61	Exponential
Cu (mg L^{-1})	0.04	1.22	28.80	3.27	0.66	Exponential
Zn (mg L^{-1})	0.36	1.70	24.60	21.17	0.23	Spherical
B (mg L^{-1})	4.47	13.57	11.45	32.94	0.96	Gaussian

spatial variation of soil properties (Table 4-13), can cause a significant impact on the yield. Variations in soil properties may strongly reflect variations in soil fertility and crop yield (Mulla and Bhatti, 1997; Schepers et al., 2004). Hence, understanding the variability of intrinsic soil fertility is the key factor for site-specific management. Overall the results of geostatistical analysis and coefficient of variation suggested high spatial variation in leaf nutrients and plant growth parameters within field which may have an impact on the fruit yield and quality.

Table 4-17. Geostatistical parameters of plant growth parameters and fruit yield for both fields.

Plant Growth Parameter	Nugget	Sill	Range (m)	Nugget Sill Ratio (%)	R^2	Model
Carmal Site						
Plant Density	3.91	7.68	60.21	50.91	0.83	Linear
Height	1.48	2.68	16.50	55.00	0.60	Exponential
No of Buds	3.80	9.60	24.50	39.58	0.58	Gaussian
Branches	0.10	0.90	37.10	0.11	0.38	Spherical
Yield (Kg ha^{-1})	1000.00	16600	27.30	6.02	0.74	Spherical
Blue Pixel (%)	0.10	4.52	28.00	2.21	0.72	Spherical
North River Site						
Plant Density	7.30	14.70	70.40	47.61	0.70	Exponential
Height	0.67	9.70	15.40	6.90	0.71	Exponential
No of Buds	1.00	1.42	24.70	70.42	0.40	Exponential
Branches	33.58	43.14	60.39	42.97	0.28	Linear
Yield (Kg ha^{-1})	820.00	19880	27.20	4.12	0.86	Exponential
Blue Pixel (%)	0.20	3.56	28.10	5.61	0.82	Exponential

4.4.8 Interpolation and Mapping of Soil Properties

The sampling points, fields boundary, bare spots and weeds mapped by Pro Mark 3 mobile mapper GPS (Thales Navigation, Santa Clara, Cal.) were imported into Arc GIS 9.3 software (ESRI, Redlands, CA) and shape files were created for visual display of Carmal Site (Fig. 4-4) and North River Site (Fig. 4-5). The Arc GIS analysis was performed to calculate the area covered by bare spot, weeds and grasses for both fields. The area contained by bare spots, weed and grasses was 18% and 27% for Carmal and North River Sites, respectively (Figs. 4-4 and 4-5).

Geostatistics combined with GIS was applied to analyze the spatial variability in soil properties for both fields. Soil parameters were interpolated using kriging combined with semivariogram parameters to produce detailed maps. Zaman and Schumann, (2006) showed that the kriged estimates were very close to the measured estimates in Florida citrus. The kriging interpolation is considered to be more accurate and reliable than other

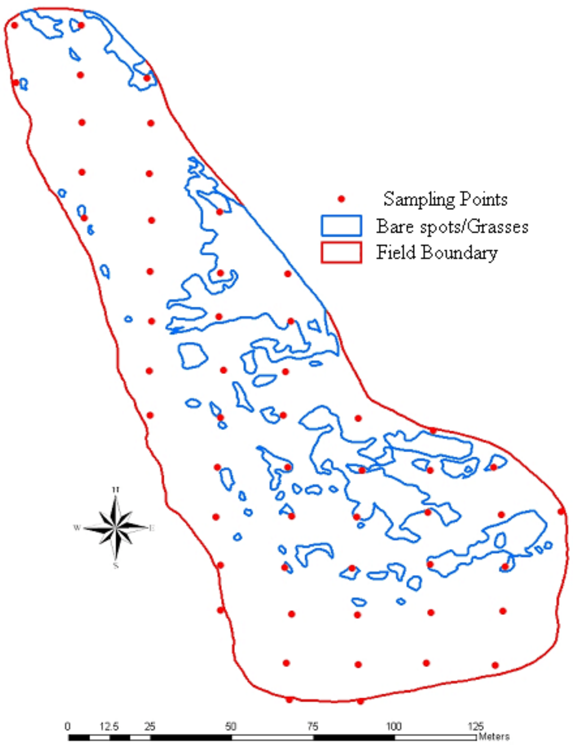


Figure 4-4. Field layout of Carmal Site.

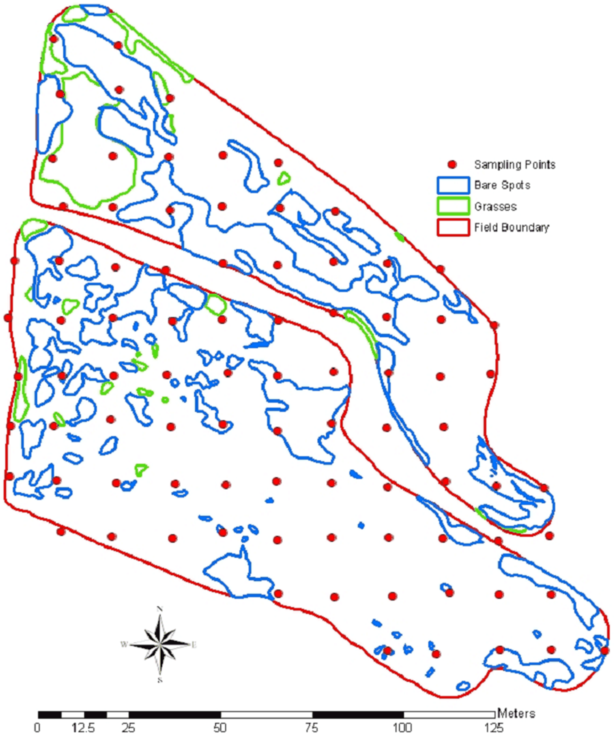


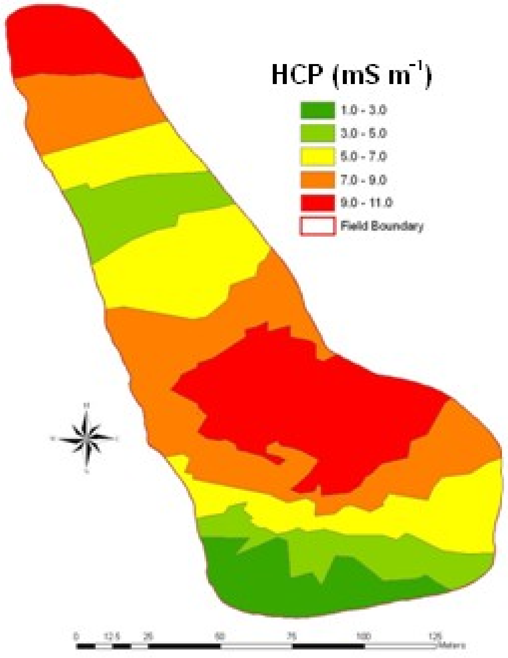
Figure 4-5. Field layout of North River Site.

methods such as inverse distance weighting (IDW) or trend surface models (Mulla et al., 1992). The maps for soil properties were produced using Arc GIS 9.3 (ESRI, Redlands, CA) software at the same scale and equal number of classes in order to allow easier comparison.

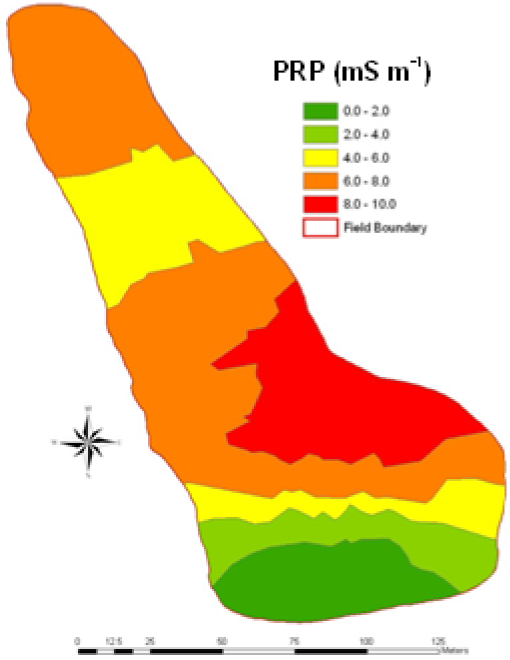
4.4.8.1 Carmal Site

The interpolated maps of HCP, PRP, θ_v, pH, EC, SOM, sand, silt, clay, NH_4^+ -N and NO_3^--N (Fig 4-6) showed gradual and non random spatial variability with significantly different values across the field. Spatial patterns of variation for HCP, PRP, θ_v, EC, SOM, clay, NH_4^+-N and NO_3^--N (Fig. 4-6 a, b, c, e, f, i, j, and k) were almost similar, showing higher value in the north and lower values in the south west part of the field. The medium values were observed in the centre of the field. The maps of NH_4^+-N and NO_3^--N, HCP, PRP, SOM, clay, θ_v and EC indicated the large spatial variability of these soil properties within field. Geostatistical range of influence from semivariogram also showed the large spatial variation of these soil properties (Table 4-12). The significant positive correlations among these soil properties also explained the similar pattern of variation of these soil properties within field (Table 4-10).

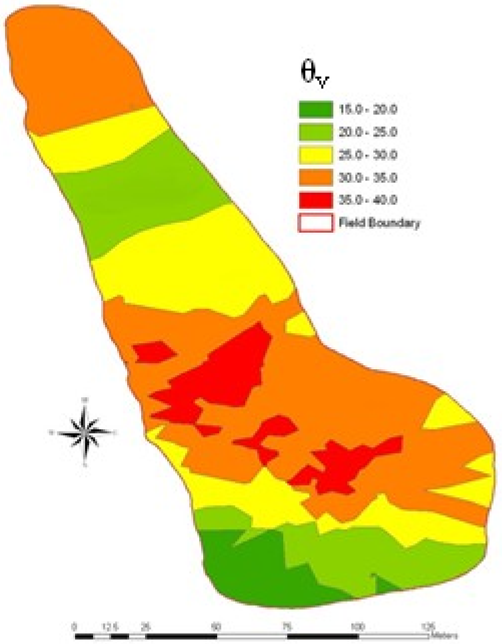
The maps of soil pH, sand and silt content indicated that these soil properties were less variable as compare to the other soil properties (Fig. 4-6 d, g and h). Geostatistical range of influence for these soil properties also suggested their less variability (Table 4-12). The lower values for the pH were observed in the southwest part of the field, and higher values were observed in the centre of the field. The soil pH map indicated that the most of the Carmal Site having the pH ranging from 5.40 to 5.60 (Fig 4-6 d). The sand and silt content having almost same pattern of the variation except the northwest of the


HCP (mS m^{-1})
1.0 - 3.0
3.0 - 5.0
5.0 - 7.0
7.0 - 9.0
9.0 - 11.0
Field Boundary
0
12.5
25
50
75
100
125
Meters

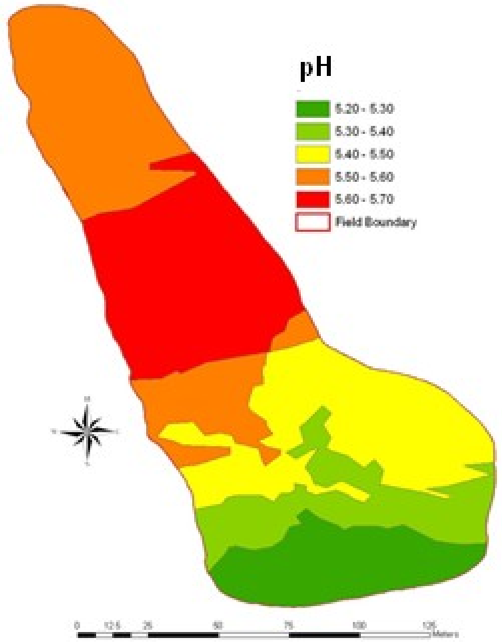
(a)


PRP (mS m^{-1})
0.0 - 2.0
2.0 - 4.0
4.0 - 6.0
6.0 - 8.0
8.0 - 10.0
Field Boundary
0
12.5
25
50
75
100
125
Meters

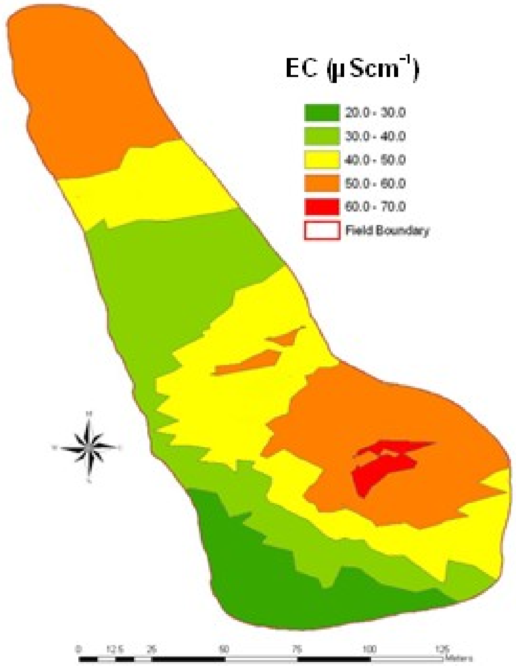
(b)


θ_v
15.0 - 20.0
20.0 - 25.0
25.0 - 30.0
30.0 - 35.0
35.0 - 40.0
Field Boundary
0
12.5
25
50
75
100
125
Meters

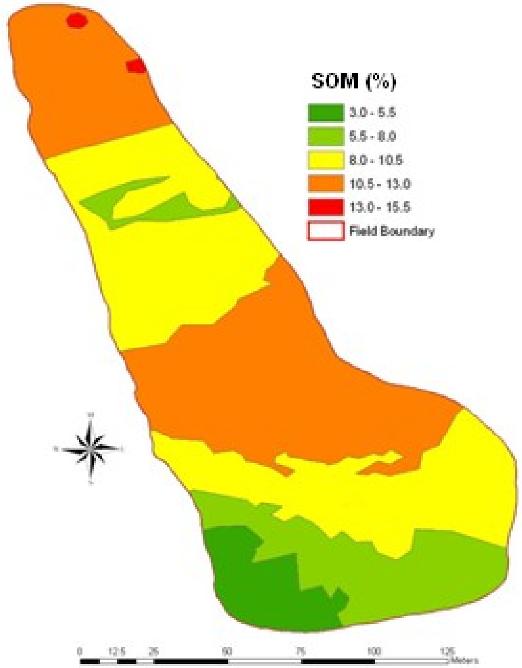
(c)


pH
5.20 - 5.30
5.30 - 5.40
5.40 - 5.50
5.50 - 5.60
5.60 - 5.70
Field Boundary
0
12.5
25
50
75
100
125
Meters

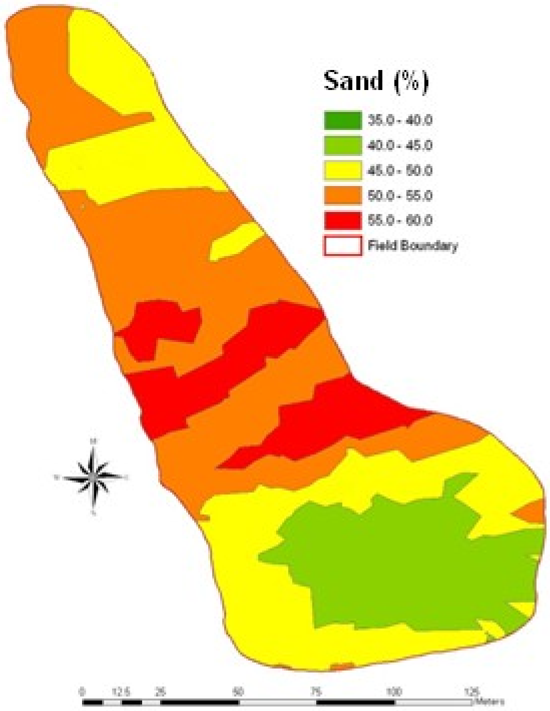
(d)


EC (µScm^{-1})
20.0 - 30.0
30.0 - 40.0
40.0 - 50.0
50.0 - 60.0
60.0 - 70.0
Field Boundary
0
12.5
25
50
75
100
125
Meters

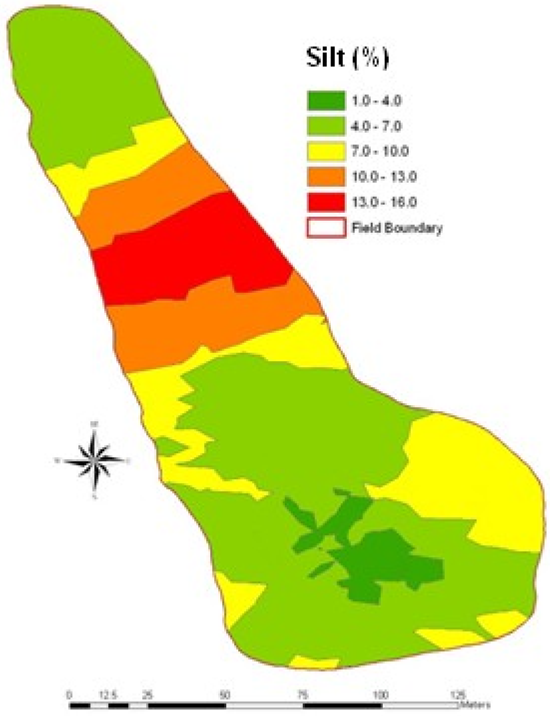
(e)


SOM (%)
3.0 - 5.5
5.5 - 8.0
8.0 - 10.5
10.5 - 13.0
13.0 - 15.5
Field Boundary
0
12.5
25
50
75
100
125
Meters

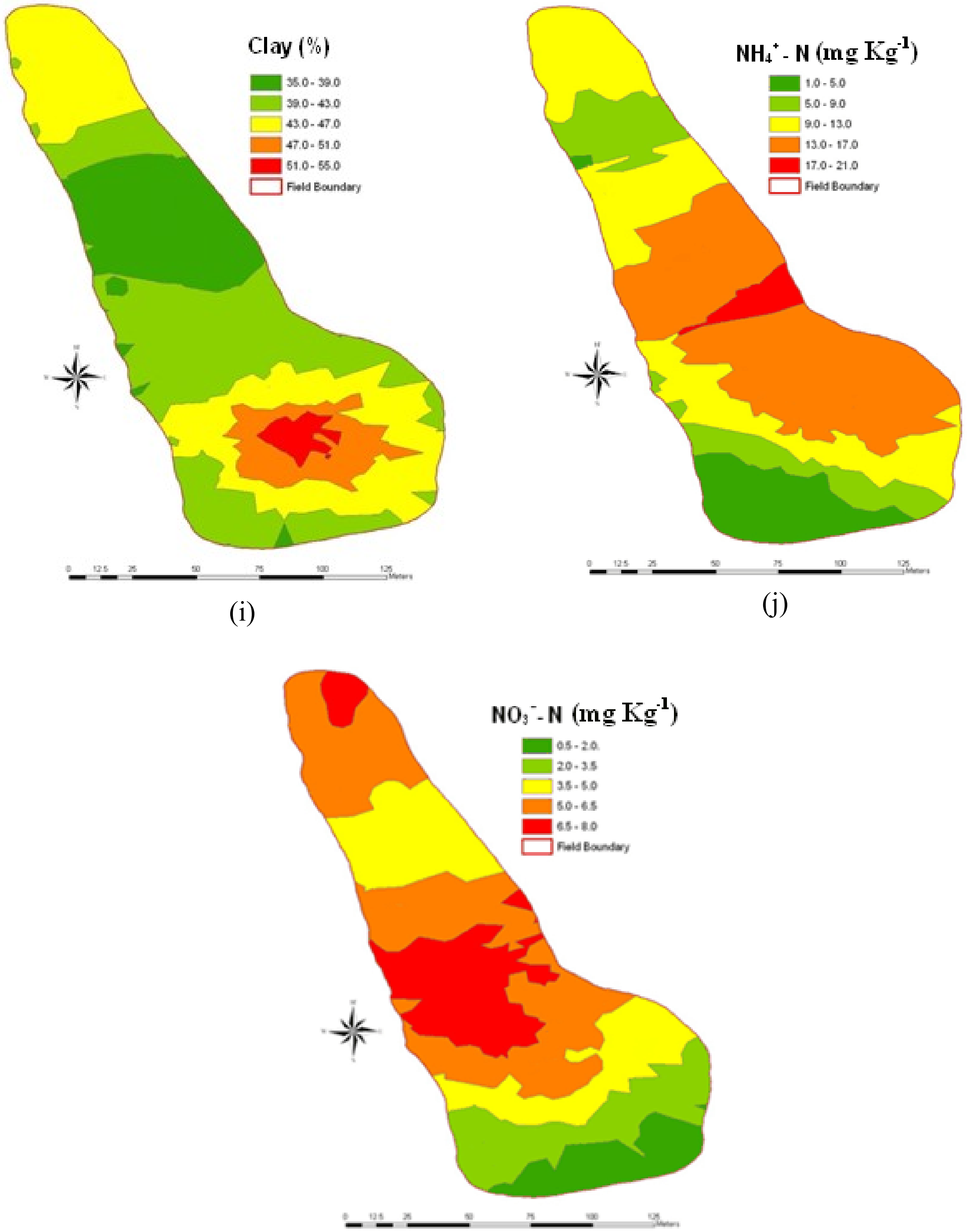
(f)


Sand (%)
35.0 - 40.0
40.0 - 45.0
45.0 - 50.0
50.0 - 55.0
55.0 - 60.0
Field Boundary
0
12.5
25
50
75
100
125
Meters

(g)


Silt (%)
1.0 - 4.0
4.0 - 7.0
7.0 - 10.0
10.0 - 13.0
13.0 - 16.0
Field Boundary
0
12.5
25
50
75
100
125
Meters

(h)



(i)

(j)

(k)

Figure 4-6. Maps of soil properties for Carmal Site. (a) Ground conductivity at horizontal co-planar geometry (HCP), (b) Ground conductivity at perpendicular co-planar geometry (PRP), (c) Moisture content, (d) pH, (e) Electrical conductivity (EC), (f) Soil organic matter (SOM), (g) Sand %, (h) Silt %, (i) Clay %, (j) Ammonium nitrogen (NH_4^+ -N), (k) Nitrate nitrogen (NO_3^--N).

field where the variation of sand and silt was different (Fig. 4-6 g, h). The similar pattern of variation for these soil properties was observed for 2nd and 3rd sampling during sprout and crop year. Overall the maps of soil properties indicated the large spatial variation within field which was also suggested by the geostatistical analysis and correlation matrix (Fig. 4-6, Tables 4-10 and 4-12).

4.4.8.2 North River Site

The maps of soil properties (Fig. 4-7, Appendix B) were developed to characterize and quantify the spatial pattern of variability. Kriged maps of soil properties suggested the substantial variability within field. The geostatistical range of influence from semivariogram, and higher CVs also indicated the large spatial variation of these soil properties within field (Tables 4-13 and 4-2). The spatial pattern of variation for HCP, PRP, θ_v, EC, SOM, clay, NH_4^+-N and NO_3^--N (Fig. 4-7 a, b, c, e, f, i, j, and k, Appendix B) were almost similar, showing higher value in the northwest, north central region, and medium values were observed in the south eastern region of the field. The lower values were observed in the centre of the field. The variation in soil properties might be due to the variation in slope with the high values of these soil variables in low lying areas and vice versa. The results of zonal statistics also supports the relationships identified (Fig. 4-11, Appendix C).

The map of the soil pH (Fig. 4-7 d, Appendix B) indicated the substantial variability across the field. The most of the North River Site having the pH ranging from 5.0 - 5.5. The geostatistical results also suggested the higher within field variability of soil pH. The map of sand content showed lower values in the northeast, northwest and north central region of the field. Higher values were observed in southeast, southwest and south central region indicating textural variation within field. More than 50% of the North River Field having the sand content ranging from 40-50% (Fig.4-7 g, Appendix B). It was observed that most of the crop areas were contained with more sand than clay for North River Site. The ground inspections revealed that the areas with higher clay content within field were weeds, bare spots and grasses. The silt content was also found to be variable across the field (Fig. 4-7 h, Appendix B). The range of variability for sand and silt content also suggested the within field variability of these soil properties (Table 4-13).

Overall the kriged maps showed that the soil properties were moderate to highly variable within field except sand and silt for both sites. The spatial variability of soil properties across the field was also explained by the range of influence and coefficient of variation for both sites. The results of correlation analysis between soil properties also supported the relationships identified by the map.

4.4.9 Interpolation and Mapping of Leaf Nutrients and Fruit Yield

4.4.9.1 Carmal Site

The kriged maps (Fig 4-8, Appendix B) showed the substantial variation in leaf nutrients and fruit yield across the field. The higher values of leaf N, K, Ca and Mg were found in northeast, northwest, and southwest region of field. Lower values were observed in southeast and centre, while the medium values were observed in the north central region of the field (Fig. 4-8 a, c, d and e, Appendix B). The pattern of variation for leaf N was similar to soil NH_4^+-N and NO_3^--N (Fig. 4-6 j and k) except the areas contained by bare spots, weeds and grasses, the significant positive correlation between leaf N and soil inorganic nitrogen also supported these results. The leaf P was found to moderately variable with higher values in north and southeast areas of the field. The lower values of P were observed in the north central region and southwest, while the medium values were observed in southeast and southwest of the field (Fig 4-8 b, Appendix B). Leaf Fe was also moderately variable with the lower values in centre and southeast, while the higher values were observed in the north, northwest central region of the field (Fig 4-8 f, Appendix B). The medium values were located in the rest of the field.

Leaf Mn was less variable indicating lower values in the centre, higher values in the north and southwest, while medium values were observed in the southeast and north central region of the field (Fig. 4-8 g, Appendix B). The range of influence also suggested the less variability of leaf Mn as compare to other leaf nutrients (Table 4-15). The leaf Cu, Zn and B were highly variable and spatial pattern of variation indicated higher values in north, and southwest of the field. The lower values were observed in the southeast and centre, while the medium values were observed in the north central region of the field (Fig. 4-8 h, i and j, Appendix B). The geostatistical results of leaf nutrients also indicated the large variation of these nutrients as indicated by their lower range of influence (Table 4-15).

Visual comparison from interpolated map of fruit yield represented a good agreement between soil properties, leaf nutrients and fruit yield. The kriged map of fruit yield showed the substantial variation within field, which was also supported by the lower range of influence and high coefficient of variation (Table 4-17 and 4-7). In general, low-yielding areas (Fig. 4-8 k, Appendix B) were in the center, surrounded by high yielding areas in the north and southeast of the field. The ground inspection revealed that the low yielding areas were located in bare patches, weeds and grasses (Fig. 4-8 l,

Appendix B). The interpolated maps of soil properties indicated that the low lying areas were rich in fertility (Fig. 4-6 a, c, e, f, j and k, Appendix B). The presence of excess inorganic nitrogen in bares spots, weeds and grass areas may be utilized to promote weeds and grasses or exposed to more leaching of nutrients into ground water. The map of leaf N, P, and K exhibited almost similar pattern of variation as fruit yield indicating more yield in the areas where leaf N and P were higher. The concentration of leaf N, P and K were in the range set by Eaton et al. (2009). Overall the maps showed the moderate to high variation of leaf nutrients and fruit yield within field which was also indicated by the geostatistical analysis and CVs.

4.4.9.2 North River Site

The kriged maps of leaf nutrients and fruit yield (Fig. 4-9, Appendix B) showed the substantial variation within field. The spatial variation in leaf N, P, K, Ca and Mg was almost similar indicating lower values in northwest, higher values in northeast, south and southeast while the medium values were observed in the centre of the field (Fig. 4-9 a, b, c, d and e, Appendix B). The pattern of variation for leaf N was opposite to soil inorganic nitrogen (Fig 4-6 j and k) because the inorganic nitrogen was higher in bare spots in the northwest, while the leaf N was observed lower in the northwest of the field (Fig. 4-9 a, Appendix B). The map of leaf Fe (Fig. 4-9 f, Appendix B) showed the lower values in the northwest and centre of the field, while the higher Fe content were located in the north central region, northeast and southeast part of the field. The medium values were observed in the north and south central part of the field.

The maps of leaf Mn and Cu (Fig. 4-9 g and h, Appendix B) showed the similar pattern of variation indicating lower values in the northwest, higher values in the northeast and southeast, while the medium values were observed in the centre of the field. The similar pattern of variation for these leaf nutrients was also indicated by the geostatistical range of influence (Table 4-16). The map of leaf Zn and B (Fig. 4-9 i and j, Appendix B) showed higher values in northeast, southeast and south central region, the lower values in the northeast and north central region, while the medium values were observed in the centre of the field indicating within field variation of leaf nutrients.

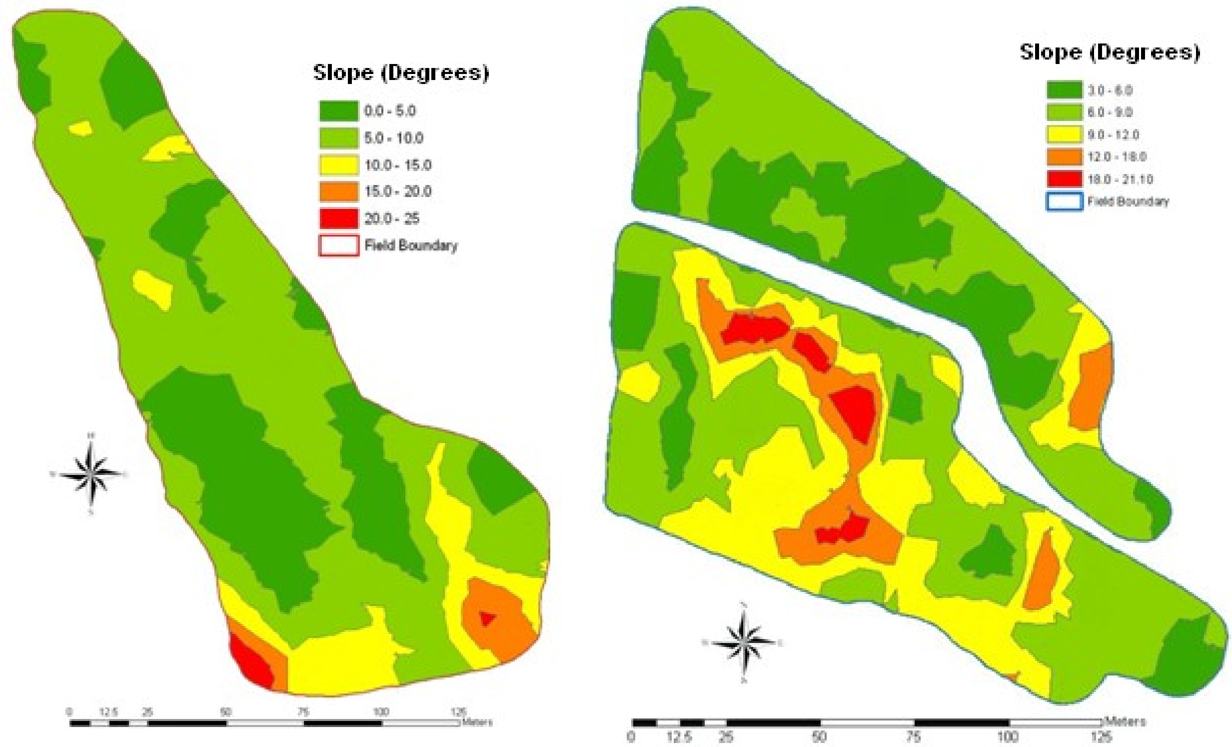
The kriged map of fruit yield (Fig. 4-9 k, Appendix B) showed the substantial variation across the field, which was also suggested by the lower range of influence and high coefficient of variation (Tables 4-17 and 4-8). The low-yielding areas (Fig. 4-9 k, Appendix B) were in the center and northwest, surrounded by high yielding areas in the north central region, southeast and southwest of the field. The low-yielding areas were located in bare spots, weeds and grasses (Fig. 4-9 l, Appendix B). The interpolated maps of soil properties suggested that the low-yielding areas surrounded by bare spots, weeds and grasses were rich in fertility (Fig. 4-7 a, c, e, f, j, k, Appendix B). The high fertility in low-yielding areas may promote weed growth and also a serious threat to the environment by leaching of nutrients to ground water. The variation of fruit yield with respect to slope (Fig. 4-11 l) suggested that the steep slope areas yielded less as compare to low lying areas. The map of leaf N, P, and K exhibited almost similar pattern of variation as fruit yield. In general kriged maps, CVs, and geostatistical analysis suggested that the leaf nutrient and fruit yield exhibited the moderate to high spatial variation within field.

4.4.10 Variation of Soil Properties and Fruit Yield with Slope

Understanding the variability of soil and landscape properties and their effect on crop yield is an important component of site-specific management systems (Li et al., 2008). In agricultural fields, yield variability is partly caused by soil variability and topographic features of the field. Although yield is a function of many host factors, including soil properties, topography, climate, biological factors, and management practices, in certain years as much as 60% or even more of the yield variability can be explained by a combination of soil properties and topographic features (Yang et al., 1998; Kravchenko and Bullock, 2000). Field topography can have a direct effect on crop growth and yield by redirecting and changing nutrients and water availability. Therefore, the relationship between soil properties and field topographic feature is important to investigate the effect of soil properties and field topography on crop yield.

The slope data collected by ASMMS was imported into Arc GIS 9.3 software and kriged maps for slope were created for both sites (Fig. 4-12). The interpolated maps of the slope were reclassified into five classes (zones) to assess the variation of soil properties with respect to slope. Zonal statistics function of Arc GIS was used to predict the mean value of the soil properties and fruit yield within the each zone of slope.

The Carmal Site has a milder slope (Ranges from 5 to 10 degrees) than North River Site (Fig. 4-12 a). The comparison of fruit yield and slope maps suggested that the high-yielding were located in low slope positions for both sites (Figs. 4-12, 4-8 k and 4-9 k). Some parts of the low lying areas were contained by bare spots, weeds and grasses (Figs. 4-8 l and 4-9 l, Appendix B). In general the bare spots, weeds and grasses were scattered throughout the field for both sites. The similar pattern of variation for the fruit yield with respect to slope was suggested by zonal statistics (Figs. 4-10 and 4-11, Appendix C). The availability of excessive nutrients in the low lying areas resulted in



(a)

(b)

Figure 4-12. Slope maps (a) Carmal Site, (b) North River Site.

higher fruit yield which was also indicated by higher but within range leaf N in low slope positions. The presence of more soil nutrients in low lying areas can result in promotion of weeds and ground water contamination. These results indicated that 20 to 30% fertilizer can be saved in bare spots, weeds and grasses areas using sensor or map based variable rate technology.

The bar charts of soil properties and fruit yield with respect to slope indicated the high values for HCP, PRP, θ_v, EC, SOM, Clay, available forms of nitrogen, and fruit yield in the low lying areas for both fields. Low values for these parameters were observed on the steep slope areas (Figs. 4-10 a, b, c, f, i, j, k, l and 4.11 a, b, c, f, i, j, k, l, Appendix C). Mann (2009) showed that the values for the HCP and PRP were lower in the low yielding areas and higher in the high yielding areas for citrus crop. Yang et al. (1998) showed that topographic variables such as elevation, slope, and aspect can explain 15 to 35% of wheat yield variability at the whole-field scale. In addition, they also reported that topographic features account for 49 to 84% of the yield variability in some areas of the field. Higher yields were generally found at lower elevation and gentle slope positions. Lower wheat yields were found at higher elevation levels and steep slope positions due to transport of nutrients in low lying areas.

The bar graphs showed that soil pH, sand and silt content were not found to be variable with respect to slope for both fields (Fig. 4-10, 4-11 d, g, and h, Appendix C). The relationship of the soil properties including HCP, PRP, θ_v, EC, SOM, Clay, and available forms of nitrogen were negative with slope indicating higher values in the low lying areas and lower values on the steep slope. While the other soil properties were not found to vary much with slope for both fields.

4.5 Summary and Conclusions

The results of classical statistics suggested moderate to high variation of soil properties, leaf nutrients, plant growth parameters and fruit yield as indicated by their CVs. Geostatistical range of influence and high to moderate spatial dependence also showed that soil properties, leaf nutrients and fruit yield were moderate to highly variable within field except soil pH, sand and silt content for both sites. The kriged maps of soil properties, leaf nutrients and fruit yield were in agreement with the results of classical and geostatistical analysis suggesting substantial variation within field. The significant positive correlation between HCP, PRP, θ_v, EC, SOM, clay, NH_4^+-N, NO_3^--N and fruit yield and their variation with respect to slope indicated that fruit yield and soil properties were generally high in low laying and reduced with the steepness of slope, indicating the potential of slope in causing variability.

The results of characterization and quantification of spatial soil variability in the wild blueberry field would be helpful in planning future soil sampling in the fields having soil and crop variability. The selection of soil sampling should be based on sampling interval suggested by semivariogram range of easily measured soil properties. The range of the variability for soil properties like HCP, PRP, and SOM suggested the grid size of approximately 15 to 20 m. Therefore, these results would help in ameliorating the unproductive areas based on proper soil sampling, soil variability characterization, and identification of the soil properties responsible for yield variability. The major yield limiting factors can be used to develop prescription maps for site-specific management of the field. The importance of the soil properties for explaining the productivity potential can further help in planning the soil sampling and management of wild blueberry fields.

CHAPTER 5

IDENTIFICATION OF SOIL PROPERTIES SIGNIFICANTLY AFFECTING WILD BLUEBERRY FRUIT YIELD

5.1 Introduction

Understanding the variability of soil properties and their effects on crop yield is a critical component of site-specific management systems. The variations in soil properties may strongly affect the variability in soil fertility and thus crop yield. Soil variability can result from complex interactions among geology, topography, and climate as well as cultivation, land use, and soil erosion (Quine and Zhang, 2002). Due to these complex interactions, it is difficult to determine the major yield-limiting soil properties. The identification of these soil properties requires an understanding of the relationship between soil and yield variability. Identifying the major soil properties responsible for yield reduction is necessary for variable rate crop management (Cassel et al., 2000; Bourennane et al., 2004, Ping et al., 2004). Yield variability within the fields can occur due to the horizontal and vertical variations of soil properties. Horizontal variations in soil properties are commonly related to yield variability (Venteris et al., 2004). Thus, the relationships between the wild blueberry production and soil properties must be explored within the root zone. Soil properties are generally correlated with yield and among themselves (Zaman et al., 2006; Ping et al., 2008).

The SOM and texture vary greatly within fields and these variations are strongly positively correlated with yield variability (Mulla and Bhatti, 1997; Ayoubi et al., 2007). The soil texture and organic matter content affect a number of soil chemical, physical, and microbiological properties (Olness and Archer, 2005). Due to their direct effect on nutrient availability and uptake, soil nutrient content is highly correlated with yield variability (Schepers et al., 2004; Yasrebi et al., 2008). The variations in soil texture can also have a large effect on variation in bulk density, hydraulic conductivity and/or soil water retention (Jiang et al., 2008). Kaspar et al. (2004) reported that soil properties such as texture, fertility, organic matter and available water can have a significant effect on corn yield.

The relationships between crop production and soil properties, and within soil properties can be studied using various statistical techniques. Simple correlation and multiple regression analyses are used to explore the relationships between soil properties and crop yield. Multiple regression attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to the observed data. However, multiple regression analysis may create unstable coefficients for these variables when there is a problem of multicollinearity (Freud and Littell, 2000). Multicollinearity arises when the number of independent variables is larger than the observations and the variables are correlated (Freud and Littell, 2000). The stepwise regression overcomes the multicollinearity with less number of predictor variables, and is widely used to assess the more influential soil factors responsible for yield variability.

There is little information available in literature about the soil properties influencing wild blueberry yield in Atlantic Canada. Exploring the relationships between soil properties and fruit yield using regression analysis will help to identify the major yield-limiting soil properties. A better understanding of these relationships could lead to more efficient implementation of strategies to improve crop productivity. Therefore, the objective of this work was to identify the soil properties significantly affecting the wild blueberry fruit yield.

5.2 Material and Methods

The relationships between the wild blueberry fruit yield, plant growth parameters, leaf nutrient and soil properties were determined using regression and correlation analysis. All the statistical analyses were performed with Minitab 15 statistical software. The coefficient of correlation (r) is a measure of the degree of linear association between any two variables when other variables are fixed. Correlation analysis was performed to find r values among the wild blueberry fruit yield, plant growth parameters, leaf nutrient and soil properties. Correlation matrices of soil properties, leaf nutrients, and growth parameters at 0-15 cm depth were created. The coefficient of determination (R^2) in the regression analysis indicates the contribution of the independent variable to the variability in dependent variable. Stepwise multiple linear regression analysis was performed to identify the factors significantly affecting the wild blueberry yield.

5.3 Result and Discussion

5.3.1 Relationships of Leaf Nutrients with Soil Properties

5.3.1.1 Carmal Site

Relationships between the leaf nutrient and soil properties were determined using correlation analysis. The correlation analysis (Table 5-1) revealed significant relationships among the soil properties and leaf nutrients. In general the soil parameters such as SOM, θ_v, clay, EC, HCP, PRP and inorganic nitrogen were significantly correlated with leaf N, P, K, Ca, Mg and Zn. The relationships among the soil properties for crop points (excluding bare spots and grasses) suggested the similar relationships as discussed in chapter 4 (Table 4-10). The leaf N was found to be significantly correlated with SOM (r = 0.54), NH_4^+-N (r = 0.63), NO_3^--N (r = 0.32), clay (r = 0.46), θ_v (r = 0.50), EC (r = 0.60), HCP (r = 0.33), and PRP (r = 0.25). These significant correlations of leaf N with the soil properties indicated that the leaf N was affected by the availability of inorganic nitrogen, θ_v, SOM and fertility status of the soil. The significant positive correlations among the leaf N and inorganic soil nitrogen suggested that the mineral nitrogen applied by farmers have a direct influence on the leaf N. The negative correlation of the leaf N with the sand content (r = -0.32) indicated the lower leaf N where there was more sand, this may be due to less retention of nutrients, more leaching of inorganic nitrogen to the ground water, less mineralization and lower uptake by the plants. The relationships of leaf N with pH and silt content were non-significant, which was also suggested by the higher range of influence from semivariogram indicating less variability of these properties (Table 4-12, Chapter 4).

The Leaf P, K and Ca were also found to be significantly correlated with soil properties including SOM, EC, clay, inorganic nitrogen and ground conductivity (r ~ 0.29 to 0.77) (Table 5-1). These positive correlations of leaf nutrients with SOM and clay indicated more leaf P, K and Ca in the areas enriched with SOM and clay content. This may be due to more availability of nutrients for the plant uptake. The relationships of P, K and Ca with sand and silt content were negative and non-significant indicating less uptake by plants in the areas with more sand and silt content. The relationships of P and K with soil pH were also non-significant. The soil pH was significantly correlated with leaf Ca (r = 0.40). The correlation analysis suggested that the leaf micronutrients were correlated non-significantly with soil properties except Fe and Cu having positive correlations with soil pH (Table 5-1). These non-significant correlations suggested that these leaf nutrients were not affected by the soil properties under study. The leaf Zn was negatively correlated with θ_v (r = -0.33) indicating less availability of leaf Zn where the soil was more moist.

The correlation analysis among the leaf nutrients suggested significant correlations between leaf N, P, K and Ca (r ~ 0.40 to 0.81) (Table 5-1). The relationships of these leaf nutrients with soil properties were also significant except soil pH, sand and silt content. The relationships of other leaf nutrients including Mg, Fe, Mn, Cu, Zn and B were non-significant with leaf N, P, K and Ca. The leaf Cu and Zn were significantly correlated with each other (r = 0.47) indicating more leaf Cu content in the areas where Zn content was more. Overall the relationships among the soil properties and leaf nutrients suggested that the nutrient uptake by the plants was affected by the soil properties, which may have an influence on the crop yield.

Multiple and Stepwise Regression

The nitrogen fertilization is a routine practice in wild blueberry production systems during the sprout year, and the fertilizer recommendations are made based on the deficiency in leaf nutrients including N, P and K (Eaton, 1988). In order to identify the soil properties affecting leaf N, multiple and stepwise regression analysis was performed using forward selection method. The multiple regression model with leaf N as response variable and soil properties as predictor variables was developed (Equation 5-1). The regression equation to predict leaf N was found to be highly significant ($p < 0.001$, $R^2 = 0.63$).

$$\textbf{Leaf N (\%)} = 2.92 - 0.03\,\theta_v + 0.09\,\text{pH} - 0.02\,\text{EC} + 0.07\,\text{SOM} - 0.01\,\text{Sand (\%)} - 0.02\,\text{Silt (\%)} - 0.01\,\text{Clay (\%)} + 0.07\,\text{NH}_4^+\text{-N} - 0.05\,\text{NO}_3^-\text{-N}$$

-- (Equation 5-1)

Table 5-1. Correlation matrix among the soil properties and leaf nutrients for Carmal Site.

	HCP	PRP	θ_v	pH	EC	SOM	Sand	Silt	Clay	NH_4-N	NO_3-N	N	P
PRP	0.64***												
θ_v	0.82 ***	0.50***											
pH	0.47**	0.35*	0.46**										
EC	0.80***	0.52***	0.64***	0.45**									
SOM	0.87***	0.56***	0.70***	0.42**	0.69***								
Sand	-0.35*	-0.22 ^{NS}	-0.44**	-0.20 ^{NS}	-0.15 ^{NS}	-0.22 ^{NS}							
Silt	-0.15 ^{NS}	0.03 ^{NS}	-0.21 ^{NS}	-0.10 ^{NS}	-0.29 ^{NS}	-0.18 ^{NS}	-0.23 ^{NS}						
Clay	0.68***	0.40*	0.67***	0.38*	0.56***	0.62***	-0.60***	-0.41**					
NH_4-N	0.75***	0.44**	0.58***	0.48**	0.62***	0.71***	-0.40**	-0.08 ^{NS}	0.61***				
NO_3-N	0.78***	0.37*	0.63***	0.45**	0.63***	0.72***	-0.19 ^{NS}	-0.20 ^{NS}	0.55***	0.54***			
N	0.33*	0.25 ^{NS}	0.50***	0.30 ^{NS}	0.60***	0.54***	-0.32*	-0.04 ^{NS}	0.46**	0.63***	0.32*		
P	0.37*	0.24 ^{NS}	0.54***	0.14 ^{NS}	0.61***	0.62***	-0.18 ^{NS}	-0.08 ^{NS}	0.35*	0.56***	0.51***	0.64***	
K	0.31*	0.30*	0.46***	0.27 ^{NS}	0.62***	0.45**	-0.10 ^{NS}	-0.24 ^{NS}	0.39*	0.43**	0.38*	0.81***	0.62***
Ca	0.29*	0.24 ^{NS}	0.42**	0.40**	0.52***	0.41**	-0.14 ^{NS}	-0.03 ^{NS}	0.33*	0.51***	0.30 ^{NS}	0.77***	0.40**
Mg	0.11 ^{NS}	-0.12 ^{NS}	0.03 ^{NS}	0.02 ^{NS}	0.25 ^{NS}	0.13 ^{NS}	0.14 ^{NS}	-0.11 ^{NS}	0.02 ^{NS}	0.14 ^{NS}	0.29 ^{NS}	-0.06 ^{NS}	0.23 ^{NS}
Fe	0.15 ^{NS}	0.16 ^{NS}	0.17 ^{NS}	0.38*	0.10 ^{NS}	0.14 ^{NS}	0.16 ^{NS}	0.05 ^{NS}	-0.06 ^{NS}	0.23 ^{NS}	0.10 ^{NS}	0.12 ^{NS}	-0.04 ^{NS}
Mn	-0.05 ^{NS}	0.21 ^{NS}	0.04 ^{NS}	-0.07 ^{NS}	-0.12 ^{NS}	-0.03 ^{NS}	0.14 ^{NS}	-0.02 ^{NS}	-0.04 ^{NS}	-0.31 ^{NS}	-0.07 ^{NS}	0.01 ^{NS}	-0.15 ^{NS}
Cu	0.02 ^{NS}	-0.05 ^{NS}	-0.13 ^{NS}	0.32*	-0.09 ^{NS}	-0.22 ^{NS}	0.18 ^{NS}	0.07 ^{NS}	0.04 ^{NS}	0.12 ^{NS}	0.19 ^{NS}	0.12 ^{NS}	-0.15 ^{NS}
Zn	-0.27 ^{NS}	-0.31 ^{NS}	-0.33*	-0.13 ^{NS}	-0.19 ^{NS}	-0.15 ^{NS}	0.19 ^{NS}	-0.12 ^{NS}	-0.13 ^{NS}	-0.19 ^{NS}	-0.02 ^{NS}	-0.26 ^{NS}	-0.30 ^{NS}
B	-0.22 ^{NS}	-0.26 ^{NS}	-0.25 ^{NS}	-0.30 ^{NS}	-0.19 ^{NS}	-0.15 ^{NS}	0.19 ^{NS}	-0.12 ^{NS}	-0.19 ^{NS}	-0.25 ^{NS}	-0.18 ^{NS}	-0.21 ^{NS}	0.05 ^{NS}

Table 5-1. Continued…

	K	Ca	Mg	Fe	Mn	Cu	Zn
Ca	0.63***						
Mg	0.13 $^{\mathrm{NS}}$	0.12 $^{\mathrm{NS}}$					
Fe	0.20 $^{\mathrm{NS}}$	0.08 $^{\mathrm{NS}}$	0.00 $^{\mathrm{NS}}$				
Mn	0.14 $^{\mathrm{NS}}$	-0.09 $^{\mathrm{NS}}$	-0.34*	0.26 $^{\mathrm{NS}}$			
Cu	0.15 $^{\mathrm{NS}}$	0.13 $^{\mathrm{NS}}$	0.19 $^{\mathrm{NS}}$	0.30 $^{\mathrm{NS}}$	0.03 $^{\mathrm{NS}}$		
Zn	-0.09 $^{\mathrm{NS}}$	-0.11 $^{\mathrm{NS}}$	0.42**	-0.15 $^{\mathrm{NS}}$	0.02 $^{\mathrm{NS}}$	0.47**	
B	-0.14 $^{\mathrm{NS}}$	-0.17 $^{\mathrm{NS}}$	0.25 $^{\mathrm{NS}}$	-0.33*	-0.18 $^{\mathrm{NS}}$	-0.30 $^{\mathrm{NS}}$	0.10 $^{\mathrm{NS}}$

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

To find the more influential factors affecting the leaf N, stepwise regression was performed. The stepwise regression removed the soil properties, which were non-significantly affecting the leaf N from the multiple regression models (Equation 5-2). The reduced model to predict the leaf was highly significant ($p < 0.001$, $R^2 = 0.58$). The removed predictors including pH, SOM, sand, silt, and clay were found to be non-significant ($p > 0.05$) as suggested by multiple regression analysis. The regression analysis suggested that soil properties contributed about 7 to 41.6% to leaf N (Table 5-3). The results of stepwise regression also suggested that the leaf N was affected by NH_4^+-N, θ_v and fertility status of the soil. The significant relationships of leaf N with ground conductivity suggested higher values of HCP in the areas where plants were healthy and having more leaf N.

$$\textbf{Leaf N (\%)} = \mathbf{2.18 - 0.01\,\theta_v - 0.02\,EC + 0.08\,NH_4^+\text{-}N}$$

-- (Equation 5-2)

5.3.1.2 North River Site

The correlation analysis (Table 5-2, Appendix D) revealed significant relationships among the soil properties and leaf nutrients. In general the soil properties were significantly correlated with leaf N, P, K, Ca, Mg and Zn. The pattern of variation and relationships among the soil properties for crop points suggested the similar relationships as Carmal Site (Table 4-11, Chapter 4). The leaf N was found to be significantly correlated with soil properties (r ~ 0.32 to 0.63) (Table 5-2, Appendix D). The relationships of leaf N with soil properties suggested that the amount of leaf nitrogen was dependent upon soil available nitrogen, SOM, EC, θ_v and clay. The relationships of leaf N with soil pH, sand and silt content were non-significant indicating that the leaf N was not affected by soil pH, sand and silt content (Table 5-2, Appendix D). The geostatistical analysis of soil properties also suggested the less variation of sand and silt content for North River Site (Table 4-13, Chapter 4). The relationships of ground conductivity with leaf N were significant, and similar to Carmal Site indicating higher values for HCP in the areas with more leaf N in the fields under study (Table 5-2, Appendix D).

The Leaf P, K and Ca were also found to be significantly correlated with SOM (r ~ 0.34 to 0.52), EC (r ~ 0.37 to 0.64), inorganic nitrogen (r ~ 0.38 to 0.66), θ_v (r ~ 0.37 to 0.62) and ground conductivity (r ~ 0.33 to 0.44) (Table 5-2, Appendix D). These positive correlations of leaf nutrients with SOM, θ_v and EC indicated more leaf P, K and Ca in the areas enriched with organic matter and were more fertile. This may be due to more availability of nutrients for the plant uptake. The relationships of leaf P and Ca with clay content were found to be significant, while leaf K was non-significantly correlated with clay (Table 5-2, Appendix D). The relationships of P, K and Ca with soil pH, sand and silt content were negative but non-significant, except a significant correlation between leaf K and silt content (r = -0.30). These non-significant correlations indicated that leaf P, K, and Ca were not influenced by texture and soil pH for North River Site. The leaf Mg, Fe, Mn, Cu, Zn and B were correlated non-significantly with soil properties except Cu having positive correlations (r = 0.28) with θ_v (Table 5-2, Appendix D). These non-significant correlations suggested that these leaf nutrients were not affected by the soil properties under study.

The correlation analysis among the leaf nutrients showed significant correlations between leaf N, P, K and Ca (r ~ 0.28 to 0.67) (Table 5-2, Appendix D). The relationships of these leaf nutrients with soil properties were similar to Carmal Site (Table 5-1) indicating more leaf nutrients in the areas concentrated with SOM, clay, EC, θ_v and available nitrogen. The relationships of other leaf nutrients including Mg, Fe, Mn, Cu, Zn and B were non-significant with leaf N, P, K and Ca (Table 5-2, Appendix D). The leaf Zn was significantly correlated with Ca ($r = 0.30$), Mg ($r = 0.38$), and Cu ($r = 0.47$) indicating direct influence of Zn on the availability of these leaf nutrients. The leaf B was also found to be significantly correlated with Mn and Zn (Table 5-2, Appendix D). Overall the correlation analysis suggested that the soil properties have a direct influence on the nutrient uptake by the plants, which may have an influence on the crop growth and productivity.

Multiple and Stepwise Regression

In order to find the influential factors affecting leaf N, the multiple and stepwise regression analysis was performed. The multiple regression model with leaf N as dependent variable and soil properties as independent variables was developed (Equation 5-3). The regression equation to predict leaf N was found to be highly significant ($p < 0.001$, $R^2 = 0.59$).

$$\textbf{Leaf N} = -0.79 + 0.10\,\theta_v - 0.05\,\text{PH} + 0.02\,\text{EC} - 0.17\,\text{SOM (\%)} + 0.02\,\text{Sand (\%)} + 0.003\,\text{Silt (\%)} + 0.04\,\text{Clay (\%)} + 0.02\,\text{NH}_4^+\text{-N} - 0.02\,\text{NO}_3^-\text{-N}$$

--- (Equation 5-3)

The stepwise regression was performed to remove the predictor variables, which were non-significantly affecting the leaf N from the multiple regression models (Equation 5-4). The reduced model to predict the leaf N was highly significant ($p < 0.001$, $R^2 = 0.56$). The removed predictors including pH, sand, silt, clay and NO_3^--N were found to be non-significant ($p > 0.05$), which was also indicated by multiple regression model. The lower p values and higher t values of the predictor variables suggested the validity of the reduced model. The exclusion of non-significant predictors resulted in small drop in R^2 suggesting the validity of the regression model. The regression analysis suggested that soil properties contributed about 11% to 42% to leaf N (Table 5-3). The results of stepwise regression indicated that the leaf N was affected by, NH_4^+-N, θ_v and SOM and EC for North River Site. The removal of NO_3^--N from the selected model may be due to more leaching, as the North River Site was found to have more sand and silt content as compare to clay content.

$$\textbf{Leaf N (\%)} = 0.46 + 0.09\,\theta_v + 0.02\,NH_4^+\text{-N} + 0.01\,EC - 0.13\,SOM$$

-- (Equation 5-4)

5.3.2 Relationships of Soil Properties with Fruit Yield

5.3.2.1 Carmal Site

The regression analysis was performed to analyze the relationships between soil properties and wild blueberry fruit yield. The regression analysis revealed significant correlations between fruit yield and soil properties as indicated by their coefficient of determination (R^2) (Fig. 5-1). In general, fruit yield was positively correlated with soil properties and ground conductivity, but were negatively correlated with sand and silt content. The stronger correlation of fruit yield with HCP ($R^2 = 0.64$) compared with PRP ($R^2 = 0.22$) suggested that the variation in soil properties can be an important factor controlling productivity and yield (Fig. 5-1). The relationships among the fruit yield and ground conductivity were in agreement with the findings of Mann (2009), suggesting higher values of HCP and PRP in high yielding areas and vice versa in Florida citrus. This relationship of ground conductivity with yield is attributed to its relationship with

Table 5-3. Regression analysis of soil properties with leaf N for both sites.

Sampling Time	Carmal Site										
	Coefficient of Determination (R^2)										
	HCP	PRP	θ_v	pH	EC	SOM	Sand	Silt	Clay	NH_4^+-N	NO_3^--N
May, 2009	19.4**	12.4**	38.2***	6.4^{NS}	35.3***	41.6***	-11.8*	-4.8^{NS}	25.2***	38.1***	33.2***
July, 2009	17.2**	19.2**	35.8***	n/a	38.6***	n/a	n/a	n/a	n/a	41.6***	34.2***
June, 2010	15.5**	10.5*	36.7**	n/a	40.9***	36.8***	n/a	n/a	n/a	40.7***	35.4***
	North River Site										
	HCP	PRP	θ_v	pH	EC	SOM	Sand	Silt	Clay	NH_4^+-N	NO_3^--N
May, 2009	21.2**	19.2**	41.7***	0.5^{NS}	39.7	21.2***	-0.2^{NS}	0.1^{NS}	10.42**	29.9***	27.1***
July, 2009	24.8***	14.3**	35.2***	n/a	37.8	n/a	n/a	n/a	n/a	32.5***	21.6***
June, 2010	16.6**	9.8*	38.9***	n/a	42.5	23.5***	n/a	n/a	n/a	37.8***	22.3***

Significance of correlations indicated by *, ** and ***, are equivalent to
p = 0.05, p = 0.01 and p = 0.001.
NS, non-significant at p = 0.05
n/a indicated no analysis of samples for that particular property

the productivity potential of soil (Sudduth et al., 2005; Li et al., 2007). The significant contribution of θ_v ($R^2 = 0.38$), NH_4^+-N ($R^2 = 0.38$), and NO_3^--N ($R^2 = 0.33$) (Fig. 5-1) to the variability in yield supports the idea of applying irrigation during dry periods and to apply fertilizers during both vegetative and crop year to sustain the nutrient level in wild blueberry plants, which may be helpful in increasing yield. The supplemental irrigation during dry year and during bud formation could result in increased yield and improved quality of the blueberries during crop year (Seymour et al. 2004; Benoit et al., 1984). Herbicides are required with the fertilizer application, in order to prevent competitors from choking out the slower growing blueberry and to increase yield (Eaton, 1988). The response of wild blueberries to the nitrogen fertilization is controversial that may be due to the timing of fertilizer application. Penney and McRae (2002) indicated 40% increase in yield with the application of fertilizer in combination with herbicides during the crop year.

The soil properties were also significantly correlated with each other (Table 4-10, Chapter 4). The SOM and EC contributed significantly 23 to 42% in yield variability as indicated by their R^2 (Fig. 5-1 and Table 5-4). The important role of SOM and EC in productivity may be due to moisture and nutrient retention (Beldin et al., 2007). The SOM also improves the soil structure by aggregating inorganic soil components (Masri and Ryan, 2006). The strong relationship between SOM and wild blueberry production can also be due to its ability to increase water and nutrient availability for plant uptake. The contribution of sand content in fruit yield variability was negative ($R^2 = -0.12$) indicating lower yield in areas with more sand content. This may be due to less retention of nutrients and water content by courser sand particles. The contribution of silt in yield variability was non-significant, while clay content contributed significantly ($R^2 = 0.25$) to yield.

Slope was generally negatively correlated with soil properties and fruit yield (Fig. 4-10, Chapter 4, Appendix C). These negative relationships revealed that high SOM and soil fertility were at the lower positions of the field. The variation of the soil properties with respect to slope was in agreement with the findings of Mann (2009). Overall the soil properties explained 23% to 64% of the yield variability (Fig. 5-1 and Table 5-4). The contribution of silt and pH to the yield variability was observed lower as compare to other soil properties. The results of regression analysis and the variation of soil properties with respect to slope suggested that the soil properties having a significant impact on wild blueberry yield.

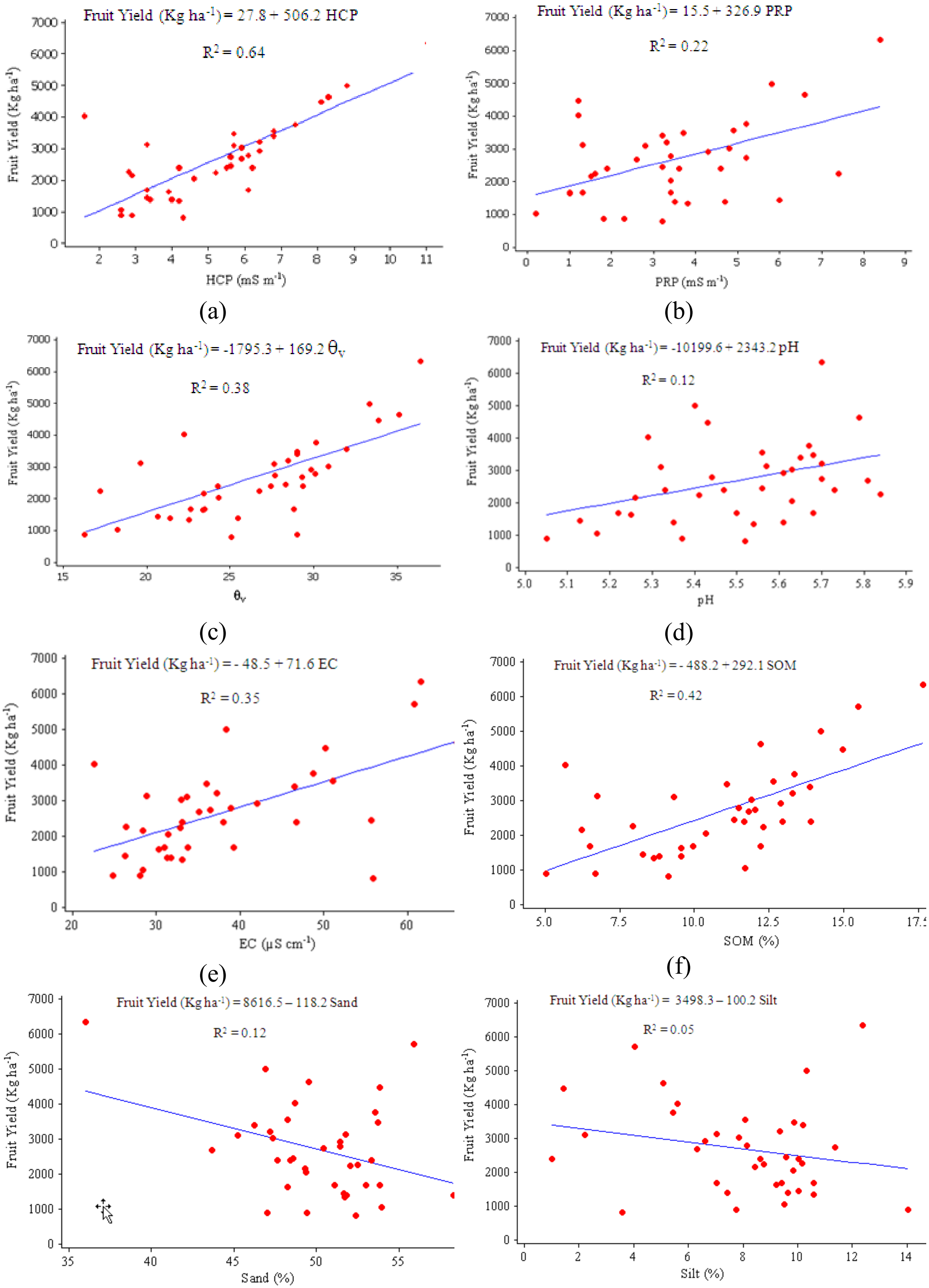
Multiple and Stepwise Regression

The joint contribution of soil properties to the variability in wild blueberry fruit yield was evaluated by stepwise multiple linear regression analysis of soil properties with fruit yield. The multiple regression model with fruit yield as response variable and soil properties as predictor variables was developed (Equation 5-5). All the soil properties during both years explained 78% of the yield variability as suggested by R^2 ($R^2 = 0.78$, $p < 0.001$).

$$\textbf{Fruit yield (Kg ha}^{-1}\textbf{)} = 18028 + 916\ \mathrm{HCP}_{(S)} - 3.8\ \mathrm{PRP}_{(S)} - 93.3\ \theta_{v\,(S)} + 111\ \mathrm{pH}_{(S)} - 20.4\ \mathrm{EC}_{(S)} - 326\ \mathrm{SOM}_{(S)} - 153\ \mathrm{Sand}_{(S)} - 235\ \mathrm{Silt}_{(S)} - 182\ \mathrm{Clay}_{(S)} + 33.1\ \mathrm{NH_4^+\text{-}N}_{(S)} - 32\ \mathrm{NO_3^-\text{-}N}_{(S)} + 273\ \mathrm{SOM}_{(c)} + 59.8\ \mathrm{NH_4^+\text{-}N}_{(c)} - 70\ \mathrm{NO_3^-\text{-}N}_{(c)}$$

-- (Equation 5-5)

Where C = Crop year and S = Sprout year.

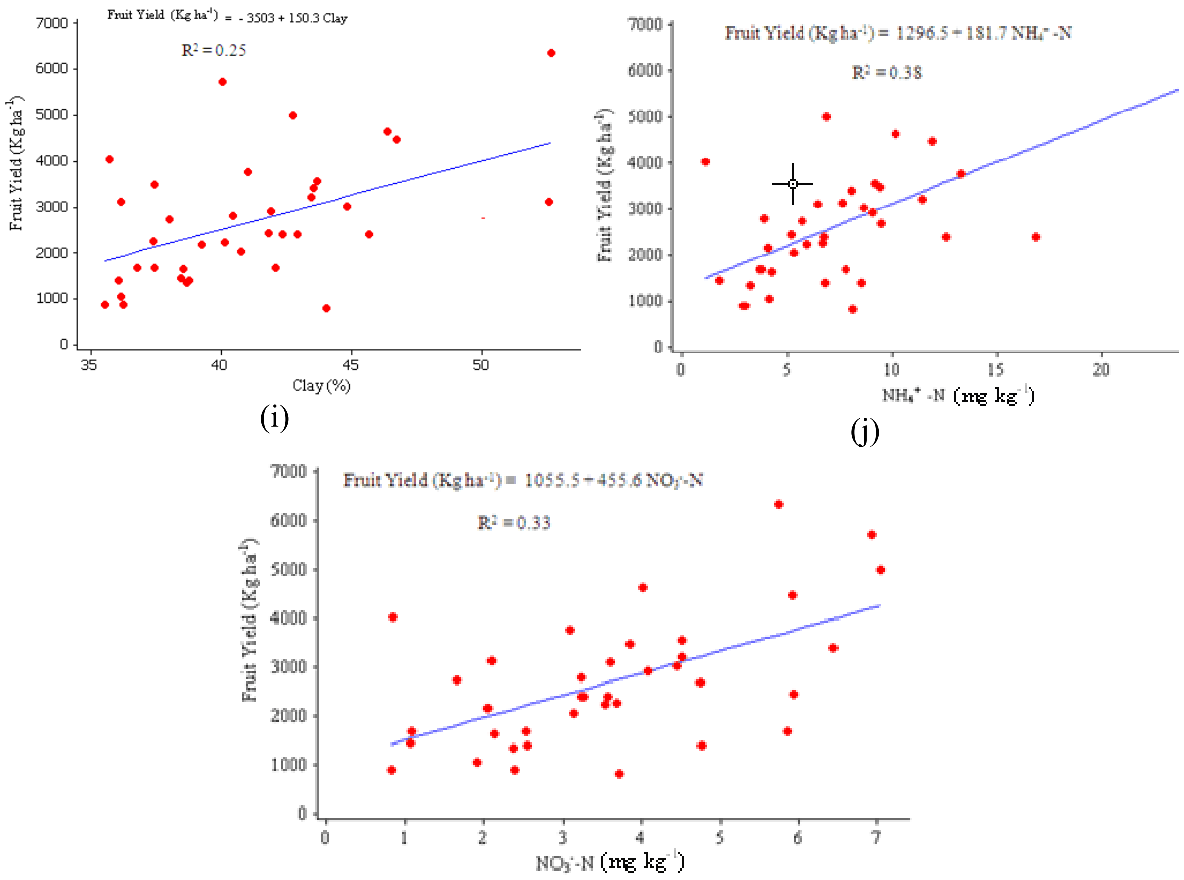

Fruit Yield (Kg ha^{-1}) = 27.8 + 506.2 HCP
R^2 = 0.64
Fruit Yield (Kg ha^{-1})
HCP (mS m^{-1})
0
1000
2000
3000
4000
5000
6000
7000
2
3
4
5
6
7
8
9
10
11
Fruit Yield (Kg ha^{-1}) = 15.5 + 326.9 PRP
R^2 = 0.22
PRP (mS m^{-1})
0
1
2
3
4
5
6
7
8
9
Fruit Yield (Kg ha^{-1}) = -1795.3 + 169.2 θ_v
R^2 = 0.38
θ_v
15
20
25
30
35
Fruit Yield (Kg ha^{-1}) = -10199.6 + 2343.2 pH
R^2 = 0.12
pH
5.0
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
5.9
Fruit Yield (Kg ha^{-1}) = - 48.5 + 71.6 EC
R^2 = 0.35
EC (µS cm^{-1})
20
30
40
50
60
Fruit Yield (Kg ha^{-1}) = - 488.2 + 292.1 SOM
R^2 = 0.42
SOM (%)
5.0
7.5
10.0
12.5
15.0
17.5
Fruit Yield (Kg ha^{-1}) = 8616.5 – 118.2 Sand
R^2 = 0.12
Sand (%)
35
40
45
50
55
Fruit Yield (Kg ha^{-1}) = 3498.3 – 100.2 Silt
R^2 = 0.05
Silt (%)
0
2
4
6
8
10
12
14

(a) (b)

(c) (d)

(e) (f)

(g) (h)



(i) (j)

(k)

Figure 5-1. Relationships of soil properties with wild blueberry fruit yield for Carmal Site. (a) HCP, (b) PRP, (c) Moisture content, (d) pH, (e) EC, (f) SOM, (g) Sand %, (h) Silt %, (i) Clay %, (j) NH_4^+ -N, (k) NO_3^--N.

The soil properties influencing wild blueberry yield significantly were determined using stepwise regression analysis. The stepwise regression reduced the multiple regression model by removing non-significant predictor variables (Equation 5-6). The reduced model to predict fruit yield was highly significant ($p < 0.001$, $R^2 = 0.66$). The removed predictors including pH, sand, silt, and clay were found to be non-significant ($p > 0.05$). The reduced model for prediction of fruit yield suggested that the soil properties including SOM, inorganic nitrogen, θ_v and HCP explained 66% of the yield variability. The validity and significance of the predictors to be included in the reduced model was suggested by lower p-value and higher t-value of each predictor variable. Overall

Table 5-4. Regression analysis of soil properties with fruit yield for Carmal Site.

Soil property	Regression Model	R^2	P-Value
2nd Sampling (2009)			
HCP (mS m^{-1})	Yield (Kg ha^{-1})= 178.6 + 477.3 HCP	0.58	0.000
PRP (mS m^{-1})	Yield (Kg ha^{-1})= 457.3 + 497.7 PRP	0.48	0.000
θ_v	Yield (Kg ha^{-1})= -2056 + 177.5 θ_v	0.46	0.000
EC (µS cm^{-1})	Yield (Kg ha^{-1})= 151.2 + 71.3 EC	0.25	0.002
NH_4^+ -N (mg Kg^{-1})	Yield (Kg ha^{-1})= 1248 + 1951 NH_4^+-N	0.50	0.000
NO_3^--N (mg Kg^{-1})	Yield (Kg ha^{-1})= 1179 + 2693 NO_3^--N	0.46	0.000
3rd Sampling (2010)			
Soil property	**Regression Model**	**R^2**	**P-Value**
HCP (mS m^{-1})	Yield (Kg ha^{-1}) = -559.4 + 506.2 HCP	0.64	0.000
PRP (mS m^{-1})	Yield (Kg ha^{-1}) = 1166 + 326.9 PRP	0.23	0.003
θ_v	Yield (Kg ha^{-1}) = -2172 + 169.2 θ_v	0.38	0.000
EC (µS cm^{-1})	Yield (Kg ha^{-1}) = 154.2 + 69.7 EC	0.24	0.002
SOM (%)	Yield (Kg ha^{-1}) = -653.9 + 306.1 SOM	0.40	0.000
NH_4^+ -N (mg Kg^{-1})	Yield (Kg ha^{-1}) = 1438 + 277.3 NH_4^+-N	0.52	0.000
NO_3^--N (mg Kg^{-1})	Yield (Kg ha^{-1}) = 1142 + 370.5 NO_3^--N	0.38	0.000

regression analysis suggested that soil properties contributed about 23% to 67% to fruit yield variability (Fig. 5-1 and Table 5-4).The results of stepwise regression indicated that the fruit yield was affected by, NH_4^+-N, NO_3^--N, θ_v during crop year and SOM during the sprout year, and there was less influence of texture, and pH on yield variability. The mean values for SOM were observed almost same during sprout and crop years indicating the tendency of SOM not to vary in two monitoring years (Table 4-1, chapter 4).

$$\textbf{Fruit yield (Kg ha}^{-1}\textbf{)} = 1134 + 723\ \mathrm{HCP}_{(c)} - 38\ \theta_{v\,(c)} - 101\ \mathrm{SOM}_{(s)} + 14\ \mathrm{NH_4^+\text{-}N}_{(c)} - 70\ \mathrm{NO_3^-\text{-}N}_{(c)}$$

--- (Equation 5-6)

Where C = Crop year and S = Sprout year.

5.3.2.2 North River Site

The contributions of soil properties to wild blueberry yield were assessed using regression analysis. Among soil properties, SOM contributed about 29 to 31% to yield variability during two monitoring years indicating the significance of SOM, as it is responsible for moisture and nutrient retention for plant uptake (Fig. 5-2 and Table 5-5, Appendix E). The soil inorganic nitrogen explained 26% to 51% variation in fruit yield during two years. The contribution of NH_4^+-N and NO_3^--N to the fruit yield was lower during the crop year. This may be due to no fertilization during crop year, and less availability of inorganic nitrogen for plant growth and crop yield. These results suggested the need to apply fertilizer during the crop year. Other studies also suggested the increase in crop growth and harvestable yield with the application of nitrogen fertilizer during the crop year (Penney and McRae 2002; Percival et al., 2003). The soil θ_v explained 28% to 37% variability in fruit yield (Fig. 5-2 and Table 5-5, Appendix E). The contributions of θ_v to fruit yield suggested that the supplemental irrigation during dry years may result an increase in harvestable yield and quality.

The fruit yield was found to be significantly correlated with HCP ($R^2 \sim 0.55$ to 0.63) and PRP ($R^2 \sim 0.47$ to 0.51) indicating higher values of ground conductivity in high yielding areas and vice versa. HCP was the highest in the high yielding areas and decreased with the productivity gradient. The similar results were observed for Carmal Site (Fig. 5-1, Table 5-4). The soil texture explained 3% to 14% variability in fruit yield. The regression analysis of sand and silt content with fruit yield suggested that these soil parameters were of less importance for wild blueberry production; however the fruit yield was significantly correlated with clay content (Fig. 5-2, Appendix E). The significant correlations of clay content with other soil properties (Table 4-11, Chapter 4) suggested the retention of nutrients and θ_v by clay content, which may have an impact on the wild blueberry fruit yield. The soil EC explained 49% to 54% variability during two monitoring years. The soil EC is a function of its water and salt content, as well as the soil structure, texture, and mineralogy (Cook and Walker, 1992). The significant positive correlation of EC with fruit yield and ground conductivity showed that ground conductivity can be used to delineate productivity zones within wild blueberry fields. These results were in agreement with the findings of Sudduth and Kitchen (2001). The contribution of soil pH in explaining yield variability was non-significant. The significant contribution of soil properties to crop yield variability was due to the combined effect of these soil properties. Iqbal et al. (2005) quantified the relationship between cotton lint yield and soil properties, and reported 65% of the yield variability due to θ_v, texture and organic matter.

Multiple and Stepwise Regression

In order to find the combined effect of soil properties on wild blueberry yield, the soil properties were regressed against fruit yield using multiple regression (Equation 5-7). The regression equation explaining the variation in yield as a function of soil properties was found to be highly significant ($p < 0.001$, $R^2 = 0.81$). The multiple regression model suggested that the soil properties in combination contributed about 81% variability in yield as indicated by its R^2 value.

$$\mathbf{Fruit\ Yield\ (Kg\ ha^{-1}) = -5070 + 385\ HCP_{(s)} + 211\ PRP_{(s)} - 0.8\ \theta_{v\,(s)} + 528\ pH_{(s)} - 13.7\ EC_{(s)} - 15\ SOM_{(s)} + 14.2\ Sand_{(s)} + 16.5\ Silt_{(s)} + 13.0\ Clay_{(s)} - 116\ NH_4^{+}\text{-}N_{(s)} - 47.0\ NO_3^{-}\text{-}N_{(s)} - 157\ HCP_{(c)} + 89.4\ PRP_{(c)} + 12.7\ Moisture\ Content_{(c)} + 33.8\ EC_{(c)} + 73.1\ NH_4^{+}\text{-}N_{(c)} - 61.8\ NO_3^{-}\text{-}N_{(c)}}$$

-- (Equation 5-7)

Where C = Crop year and S = Sprout year

The stepwise regression analysis removed the predictor variable, which were less important in explaining fruit yield variability. The model was developed with the predictors having significant impact on yield (Equation 5-8). The soil properties significant at 5% confidence level were included in the reduced model using forward selection method of stepwise regression. The stepwise regression indicated the greatest contribution to yield variability was explained by inorganic nitrogen, HCP and EC. These predictor variables were significant ($p < 0.001$, $R^2 = 0.77$) and explained approximately 77% spatial variability in yield. The presence of NH_4^+-N in the reduced model for both years indicated the importance of nitrogen fertilizer and its timing of application in explaining yield variability. These results were in agreement with the findings of Penney and McRae (2000).

$$\textbf{Fruit Yield (Kg ha}^{-1}\textbf{)} = -537.60 + 196\,HCP_{(c)} - 132\,NH_4^+\text{-}N_{(s)} + 105\,NH_4^+\text{-}N_{(c)} + 21.5\,EC_{(c)} \quad \text{--- (Equation 5-8)}$$

The results of regression analysis also suggested that the soil texture and pH was of less importance in explaining yield variability for North River site. Overall the results of regression analysis showed that the soil properties explained significant variability in wild blueberry fruit yield for both sites. The relationships of HCP with fruit yield and other soil properties suggested that HCP can be used to predict fruit yield and to develop productivity zones for site specific application of agricultural inputs. There are a variety of factors other than soil properties partially contributing to yield variability, which have not been addressed. Disease and insect damage are obvious examples. Weeds competing with wild blueberry, pollination with bees, seasonal variability and winter kill can also negatively impact fruit yield.

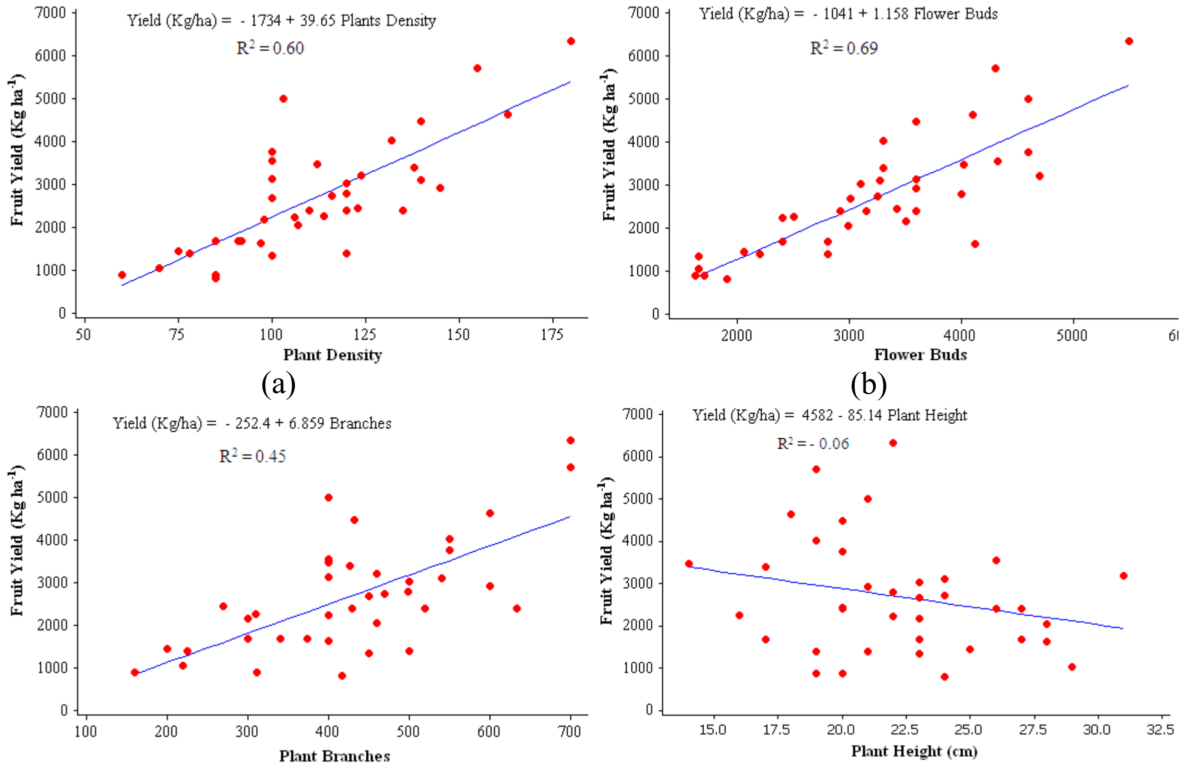
5.3.3 Relationships of Plant Growth Parameters with Fruit Yield

5.3.3.1 Carmal Site

The relationships among the plant growth parameters and fruit yield were determined using correlation analysis. Significant positive correlation between wild blueberry yield and number of buds (r = 0.83) (Table 5-6, Appendix E) suggested that more number of flower buds during the sprout year having significant impact on the yield. The fruit yield was also significantly correlated with number of plants in a grid (r = 0.77) and number of branches (r = 0.67) indicating more number of plants in a grid have more number of branches and hence an increase in the yield. The plants at Carmal site were not too dense and most of the sampling points were found to have 110 to 130 plants/0.25m^2. The plant height was found to have a negative but non-significant impact on the yield (Table 5-6, Appendix E) indicating the decrease in yield as the plant height increases (Fig. 5-3d). This may be due to more vegetative growth resulting in lower yield. The plant density was significantly correlated with number of buds and branches (Table 5-6, Appendix E), while the relationship of plant density with height was non-significant (r = 0.18) for Carmal Site. The relationship of number of buds with plant height (r = -0.02) was non-significant, while number of buds were found to have significant correlation with branches (r = 0.56). Overall the results of regression analysis suggested that more number of flower buds, medium plant density (110 to 130 plants/0.25 m^2), and medium height of plant (17 to 22 cm) resulted in higher yield (Fig. 6-3). These results were in agreement with the finding of Glass et al. (2005).

5.3.3.2 North River Site

The fruit yield was significantly correlated with plant density (r = 0.49), number



(a) (b) (c) (d)

Figure 5-3. Relationships of fruit yield with plant growth parameters for Carmal Site. (a) Plant density, (b) No. of buds, (c) No. of branches, (d) plant height.

of buds (r = 0.85) and number of branches (r = 0.40), while the relationship of fruit yield with the with plant height (r = -0.02) was negative and non-significant (Table 5-6, Appendix E). The correlation matrix (Table 5-6, Appendix E) exhibited the similar relationships among the fruit yield and plant growth parameters as Carmal Site indicating lower yield in the areas with more plant height, less number of flower buds and lower plant density. The regression analysis of the fruit yield with the plant density suggested that the plant density of 120 to135 plants/0.25m^2 resulted in higher yield. These results also suggested that at few sampling points where plants were too dense, resulted in lower yield. The negative but non-significant correlations among the fruit yield and plant height suggested the more vegetative growth, thus resulting in reduced yield. In North River field the optimum plant height producing higher yield was approximately 12 to 18 cm (Fig. 5-4 d, Appendix E). There was non-significant trend of variation in fruit yield with respect to plant height. The classical statistics for plant growth parameters (Table 4-7 and 4-8, Chapter 4) suggested that mean plant density, and number of branches were almost similar, while the flower buds were higher for Carmal Site that resulted higher mean fruit yield for this site.

5.3.4 Relationships of Leaf Nutrients with Fruit Yield

5.3.4.1 Carmal Site

The correlation analysis (Table 5-7) revealed significant correlations among the leaf nutrients and fruit yield. The fruit yield was significantly correlated with leaf N (r ~ 0.53 to 0.58), P (r ~ 0.66 to 0.76), K (r ~ 0.39 to 0.46) and Ca (r ~ 0.30 to 0.32). These positive correlations indicated that the plant with more leaf N, P, K, and Ca were healthier and resulted in increased yield during crop year. These results were in agreement with the finding of Zaman et al. (2009), who found higher leaf N, P and fruit yield in low lying areas and vice versa indicating positive correlation of fruit yield with leaf N and P. The fertilizer recommendations in wild blueberry cropping system are based on leaf N, P, and K levels (Eaton, 1988). The N, P and K fertilizers are applied during sprout year if these nutrients are below the standards set by Eaton et al. (2009) and Travett (1972). The relationships of fruit yield with leaf Mg, Fe, Mn, Cu, and B were non-significant indicating less impact of these leaf nutrients during fruit development (Table 5-7). The leaf Zn was found to be significantly correlated with fruit yield indicating the contribution of leaf Zn to explain variability in fruit yield.

5.3.4.2 North River Site

The correlation analysis exhibited significant correlations among the fruit yield and leaf macro nutrients (Table 5-7). These relationships were similar to the Carmal Site indicating the importance of leaf macro nutrients in explaining yield variation. The leaf macro nutrient during the crop year were observed lower as compare to sprout year (Table 4-6, Chapter 4) indicating the transport of these nutrients into fruit development process. The relationships of fruit yield with leaf micro nutrients were non-significant except leaf Cu and Zn with significant positive correlations (Table 5-7). Overall the significant relationships of fruit yield with leaf macro and micro nutrients including N, P, K, Ca, Zn and Cu suggested the importance of these leaf nutrients in explaining variation in yield for both sites. The leaf Mg, Mn, B, and Fe were correlated non-significantly with fruit yield indicating that these leaf nutrient having less impact on fruit yield. The significant positive correlations among the fruit yield and leaf N and P suggested the increase in fruit yield as the leaf N and P level increases. The maps of leaf nutrients also showed that the fruit yield was higher in the areas where the leaf N, and P were higher and vice versa (Fig. 4-8 and 4-9, Chapter 4, Appendix B). The nutrient management practices are implemented based on leaf nutrient concentration do not provide an accurate estimate of the nutrients that are either available or in plants itself. Looking at these results will bring back soil related factors that can be used to develop nutrient management plan for wild blueberries.

5.3.5 Relationship of Leaf N with Plant Height

The regression analysis was performed to examine the relationship between leaf N and plant height (Fig. 5-5) for both sites. The leaf N was non-significantly correlated

Table 5-7. Correlation analysis of leaf nutrients with fruit yield for both sites.

Carmal Site

Coefficient of correlation (r)

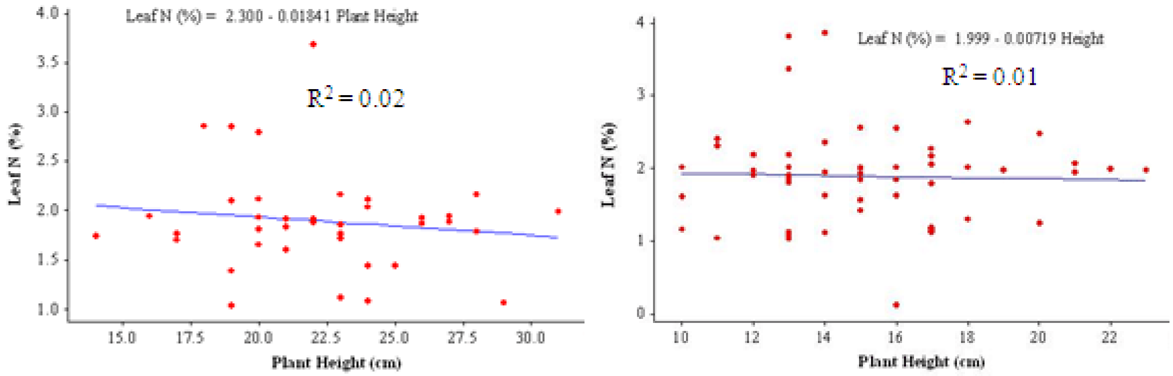
Sampling Time	N	P	K	Ca	Mg	Fe	Mn	Cu	Zn	B
July, 2009	0.53***	0.66***	0.46***	0.30*	0.16^{NS}	0.09^{NS}	0.21^{NS}	-0.11^{NS}	0.33*	-0.07^{NS}
June, 2010	0.58***	0.49***	0.39**	0.32*	0.11^{NS}	0.05^{NS}	0.24^{NS}	-0.15^{NS}	0.35**	-0.11^{NS}

North River Site

Sampling Time	N	P	K	Ca	Mg	Fe	Mn	Cu	Zn	B
July, 2009	0.55***	0.40**	0.33*	0.12^{NS}	-0.19^{NS}	-0.05^{NS}	0.18^{NS}	0.32*	0.30*	0.16^{NS}
June, 2010	0.48***	0.33*	0.29*	0.19^{NS}	-0.24^{NS}	-0.01^{NS}	0.20^{NS}	0.30*	0.33*	0.13^{NS}

Significance of correlations indicated by *, ** and ***, are equivalent to p = 0.05, p = 0.01 and p = 0.001.

NS, non significant at p = 0.05



(a) (b)

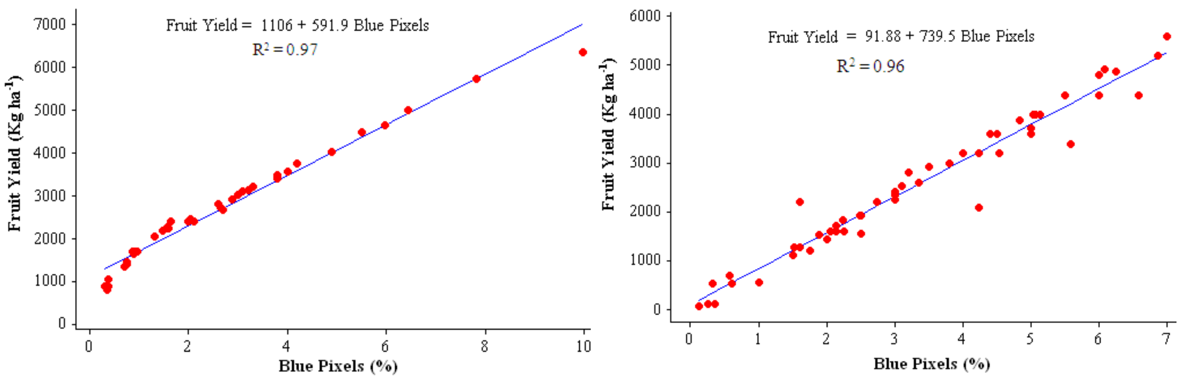
Figure 5-5. Relationships of leaf nitrogen with plant height. (a) Carmal Site (b) North River Site.

with plant height for both sites. The mean values for the leaf N for both sites were in the range set by Eaton et al., (2009) for Nova Scotia. Leaf N concentrations in both fields were at a level of sufficiency (> 1.6%), according to the standard proposed by Trevett (1972). The results of regression analysis suggested that there was no effect of leaf N on the plant height. This may be due to within set standard availability of leaf N and medium plant height (15 to 20 cm) for both sites (Fig. 5-5).

5.3.6 Relationships of Blue Pixels with Fruit Yield

The fruit yield was harvested in 1st week of August using 0.5 x 0.5 m quadrant in each grid along with the GPS coordinates. The photographs were taken using digital color camera at each grid point. Fruit samples were collected by hand-harvesting out of the 0.5 x 0.5 m quadrant immediately after photographing, using hand-raking. Blueberries were separated from debris including leaves, grass, and weeds for each sample and weighed at the time of harvest. Two more photographs were taken in each grid using 0.5 x 0.5 m quadrant to predict yield using regression equation, and to cover all yield variability.

The blue pixel ratio, representing the percentage of blue pixels in the harvested quadrant region of each image in both fields, was calculated with custom software. The



(a) (b)

Figure 5-6. Relationships fruit yield with blue pixel ratio (a) Carmal Site (b) North River Site.

percentage blue pixels varied from 0.30% to 8.99% in Carmal Site, and from 0.12% to 7.00% in North River Site (Tables 4-7 and 4-8, Chapter 4). The lower blue pixel ratios were due to less yield or weeds (no blueberry plants) within blueberry fields. The cause of bare spots in wild blueberry fields is due to natural colonization of plants developed from native stands on deforested farmland by removing competing vegetation (Eaton, 1988). The bare spots in the both fields were mapped using mobile mapper GPS. The bare spot areas varied from 18% to 27% of the total field area and were scattered throughout the fields (Figs. 4-4 and 4-5, Chapter 4). Percentage blue pixels were significantly correlated with manually harvested fruit yield in Carmal Site ($R^2 = 0.97$; $p < 0.001$) and North River Field ($R^2 = 0.96$; $p < 0.001$) (Fig. 5-6). These results were in agreement with the findings of Zaman et al. (2008 and 2010a). This information could be used to implement site-specific management practices within the blueberry fields to optimize productivity while minimizing the environmental impact of farming operations.

5.4 Summary and Conclusions

The relationships between wild blueberry fruit yield, soil properties, leaf nutrients and plant growth parameters were studied using regression and correlation analysis. The contribution of various soil properties to the variability in yield were determined using stepwise multiple linear regression analysis. Soil parameters were significantly correlated with leaf N, P, K, Ca, Zn, and B except pH, and silt content. The stepwise regression suggested that the leaf N was dependent upon soil inorganic nitrogen, θ_v and EC representing fertility status for both sites. The fruit yield was significantly correlated with soil properties except silt content. The stepwise regression showed that θ_v, HCP, NH_4^+-N, NO_3^--N, SOM and EC having more contribution in explaining yield variability, and were found to be major yield influencing factors for both fields. The nutrient management practices are implemented based on leaf nutrient concentration do not provide an accurate estimate of the nutrients that are either available or in plants itself. Looking at these results will bring back soil related factors that can be used to develop nutrient management plan for wild blueberries. The highly significant correlation of fruit yield with HCP suggested that EMI can be used to predict fruit yield and to develop management zones for site-specific fertilization.

The relationships of fruit yield with plant growth parameters suggested that higher number of buds, more plant density and branches during sprout year resulted in higher yield during crop year. These results indicated that the plant with more leaf N, P, and K were healthy and resulted in increased yield during crop year for both sites. The significant correlation between percentage blue pixels and manually harvested fruit yield suggested that there is a real potential to estimate fruit using digital photography within wild blueberry fields. Relationships between crop production and soil properties could help to identify major yield influencing soil properties to develop management zones for site-specific management of wild blueberry fields.

CHAPTER 6

DELINEATION OF MANAGEMENT ZONES FOR SITE-SPECIFIC FERTILIZATION

6.1 Introduction

The concept of management zones has been proposed as a solution to the problems associated with soil variability and its impact on the application of agricultural inputs in site-specific manner. The delineation of management zones is a way of classifying the spatial variability within a field into sub-regions with similar soil properties and crop growth parameters, where a uniform rate of a particular crop input is appropriate (Li et al., 1999). The basic idea of management zones is that fields can be sampled where soil samples are composited from field subregions (zones) with similar input use efficiency, crop yield potential or environmental impacts (Pocknee et al., 1996). Each management zone can be characterized via minimal amount of sampling required to describe soil characteristics. Therefore, zone sampling can minimize the number of soil samples necessary for field characterization compared to intensive soil sampling.

Present nutrient management recommendations are typically uniform. However, the soils are highly variable spatially and therefore, the uniform management of agricultural inputs may results in over-application in areas with high productivity and under-application in areas with low productivity (Schumann et al., 2003). Site-specific management of nutrients has been acknowledged as one means of addressing this problem (Patzold et al., 2008). The most popular approach to manage spatial variability within fields is the use of management zones (MZs), in which field that have relatively homogeneous attributes in landscape and soil condition are subdivided, and this technique can be used to direct variable rate fertilizer application (Ferguson et al., 2003).

Precision agriculture (PA) requires detailed information about soil and crop conditions within fields to delineate management zones, defined as a sub-region of a field that expresses a relatively homogeneous combination of yield-limiting factors for which a single rate of a specific crop input can be applied (Doerge, 1999). The easily measured soil properties using sensors and their impact on yield have shown a great potential for the development of management zones. Sensor-based measurements can provide noninvasive, quantitative, and precise data reflecting soil productivity at relatively low cost (Mulla and Schepers, 1997). In addition, the GIS software and geostatistics have made it possible to combine data from various easily measured field attributes with sensors (for example, ECa map, terrain attributes, aerial images, and yield maps) to predict soil productivity and crop yield. To explore the complex relationships among the variables including landscape attributes, soil fertility parameters, and crop yield using multivariate analysis is essential for site-specific nutrient management. Multivariate statistical techniques such as cluster analysis, principal component analysis (PCA), neural networks, and classification and regression trees (CART) have been used to assess the soil spatial variability and to manage it in site-specific fashion (Bang, 2005).

Cluster analysis has been one of the most frequently used computational methods for developing soil and crop MZs (Chang et al., 2003; Schepers et al., 2004). The primary objective of cluster analysis is to define the structure of the data by placing the most similar observations into groups, and to define different productivity potentials within field. Cluster analysis is generally characterized as a descriptive, a theoretical, and non-inferential method. Since cluster analysis has no statistical basis upon which to draw statistical inferences from a sample to a population, it is used primarily as an explanatory technique. Therefore, clustering solutions are not unique, as the cluster membership is dependent upon the variables used as the basis for similarity or dissimilarity measure. The addition or deletion of relevant variables can have substantial impacts on the cluster analysis, resulting in different MZs for a given field (Hair et al., 1998; Stamatis, 2002).

The selection of the variables for cluster analysis could be critical to optimize the efficiency of a management zone strategy. Several studies have compared and evaluated different techniques to delineate management zones (Chang et al., 2004; Fleming et al., 2004; Mallarino and Wittry, 2004). The variable selection for cluster analysis influences management zone delineation in terms of capturing the spatial variability of soil characteristics and crop yields within a field and among fields. In the past studies, a number of agronomic factors affecting fruit yield have been considered as cluster analysis variables for delineating productivity/management zones (Bang, 2005; Chang et al., 2004; Fleming et al., 2004; Li et al., 2008). Potential sources of information commonly used to define soil-based MZs include EC_a survey, aerial photography, landscape attributes (elevation, slope, and aspect), and soil surveys (Doerge, 1999). Each parameter directly or indirectly reflects field characteristics related to crop yield and is relatively stable over time (Sudduth et al., 2000; Mueller et al., 2003).

Since each field may have different characteristics important to crop management, different clustering variables may be required to characterize soil spatial variability in each field for the development of MZs. Currently, the management practices are implemented uniformly within wild blueberry fields with inadequate attention given to the spatial pattern of variability in soil properties, leaf nutrient, fruit yield and topographic features. The objective of this work was to develop management zones for site-specific fertilization based on soil variability.

6.2 Material and Methods

Research study was conducted on two wild blueberry fields in central Nova Scotia, Canada. Cluster analysis was performed using Minitab 15 statistical software to observe the spatial patterns of natural productivity groups that exist in the field due to the variations in soil properties. This analysis structures the data into the natural clusters/groups without prior knowledge of their productivity potential (Fridgen et al., 2004; Schepers et al., 2004). The analysis of variance (ANOVA) using least significant difference (LSD) procedure (SAS Institute, Cary, NC, USA) was used to compare the means in different productivity zones at 5% level of significance.

The objective of the cluster analysis was to place spatial soil properties and fruit yield data into naturally occurring cluster groups aiming to minimize within-cluster variance and maximize between cluster variance to develop MZs. Results of the cluster analysis were presented as dendrograms. A dendrogram represents different clusters and the distinctness of the cluster from its closest neighbor. Distinctness is the distance between a node and a branch towards the horizontal (X) direction.

6.3 Results and Discussions

6.3.1 Cluster Analysis of Soil Variables and Fruit Yield

6.3.1.1 Carmal Site

Cluster analysis of soil properties and fruit yield grouped the correlated variables based on their similarity level and a dendrogram was produced (Fig. 6-1). The results of cluster analysis suggested that soil pH, sand, silt and PRP fall in unique clusters indicating their less impact on the fruit yield. (Fig. 6-1) The regression analysis of these soil properties with fruit yield (Fig. 5-1 and Table 5-4, Chapter 5) also indicated their less impact on the fruit yield. The similarity level of these soil properties with yield was very low (Fig. 6-1). The higher geostatistical range of influence and lower CVs also indicated the less variability of sand, silt and soil pH within field (Tables 4-12 and 4-1, Chapter 4).

The soil properties including NH_4^+-N, NO_3^--N, HCP, EC, SOM, θ_v and clay were grouped together with the fruit yield at a similarity level of around 60 to 80% for both monitoring years (Fig. 6-1). The inorganic nitrogen along with HCP during crop year were closely grouped with fruit yield at a similarity level of greater than 70% (Fig. 6-1) suggesting that the application of inorganic nitrogen during the crop year may have a significant impact on the yield. The soil EC, SOM, θ_v and clay during sprout and crop year were also grouped with fruit yield at a similarity level of 50 to 65% (Fig. 6-1). The relationships of these soil properties with the fruit yield (Fig. 5-1, Table 5-4, Chapter 5) and their higher spatial variation as shown by their lower range of influence and higher CVs (Table 4-12 and 4-1, Chapter 4) indicated the major contribution of these soil properties to the fruit yield variability. The grouping of data into natural clusters depends upon the internal homogeneity and externally heterogeneity (Fleming et al., 2004). The dendrogram suggested the internal homogeneity of soil properties with fruit yield except sand, silt, PRP and pH.

The close grouping of fruit yield with the HCP at a similarity level greater than 70% (Fig. 6-1), its relationship with fruit yield (Fig. 5-1, Chapter 5) and soil properties (Table 4-10, Chapter 4), its variation with respect to slope (Fig. 4-10, Chapter 4) and its higher spatial variation (Tables 4-12 and 4-1) suggested that HCP in combination with slope can be used to develop management zones for site-specific fertilization, due to its ease of measurement and rapid data collection. Several researchers used different soil parameters in combination to develop management zones (i) EC_a, NIR and slope data (Schepers et al., 2004); (ii) EC_a and NIR (Fleming et al., 2004); (iii) NIR and landscape attributes (Fleming et al., 2000); and (iv) EC_a and landscape attributes (Fraisse et al., 1999). Overall the grouping of soil parameters with the fruit yield explained that the inorganic nitrogen, HCP, EC, SOM, θ_v and clay were important parameters to describe yield variability within field. The stepwise regression of the soil properties with fruit yield also support these results.

6.3.1.2 North River Site

The dendrogram of soil variables with fruit yield (Fig. 6-2, Appendix F) suggested that fruit yield, EC, HCP, NH_4^+-N and NO_3^--N were clustered in the same group with the similarity level of around 65%. The similarity level of soil EC with the fruit yield during two monitoring years was greater than 80% indicating that the soil fertility having a significant impact on crop productivity. The inorganic nitrogen, SOM, clay and θ_v during sprout year fell in different cluster, but this group was found to be in relation with the fruit yield at the similarity level of 50 to 55%. The lower mean values of inorganic nitrogen during the crop year (Table 4-2, Chapter 4) and its relationships to the fruit yield (Fig. 5-2, Table 5-5, Chapter 5) indicated that the timing of nitrogen fertilizer could be important in explaining fruit yield variability. These results were in agreement with the finding of Penney and McRae, (2002). In general clustering of variables into different groups explained that NH_4^+-N, NO_3^--N, HCP, EC, SOM, and θ_v were important parameters for fruit yield which was also suggested by regression analysis of the soil

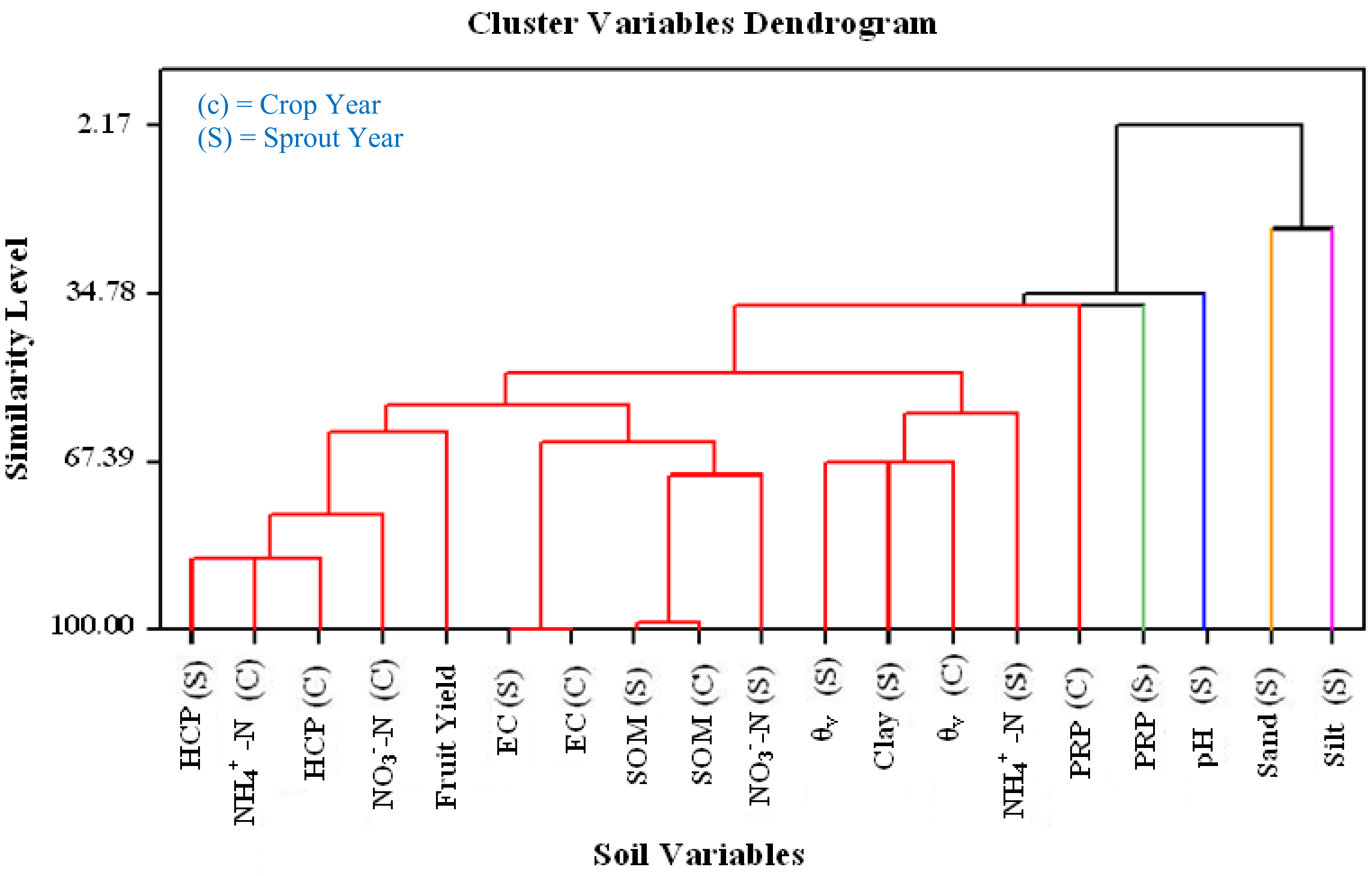


Figure 6-1. Dendrogram of soil variables along with fruit yield for Carmal Site.

properties with the fruit yield. These soil properties exhibited high spatial variation as indicated by their lower range of variability (Table 4-13, Chapter 4) higher CVs (Table 4-2, Chapter 4), and their variation with respect to slope suggesting that spatial variability having a significant impact on fruit yield.

The soil pH, sand and silt fell in unique clusters, and their similarity level with the fruit yield cluster group was very low (Fig. 6-2, Appendix F) indicating the less importance of these variables in explaining yield variability. The non-significant correlation of these soil properties with the fruit yield (Fig. 5-2, Chapter 5) also suggested the lower importance of these variables, while characterizing and managing soil and crop variability within wild blueberry fields. The grouping of fruit yield with the HCP at a similarity level greater than 65% (Fig. 6-2, Appendix F), and its relationship with fruit yield ($R^2 = 0.62$) (Fig. 5-2, Chapter 5) indicated higher values of HCP in high yielding areas and vice versa suggesting that ground conductivity can be a potential variable to develop management zones. Mann (2009) also found the higher ground conductivity values in high yielding areas for Florida citrus. The other soil parameters including NH_4^+-N, NO_3^--N, HCP, EC, SOM, and θ_v were also significantly correlated with fruit yield.

The strength of the relationships between soil properties, sensor-based ground conductivity and fruit yield can be used to assess the potential clustering variables to develop MZs. This indicated that variable selection to develop prescription maps using cluster analysis for each field would likely be important to achieve maximum efficacy in management zone delineation. In this study, HCP, fruit yield, and slope were considered as potential variables to delineate management zone, because these attributes generally showed better correlations with soil properties and fruit yield.

6.3.2 Cluster Analysis of Observations to Develop Management Zones

6.3.2.1 Carmal Site

The soil properties and fruit yield data were used to develop management zones representing areas of very good, good, medium, low and very low productivity using cluster analysis. Cluster analysis grouped soil and fruit yield sample points with similar patterns in attributes. The dendrogram was produced by performing observation cluster analysis to identify the natural productivity potentials within field. The dendrogram (Fig. 6-3) clustered the soil properties and fruit yield data into five groups based on their similarity level. The productivity levels to develop management zones were decided based on fruit yield data i.e. very good (Fruit yield > 5000 kg ha^{-1}), good (Fruit yield 4000 to 5000 kg ha^{-1}), medium (Fruit yield 2500 to 4000 kg ha^{-1}), poor (Fruit yield 1500 to 2500 kg ha^{-1}), and very poor (Fruit yield < 1500 kg ha^{-1}). The significant correlations of fruit yield with soil properties (Fig. 5-1, Table 5-4, Chapter 5) also support the defined productivity zones. The natural grouping of the productivity zones suggested that most of the Carmal Site fall in medium to high productivity potential (Fig. 6-3) and there were couple of data points fall in very good productivity zones indicating the high yielding areas. The clustered observations in each group exhibited the internal homogeneity and external heterogeneity at a similarity level of greater than 70% (Fig. 6-3). The results of cluster analysis could differentiate the areas with different fertility status.

The mean comparison of five productivity zones was performed using ANOVA. Soil properties including inorganic nitrogen, SOM, EC, θ_v, clay, HCP, PRP and fruit yield followed the trends indicated by the management zones with the highest nutrient and yield in the very good and good productivity zones, intermediate levels in the

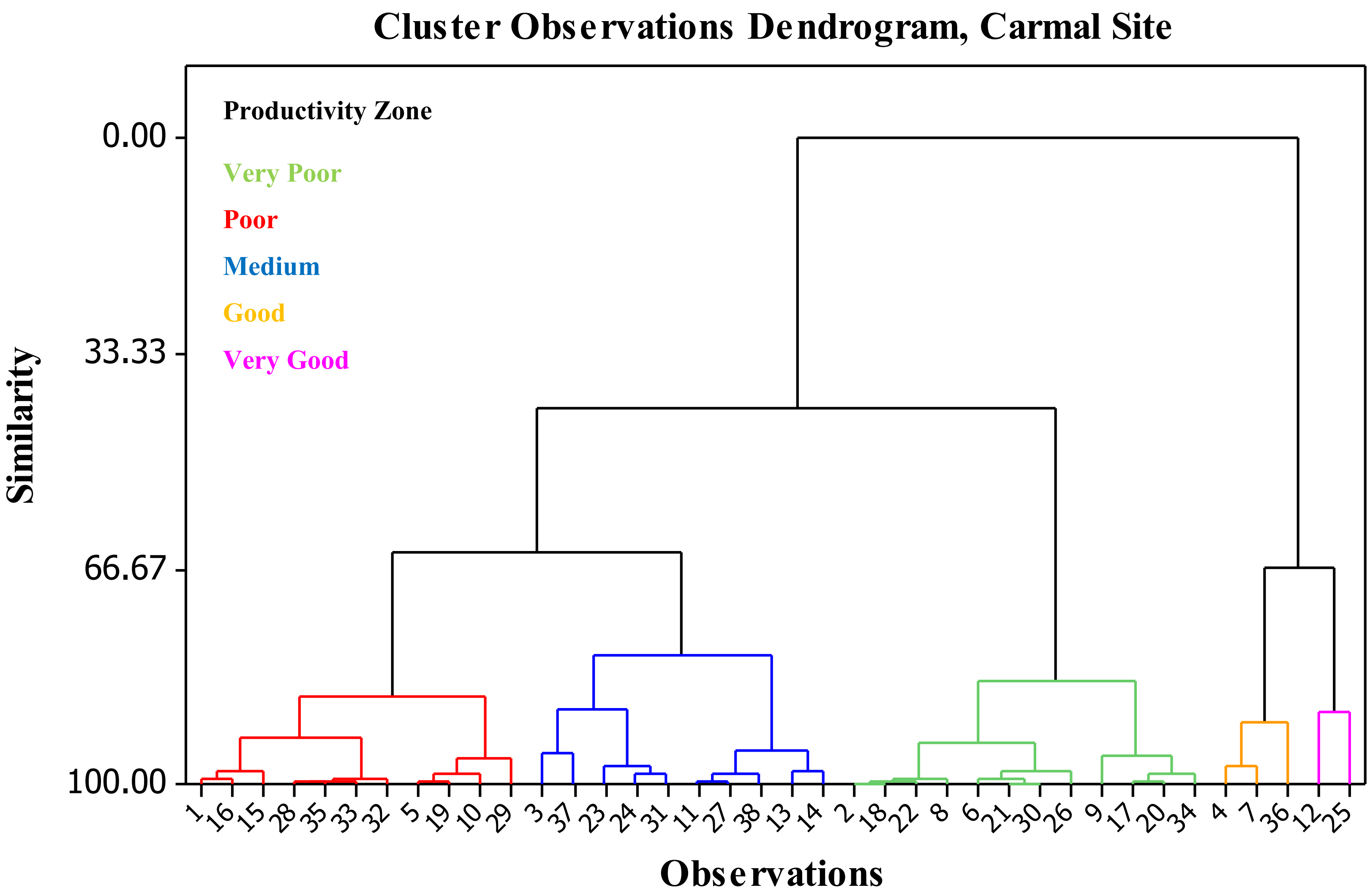


Figure 6-3. Observation dendrogram of soil variables along with fruit yield for Carmal Site.

medium zones, and lowest levels in poor and very poor productivity zones. The fruit yield, θ_v and inorganic nitrogen were significantly different in developed management zones except poor and very poor MZs (Table 6-1). ANOVA test using LSD method suggested that soil pH and silt content were similar for all productivity zones indicating non-significant differences (Table 6-1). The HCP was significantly different in each productivity zones except poor and very poor zones having non-significant differences. The mean values of fruit yield, HCP, SOM, EC, θ_v, NH_4^+-N, and NO_3^--N were observed higher in very good productivity zones and dropped significantly and were lower in very poor productivity zone (Table 6-1). The results of ANOVA suggested that the soil EC was non-significantly different between good and very good zones, and poor and very poor zones, while it was significantly different between medium and good productivity zones. The very good productivity zone was found to have more clay content, but there were non-significant differences among poor, very poor, good and very good productivity zones. The mean clay content for medium productivity zone was significantly different from other zones (Table 6-1).

The cluster analysis (Fig. 6-3) and comparison of means (Table 6-1) of soil properties and fruit yield, and their variation with respect to slope (Fig. 4-10, Chapter 4) as indicated by zonal statistics suggested that the soil properties including HCP, inorganic nitrogen and fruit yield were significantly different in each management zone (Table 6-1). These results indicated that fruit yield in low lying areas increased as the SOM, EC, θ_v, and inorganic nitrogen increase in the root zone. The fruit yield was less in very steep slope zones (Very poor) where the amount of soil nutrients were also less as compare to other zones in the field. The uniform application of agrochemicals will provide less

Table 6-1. Comparison of mean fruit yield and soil properties for management zones on the basis of fruit yield for Carmal Site.

Soil Properties	Fruit Yield (Kg ha^{-1}) Management Zone				
	Zone 1 Yield <1500 (Very Poor)	Zone 2 Yield 1500-2500 (Poor)	Zone 3 Yield 2500- 4000 (Medium)	Zone 4 Yield 4000-5000 (Good)	Zone 5 Yield > 5000 (Very Good)
Fruit Yield (Kg ha^{-1})	1322.22**e**	2413.20**d**	3360**c**	4707.00**b**	6032.00**a**
HCP (mSm^{-1})	3.66**b**	4.96**b**	5.60**c**	8.4**b**	10.05**a**
PRP (mSm^{-1})	2.68**b**	3.49**b**	3.47**b**	4.54**ab**	7.05**a**
θ_v	23.07**bc**	26.19**b**	27.88**c**	34.10**a**	30.34**ab**
pH	5.3 **a**	5.56**a**	5.56**a**	5.54**a**	5.58**a**
EC (μScm^{-1})	32.83**b**	36.64**b**	37.89**b**	51.47**a**	61.18**a**
SOM (%)	8.83**b**	11.09**b**	11.07**c**	13.81**ab**	16.59**a**
Sand (%)	51.87**ab**	49.70**ab**	49.35**a**	50.11**ab**	45.94**b**
Silt (%)	9.07**a**	8.39**a**	7.22**a**	5.61**a**	8.22**a**
Clay (%)	38.21**a**	41.70**a**	42.02**b**	45.28**a**	46.34**a**
NH_4^+ -N (mg Kg^{-1})	4.84**bc**	7.51**b**	8.42**c**	9.66**b**	16.62**a**
NO_3^--N (mg Kg^{-1})	2.59**cd**	3.46**bc**	3.75**d**	5.65**ab**	6.36**a**

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

nutrients for the plants located on the steep slopes. The reason is that nutrients erode from steep slope areas to low lying areas within fields.

Most of the Carmal Site has a milder slope (Ranges from 5 to 10 degrees) with 18% coverage by bare spots, weeds and grasses (Fig. 6-5). The results indicated the higher fertility and fruit yield in low lying areas; however 4.2% of the bare spots, weeds and grasses were also contained in low lying areas (Fig. 6-5). Unnecessary fertilization in bare spots, weeds and grasses located in low lying areas may deteriorate water quality, promote weed/grasses growth by restricting the nutrient availability of surrounding blueberries, which will ultimately result in reduced yield and increase cost of production. Under-fertilization restricts yield and can reduce berry quality (Percival and Sanderson, 2004). Zaman et al., (2008) reported 30 to 50% bare spots within wild blueberry fields.

Defining bare spots as a separate class while delineating management zone would be helpful in saving significant amount of fertilizer.

The appropriate management zones based on soil spatial variability could be used for variable rate application of agro-chemicals within wild blueberry fields. The definition of site-specific management zones rely on spatial information that is stable or predictable over time and is related to fruit yield. Therefore, the spatial data sources, such as yield data, soil properties and topographic features may be needed to delineate MZs (Li et al., 2007). The relationships of fruit yield with HCP, SOM, EC, θ_v and inorganic nitrogen (Fig. 5-1, Table 5-4, Chapter 5), their stability over time, and variation with respect to slope suggested that HCP in combination with fruit yield and other soil properties data would be helpful in defining productivity zones for site-specific fertilization.

The field was divided into five (very poor, poor, medium, good, and very good) zones (Fig. 6-5 a) using clustered observation in different groups on the basis of variation in fruit yield and soil properties. The interpolation technique, kriging, was applied to clustered data sets based on class membership to produce detailed maps representing different management zones. The management zones developed by Arc GIS 9.3 in combination with cluster analysis represented different levels of productivity across the field. The visual comparison of the management zones with fruit yield (Fig. 6-5 a and b) indicated the higher fruit yield in the areas with more fertility levels. The very good productivity zones was located in the centre and northeast central region of the field, fruit yield was observed lower in these areas as these areas were occupied by bare spots, grasses and weeds (Fig. 6-5 d). These results suggested that wild blueberry crop likes

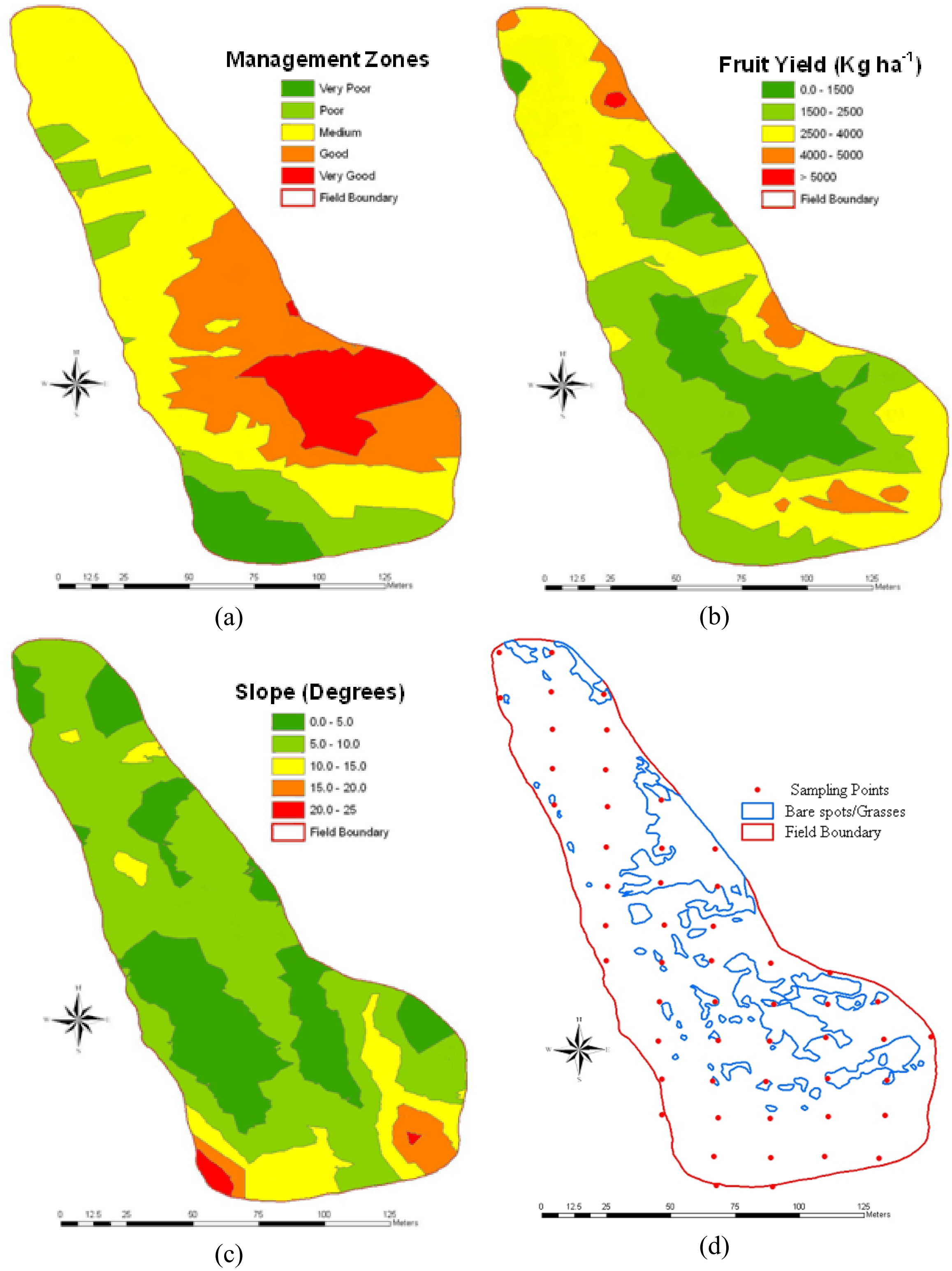


Figure 6-5. Comparison of delineated productivity zones for Carmal Site (a) Management Zones, (b) Fruit Yield, (c) Slope, (d) Field layout.

medium to high fertility levels for its growth and development. The medium productivity management zone was located in north and southeast of the field, while the fruit yield was also in average range in those areas (Fig. 6-5 a and b).

The visual comparison of the management zones with the slope map suggested that the very good productivity zone was located in low lying areas while the very poor productivity zone was located at steep slopes (Fig. 6-5 a and c). The fruit yield was also observed higher in low lying areas and dropped with steepness of the slope. The comparison of the means in prescribed zones based on soil properties and fruit yield showed the trends indicating highest nutrient and yield in the high productivity low lying zones, intermediate levels in the medium zones, and lowest levels in the low productivity steep slope zones (Table 6-1). The fertilizer can be saved by adjusting the rate of application based on the developed management zones. The 18% of the fertilizer can be saved by allocating zero rate to bare spots, weeds and grasses areas. Overall the results of cluster analysis, comparison of the means using ANOVA and visual comparison of maps suggested the validity of the prescribed zones. These results also indicated that fruit yield, soil properties and topographic features data would be helpful in ameliorating productivity/management zones for site-specific fertilization.

6.3.2.2 North River Site

The soil properties and fruit yield data were clustered to develop MZs based on natural grouping of the data with similar pattern in attributes. The dendrogram was produced to define productivity potential i.e. very good (Fruit yield > 4000 kg ha^{-1}), good (Fruit yield 3000 to 4000 kg ha^{-1}), medium (Fruit yield 2000 to 3000 kg ha^{-1}), poor (Fruit yield 1000 to 2000 kg ha^{-1}), and very poor (Fruit yield < 1000 kg ha^{-1}) (Fig. 6-4). The productivity potential to develop management zones were decided based on fruit yield data as it was significantly correlated with soil properties (Fig. 5-2, Table 5-5, Chapter 5). The natural grouping of the productivity zones suggested that most of the North River Site fall in poor to good productivity potential (Fig. 6-4) and there were less number of data points fall in very poor and very good productivity zones. The clustered observations in each group were internally homogeneous at a similarity level of greater than 75% (Fig. 6-4). Once soil properties and fruit yield were assigned with zone classification based on cluster analysis, the data were exported and analyzed by one-way variance analysis to provide an indication of statistical distinction between the different potential management zones.

The mean comparison of five productivity zones using LSD method suggested that soil properties including inorganic nitrogen, SOM, EC, θ_v, clay, HCP, PRP and fruit yield followed the similar trend as Carmal Site indicating high fruit yield in very good productivity zones, medium in the medium productivity zone, and lowest in low productivity zones. The mean fruit yield and inorganic nitrogen were significantly different in all management zones (Table 6-2) except medium and poor productivity zone where there were non-significant differences among inorganic nitrogen and θ_v. Analysis of variance suggested that the mean soil pH was similar for all productivity zones indicating non-significant differences (Table 6-2). The HCP and PRP were significantly different in each productivity zones except poor and very poor zones having non-significant differences in PRP.

The higher fertility status and fruit yield were observed in very good productivity zone, and the productivity status dropped significantly and was lowest in very poor zone

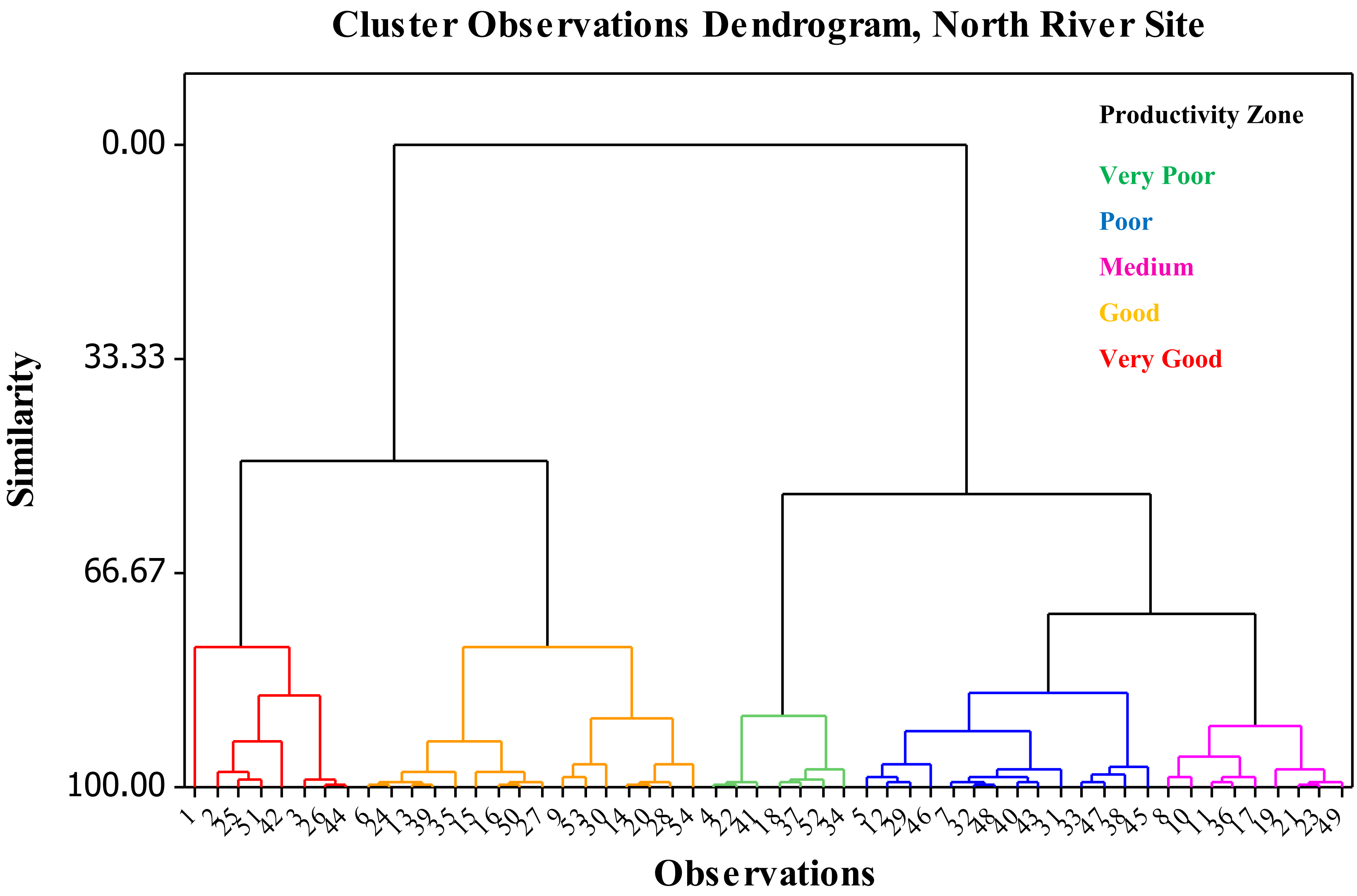


Figure 6-4. Observation dendrogram of soil variables along with fruit yield for North River Site.

(Table 6-2). The soil EC, clay and θ_v were non-significantly different between poor and medium, poor and very poor productivity zones. The soil EC, clay and θ_v were significantly different between medium and good, good and very good productivity zones. The SOM was significantly different for each zone except poor and very poor zone with non-significant differences (Table 6-2). The sand and silt content were significantly different for poor and good productivity zones while there were non-significant differences for these soil properties among the other management zones. These results revealed distinctly different soil properties and fruit yield for the delineated management zones (Table 6-2).

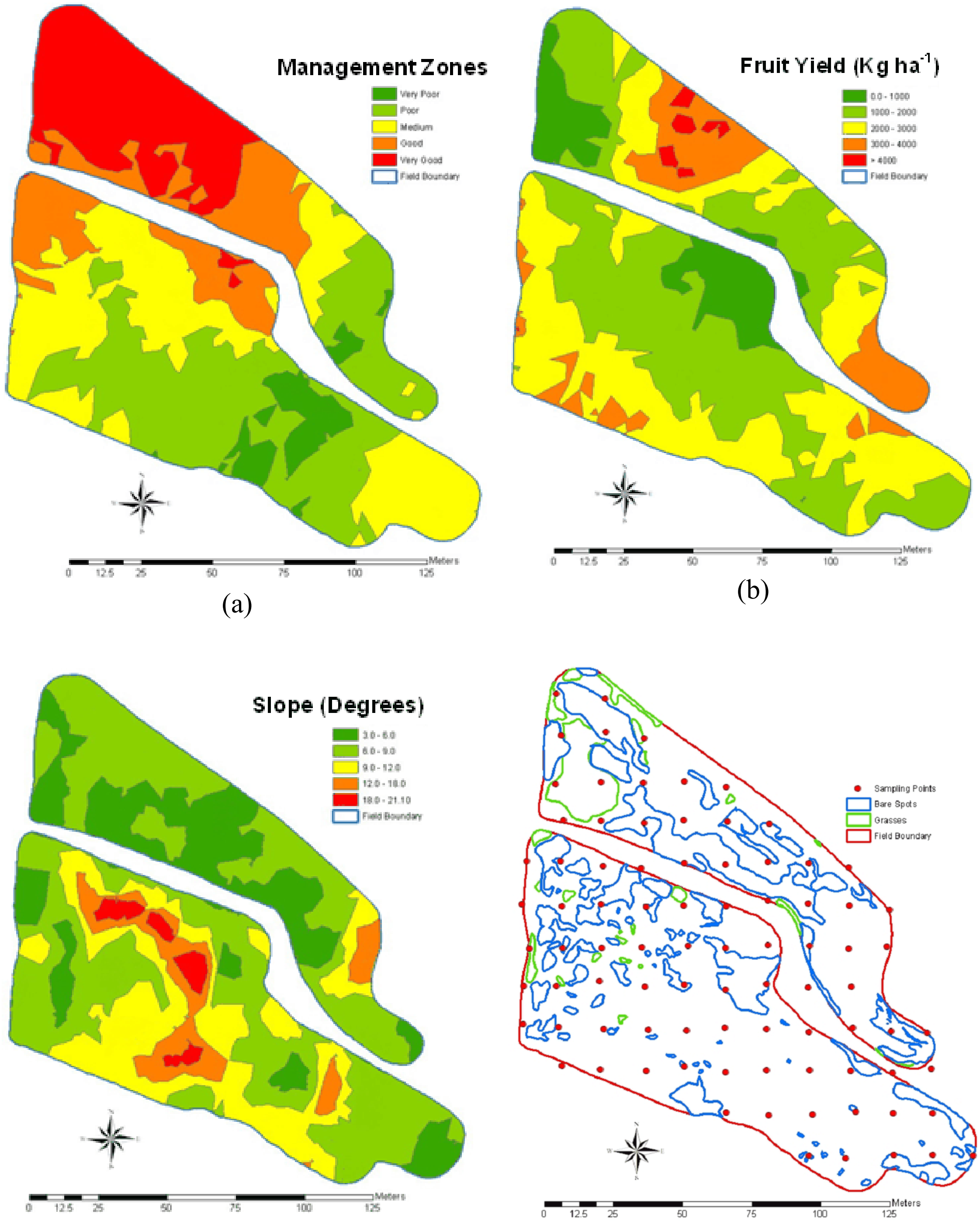
The defined classes based on fruit yield and productivity potential suggested by cluster analysis was interpolated to develop management zones for variable rate fertilization. The numbers of productivity/management zones were similar to the Carmal Site. The developed management zones represent the substantial variation of productivity/fertility across the field (Fig. 6-6 a). The map comparison of the management zones with fruit yield (Fig. 6-6 a and b) suggested the higher fruit yield in the areas with high fertility levels and vice versa. The very good productivity zones were located in north, northwest and north central region of the field. The 7% of bare spots, weeds and grasses areas were contained in good and very good productivity zone (Fig. 6-6 a and d). The fruit yield was observed lower in these areas as these areas were occupied by bare spots, grasses and weeds (Fig. 6-6 d). The north central region of the field resulted in highest yield. This may be due to high fertility status, as this part of the field was located in very good productivity zone. These results suggested variation of the fruit yield and productivity across the field (Fig.6-6 a and b).

Table 6-2. Comparison of mean fruit yield and soil properties for management zones on the basis of fruit yield for North River Site.

Soil Properties	Fruit Yield (Kg ha^{-1}) Management Zone				
	Zone 1 Yield <1000 (Very Poor)	Zone 2 Yield 1000-2000 (Poor)	Zone 3 Yield 2000- 3000 (Medium)	Zone 4 Yield 3000-4000 (Good)	Zone 5 Yield > 4000 (Very Good)
Fruit Yield (Kg ha^{-1})	367.30**e**	1543.10**d**	2330.70**c**	3412.56**b**	4825.00**a**
HCP (mSm^{-1})	3.06**e**	4.65**cd**	5.65**c**	7.65**b**	11.41**a**
PRP (mSm^{-1})	3.98**c**	4.30**c**	4.87**c**	6.36**b**	8.92**a**
θ_v	21.62**c**	22.98**c**	24.14b**c**	26.56**b**	31.58**a**
pH	5.43**a**	5.38**a**	5.34**a**	5.45**a**	5.45**a**
EC (μScm^{-1})	30.63**c**	35.94**c**	41.38**c**	52.97**b**	72.63**a**
SOM (%)	7.12**d**	7.99**d**	7.84**c**	8.66**b**	11.93**a**
Sand (%)	50.43**ab**	56.03**a**	53.69**ab**	43.02**b**	51.76**ab**
Silt (%)	41.18**ab**	35.37**b**	39.28**ab**	45.48**a**	37.85**ab**
Clay (%)	7.89**c**	8.53**c**	8.20**c**	9.67**b**	13.61**a**
NH_4^+ -N (mg Kg^{-1})	6.26**c**	5.04**c**	5.48**c**	8.11**b**	11.87**a**
NO_3^--N (mg Kg^{-1})	3.93**c**	4.29**bc**	4.89**bc**	5.85**b**	8.44**a**

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

The map comparison and zonal statistic function of Arc GIS 9.3 indicated that the very good productivity zone with higher fruit yield was located in low lying areas while lower fruit yield and very poor productivity zones were located at steep slopes, which was similar to Carmal Site (Fig. 6-6 a and c). The mean comparison in different management zones also indicated the similar results as Carmal Site (Table 6-2). Most of the North River Site has a slope ranging from 0 to 10 degrees with the 27% coverage by bare spots, weeds and grasses (Fig. 6-6). The results indicated the higher fertility and fruit yield in low lying areas; however 5% of the bare spots, weeds and grasses were also contained in low lying areas. The high yielding areas, bare spots and weeds were located in good and very good productivity zone similar to Carmal Site. Based on these results it is proposed to allocate zero fertilizer to the bare spots, weed and grasses by defining a separate class in the delineated management zone. The fertilizer recommendations based



(a)

(b)

(c)

(d)

Figure 6-6. Comparison of delineated productivity zones for North River Site (a) Management Zones, (b) Fruit Yield, (c) Slope, (d) Field layout on developed management zones after characterization of soil variability can be helpful in increasing input use efficiency, increase farm profitability by reducing environmental risks.

The number of management zones depends upon desired measurement sensitivity and the level of within field variability (Li et al., 2007). For this study, separation into five management zones proved to be a good compromise between sensitivity and visually discernable variability patterns of soil properties, fruit yield and topographic features. For farmers to adopt site-specific management, the development of management zones must be functional, and economically feasible. Complex field assessments and data manipulation may not be justifiable in terms of time, benefit or economics. Therefore cluster analysis, based on the assumption that grouping data points into naturally occurring clusters will reduce within zone variability, provides an opportunity for identifying management zones in a site and, potentially, applying site-specific management to maximize crop production across the entire field. This also represents a simplified approach for identifying threshold parameters related to yield potential.

6.3.3 Variable Selection to Develop Management Zones

The potential resources commonly used to define management zones are management history, aerial images, topographic features, yield maps, fertility maps, and sensors for detecting soil property information (e.g., electrical conductivity) (Ortega and Santibanez, 2007). Another procedure uses relatively stable soil properties such as EC_a and/or landscape features in conjunction with fruit yield to estimate patterns of soil variability (Ping et al., 2005). The soil property selected to develop prescription maps must have a significant correlation with the fruit yield (Kitchen et., 2005). In this study soil properties including HCP, SOM, EC, θ_v, clay, NH_4^+-N, and NO_3^--N were significantly correlated with the fruit yield during two monitoring years for both site (Figs. 5-1 and 5-2; Tables 5-4 and 5-5, Chapter 5). The higher correlation of the HCP with the fruit yield, and significantly different mean values in each productivity zone for both site (Tables 6-1 and 6-2) suggested that ground conductivity can be used to develop management zones for site specific fertilization. The stepwise regression analysis also suggested that the HCP was one of the more influential soil properties affecting wild blueberry fruit yield at both sites. The comparison of the kriged maps of management zones, fruit yield and HCP also suggested the higher values for ground conductivity in very good productivity zones and lower values were observed in very poor productivity zones (Figs. 6-7 and 6-8, Appendix F) for both sites. Fruit yield was also higher in the areas with more productivity and higher HCP values. Therefore, ground conductivity maps obtained by Dual EM could be used to develop prescription maps for site-specific fertilization.

The variation of the soil properties and fruit yield with respect to slope (Figs. 4-10 and 4-11, Chapter 4) suggested the potential of the slope to develop management zones. The fruit yield was negatively correlated with slope indicating higher yield in low lying areas. The higher significant correlation of the fruit yield with the blue pixels (Fig. 5-6, Chapter 5) suggested that digital color photography can be used to map wild blueberry fruit yield rapidly and reliably. To attain maximum efficiency of crop inputs through a management zone strategy, the following practical considerations for delineating management zones were suggested by Doerge (1999): a relationship with crop yield, low cost of data, data that are quantitative and repeatable, high density of the data, permanence of the collected data and scale of the data appropriate to the variable rate management anticipated. The results of this study indicated that ground conductivity (HCP), slope measurement and fruit yield is especially appealing to identify management zones within wild blueberry fields because these measurements are rapid, noninvasive and cost effective.

6.4 Summary and Conclusions

The cluster analysis of the soil variables with the fruit yield suggested that HCP, inorganic nitrogen, EC, SOM, and θ_v were closely grouped with the fruit yield at a similarity level of greater than 70%. The results of stepwise regression also indicated that these soil parameters were more influential in explaining yield variability. The mean comparison of the soil properties and fruit yield using ANOVA suggested that fruit yield, HCP, inorganic nitrogen, SOM and EC were significantly different among the developed management zones except poor and very poor zones. The visual comparison of the productivity zones with the fruit yield suggested the highest yield in very productive zone and lowest fruit yield was observed in very poor productivity zones. The results of clustering analysis, comparison of means, relationships of fruit yield with other soil variables and their variation with respect to slope suggested that HCP, slope and fruit yield data can be used to delineate management zones for site-specific fertilization in wild blueberry fields.

The results of this study showed that zones created by cluster analysis could provide a way to group and manage the spatial variability of soil properties and fruit yield within fields. The coefficients of variation and lower range of influence for soil properties and fruit yield indicated considerable variability and that site-specific nutrients management is needed. The spatial variability of soil properties was quantified by geostatistical tools and aggregated into MZs using cluster analysis. The optimum number of MZs for this study area were five and ANOVA indicated the heterogeneity of soil fertility among them. This would provide a basis of information for rationally managing soil nutrients of wild blueberry field.

The wild blueberry is a unique crop with significant bare spots within field, unlike other cropping systems. The uniform fertilization in bare spots, weed and grasses will not only deteriorate water quality but also promote weeds and grasses by restricting the nutrient availability of the surrounding blueberries. This practice will ultimately result in reduced yield by increasing cost of production. Therefore, it is proposed to define a separate class for bare spots, weeds and grasses while delineating management zones, to allocate zero fertilizer rate in those areas using variable rate spreader. Consequently, the application of MZs should increase input use efficiency, reduce cost of production, maximize environmental benefits and improve the quality of wild blueberry fruit.

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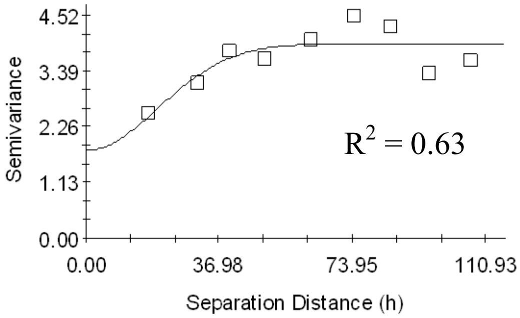
APPENDICES

Appendix A



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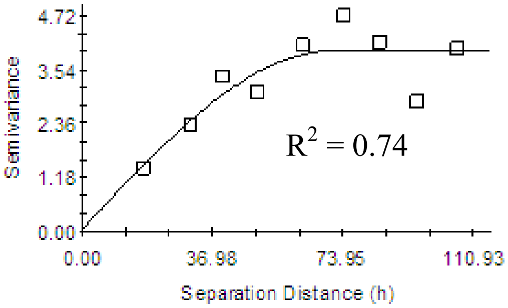

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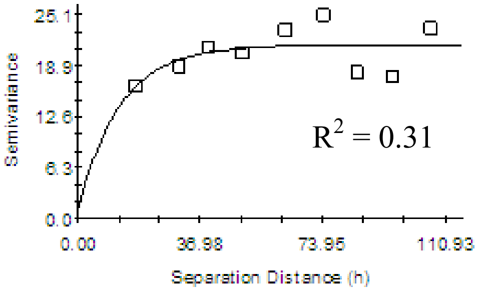

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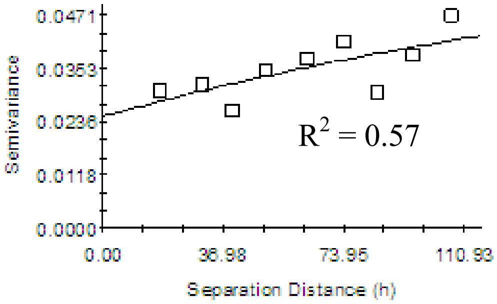

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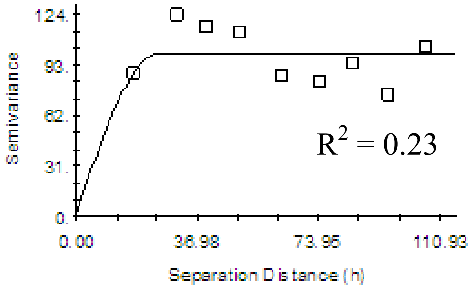

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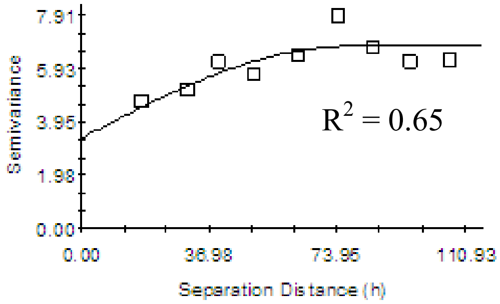

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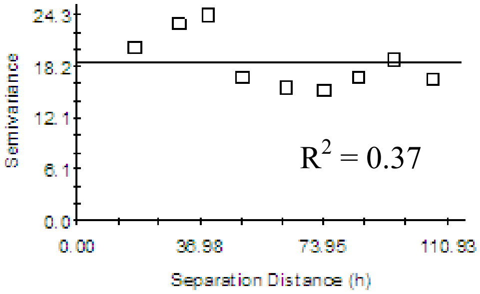

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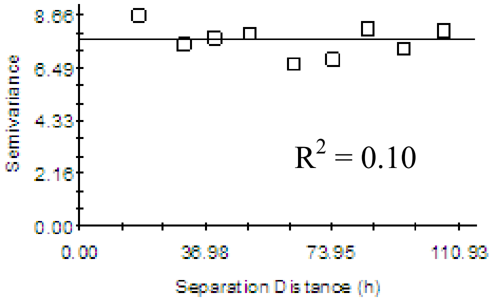

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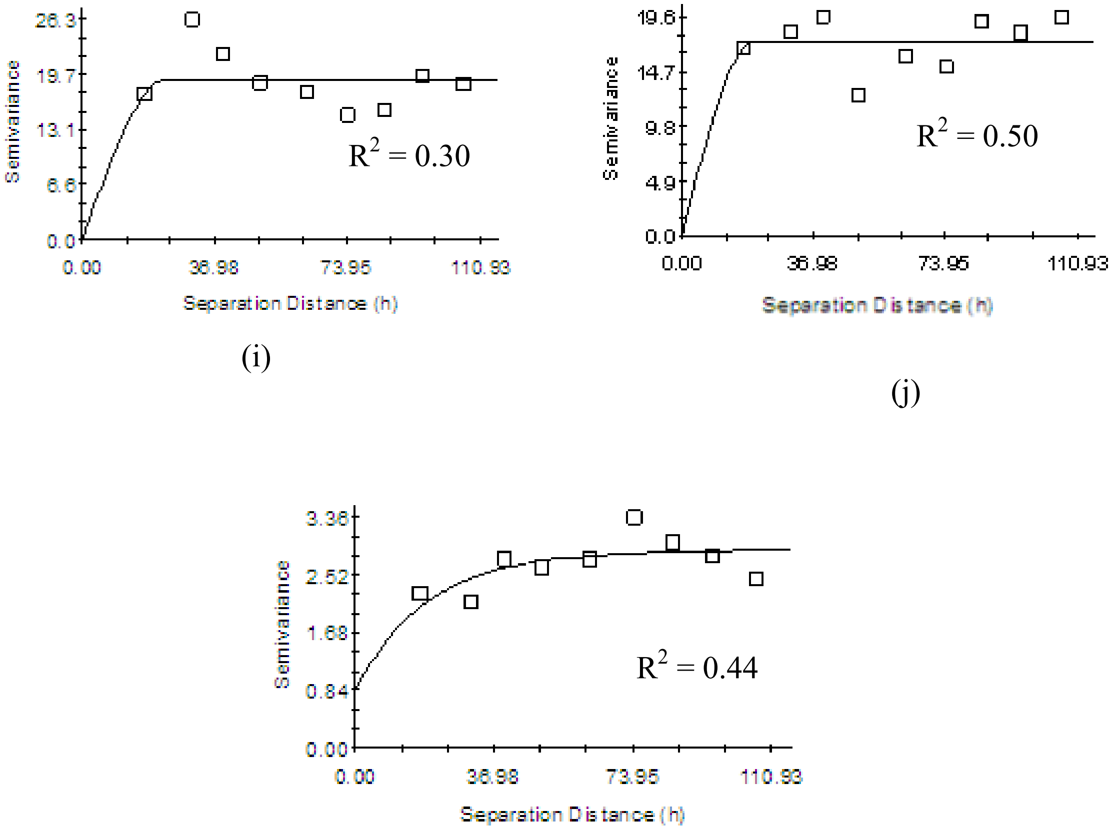
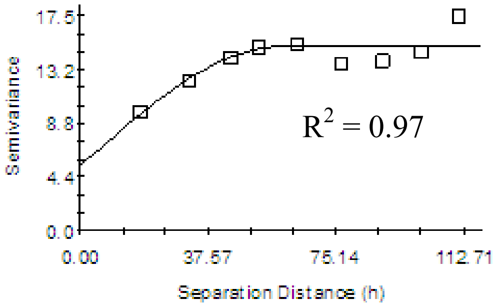


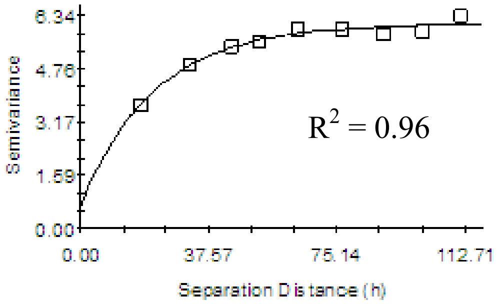
(i)

(j)

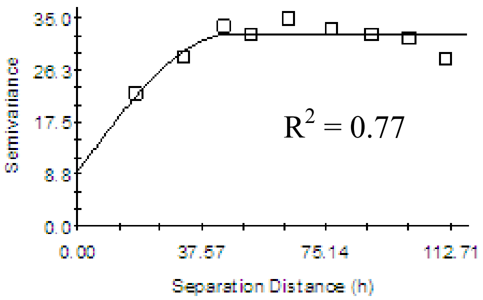
Figure 4-2. Semivarigrams of soil properties for Carmal Site. (a) Ground conductivity at horizontal co-planar geometry (HCP), (b) Ground conductivity at perpendicular co-planar geometry (PRP), (c) Moisture content, (d) pH, (e) Electrical conductivity (EC), (f) Soil organic matter (SOM), (g) Sand %, (h) Silt %, (i) Clay %, (j) Ammonium nitrogen (NH_4^+ -N), (k) Nitrate nitrogen (NO_3^--N).


17.5
13.2
8.8
4.4
0.0
Semivariance
0.00
37.57
75.14
112.71
Separation Distance (h)
$R^2 = 0.97$

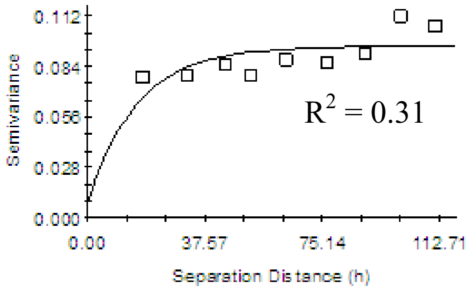
(a)


6.34
4.76
3.17
1.59
0.00
Semivariance
0.00
37.57
75.14
112.71
Separation Distance (h)
$R^2 = 0.96$

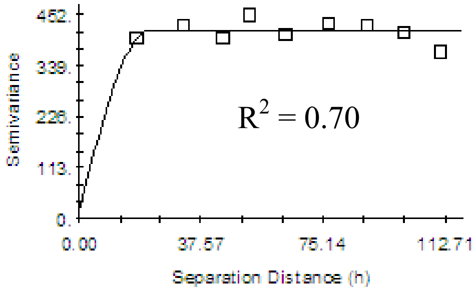
(b)


35.0
26.3
17.5
8.8
0.0
Semivariance
0.00
37.57
75.14
112.71
Separation Distance (h)
$R^2 = 0.77$

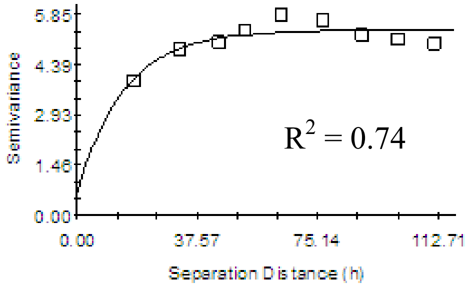
(c)


0.112
0.084
0.056
0.028
0.000
Semivariance
0.00
37.57
75.14
112.71
Separation Distance (h)
$R^2 = 0.31$

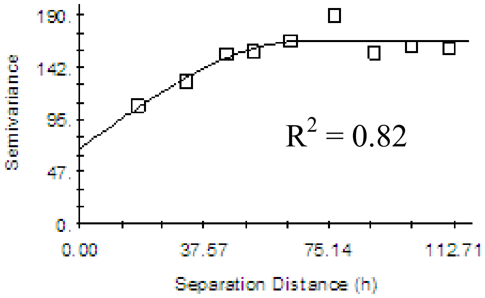
(d)


452.
339.
226.
113.
0.
Semivariance
0.00
37.57
75.14
112.71
Separation Distance (h)
$R^2 = 0.70$

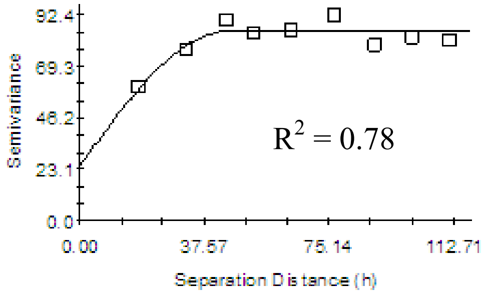
(e)


5.85
4.39
2.93
1.46
0.00
Semivariance
0.00
37.57
75.14
112.71
Separation Distance (h)
$R^2 = 0.74$

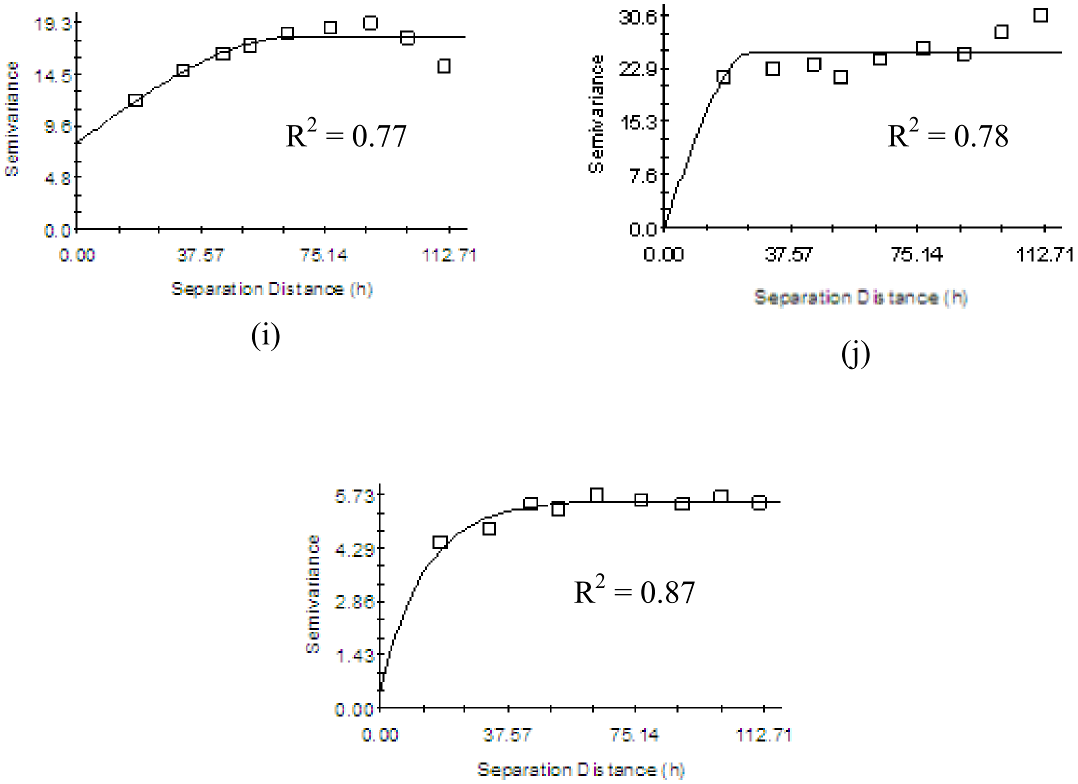
(f)


190.
142.
95.
47.
0.
Semivariance
0.00
37.57
75.14
112.71
Separation Distance (h)
$R^2 = 0.82$

(g)


92.4
69.3
46.2
23.1
0.0
Semivariance
0.00
37.57
75.14
112.71
Separation Distance (h)
$R^2 = 0.78$

(h)



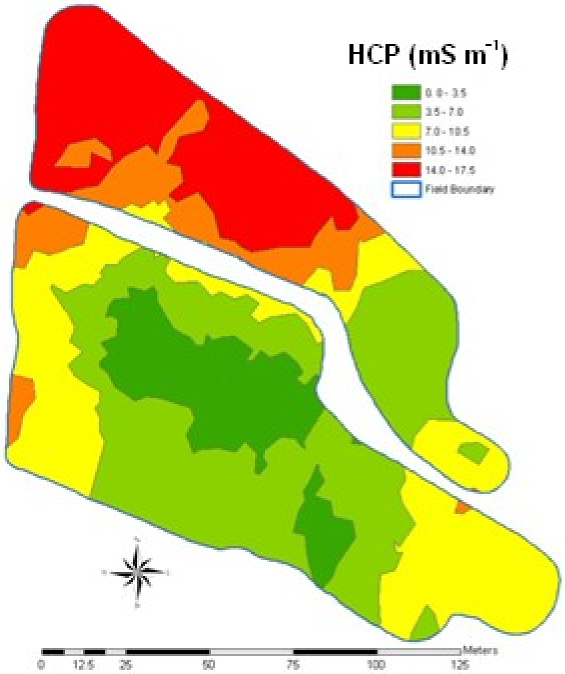
(i)

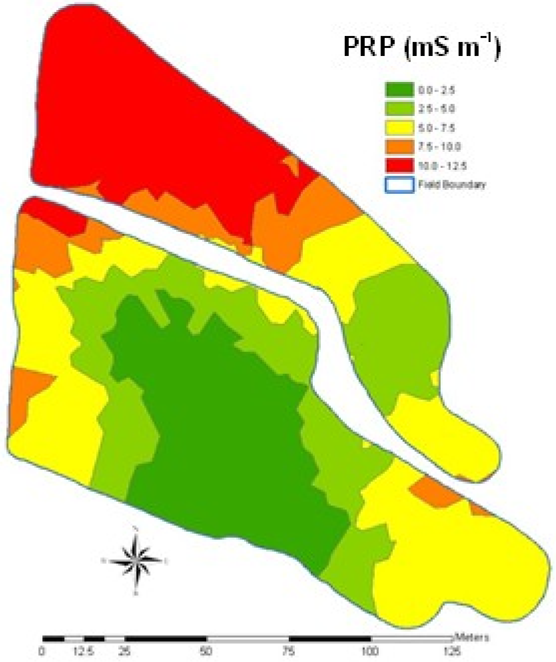
(j)

(k)

Figure 4-3. Semivarigrams of soil properties for North River Site (a) Ground conductivity at horizontal co-planar geometry (HCP), (b) Ground conductivity at perpendicular co-planar geometry (PRP), (c) Moisture content, (d) pH, (e) Electrical conductivity (EC), (f) Soil organic matter (SOM), (g) Sand %, (h) Silt %, (i) Clay %, (j) Ammonium nitrogen (NH_4^+ -N), (k) Nitrate nitrogen (NO_3^--N).

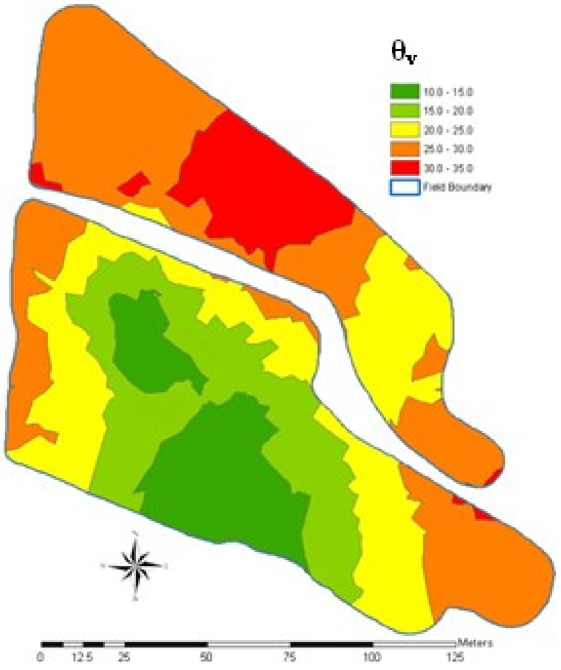
Appendix B

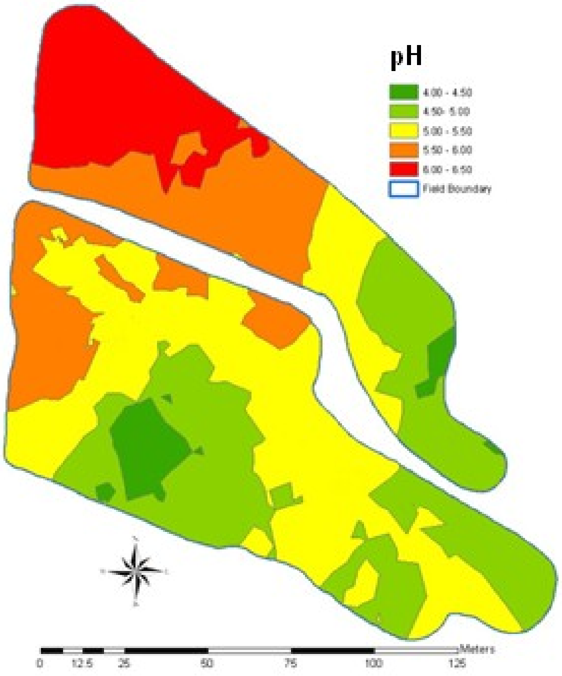




(a)

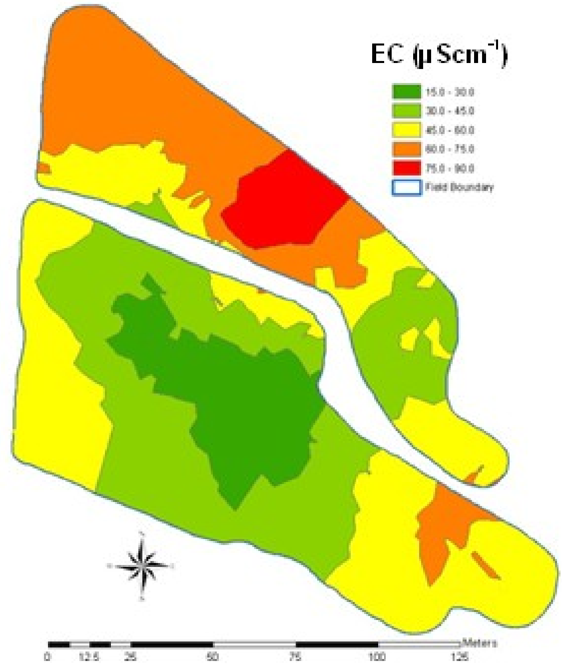
(b)



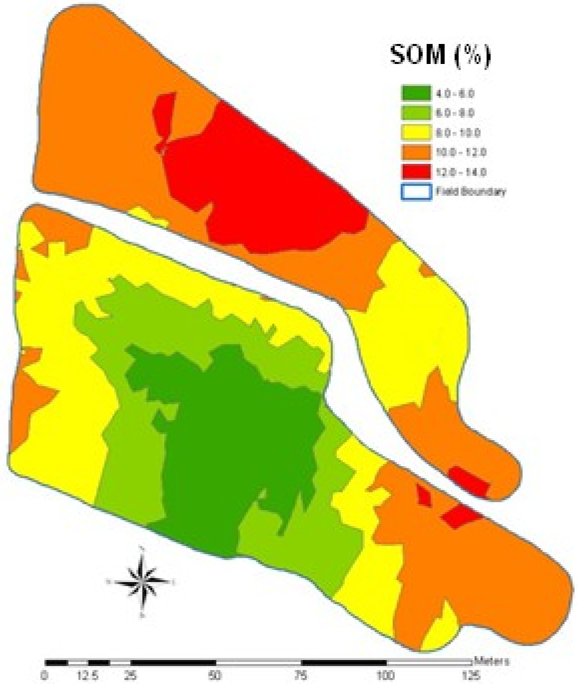


(c)

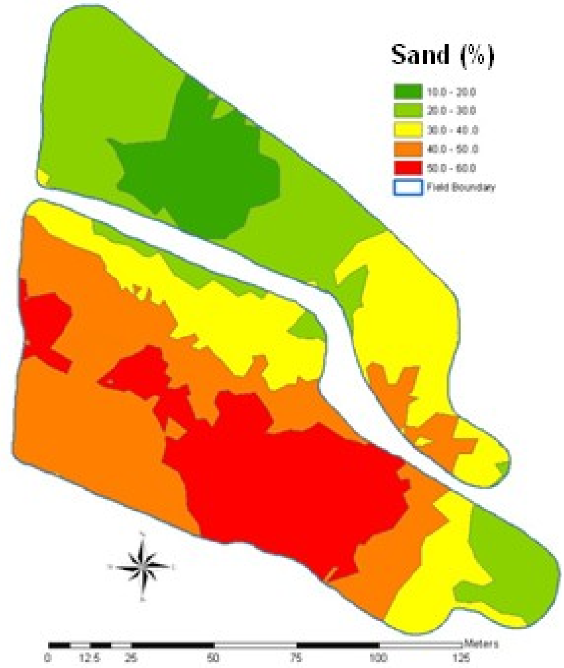
(d)


EC (µScm^{-1})
15.0 - 30.0
30.0 - 45.0
45.0 - 60.0
60.0 - 75.0
75.0 - 90.0
Field Boundary
Meters
0
12.5
25
50
75
100
125

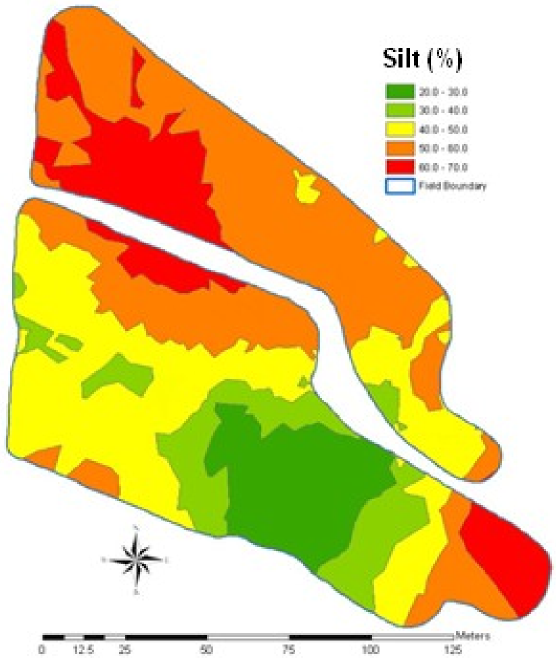
(e)


SOM (%)
4.0 - 6.0
6.0 - 8.0
8.0 - 10.0
10.0 - 12.0
12.0 - 14.0
Field Boundary
Meters
0
12.5
25
50
75
100
125

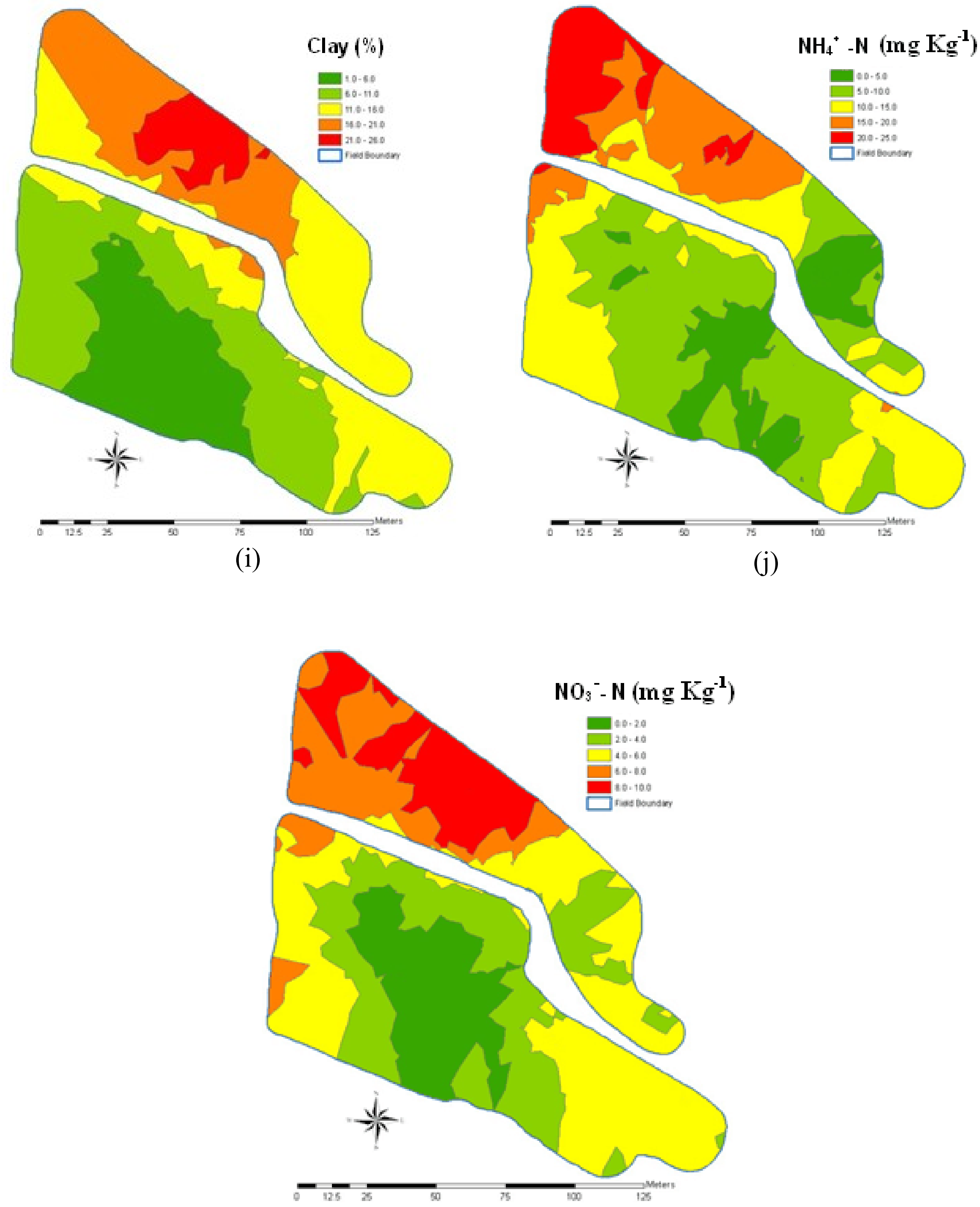
(f)


Sand (%)
10.0 - 20.0
20.0 - 30.0
30.0 - 40.0
40.0 - 50.0
50.0 - 60.0
Field Boundary
Meters
0
12.5
25
50
75
100
125

(g)


Silt (%)
20.0 - 30.0
30.0 - 40.0
40.0 - 50.0
50.0 - 60.0
60.0 - 70.0
Field Boundary
Meters
0
12.5
25
50
75
100
125

(h)

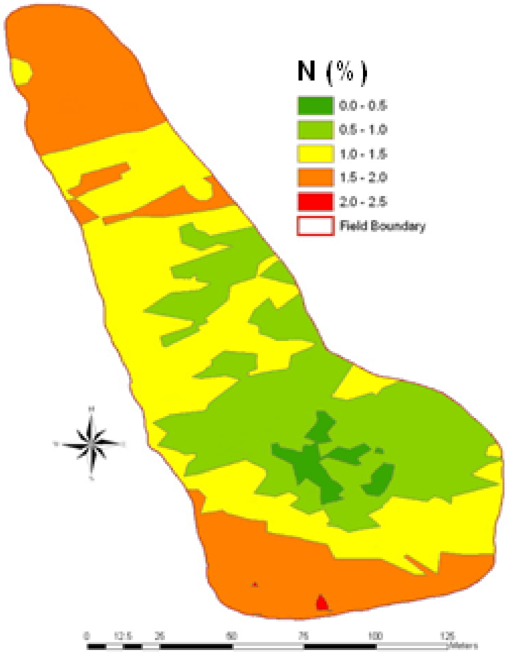


(i)

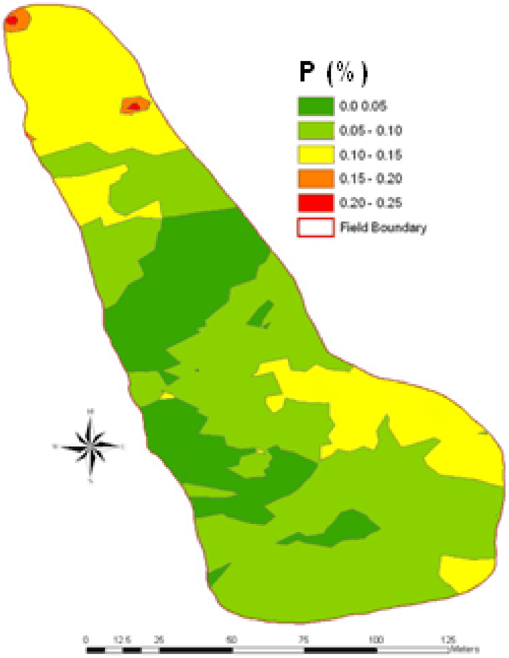
(j)

(k)

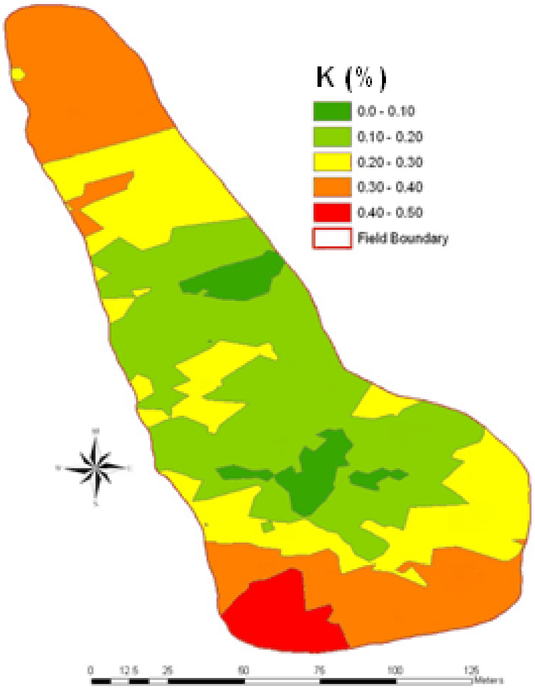
Figure 4-7. Maps of soil properties for North River Site (a) Ground conductivity at horizontal co-planar geometry (HCP), (b) Ground conductivity at perpendicular co-planar geometry (PRP), (c) Moisture content, (d) pH, (e) Electrical conductivity (EC), (f) Soil organic matter (SOM), (g) Sand %, (h) Silt %, (i) Clay %, (j) Ammonium nitrogen (NH_4^+ -N), (k) Nitrate nitrogen (NO_3^--N).


N (%)
🟩 0.0 - 0.5
🟩 0.5 - 1.0
🟨 1.0 - 1.5
🟧 1.5 - 2.0
🟥 2.0 - 2.5
☐ Field Boundary
0
12.5
25
50
75
100
125
Meters

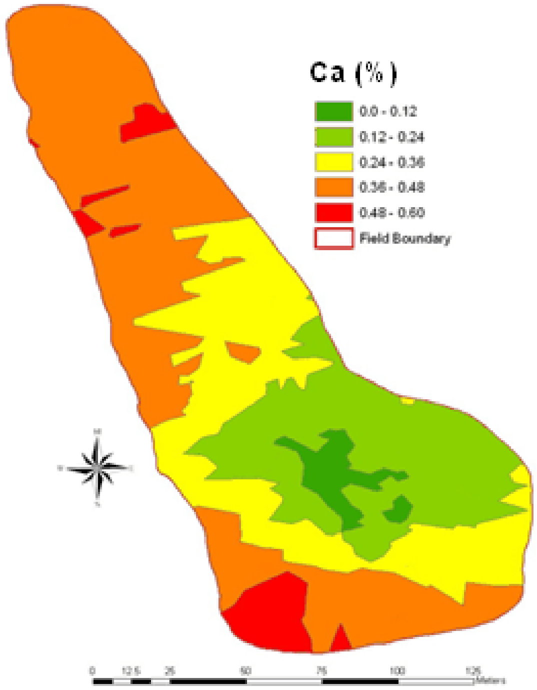
(a)


P (%)
🟩 0.0 0.05
🟩 0.05 - 0.10
🟨 0.10 - 0.15
🟧 0.15 - 0.20
🟥 0.20 - 0.25
☐ Field Boundary
0
12.5
25
50
75
100
125
Meters

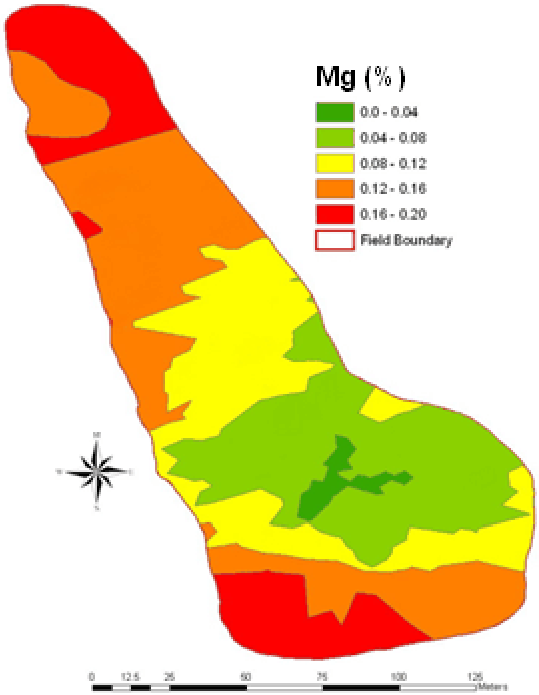
(b)


K (%)
🟩 0.0 - 0.10
🟩 0.10 - 0.20
🟨 0.20 - 0.30
🟧 0.30 - 0.40
🟥 0.40 - 0.50
☐ Field Boundary
0
12.5
25
50
75
100
125
Meters

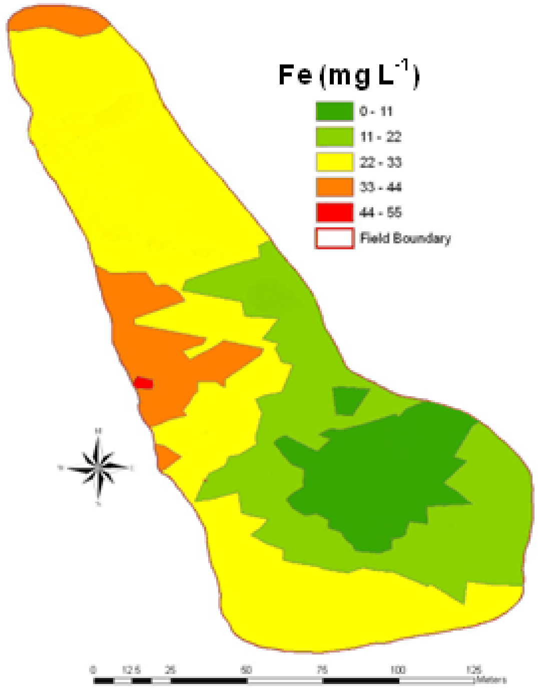
(c)


Ca (%)
🟩 0.0 - 0.12
🟩 0.12 - 0.24
🟨 0.24 - 0.36
🟧 0.36 - 0.48
🟥 0.48 - 0.60
☐ Field Boundary
0
12.5
25
50
75
100
125
Meters

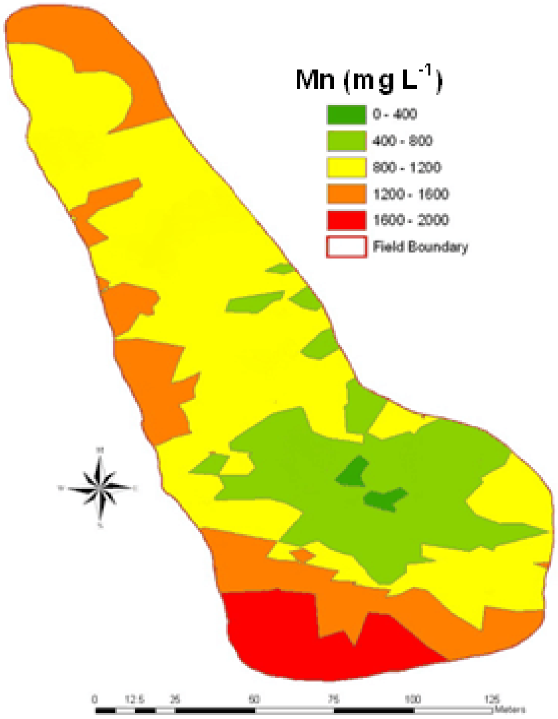
(d)


Mg (%)
0.0 - 0.04
0.04 - 0.08
0.08 - 0.12
0.12 - 0.16
0.16 - 0.20
Field Boundary
0
12.5
25
50
75
100
125
Meters

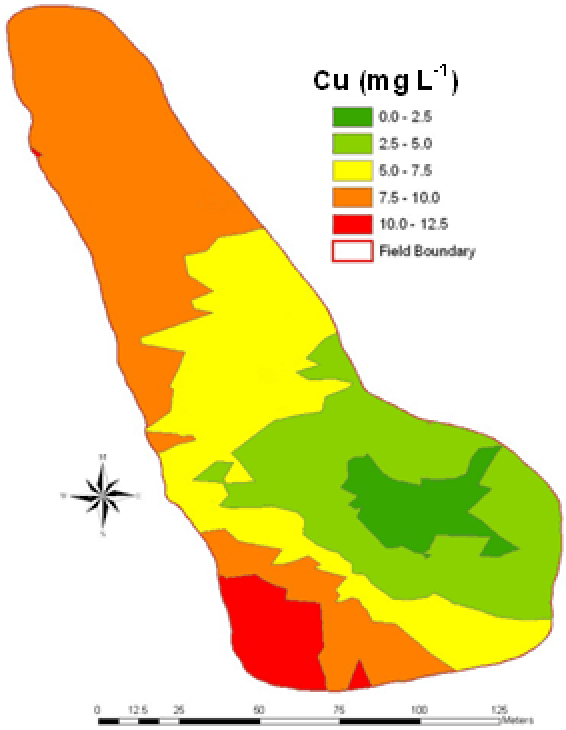
(e)


Fe (mg L-1)
0 - 11
11 - 22
22 - 33
33 - 44
44 - 55
Field Boundary
0
12.5
25
50
75
100
125
Meters

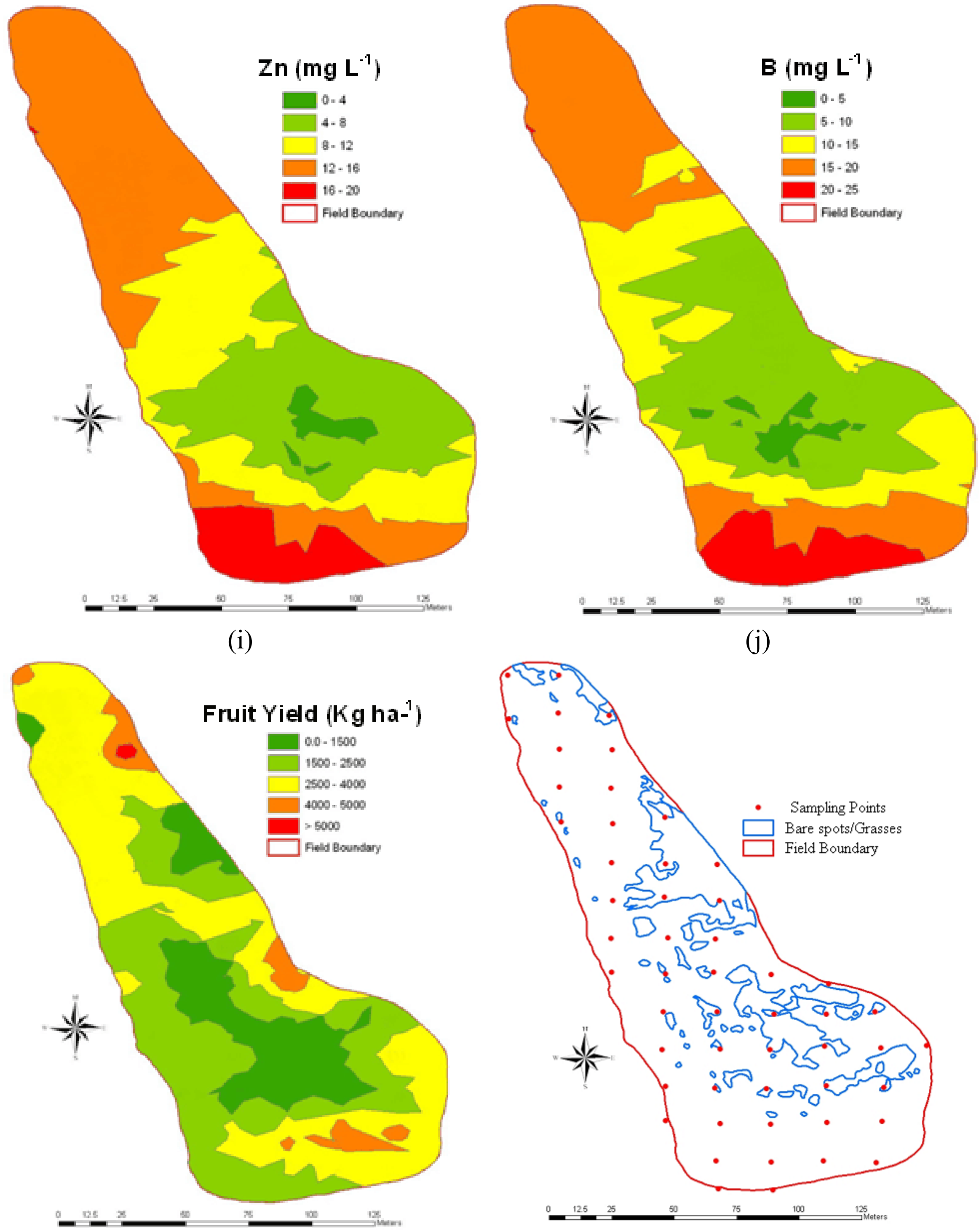
(f)


Mn (mg L-1)
0 - 400
400 - 800
800 - 1200
1200 - 1600
1600 - 2000
Field Boundary
0
12.5
25
50
75
100
125
Meters

(g)


Cu (mg L-1)
0.0 - 2.5
2.5 - 5.0
5.0 - 7.5
7.5 - 10.0
10.0 - 12.5
Field Boundary
0
12.5
25
50
75
100
125
Meters

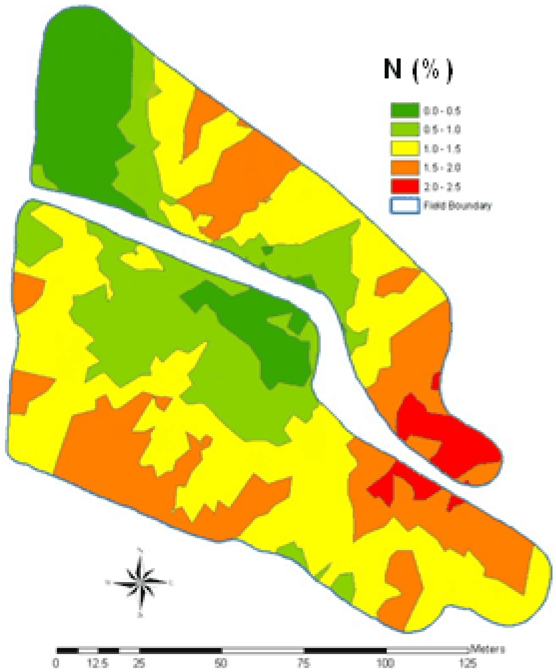
(h)



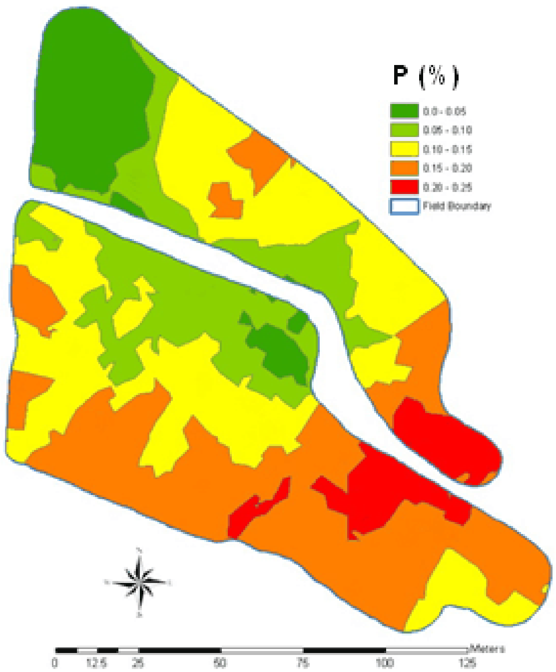
(i) (j)

(k) (l)

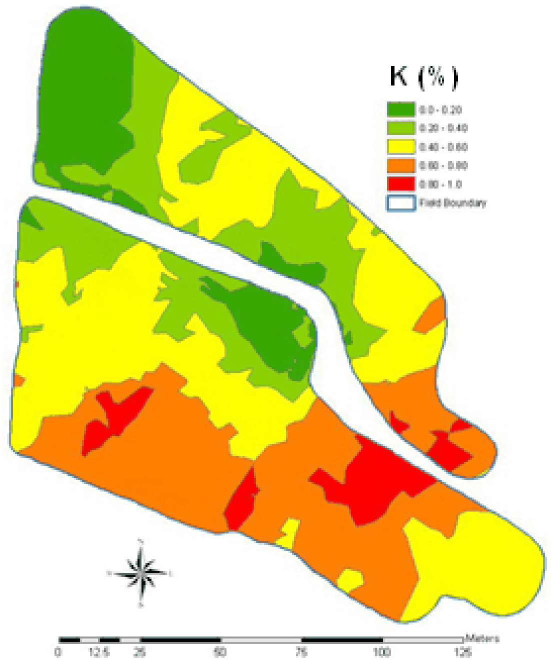
Figure 4-8. Maps of leaf nutrients and fruit yield for Carmal Site. (a) Nitrogen (N), (b) Phosphorus(P), (c) Potassium (K), (d) Calcium (Ca), (e) Magnesium (Mg), (f) Ferric (Fe), (g) Manganese (Mn), (h) Copper (Cu), (i) Zinc (Zn), (j) Boron (B), (k) Fruit yield, (l) Field layout.


N (%)
🟩 0.0 - 0.5
🟩 0.5 - 1.0
🟨 1.0 - 1.5
🟧 1.5 - 2.0
🟥 2.0 - 2.5
Field Boundary
0
12.5
25
50
75
100
125
Meters

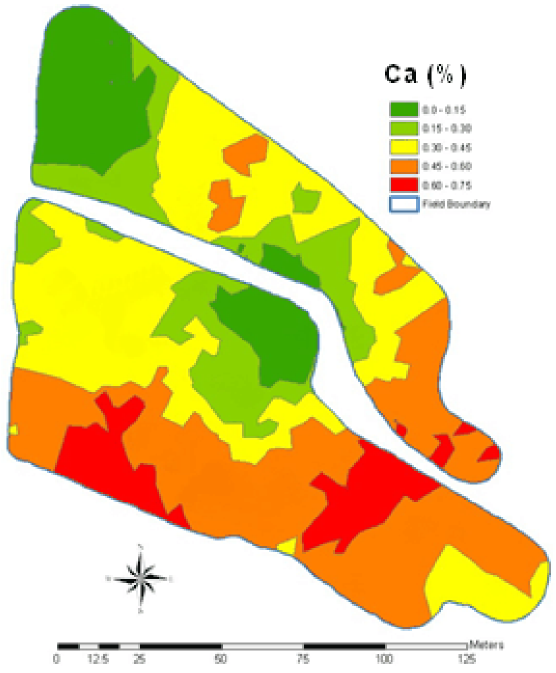
(a)


P (%)
🟩 0.0 - 0.05
🟩 0.05 - 0.10
🟨 0.10 - 0.15
🟧 0.15 - 0.20
🟥 0.20 - 0.25
Field Boundary
0
12.5
25
50
75
100
125
Meters

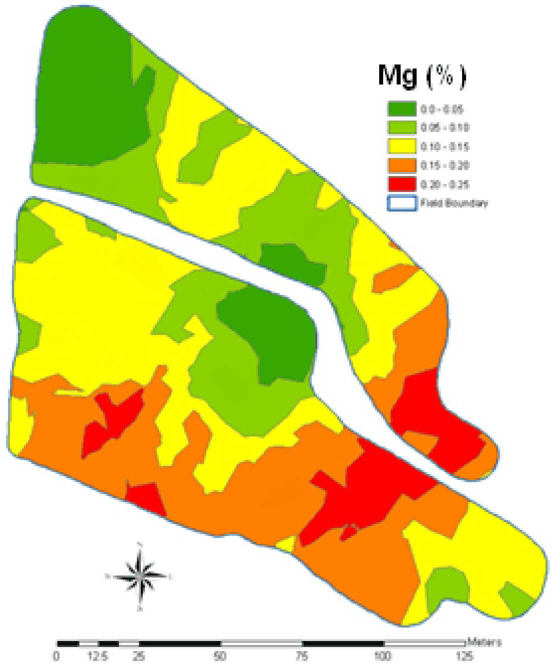
(b)


K (%)
🟩 0.0 - 0.20
🟩 0.20 - 0.40
🟨 0.40 - 0.60
🟧 0.60 - 0.80
🟥 0.80 - 1.0
Field Boundary
0
12.5
25
50
75
100
125
Meters

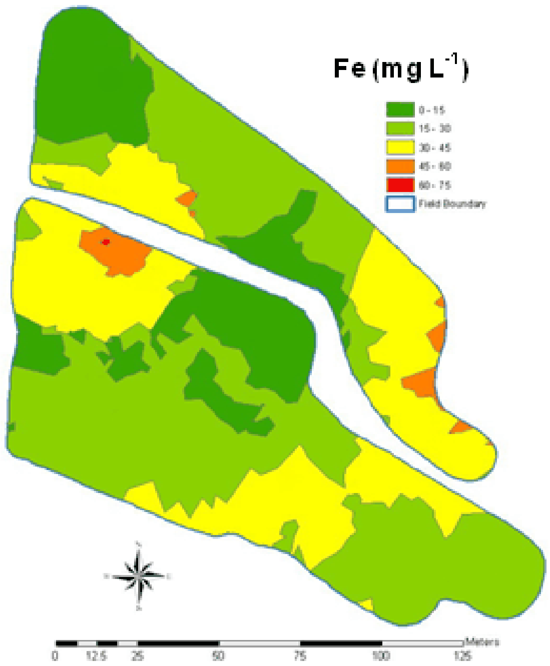
(c)


Ca (%)
🟩 0.0 - 0.15
🟩 0.15 - 0.30
🟨 0.30 - 0.45
🟧 0.45 - 0.60
🟥 0.60 - 0.75
Field Boundary
0
12.5
25
50
75
100
125
Meters

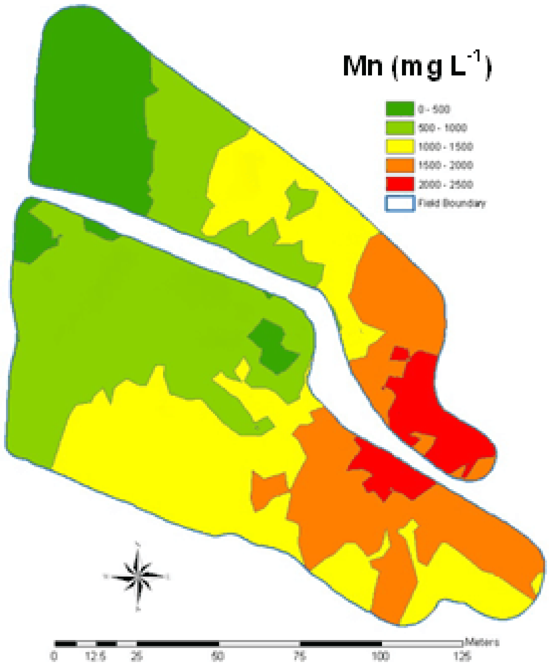
(d)


Mg (%)
0.0 - 0.05
0.05 - 0.10
0.10 - 0.15
0.15 - 0.20
0.20 - 0.25
Field Boundary
Meters
0
12.5
25
50
75
100
125

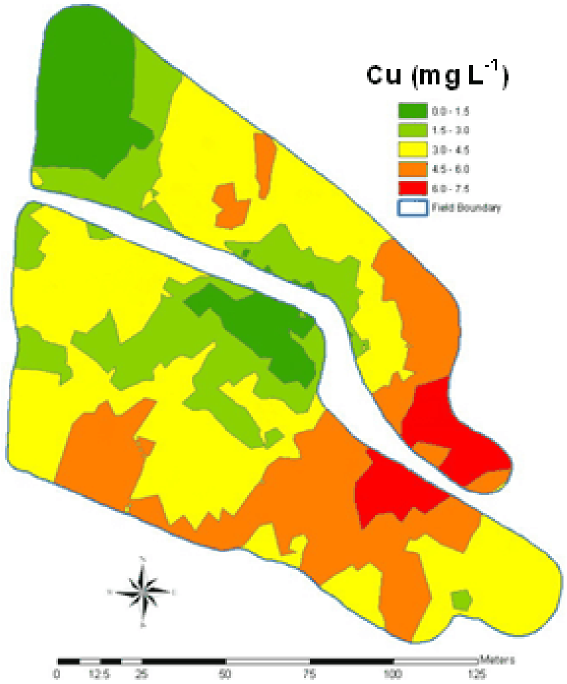
(e)


Fe (mg L^{-1})
0 - 15
15 - 30
30 - 45
45 - 60
60 - 75
Field Boundary
Meters
0
12.5
25
50
75
100
125

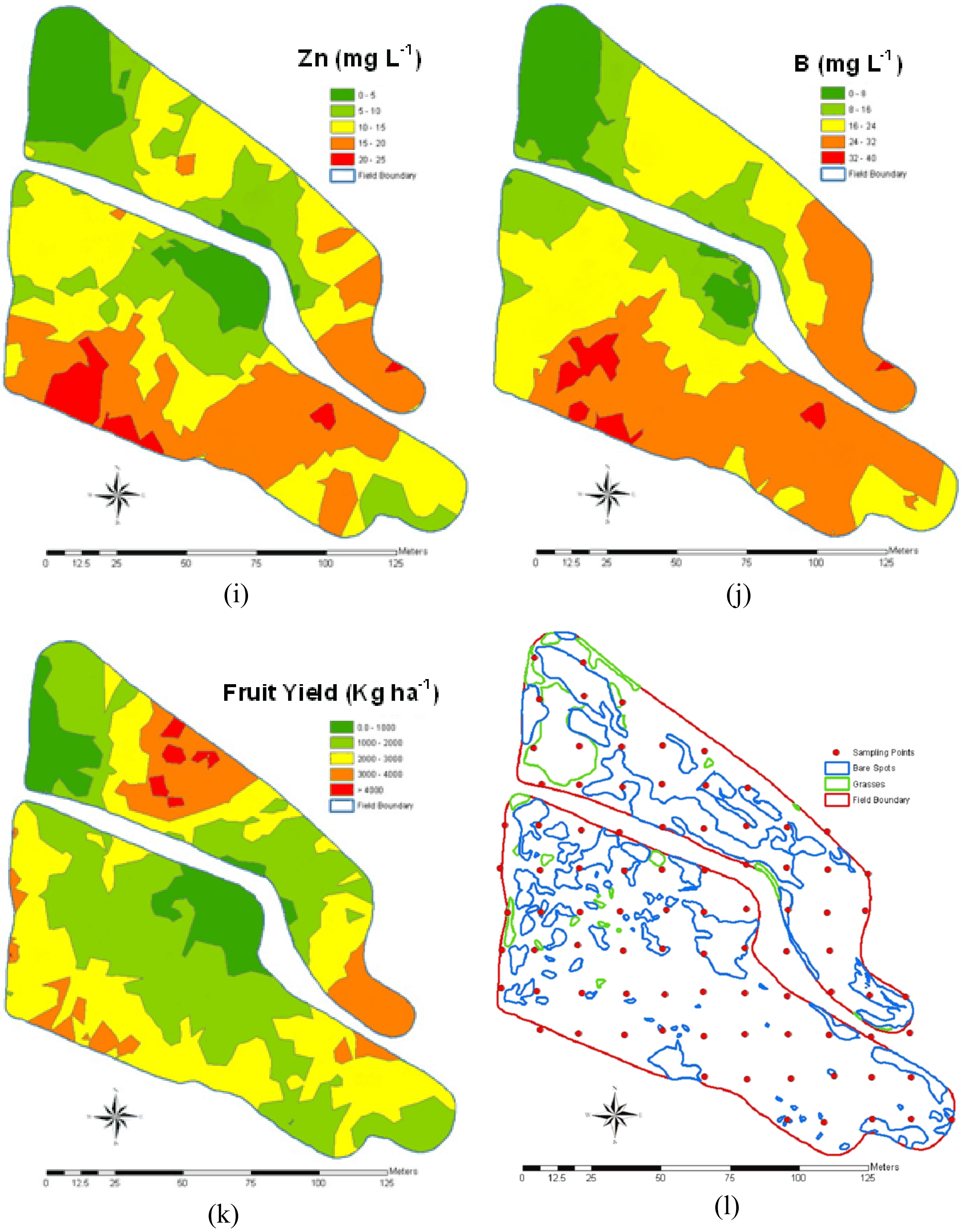
(f)


Mn (mg L^{-1})
0 - 500
500 - 1000
1000 - 1500
1500 - 2000
2000 - 2500
Field Boundary
Meters
0
12.5
25
50
75
100
125

(g)


Cu (mg L^{-1})
0.0 - 1.5
1.5 - 3.0
3.0 - 4.5
4.5 - 6.0
6.0 - 7.5
Field Boundary
Meters
0
12.5
25
50
75
100
125

(h)



(i)

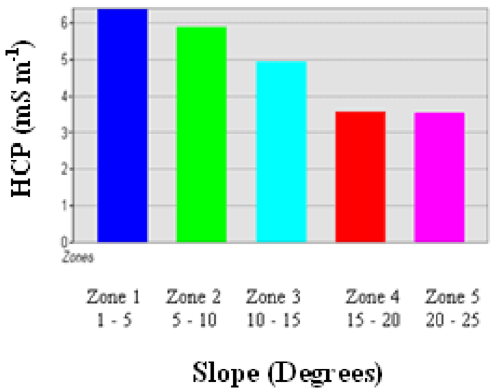
(j)

(k)

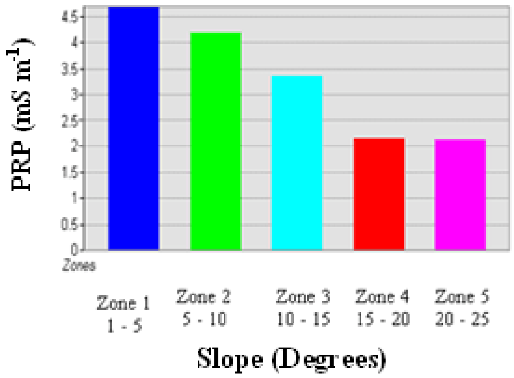
(l)

Figure 4-9. Maps of leaf nutrients and fruit yield for North River Site. (a) Nitrogen (N), (b) Phosphorus(P), (c) Potassium (K), (d) Calcium (Ca), (e) Magnesium (Mg), (f) Ferric (Fe), (g) Manganese (Mn), (h) Copper (Cu), (i) Zinc (Zn), (j) Boron (B), (k) Fruit yield, (l) Field layout.

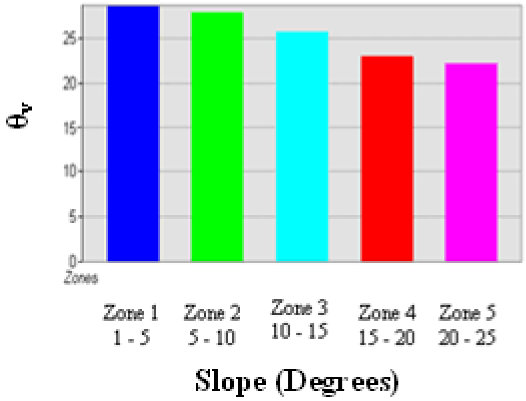
Appendix C



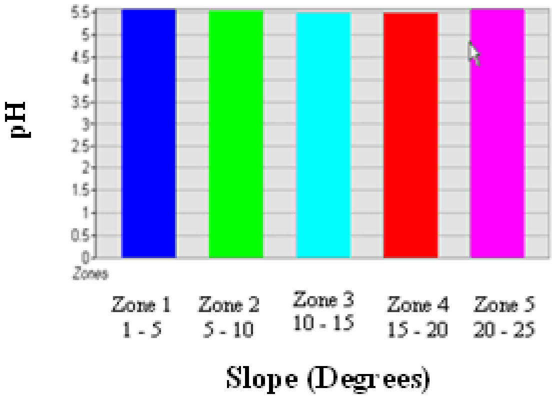
(a)



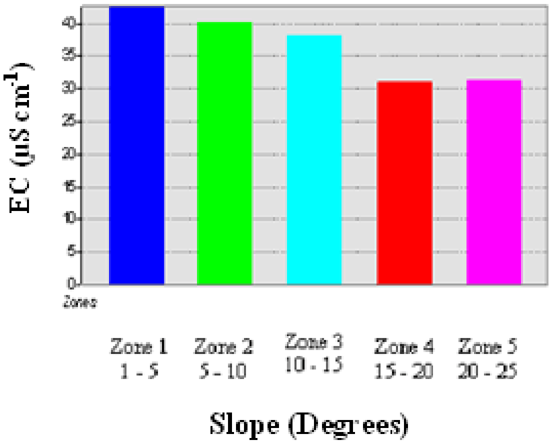
(b)



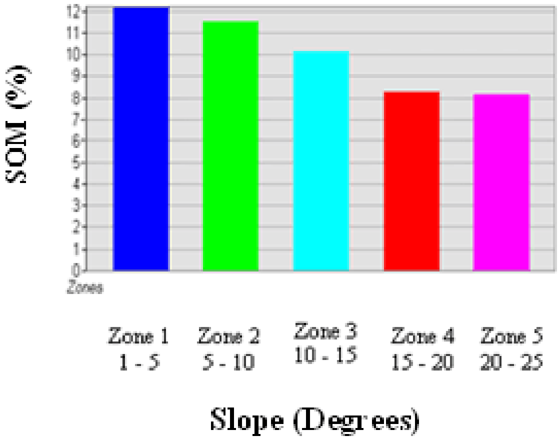
(c)



(d)



(e)



(f)

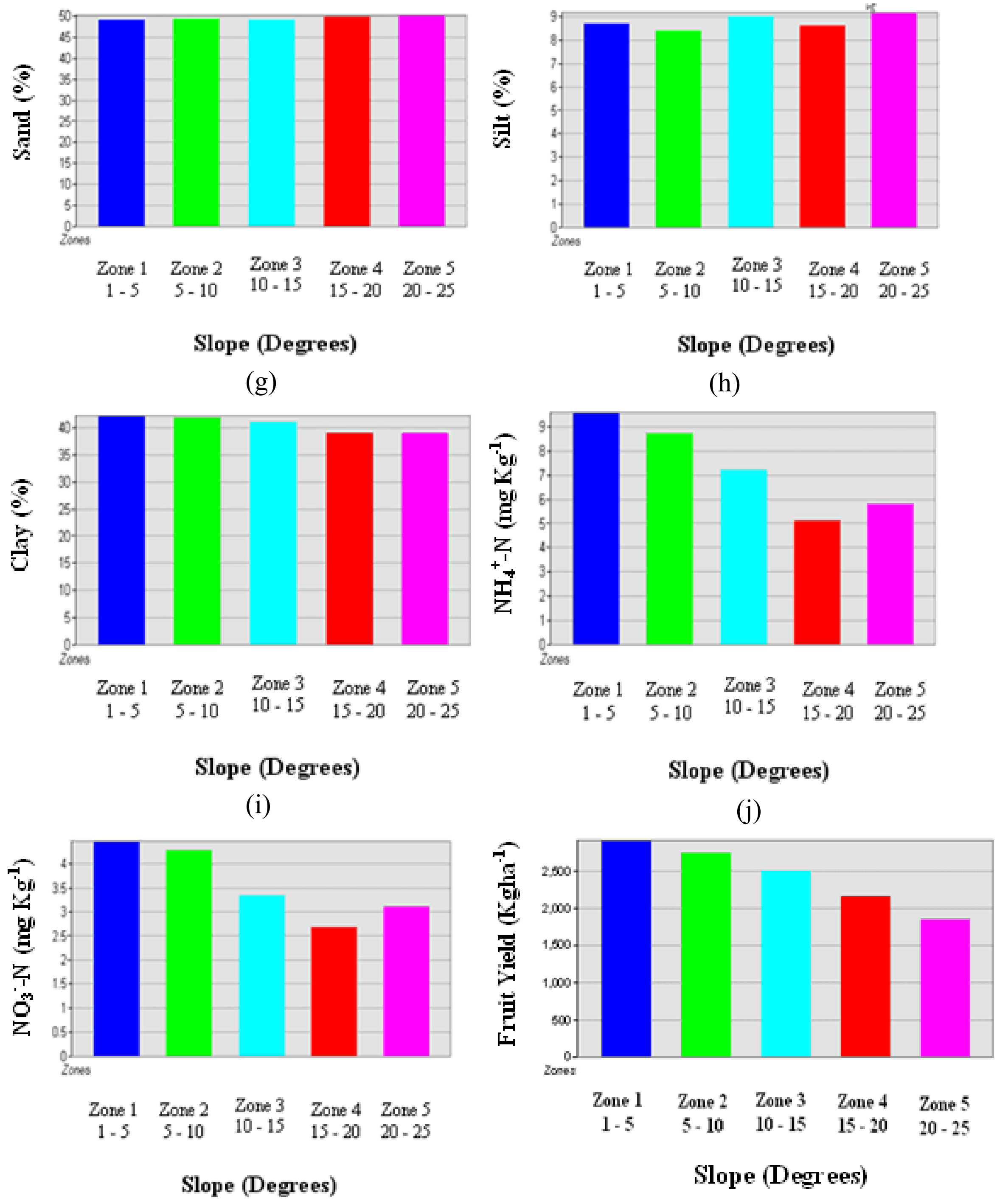
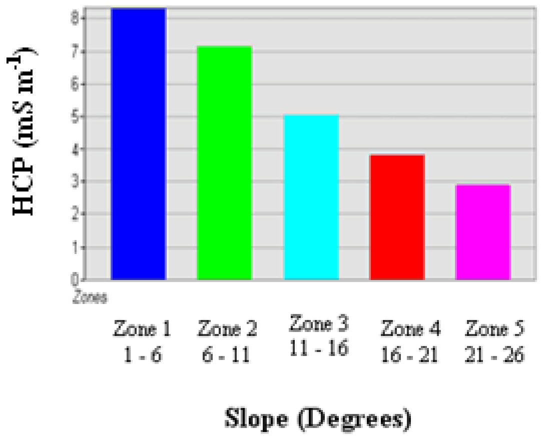
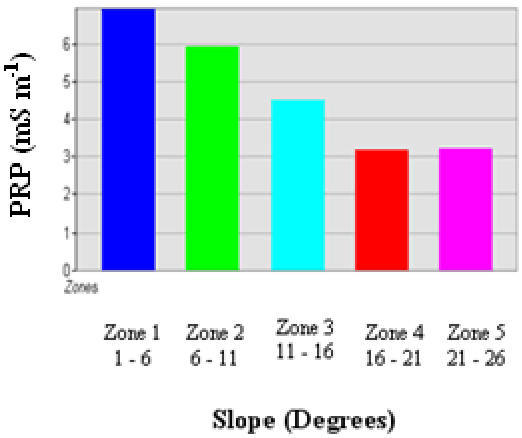


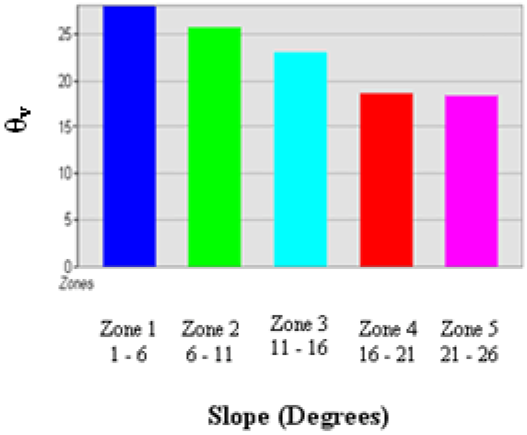
Figure 4-10. Bar graphs showing the variation of soil properties and fruit yield with slope for Carmal Site (a) Ground conductivity at horizontal co-planar geometry (HCP), (b) Ground conductivity at perpendicular co-planar geometry (PRP), (c) Moisture content, (d) pH, (e) Electrical conductivity (EC), (f) Soil organic matter (SOM), (g) Sand %, (h) Silt %, (i) Clay %, (j) Ammonium nitrogen (NH_4^+ -N), (k) Nitrate nitrogen (NO_3^--N), (l) Fruit yield


HCP (mS m^{-1})
0
1
2
3
4
5
6
7
8
Zones
Zone 1
1 - 6
Zone 2
6 - 11
Zone 3
11 - 16
Zone 4
16 - 21
Zone 5
21 - 26
Slope (Degrees)

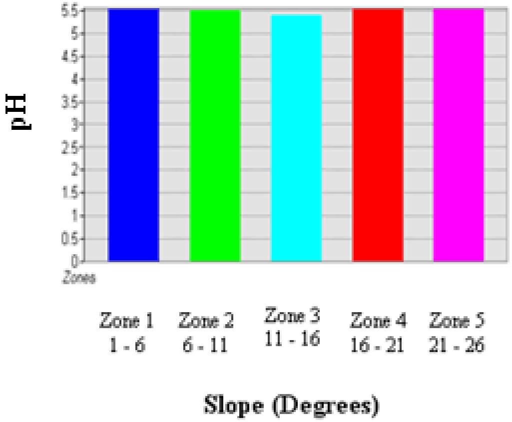
(a)


PRP (mS m^{-1})
0
1
2
3
4
5
6
Zones
Zone 1
1 - 6
Zone 2
6 - 11
Zone 3
11 - 16
Zone 4
16 - 21
Zone 5
21 - 26
Slope (Degrees)

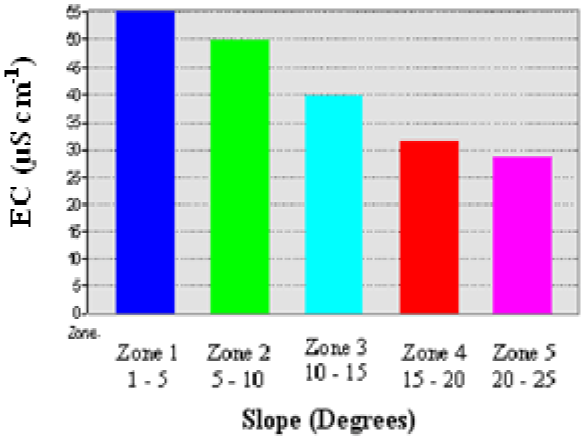
(b)


θ_v
0
5
10
15
20
25
Zones
Zone 1
1 - 6
Zone 2
6 - 11
Zone 3
11 - 16
Zone 4
16 - 21
Zone 5
21 - 26
Slope (Degrees)

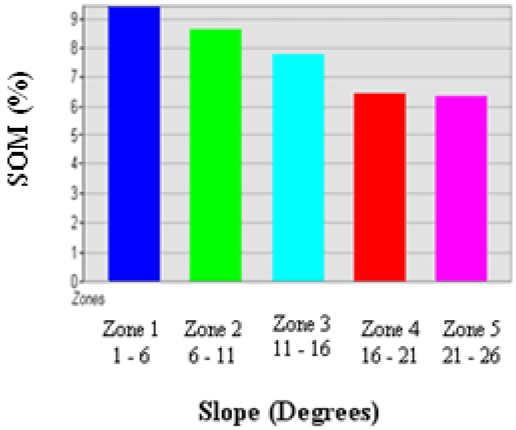
(c)


pH
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
Zones
Zone 1
1 - 6
Zone 2
6 - 11
Zone 3
11 - 16
Zone 4
16 - 21
Zone 5
21 - 26
Slope (Degrees)

(d)


EC (µS cm^{-1})
0
5
10
15
20
25
30
35
40
45
50
55
Zone.
Zone 1
1 - 5
Zone 2
5 - 10
Zone 3
10 - 15
Zone 4
15 - 20
Zone 5
20 - 25
Slope (Degrees)

(e)


SOM (%)
0
1
2
3
4
5
6
7
8
9
Zones
Zone 1
1 - 6
Zone 2
6 - 11
Zone 3
11 - 16
Zone 4
16 - 21
Zone 5
21 - 26
Slope (Degrees)

(f)

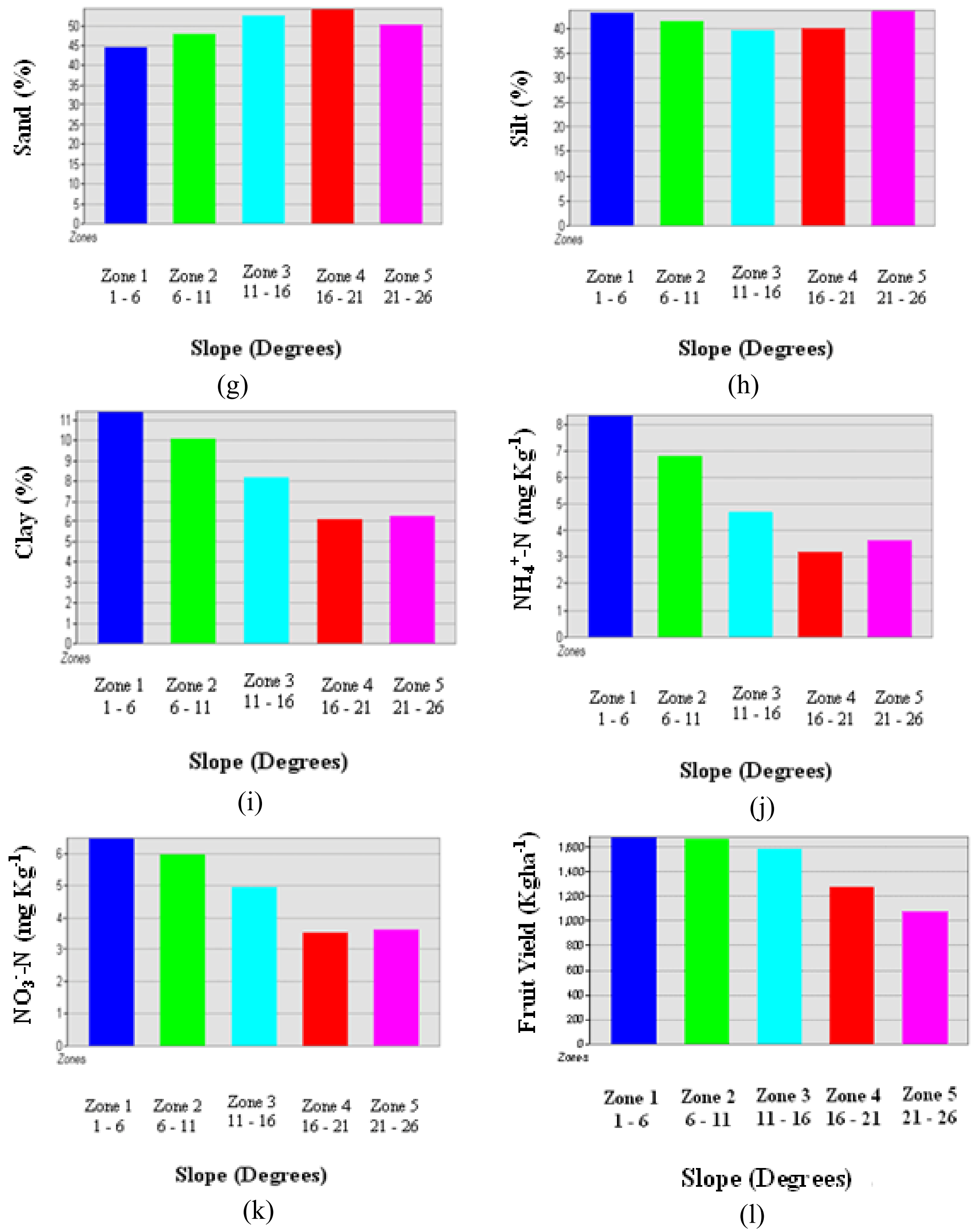


Figure 4-11. Bar graphs showing the variation of soil properties with slope for North River Site (a) Ground conductivity at horizontal co-planar geometry (HCP), (b) Ground conductivity at perpendicular co-planar geometry (PRP), (c) Moisture content, (d) pH, (e) Electrical conductivity (EC), (f) Soil organic matter (SOM), (g) Sand %, (h) Silt %, (i) Clay %, (j) Ammonium nitrogen (NH_4^+ -N), (k) Nitrate nitrogen (NO_3^--N), (l) Fruit yield.

Appendix D

Table 5-2. Correlation matrix among the soil properties and leaf nutrients for North River Site.

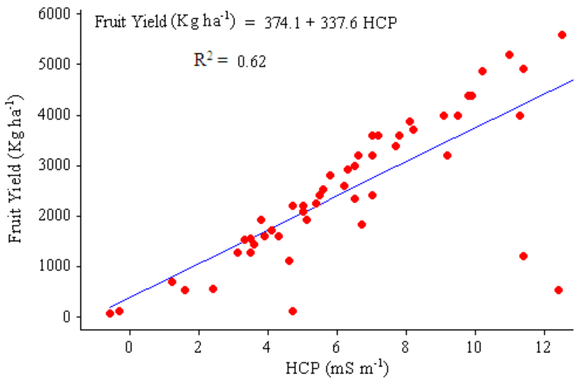
	HCP	PRP	θ_v	pH	EC	SOM	Sand	Silt	Clay	NH4-N	NO3-N	N	P
PRP	0.88***												
θ_v	0.81***	0.89***											
pH	0.01	0.05 ^{NS}	-0.06 ^{NS}										
EC	0.87***	0.74***	0.67***	-0.01 ^{NS}									
OM	0.70***	0.81***	0.81***	0.08 ^{NS}	0.67***								
Sand	-0.22^{NS}	-0.31*	-0.27*	-0.01 ^{NS}	-0.17 ^{NS}	-0.13 ^{NS}							
Silt	0.12 ^{NS}	0.19 ^{NS}	0.16 ^{NS}	-0.11 ^{NS}	0.05 ^{NS}	-0.02 ^{NS}	-0.89***						
Clay	0.46***	0.60***	0.56***	0.16 ^{NS}	0.35**	0.67***	-0.43**	0.16 ^{NS}					
NH4-N	0.65***	0.69***	0.68***	0.07 ^{NS}	0.55***	0.63***	-0.09 ^{NS}	-0.03 ^{NS}	0.48***				
NO3-N	0.76***	0.79***	0.74***	0.03 ^{NS}	0.68***	0.68***	-0.09 ^{NS}	-0.05 ^{NS}	0.43**	0.63***			
N	0.42**	0.33*	0.65***	-0.06 ^{NS}	0.63***	0.46***	-0.03 ^{NS}	-0.03 ^{NS}	0.32*	0.54***	0.52***		
P	0.37*	0.28*	0.62***	-0.03 ^{NS}	0.64***	0.52***	0.05 ^{NS}	-0.17 ^{NS}	0.38**	0.66***	0.51***	0.67***	
K	0.40**	0.30*	0.37**	-0.02 ^{NS}	0.44**	0.34*	0.22 ^{NS}	-0.30*	0.12 ^{NS}	0.39**	0.38**	0.46***	0.52***
Ca	0.44**	0.25 ^{NS}	0.37**	-0.06 ^{NS}	0.37**	0.35**	-0.18 ^{NS}	0.07 ^{NS}	0.28*	0.65***	0.47***	0.38**	0.55***
Mg	-0.04 ^{NS}	0.06 ^{NS}	-0.01 ^{NS}	-0.03 ^{NS}	-0.01 ^{NS}	0.03 ^{NS}	0.06 ^{NS}	-0.07 ^{NS}	-0.04 ^{NS}	-0.05 ^{NS}	0.11 ^{NS}	-0.02 ^{NS}	-0.06 ^{NS}
Fe	-0.07 ^{NS}	-0.02 ^{NS}	-0.01 ^{NS}	0.09 ^{NS}	-0.12 ^{NS}	-0.05 ^{NS}	-0.23 ^{NS}	0.21 ^{NS}	0.12 ^{NS}	0.04 ^{NS}	-0.13 ^{NS}	-0.15 ^{NS}	-0.04 ^{NS}
Mn	-0.04 ^{NS}	-0.05 ^{NS}	0.07 ^{NS}	-0.02 ^{NS}	0.10 ^{NS}	0.11 ^{NS}	-0.07 ^{NS}	-0.03 ^{NS}	0.15 ^{NS}	-0.04 ^{NS}	-0.06 ^{NS}	0.19 ^{NS}	0.27*
Cu	0.11 ^{NS}	0.21 ^{NS}	0.28*	0.19 ^{NS}	0.06 ^{NS}	0.15 ^{NS}	-0.27 ^{NS}	0.15 ^{NS}	0.21 ^{NS}	0.05 ^{NS}	0.21 ^{NS}	0.16 ^{NS}	0.03 ^{NS}
Zn	0.10 ^{NS}	0.14 ^{NS}	0.09 ^{NS}	0.03 ^{NS}	0.01 ^{NS}	0.05 ^{NS}	-0.19 ^{NS}	0.19 ^{NS}	0.15 ^{NS}	0.09 ^{NS}	0.22 ^{NS}	0.03 ^{NS}	0.04 ^{NS}
B	0.05 ^{NS}	-0.06 ^{NS}	0.01 ^{NS}	-0.18 ^{NS}	0.06 ^{NS}	-0.04 ^{NS}	-0.02 ^{NS}	-0.06 ^{NS}	0.08 ^{NS}	0.03 ^{NS}	0.06 ^{NS}	0.18 ^{NS}	0.20 ^{NS}

Table 5-2. Continued

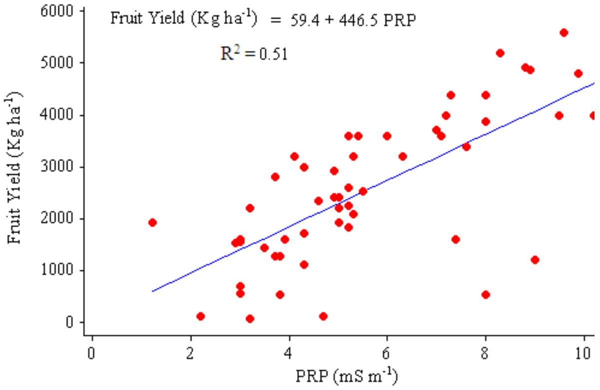
	K	Ca	Mg	Fe	Mn	Cu	Zn
Ca	0.28*						
Mg	0.19^{NS}	0.24^{NS}					
Fe	-0.19^{NS}	0.12^{NS}	-0.03^{NS}				
Mn	-0.02^{NS}	0.12^{NS}	-0.14^{NS}	-0.08^{NS}			
Cu	0.15^{NS}	0.23^{NS}	0.17^{NS}	0.13^{NS}	0.24^{NS}		
Zn	0.08^{NS}	0.30*	0.38**	0.08^{NS}	-0.03^{NS}	0.47 ***	
B	0.19^{NS}	0.24^{NS}	0.10^{NS}	-0.03^{NS}	0.33 *	0.09^{NS}	0.27 *

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

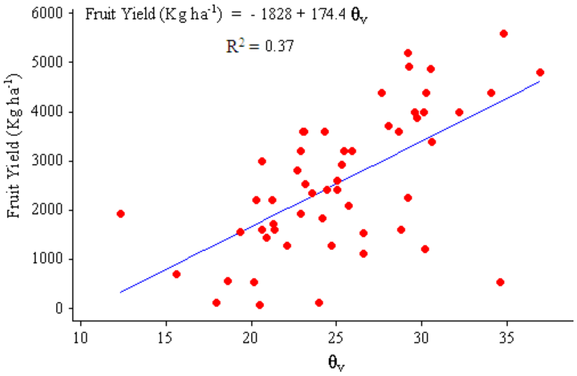
Appendix E



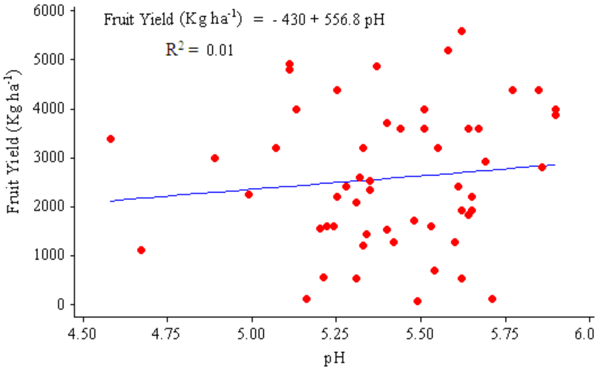
(a)



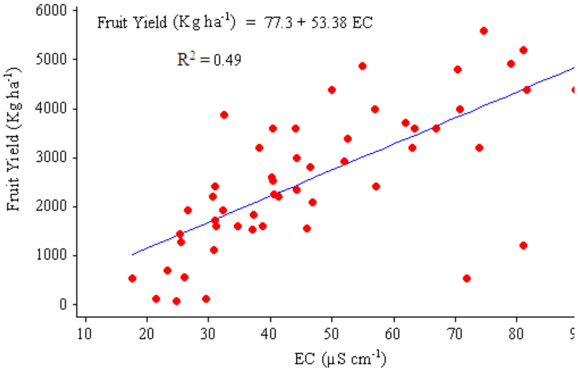
(b)



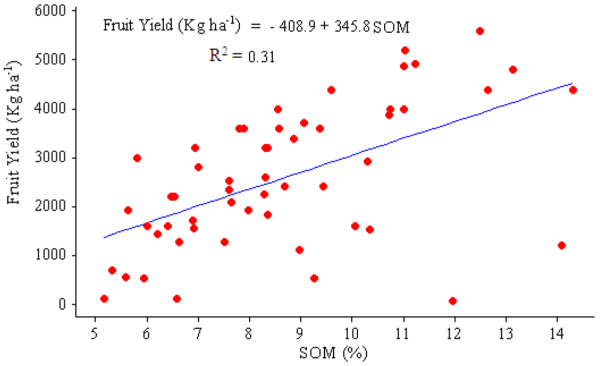
(c)



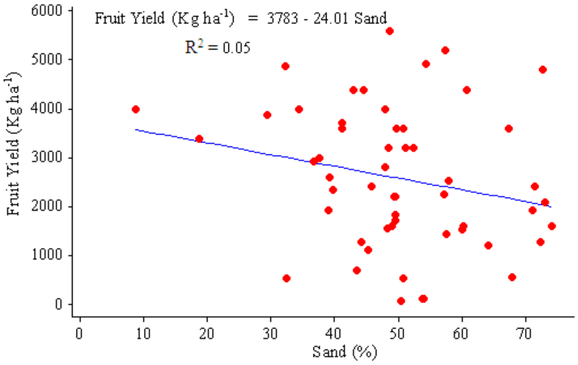
(d)



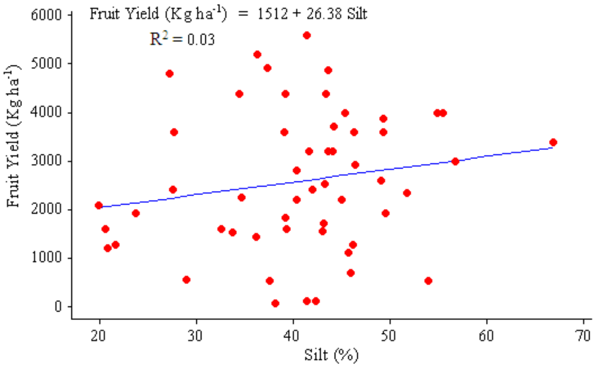
(e)



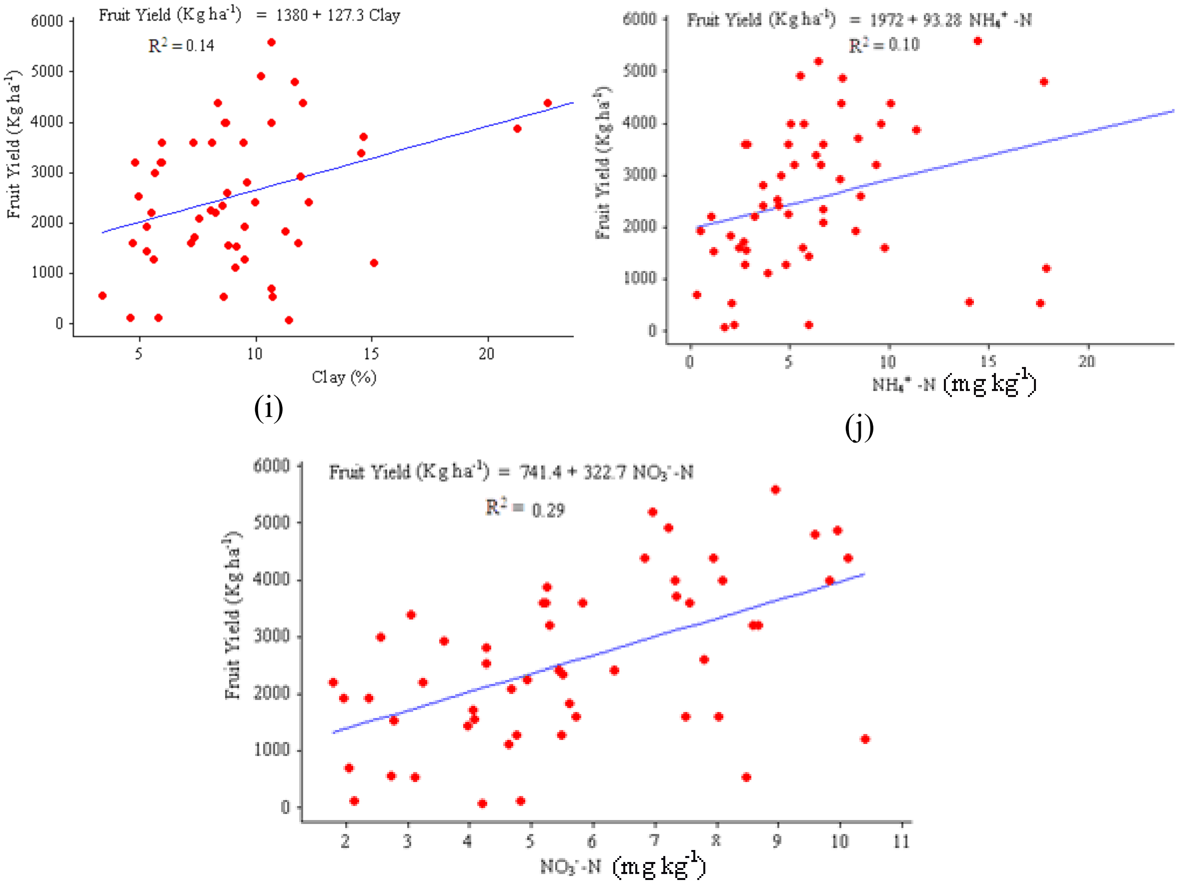
(f)



(g)



(h)



(i)

(j)

(k)

Figure 5-2. Relationships of soil properties with wild blueberry fruit yield for North River Site. (a) HCP, (b) PRP, (c) Moisture content, (d) pH, (e) EC, (f) SOM, (g) Sand %, (h) Silt %, (i) Clay %, (j) NH_4^+ -N, (k) NO_3^--N.

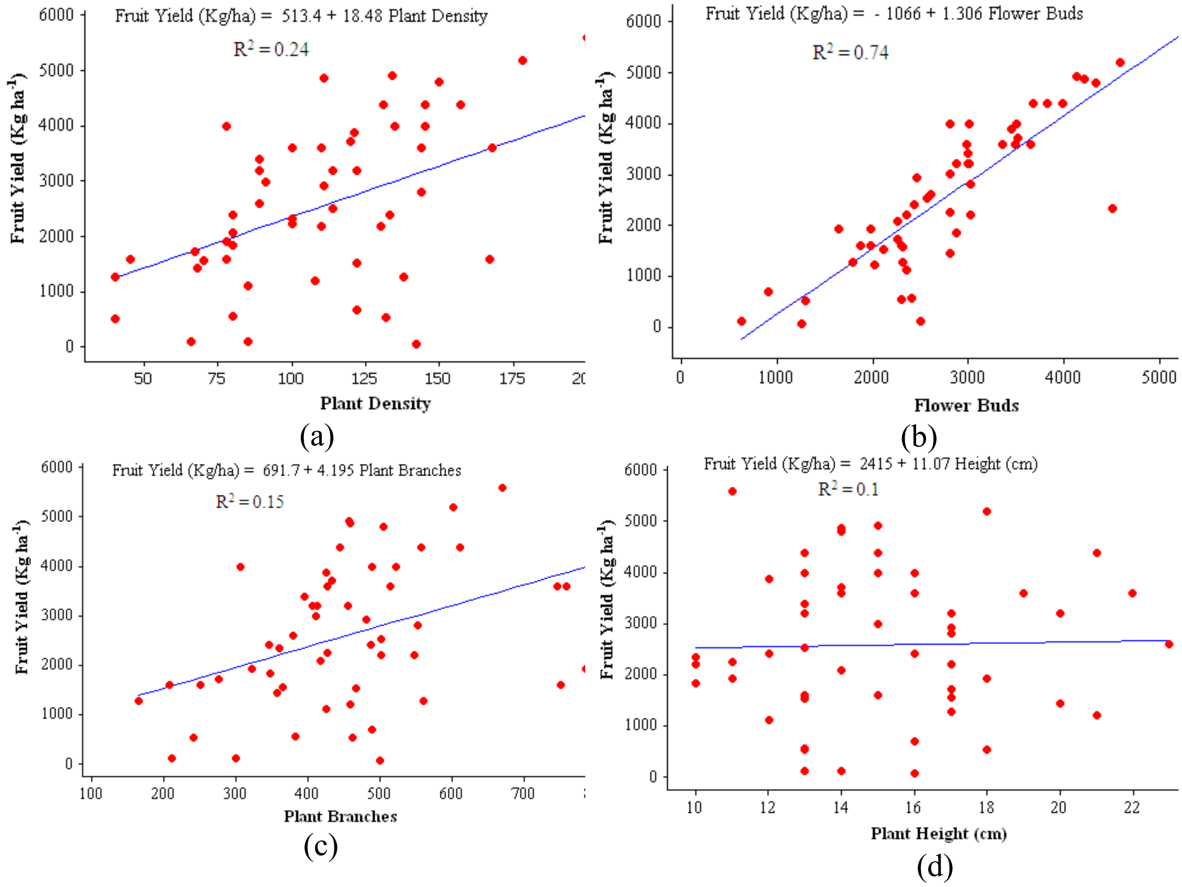
Table 5-5. Regression analysis of soil properties with fruit yield for North River Site.

2nd Sampling (2009)			
Soil property	**Regression Model**	**R^2**	**P-Value**
HCP (mS m^{-1})	Yield (Kg ha^{-1}) = 545.1 + 319.7 HCP	0.56	0.000
PRP (mS m^{-1})	Yield (Kg ha^{-1}) = 1187 + 320.1 PRP	0.30	0.000
θ_v	Yield (Kg ha^{-1}) = -1267 + 152 θ_v	0.28	0.000
EC (μS cm^{-1})	Yield (Kg ha^{-1}) = -342.3 + 63.6 EC	0.55	0.002
NH_4^+ -N (mg Kg^{-1})	Yield (Kg ha^{-1}) = 1494 + 232.8 NH_4^+-N	0.29	0.000
NO_3^--N (mg Kg^{-1})	Yield (Kg ha^{-1}) = 1395 + 343.9 NO_3^--N	0.31	0.000
3rd Sampling (2010)			
Soil property	**Regression Model**	**R^2**	**P-Value**
HCP (mS m^{-1})	Yield (Kg ha^{-1}) = -844.4 + 357.7 HCP	0.64	0.000
PRP (mS m^{-1})	Yield (Kg ha^{-1}) = -1479 + 464.2 PRP	0.50	0.003
θ_v	Yield (Kg ha^{-1}) = -1958 + 151.5 θ_v	0.29	0.000
EC (μS cm^{-1})	Yield (Kg ha^{-1}) = -361.9 + 68.3 EC	0.51	0.000
SOM (%)	Yield (Kg ha^{-1}) = -352.7 + 341.7 SOM	0.30	0.000
NH_4^+ -N (mg Kg^{-1})	Yield (Kg ha^{-1}) = 2010 + 12.6 NH_4^+-N	0.12	0.015
NO_3^--N (mg Kg^{-1})	Yield (Kg ha^{-1}) = 1395 + 343.9 NO_3^--N	0.27	0.000

Table 5-6. Correlation matrix among the plant growth parameters and fruit yield for both sites.

	Carmal Site					North River Site			
	Yield	Plants in Grid	No. of Buds	Height		Yield	Plants in Grid	No. of Buds	Height
Plants in Grid	0.77***				Plants in Grid	0.49***			
No. of Buds	0.83***	0.62***			No. of Buds	0.85***	0.42**		
Height	-0.24^{NS}	0.18^{NS}	-0.01^{NS}		Height	-0.02^{NS}	0.08^{NS}	-0.10^{NS}	
Branches	0.67***	0.81***	0.56***	0.12^{NS}	Branches	0.40**	0.77***	0.33*	0.15^{NS}

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



(a)

(b)

(c)

(d)

Figure 5-4. Relationships of fruit yield with plant growth parameters for North River Site. (a) Plant density, (b) No. of buds, (c) No. of branches, (d) plant height.

Appendix F

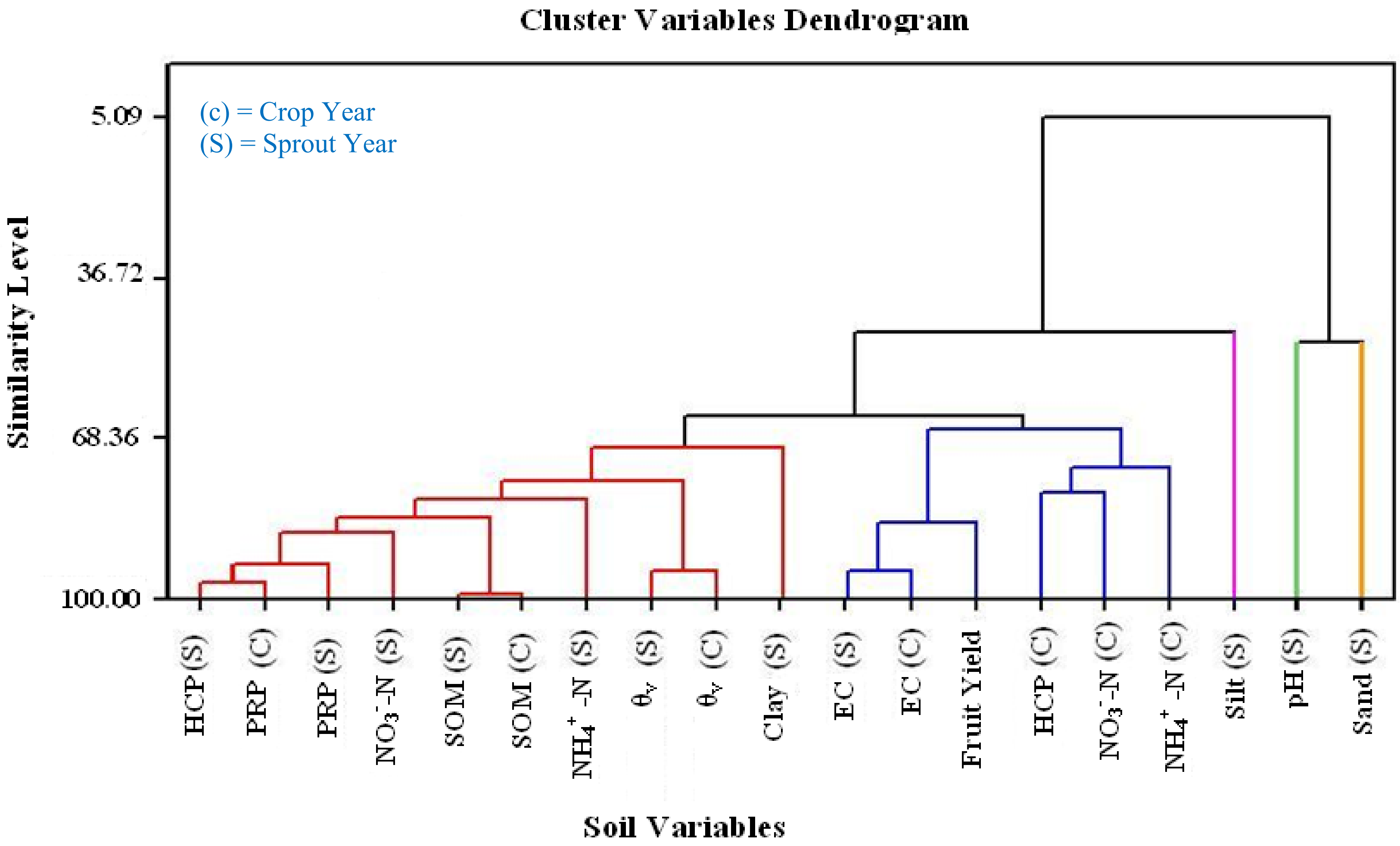
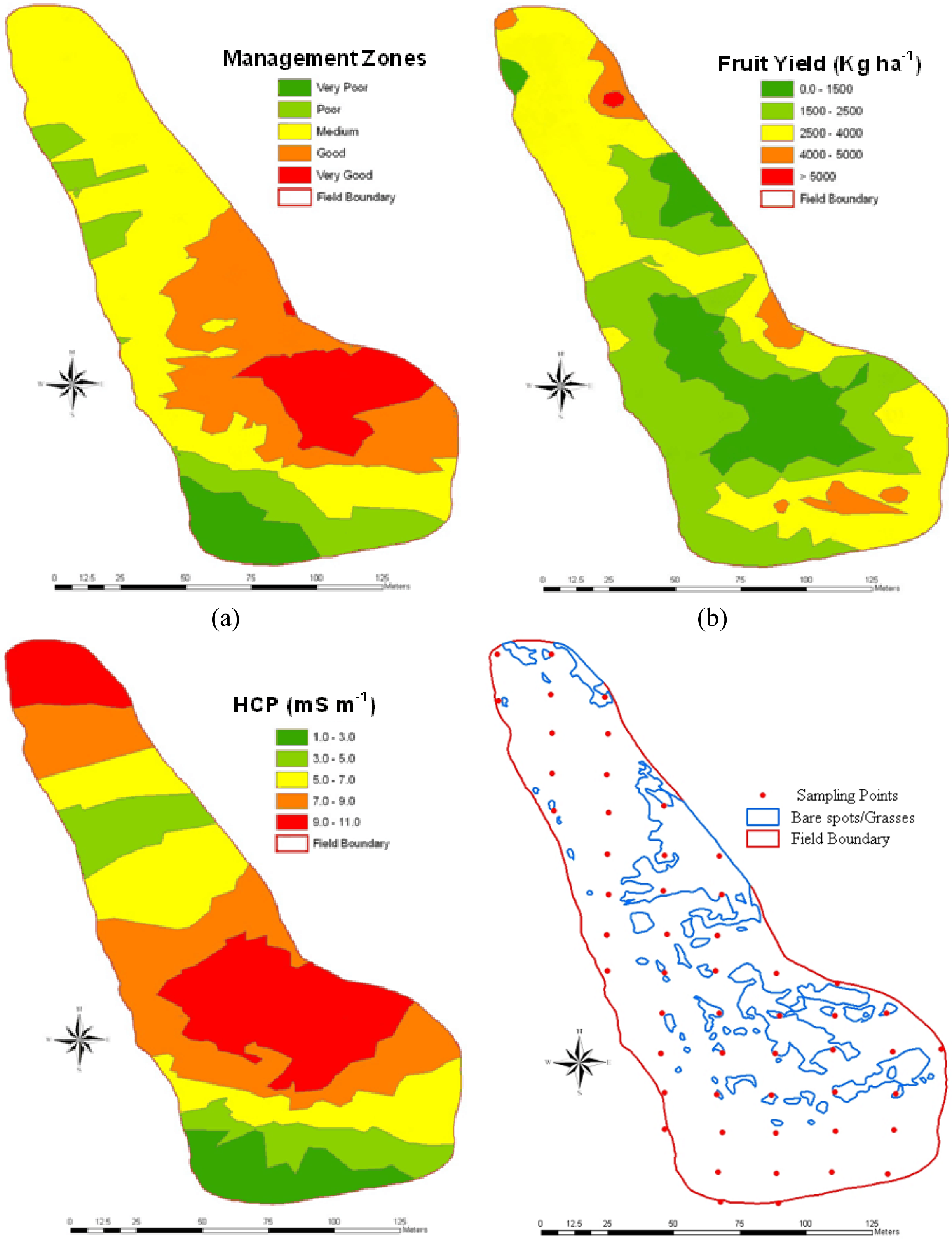


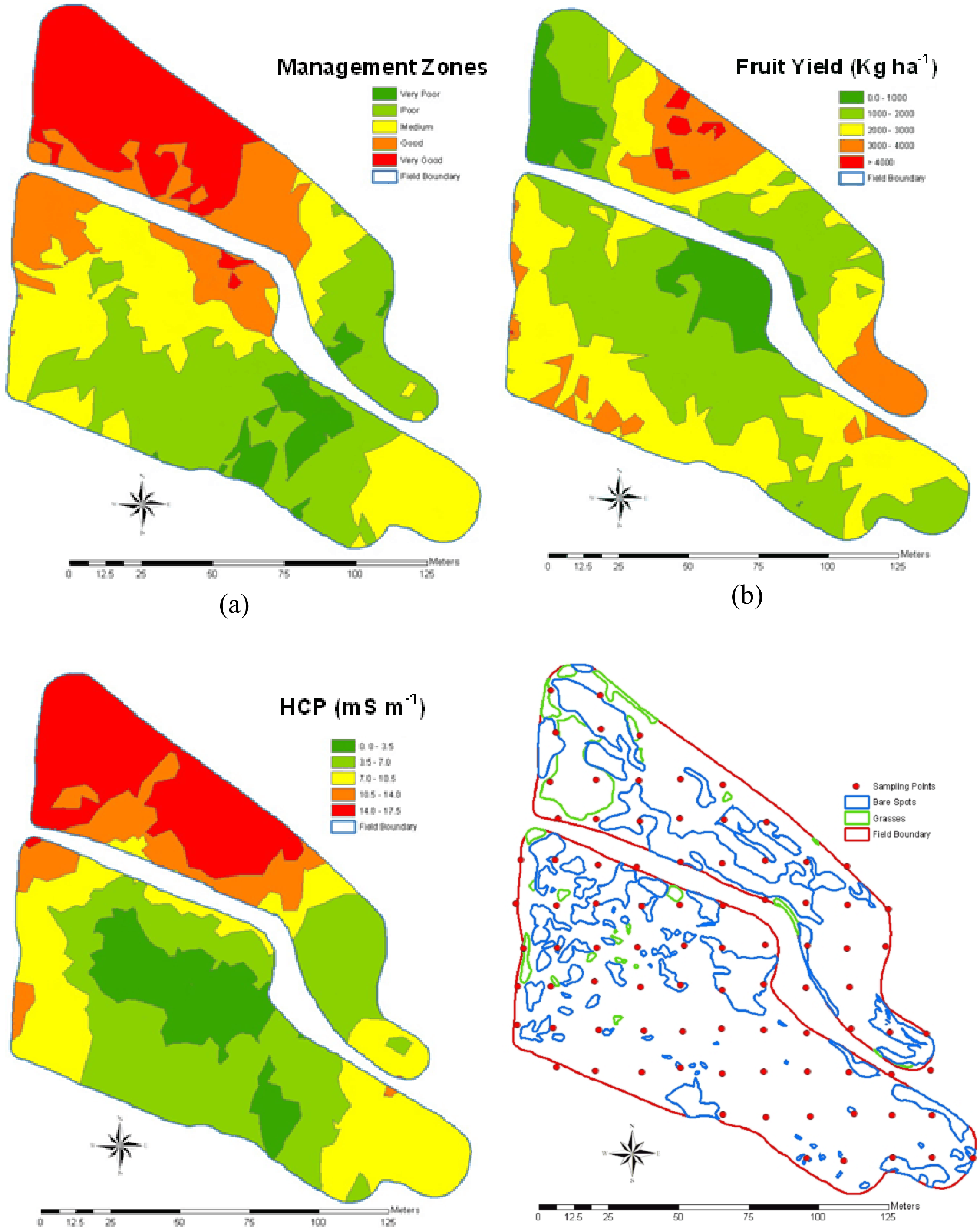
Figure 6-2. Dendrogram of soil variables along with fruit yield for North River Site.



(a) (b)

(c) (d)

Figure 6-7. Kriged Maps for Carmal Site (a) Management Zones, (b) Fruit Yield, (c) HCP, (d) Field layout.



(a) (b) (c) (d)

Figure 6-8. Kriged Maps for North River Site (a) Management Zones, (b) Fruit Yield, (c) HCP, (d) Field layout.