DELINEATING MANAGEMENT ZONES FOR SITE SPECIFIC FERTILIZATION IN WILD BLUEBERRY FIELDS

A. A. Farooque, Q. U. Zaman, A. W. Schumann, A. Madani, D. C. Percival

ABSTRACT. *The concept of management zones has been proposed as a solution to the problems associated with the soil variability to more efficiently apply agricultural inputs on a site-specific basis. This study was designed to characterize and quantify the spatial variation in soil properties and wild blueberry fruit yield and to delineate management zones for site-specific fertilization. Two wild blueberry fields were selected in central Nova Scotia, and a grid pattern (15×15 m) was established at experimental sites to collect soil and fruit yield samples. The soil samples were analyzed for ammonium nitrogen (NH_4^+-N), nitrate nitrogen (NO_3^--N), pH, electrical conductivity (EC), texture, and soil organic matter (SOM). The volumetric moisture content (θ_v) and ground conductivity data including horizontal coplanar geometry (HCP) and perpendicular coplanar geometry (PRP) were also recorded at the same grid points. The location of the sampling points were marked with a differential global positioning system (DGPS), and field boundary, bare spots, weeds, and grass patches were also mapped.*

The cluster analysis was performed to group the soil and fruit yield data into five zones termed as 'very poor,' 'poor,' 'medium,' 'good,' and 'very good' without prior knowledge of productivity potential with the internal homogeneity and external heterogeneity at a similarity level of greater than 70%. The coefficient of variation, geostatistical range of influence, and kriged maps suggested moderate to high variability of soil properties and fruit yield except soil pH and silt. The results of correlation matrix suggested significant relationships among the fruit yield and the soil properties. The results of ANOVA indicated that the fruit yield, HCP, PRP, θ_v, SOM, and inorganic nitrogen were significantly different in developed management zones except poor and very poor zones. The significant positive correlations of HCP and PRP with soil properties and fruit yield suggested that the ground conductivity data can be used to develop management zones for site-specific fertilization.

Keywords. *Ground conductivity, Management zones, Spatial variability, Variable rate fertilization, Wild blueberry.*

Northeastern North America is the world's leading producer of wild blueberry with over 86,000 ha under management, producing 112 million kg of fruit valued at $470 million annually (Yarborough, 2009). Wild blueberry fields are developed from native stands on deforested farmland by removing competing vegetation (Eaton, 1988). The crop is unique, as it is native to North America and has never been cultivated. Wild blueberries follow a two-year production cycle where one year produces vegetative growth, followed by a year in which bloom, pollination, and fruit growth and development occur. The majority of fields are situated in naturally acidic soils that are low in nutrients and have high proportions of bare spots, weed patches, and gentle to severe topography (Trevett, 1962; Zaman et al., 2010b). Currently, crop management practices are implemented uniformly with inadequate attention being given to substantial variation in soil/plant characteristics, topographic features, and fruit yield within wild blueberry fields (Zaman et al., 2008).

Typically, producers manage their fields uniformly on a block basis, with block size varying from one or two to several hundred hectares (Schueller et al., 1999). Consequently, they implicitly disregard within-field variation. Uniform management of large fields, without characterizing the spatial variability of soil properties could result in under-fertilization of high yielding areas, thus lowering yield, and over-fertilization of low-yielding areas which may lead to increased cost of production, reduced economic return, nutrient leaching, and environmental contamination (Schumann et al., 2003). Hence, there is an emerging need for increased crop production efficiency, profitability, and environmental protection, but these cannot be achieved if the wild blueberry fields are managed as a single unit. However, spatially variable fertilizer application can overcome these problems and is more favorable economically compared with uniform rate application (Mann et al., 2010).

Spatially variable fertilizer application depends on understanding and accurately identifying the underlying soil/crop factors responsible for yield variability. Variation in soil physical, chemical, and biological properties is considered to be the most important factors responsible for

---

Submitted for review in June 2011 as manuscript number SW 9221; approved for publication by the Soil & Water Division of ASABE in November 2011.

The authors are **Aitazaz Ahsan Farooque, ASABE Member,** Graduate Student, Engineering Department, Nova Scotia Agriculture College, Truro, NS, Canada; **Qamar Uz Zaman, ASABE Member,** Associate Professor, Engineering Department, Nova Scotia Agriculture College, Truro, NS, Canada; **Arnold Walter Schumann, ASABE Member,** Associate Professor, Citrus Research and Education Center, University of Florida, Lake Alfred, Florida; **Ali Madani,** Professor, Engineering Department, Nova Scotia Agriculture College, Truro, NS, Canada; and **David Charles Percival,** Associate Professor, Department of Environmental Sciences, Nova Scotia Agriculture College, Truro, NS, Canada. **Corresponding author:** Qamar Uz Zaman, Engineering Department, Nova Scotia Agriculture College, P.O. Box 550, Truro, B2N 5E3, NS, Canada; phone: 902-893-5426; e-mail: qzaman@nsac.ca.

yield variability (Ping et al., 2005). Hence, characterization of variable soil fertility is important for variable-rate fertilization. The most popular approach to manage spatial variability within fields is the use of management zones (MZs), in which the field is subdivided into smaller areas that have relatively homogeneous attributes like landscape and soil condition, and this technique can be used to direct variable rate fertilizer application (Ferguson et al., 2003). Management zones can be based on soil survey maps (Wibawa et al., 1993) and remotely sensed maps of yield estimates (Boydell and McBratney, 2002); easily measured soil properties and fruit yield (Mann et al., 2010). The concept of MZs 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 MZs 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., 2008). The basic idea of management zones is that fields can be sampled where soil samples are composited from field sub-regions (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.

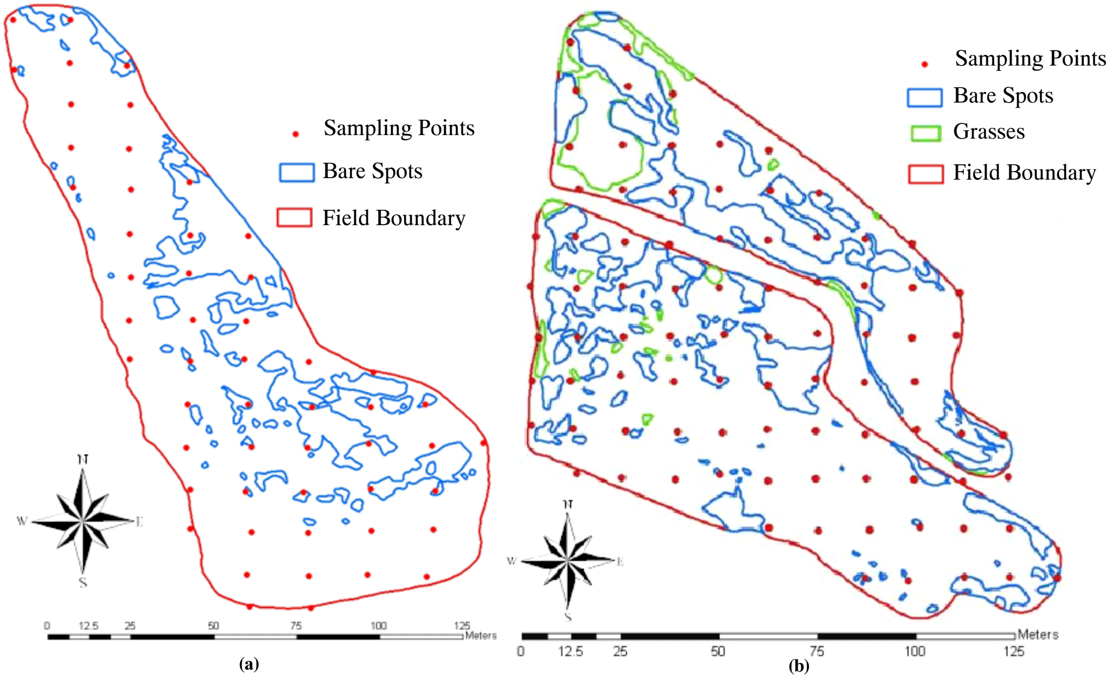
In the past studies, a number of agronomic factors affecting fruit yield have been considered as variables for delineating productivity/MZs (Chang et al., 2004; Li et al., 2008). Potential sources of information commonly used to define soil-based MZs include depth-weighted average of bulk electrical conductivity (termed apparent soil electrical conductivity, ECa) 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). Such attributes can be used either individually or in combination with each other. Yield mapping using yield monitoring systems is a logical starting point for site-specific nutrient management and it is also effective for the identification of potential MZs (Boydell and McBratney, 2002).

Many researchers have attempted to characterize and quantify the spatial variation in soil properties, leaf nutrients and fruit yield to delineate MZs for different cropping systems (McBratney and Pringle 1999; Wong and Asseng, 2006; Li et al., 2008; Mann et al., 2010). However, to date little attention has been paid to wild blueberry production system. Wild blueberry producers are generally well aware of soil variability within fields (Zaman et al., 2008 and 2010a); however, there were no adequate tools to characterize, quantify and manage their fields based on spatial variability. Therefore, the objectives of this research were to characterize and quantify the spatial variation in soil properties and wild blueberry fruit yield and to delineate MZs for site-specific fertilization.

METHODOLOGY

STUDY AREA

Two wild blueberry (*Vaccinium angustifolium* Ait.) fields were selected in central Nova Scotia, Canada to assess the spatial variability in soil properties and fruit yield to develop MZs. The selected fields were Carmal Site (1.2 ha; 45°.44′ N, 63°.54′ W) and the North River Site (1.6 ha; 45°.27′ N, 63°.12′ W). The area contained by bare spots, weeds and grasses was 18% and 27% for Carmal and North River Sites, respectively (fig. 1). Both fields were in their vegetative sprout year of the biennial crop production cycle in 2009, and crop year in 2010. The selected fields had been under commercial management over the past decade and received biennial pruning by mowing for the past several years along with conventional fertilizer, weed and disease management practices. The inorganic fertilizer was applied in third week



(a) (b)

Figure 1. Field layouts of selected wild blueberry fields: (a) Carmal Site and (b) North River Site.

of May, 2009 (Sprout year) using surface broadcast method at recommended rate for wild blueberry, of 32 kg N ha^{-1}. Ammonium sulphate (16.5%), Di-ammonium phosphate (34.5%), Potash (4.5%), and sand and/or clay filler (44.5%) constituted the inorganic fertilizer. The soil at the experimental sites is classified as sandy loam (Orthic Humo-Ferric Podzols), which is a well-drained acidic soil. These acidic soils, known as "Truro 52," are of the Hebert association and are mostly found in the Colechester County of Nova Scotia, Canada (Webb and Langille, 1996).

Sampling Strategy

Ground conductivity survey data, HCP and PRP were utilized to develop a sampling strategy to collect soil and fruit yield samples from both fields. The exponential and gaussian models of semivariogram were found to best fit the HCP and PRP data, respectively. The grid size to collect soil 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. 2). 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 × 15 m was selected for sampling at both sites.

Soil Sampling and Analysis

A grid pattern of sampling points was established at each experimental site to collect soil (n=56 and n=86 for Carmal and North River Sites, respectively) and fruit yield samples (n=114 and n=168 for Carmal and North River Sites, respectively). The sampling coordinates for each grid point were recorded using a ProMark3 mobile mapper DGPS (Thales Navigation, Santa Clara, Calif.). The field boundary, bare spots, weeds, and grasses were also mapped using mobile mapper DGPS.

Soil samples were collected three times during this study (May 2009, July 2009, and June 2010) from 0- to 15-cm depth at each grid point using sampling auger. Five samples were collected from each grid point to obtain a representative pooled soil sample. The pooled soil samples were labeled and placed into two separate bags. One of the sample bags for each sampling location was placed in the refrigerator, and the other was placed in the greenhouse for air drying. The soil samples from the refrigerator were analyzed for NH_4^+-N and NO_3^--N (Technicon Industrial Systems, 1973 and 1978) using Technicon Auto-analyzer (Technicon Autoanalyzer-2, Terry Town, N.Y.). The air dried soil samples from the greenhouse were ground using a soil grinding machine (Nasco Farm & Ranch Co, Fort Atkinson, Wis.), and passed through a 2-mm sieve.

The sieved soil samples were analyzed for soil texture using hydrometer method (Day, 1965). Loss on ignition method (Davies, 1974) was utilized for the determination of SOM. Soil pH and EC were determined using 1:2.5 soil: water suspension. Soil pH was measured by inserting the Corning 450 (Corning, Incorporated, Corning, N.Y.) pH meter in soil water suspension (Mclean, 1982). Soil EC was measured by inserting the Accument 50 (Fisher Scientific, Hampton, N.H.) EC meter in soil water suspension (Rhoades, 1982). Soil θ_v was recorded by inserting TDR-300 (Time domain reflectometry) probes (Spectrum Technologies, Inc, Plainfield, Ill.) 15 cm below the soil surface. Soil texture and pH were measured once as these properties do not tend to change for two monitoring years. HCP and PRP readings using ground conductivity meter (Dual EM, Milton, Ont., Canada) were also recorded at each grid point.

Fruit Yield Sampling

The fruit yield was measured and mapped using calibrated digital color photography (Zaman et al., 2008 and 2010a) in first week of August during crop year (2010). A 10-megapixel 24-bit digital color camera (Canon Canada, Inc., Mississauga, Ont.) was mounted on a tripod, positioned 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. The images were processed using custom software developed with the Pascal programming language using the Delphi 5.0 compiler (Borland, Austin, Tex.) to determine the blue pixels, representing the fruit in the image. The fruit yield was also harvested manually using hand rakes from the same quadrant at each grid point. Two more photographs along with DGPS positions in each grid were taken to cover all within field variability. The detail procedure can be adopted from Zaman et al. (2008 and 2010a).

Statistical Analysis

The normality was tested using Anderson-Darling (A-D) test at a significance level of 5% and non-normal data were normalized using logarithmic transformations. Classical statistics were utilized to calculate minimum, maximum, mean, standard deviation, coefficient of variation (CV) and skewness using Minitab 15 statistical software (Minitab Inc., New York, N.Y.). Classical statistics provides the overall variability of the soil properties; however, it does not provide the spatial trend. Therefore, geostatistical analysis was performed using GS+ Geostatistics for the Environmental Sciences Version 9 software (Gamma Design Software, LLC,

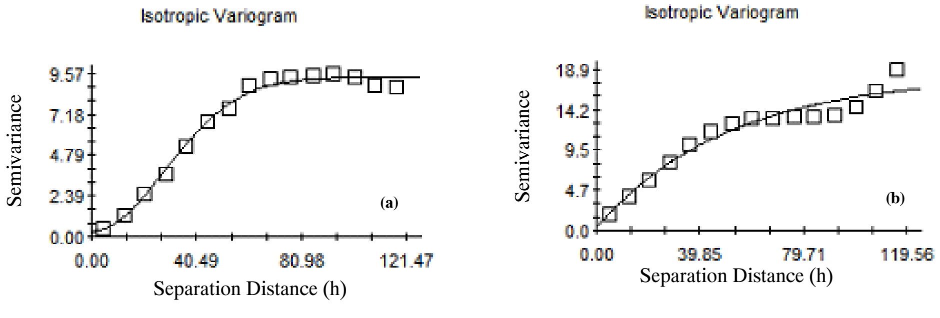


Figure 2. Semivarigrams of ground conductivity (a) Carmal Site, (b) N. River Site.

Plainwell, Mich.) to characterize the spatial variability in soil properties and fruit yield. The semivariograms were produced for each soil property and fruit yield to ascertain the degree of spatial variability between neighboring observations. There was no anisotropy (Anisotropy ratio = 1) evident in directional semivariograms for soil properties and fruit yield for both sites. Therefore, isotropic models for semivariograms were fitted using GS+ software.

The correlation coefficient (r) between soil properties and fruit yield were determined via Pearson Correlation using Minitab 15 Statistical software. Geostatistics combined with geographical information system (GIS) was applied to generate detailed maps in ArcGIS 9.3 (ESRI, Redlands, Calif.) to analyze the spatial variability of soil properties and fruit yield visually. All the parameters were interpolated using ordinary kriging interpolation technique. Our data showed that the kriged estimates were very close to the measured estimates. The maps were produced at the same scale and equal number of classes in order to allow easier comparison.

Cluster analysis was performed using Minitab 15 statistical software to observe the spatial patterns of natural productivity groups aiming to minimize within-cluster variance and maximize between cluster variance to develop MZs. Results of the cluster analysis are presented as dendrograms in figure 3. A dendrogram represents different clusters and the distinctness of the cluster from its closest neighbor. The analysis of variance (ANOVA) was performed and the means were compared with least significant difference (LSD) at 5% level of significance using PROC GLM (SAS Institute, Cary, N.C.). The clustered data based on the class membership (zones) was imported into ArcGIS 9.3 software to develop the MZs.

RESULTS AND DISCUSSION

DESCRIPTIVE STATISTICS OF SOIL PROPERTIES AND FRUIT YIELD

The A–D normality test of soil properties and fruit yield data suggested that all parameters were normally distributed ($p>0.05$) except EC, SOM, sand, clay, and inorganic N for both sites. Soil properties were fitted in normal distribution using logarithmic transformations for both sites except SOM and sand content for Carmal Site. Parkin and Robinson (1992) suggested that many soil properties having skewed distributions are log normally distributed. The underlying reason for normal and non-normal distributions of some of these soil properties at two monitoring sites are unknown, but management practices and temporal effects seem to be likely causes.

The coefficient of variation (CV) is a first approximation of field heterogeneity and according to Wilding (1985), soil properties are least variable if the CV< 15%, moderate with CVs ranging from 15% to 35% and most with CVs > 35%. Summary statistics of soil properties for Carmal (table 1) and North River (table 2) Sites showed that soil properties had high CVs showing moderate to high variability except soil pH, sand and clay for Carmal and soil pH for North River Site with the CVs less than 11% indicating least variability. Soil pH was in acidic range with the mean value of 5.52 for both sites (tables 1 and 2). Mean values of SOM, θ_v, and inorganic nitrogen (N) were observed higher for the Carmal Site as compared to the North River Site. This may be due to the presence of more clay content (41.88%) for Carmal Site. The inorganic N had a highly skewed distribution with high CVs indicating large variation for both sites. Highly skewed distribution of inorganic N may be due to application of nitrogen fertilizer several weeks prior to soil sampling, and no fertilization during the crop year. Other studies evaluating spatial variation also found moderate to high CVs for these soil properties except pH (Cox et al., 2003; Brye, 2006), which may be due in part to the logarithmic scale of pH measurement.

Soil properties for second (July 2009) and third (June 2010) soil sampling also exhibited moderate to high variation as the CVs ranging from 17% to 90% (tables 1 and 2) for both sites. The mean values for NH_4^+-N, NO_3^--N, and EC were observed lower for second and third sampling as compared to first sampling. This could be due to the uptake of nitrogen by plants and leaching of nutrients to the ground water

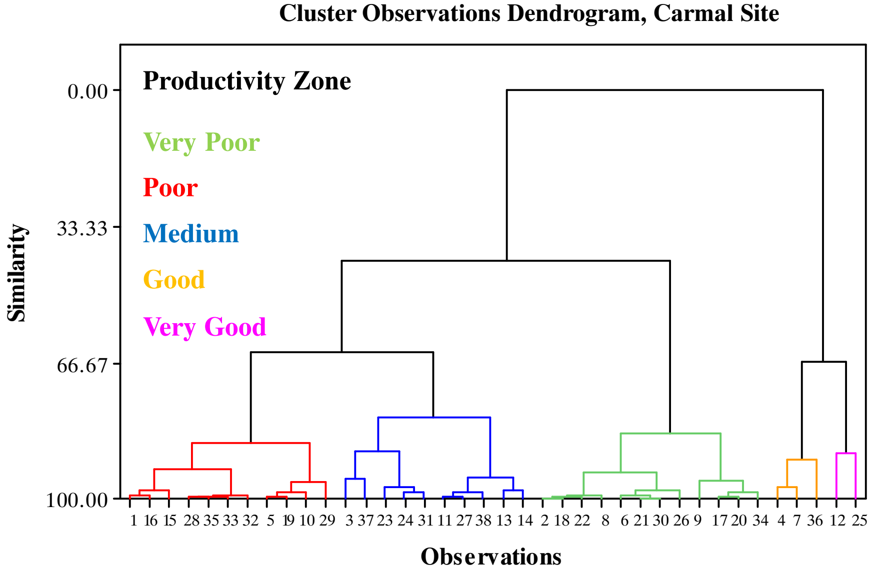


Figure 3. Observation dendrogram of soil variables along with fruit yield for Carmal Site.

Table 1. Summary statistics of soil properties and fruit yield 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

August, 2010 (fruit yield sampling)

Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
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

(tables 1 and 2). The variation in SOM was small as suggested by its CVs and mean values, indicating the tendency of SOM not to change significantly in two monitoring years for both sites (tables 1 and 2). The descriptive statistics of fruit yield and blue pixel (tables 1 and 2) suggested that fruit yield was highly variable with the CVs of 49.52% and 55.36% for Carmal and North River Sites, respectively. The mean fruit yield was lower for the North River Site as compared to the Carmal Site; this may be due to more coverage by bare spots and grasses, rocky nature of soil, and availability less nutrients for plant growth and development. The variability in soil properties and fruit yield may be due to the intrinsic and extrinsic sources of variability. Intrinsic variability is due to natural variations in soil, and extrinsic variability is caused in the field as part of crop management operations (Cemek et al., 2007). These results also probably reflect the influence of temporal dynamics on the measured parameters due to sampling at different times during the study.

SPATIAL VARIATION OF SOIL PROPERTIES AND FRUIT YIELD

Geostatistical analysis was performed to produce semivariograms in order to assess the spatial variation in soil properties and fruit yield. In the Carmal Site, gaussian, spherical, exponential, and linear models were found to best fit the data. The best fitted semivariogram models for North River Site were exponential, spherical, and gaussian. The semivariogram parameters (nugget, sill, and range) best describing the spatial structure of variogram uses the coefficient of determination (R^2) and sums of squares (RSS) to select the best models, and model parameters that maximize R^2 and minimize RSS values.

The geostatistical parameters of soil properties and fruit yield showed moderate to large variation within the field as indicated by their semivariogram range of influence (< 30 m) except soil pH, PRP, SOM, and silt for Carmal Site (table 3). 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

Table 2. Summary statistics of soil properties and fruit yield 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 (015 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

August, 2010 (Fruit Yield Sampling)

Parameters	Min	Max	Mean	S.D	C.V (%)	Skewness
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

spatial dependency for a ratio greater than 75% (Cambardella et al., 1994). Semivariogram of soil properties for first soil sampling (0-15 cm) and fruit yield for Carmal Site indicated strong spatial dependence for variables such as PRP, θ_v, EC, clay, and inorganic N (table 3). Strong spatially dependent variables may be controlled by intrinsic soil characteristics, such as texture, mineralogy, and microorganisms. Another class of soil variables such as sand, silt, pH, and SOM showed moderate-to-low spatial dependence with the nugget to sill ratio >25% for Carmal Site (table 3). Extrinsic variations such as weather conditions, topography and management practices may control the variability of moderate to weak spatially dependent variables. NO_3^--N during the first soil sampling (May, 2009) and NH_4^+-N for second sampling (July, 2009) exhibited moderate spatial dependence. This may be controlled by extrinsic factor such as fertilizer application.

Soil properties for the North River Site were highly variable within fields with the range of influence less than 30 m and nugget-to-sill ratio less than 15%, except θ_v, sand, silt, and clay showing moderate variability (table 4). Similar pattern of variation for the soil properties was observed for second (sprout year) and third (crop year) sampling for both sites (tables 3 and 4). Fruit yield was found to be strongly spatial dependent (<25%) indicating that the fruit yield variability was controlled by the soil properties for both sites (tables 3 and 4). Variations in soil properties corresponding with the variability in fruit yield provided strong evidence that soil variability is a major factor affecting localized yield reduction. The large spatial dependency and lower range of influence of soil properties in field showing yield variability have been reported for different crops (Zaman and Schumann, 2006; Li et al., 2008).

The scale of spatial correlation varied in distance from 12 to 85.86 m, for selected soil properties and fruit yield (tables 3 and 4). Most of the soil properties were found to have the range of influence varying from 20 to 50 m. At distances shorter than this range, variability is non-random (Oliver, 1987). The results of this study suggest that a sampling interval ~15 to 20 m would provide reliable predictions for managing the within field variation in wild blueberry fields.

Table 3. Semivarigram parameters of soil properties and fruit yield 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

August, 2010 (fruit yield sampling)

Parameters	Nugget	Sill	Range (m)	Nugget Sill Ratio (%)	R^2	Model
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

RELATIONSHIPS AMONG THE SOIL PROPERTIES AND FRUIT YIELD

The correlation matrix used to describe the impact of soil variability on crop productivity (tables 5 and 6 for Carmal and North River Sites, respectively) revealed significant relationships among soil properties and fruit yield. In general, the soil parameters were significantly correlated with each other and fruit yield except soil silt content for both sites (tables 5 and 6). Significant positive correlations of HCP and PRP with θ_v suggested the linear trend indicating that the ground conductivity values are influenced greatly with the moisture level in the soil. HCP was significantly correlated with sand (r=-0.32) for Carmal Site (table 5), while the relationship of HCP with sand was non-significant for North River Site (table 6). Ground conductivity was significantly correlated with fruit yield suggesting higher values of HCP and PRP in high yielding areas and vice versa. These results were in agreement with the findings of Mann et al. (2010).

The θ_v was significantly correlated with pH (r=0.41 to 0.43), EC (r=0.67), SOM (r~0.73 to 0.78), clay (r~0.59 to 0.62), NH_4^+-N (r~0.58 to 0.65), NO_3^--N (r~0.71 to 0.73), and fruit yield (r~0.61 to 0.62) for both sites. These positive relationships suggested higher values of θ_v, inorganic N, EC, HCP, and PRP in the areas having more clay and SOM, which may be due to more retention of moisture, available N, and soluble salts by fine clay particles. Soil pH was significantly correlated with EC, SOM, inorganic N, and fruit yield, while the other soil parameters were non-significantly correlated with pH for Carmal Site (table 5). Soil pH was significantly correlated with EC (r=0.33), while the relationships of pH with other soil properties were non-significant for North River Site (table 6). Soil θ_v, inorganic N, clay, EC, and fruit yield were negatively correlated with the sand content

Table 4. Semivarigram parameters of soil properties and fruit yield 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

August, 2010 (fruit yield sampling)

Parameters	Nugget	Sill	Range (m)	Nugget Sill Ratio (%)	R^2	Model
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

Table 5. Correlation matrix among the soil properties for the first soil sampling (0-15 cm) and fruit yield for Carmal Site.

	HCP[a]	PRP	θ_v	pH	EC	SOM	Sand	Silt	Clay	NH$_4^+$-N	NO$_3^-$-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***	-0.22 ^{NS}			
NH$_4^+$-N	0.71***	0.43**	0.58***	0.36*	0.59***	0.64***	-0.33 ^{NS}	-0.04 ^{NS}	0.50**		
NO$_3^-$-N	0.82***	0.50**	0.71***	0.41**	0.59***	0.74***	-0.19 ^{NS}	-0.20 ^{NS}	0.49**	0.59***	
Yield	0.80***	0.47**	0.62***	0.35*	0.60***	0.65***	-0.34*	-0.22 ^{NS}	0.60***	0.62***	0.58***

[a] 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.

Table 6. Correlation matrix among the soil properties for the first soil sampling (0-15 cm) and fruit yield for North River Site.

	HCP[a]	PRP	θ_v	pH	EC	SOM	Sand	Silt	Clay	NH_4^+-N	NO_3^--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***	0.03NS	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			
NH_4^+-N	0.72***	0.63***	0.65***	0.12 NS	0.60***	0.61***	-0.18 NS	0.03 NS	0.49***		
NO_3^--N	0.77***	0.75***	0.73***	0.04 NS	0.68***	0.70***	-0.17 NS	0.01 NS	0.49***	0.63***	
Yield	0.78***	0.72***	0.61***	0.10 NS	0.70***	0.55***	-0.23 NS	0.18 NS	0.38**	0.32*	0.54***

[a] 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.

indicating lower fertility, less moisture, and inorganic N availability for plant uptake, and more exposure of leaching which may cause an impact on fruit yield and a threat to water quality.

Overall the positive correlations of soil properties including SOM, EC, θ_v, NH_4^+-N, NO_3^--N, clay content, and fruit yield with HCP and PRP suggested that ground conductivity can be used to assess the fertility status, predict soil properties, to visualize its impact on the yield and ameliorate productive and unproductive areas within a field. Currently, the fertilizer recommendations in the wild blueberry cropping system are based on leaf nutrient concentrations. Nutrient management practices based on leaf nutrient concentration in wild blueberry cropping system do not provide an accurate estimate of the nutrients that are either available or in plants itself. These results will bring back soil-related factors that can be used to develop nutrient management plans for wild blueberries. The positive correlations among the soil properties and fruit yield suggested that soil properties including HCP, PRP, θ_v, EC, SOM, clay, NH_4^+-N, and NO_3^--N are one of the major yield limiting factors. These results could be used to develop MZs based on the variation of easily measured soil properties such as HCP, PRP, and fruit yield mapping using digital color photography for variable rate application of fertilizer to increase farm profitability by reducing environmental contamination. 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 have negative impact on fruit yield.

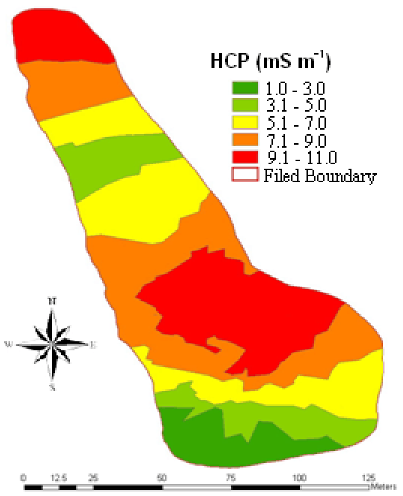
Mapping of Soil Properties and Fruit Yield

The interpolated maps of soil properties and fruit yield showed gradual and non-random spatial variability with significantly different values across the field for both sites. Due to space constraints, only the maps of Carmal Site are discussed here (fig. 4). Spatial patterns of variation for HCP, PRP, θ_v, EC, SOM, clay, NH_4 $^+$-N, NO_3^--N, and fruit yield (figs. 4a-4l) were almost similar for Carmal Site. Higher values for these parameters were observed in the north and lower values in the south west part of the field (figs. 4a-4l). The medium values were observed in the center of the field. These maps showed large spatial variability of these parameters within field for Carmal Site (fig. 4). Maps of soil pH, sand, and silt content indicated less variability as compared to the other soil properties (figs. 4d, g, and h) for Carmal Site. Geostatistical range of influence (table 3) and significant positive correlations among these soil properties (table 5) also supported the relationships identified by the maps. The similar pattern of variation for these soil properties was observed for second and third sampling during sprout and crop year.

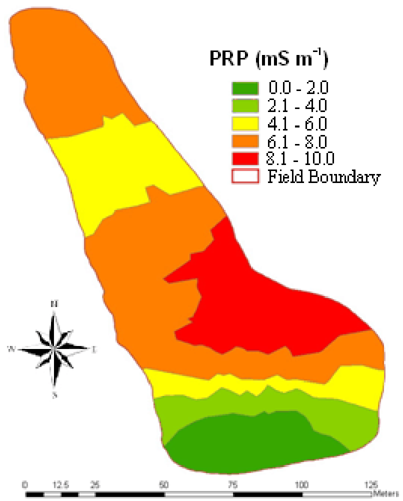
Kriged map of fruit yield (fig. 4l) showed substantial spatial variation across the field, which was also indicated by the lower range of influence and high CVs (tables 1, 2, 3, and 4) for Carmal Site. In general, low-yielding areas (fig. 3l) were in the center, surrounded by high yielding areas in the north and southeast of the field for Carmal Site. Ground inspections revealed that the low-yielding areas were located in bare patches, weeds, and grasses (figs. 1 and 4l). Maps also showed that the fruit yield was higher in the areas with more nutrients, moisture, and organic matter. The significant positive correlations among HCP, PRP, θ_v, EC, SOM, clay, NH_4^+-N, and NO_3^--N also supported these results. Collectively, the results of classical statistics, geostatistical range of influence, correlation matrix, and kriged maps suggested moderate to high variability in soil properties and fruit yield within field except soil pH, sand and silt content for Carmal Site.

Delineation of Management Zones Using Cluster Analysis

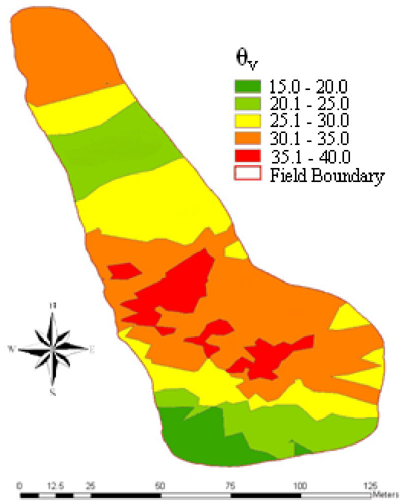
The results of characterization and quantification of variability confirmed the existence of spatial variability in wild blueberry fields emphasizing the need for developing MZs for site-specific fertilization. The soil properties and fruit yield data were clustered by performing observation cluster analysis using Minitab 15 statistical software to group the soil and fruit yield sample points with similar patterns in attributes. Due to space constraints, only the dendrogram of Carmal Site is discussed here (fig. 3) representing clustered soil and fruit yield data into five groups based on their similarity level. The productivity levels to develop MZs 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}) for Carmal Site (fig. 3). The significant correlations of fruit yield with soil properties also support the defined productivity zones (table 5).


HCP (mS m^{-1})
1.0 - 3.0
3.1 - 5.0
5.1 - 7.0
7.1 - 9.0
9.1 - 11.0
Filed Boundary
N
W
E
S
0
12.5
25
50
75
100
125
Meters

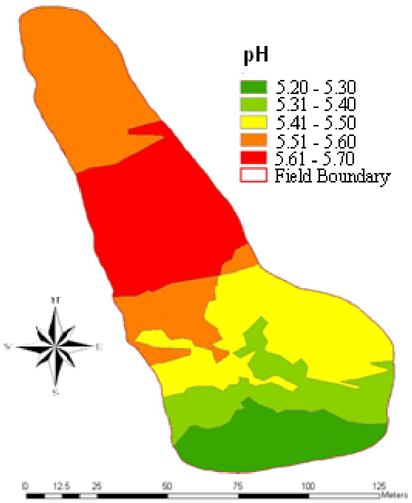
(a)


PRP (mS m^{-1})
0.0 - 2.0
2.1 - 4.0
4.1 - 6.0
6.1 - 8.0
8.1 - 10.0
Field Boundary
N
W
E
S
0
12.5
25
50
75
100
125
Meters

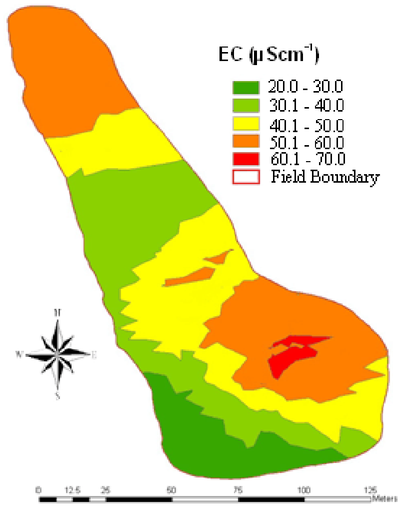
(b)


θ_v
15.0 - 20.0
20.1 - 25.0
25.1 - 30.0
30.1 - 35.0
35.1 - 40.0
Field Boundary
N
W
E
S
0
12.5
25
50
75
100
125
Meters

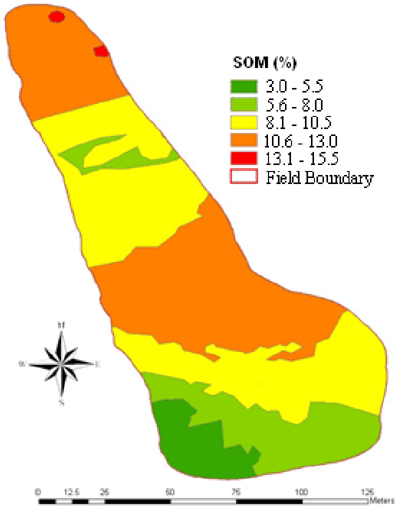
(c)


pH
5.20 - 5.30
5.31 - 5.40
5.41 - 5.50
5.51 - 5.60
5.61 - 5.70
Field Boundary
N
W
E
S
0
12.5
25
50
75
100
125
Meters

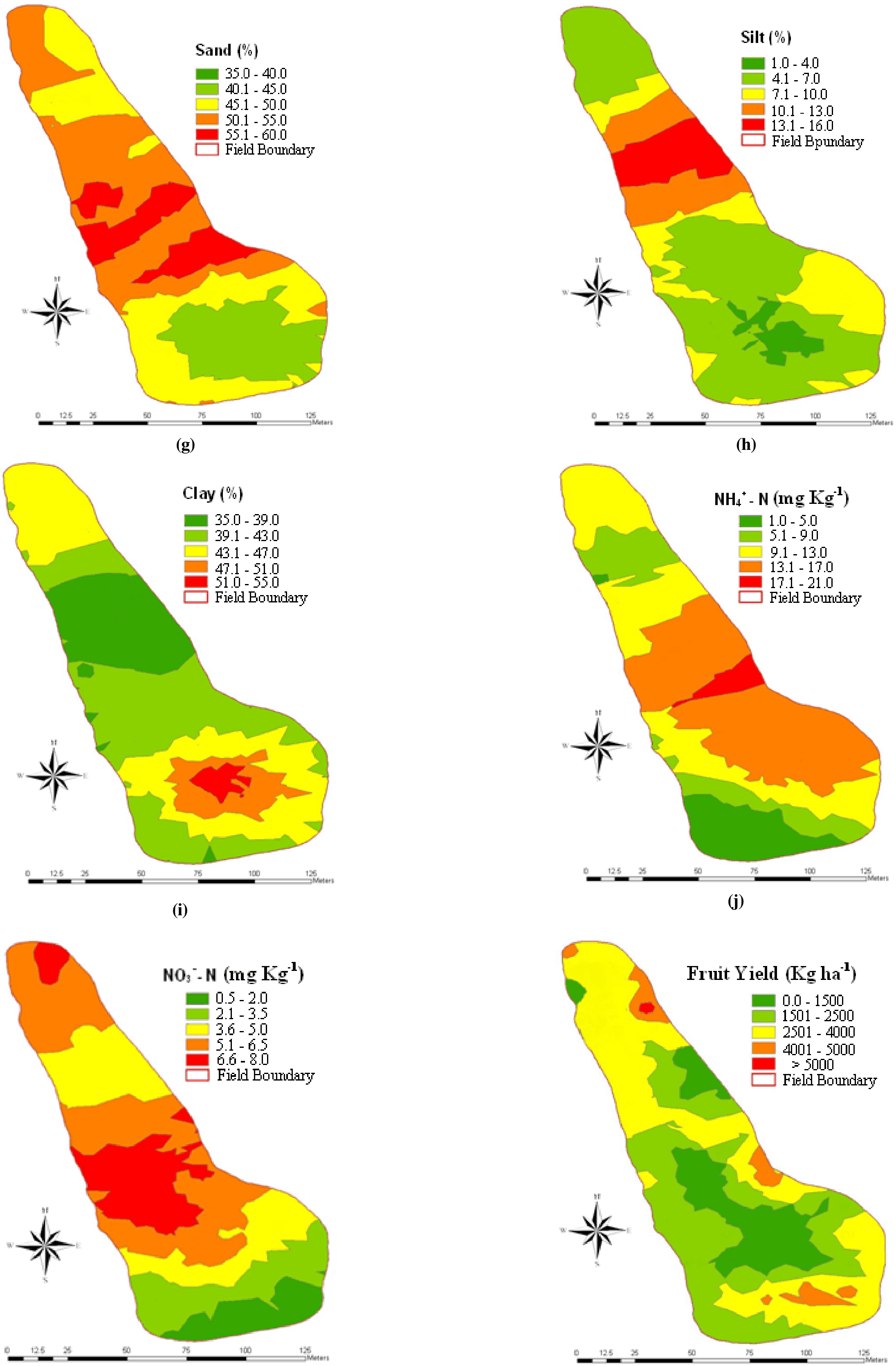
(d)


EC (µScm^{-1})
20.0 - 30.0
30.1 - 40.0
40.1 - 50.0
50.1 - 60.0
60.1 - 70.0
Field Boundary
N
W
E
S
0
12.5
25
50
75
100
125
Meters

(e)


SOM (%)
3.0 - 5.5
5.6 - 8.0
8.1 - 10.5
10.6 - 13.0
13.1 - 15.5
Field Boundary
N
W
E
S
0
12.5
25
50
75
100
125
Meters

(f)



(g) (h)

(i) (j)

(k) (l)

Figure 4. Kriged maps of soil properties and fruit yield for Carmal Site. (a) Horizontal coplanar geometry (HCP), (b) perpendicular coplanar geometry (PRP), (c) volumetric moisture content (θ_V), (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), and (l) fruit yield.

The natural grouping of soil properties and fruit yield data suggested that most of the sample points fall in poor to good productivity potential (fig. 3) and a of couple data points fell in very good productivity zones indicating the high yielding areas for Carmal Site. The clustered observations in each group exhibited the internal homogeneity and external heterogeneity at a similarity level of greater than 70% (fig. 3). The results of cluster analysis could differentiate the areas with different fertility status within fields. Once soil properties and fruit yield were assigned with zone classification based on cluster analysis, the data were exported and analyzed by ANOVA to provide an indication of statistical distinction between the different potential MZs.

Soil properties including inorganic N, SOM, EC, θ_v, clay, HCP, PRP, and fruit yield followed the trends indicated by the MZs with the highest nutrient and yield in the very good and good zones, intermediate levels in the medium zones, and lowest levels in poor and very poor zones (table 7 and 8) for both sites. The fruit yield was significantly different in all MZs (table 7 and 8). The HCP, θ_v, SOM, and inorganic N were significantly different in developed management zones except poor and very poor MZs (table 7) for Carmal Site. The θ_v, SOM, EC, and inorganic N were significantly different in all management zones (table 8) except poor and very poor zones with non-significant differences for North River Site. The ground conductivity was significantly different in the delineated MZs except non-significant differences in medium and poor zones for HCP, and poor and very poor zones for PRP (table 8) for North River Site. There were non-significant differences for soil pH and silt content for all MZs (table 7). The results of ANOVA indicated that the soil EC was non-significantly different in all MZs except medium and good productivity zones for Carmal Site (table 7).

These results showed that fruit yield, HCP, inorganic N, and SOM can be the potential variables to develop MZs in wild blueberry fields. The definition of site-specific MZs relies on spatial information that is stable or predictable over time and is related to fruit yield (Sudduth et al., 2000). The significant relationships of fruit yield with HCP, SOM, EC, θ_v, and inorganic nitrogen (table 5 and 6) and their stability over time suggested that ground conductivity in combination with fruit yield and other soil properties data would be helpful in defining productivity zones for site-specific fertilization in wild blueberry fields.

Table 7. Comparison of mean fruit yield and soil properties for management zones for Carmal Site.

	Fruit Yield (Kg ha^{-1}) Management Zone[a]				
Soil Properties	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**

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

Table 8. Comparison of mean fruit yield and soil properties for management zones on for North River Site.

	Fruit Yield (Kg ha^{-1}) Management Zone[a]				
Soil Properties	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**

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

The clustered data based on their class membership was imported in ArcGIS 9.3 and ordinary kriging interpolation was applied to produce detailed maps representing MZs, i.e. very poor, poor, medium, good, and very good zones (fig. 5). Due to space constraints, only the MZs of Carmal Site are discussed here (fig. 5). The developed MZs represented different levels of productivity across the study sites emphasizing the need for variable rate application of agrochemicals. The visual comparison of the MZs with fruit yield (fig. 5a and b) indicated the higher fruit yield in the areas with more productivity levels and vice versa. The good and very good zones were located in the center and northeast central region of the field. In some part of the good and very good MZs in the experimental field, the fruit yield was observed lower as these areas were occupied by bare spots, grasses, and weeds (fig. 5). The medium productivity management zone was located in north and southeast of the field, while the fruit yield was also in medium range in those areas for Carmal Site (fig. 5a and b). Unnecessary fertilization in bare spots, weeds, and grasses located in good and very good zone 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). The wild blueberry is a unique crop with significant bare spots within field, unlike other cropping systems. Zaman et al. (2008) reported 30% to 50% bare spots within wild blueberry fields of Nova Scotia. Defining bare spots as a separate class while delineating MZs and allocating zero fertilizer rates using variable rate spreader would be helpful in saving significant amount of fertilizer. These results would assist in planning future soil sampling in the fields having soil and/or crop variability for identification of yield-limiting soil properties. These soil properties can be used to develop prescription maps for site-specific management of agricultural inputs in wild blueberry fields to increase farm profitability and reduce environmental impact.

CONCLUSIONS

The main tasks of this research were to characterize and quantify the spatial variation in soil properties and wild blueberry fruit yield and to develop management zones for variable rate fertilization. The results of this study confirmed the existence of large spatial variability within wild blueberry fields emphasizing the need for site-specific nutrient management. The results also revealed the dependence of variable yield in blueberry fields on SOM, N content and EC. Furthermore, the geostatistical analysis indicated that the selection of soil sampling should be based on sampling interval suggested by semivariogram range of the above mentioned easily measured soil properties. The range of the variability for soil properties like HCP, PRP, and SOM suggested that the grid size of approximately 15 to 20 m would provide reliable predictions. The results of clustering analysis, comparison of means, relationships of fruit yield with other soil variables suggested that ground conductivity and fruit yield data can be used to delineate MZs for site-specific fertilization in wild blueberry fields. The results of this study showed that MZs could provide a way to group

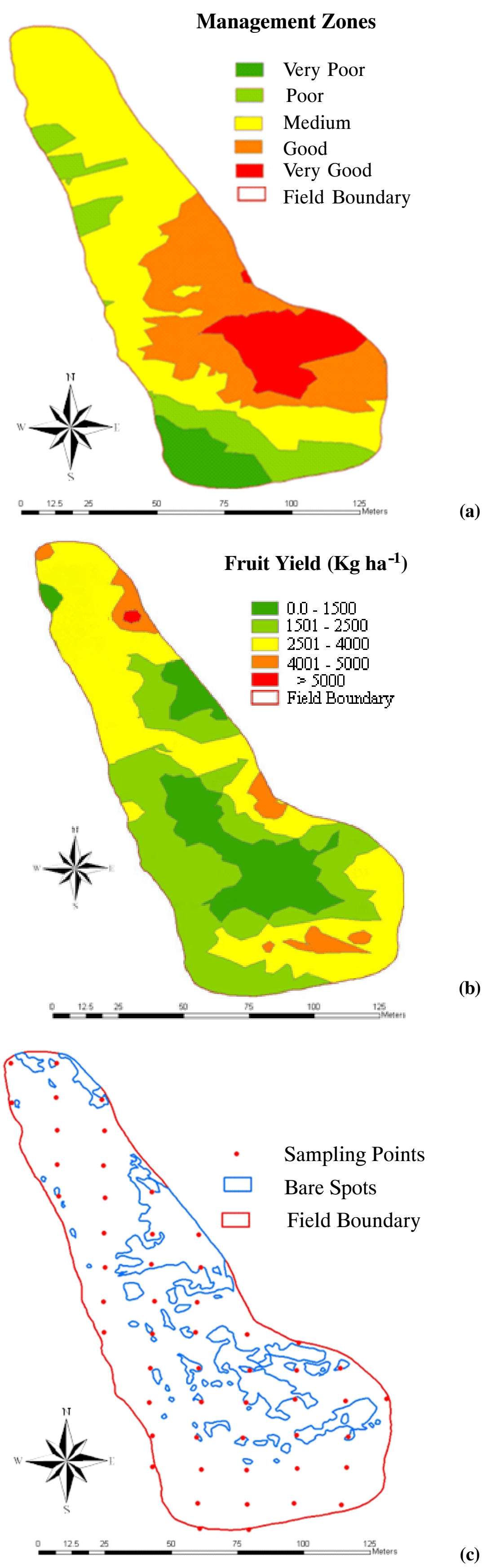


Figure 5. Comparison of delineated management zones for Carmal Site: (a) management zones, (b) fruit yield, and (c) field layout.

and manage the spatial variability of soil properties and fruit yield within fields. 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.

ACKNOWLEDGEMENTS

This work was supported by Oxford Frozen Foods Ltd., the Wild Blueberry Producers Association of Nova Scotia, the Nova Scotia Wild Blueberry Institute, Nova Scotia Department of Agriculture. The authors would like to thank Gary Brown and Doug Wyllie (farm managers at Bragg Lumber Company), Dr. Young Ki Chang (postdoctoral fellow), Travis Esau, Morgan Roberts, Fahad Khan, Shoaib Saleem (research assistants), and Kelsey Laking (technician) for their assistance during the experiment.

REFERENCES

Boydell, B., and A. B. McBratney. 2002. Identifying potential within-field management zones from cotton yield estimates. *Precis. Agri.* 3(1): 9-23.

Brye, K. R. 2006. Soil biochemical properties as affected by land leveling in a clayey aquert. *Soil Sci. Soc. Amer. J.* 70 (1): 1129-1139.

Cambardella, C. A., T. B. Moorman, T. B. Parkin, D. L. Karlen, R. F. Turco, and A. E. Konopka. 1994. Field scale variability of soil properties in Central Iowa soils. *Soil Sci. Soc. Amer. J.* 58 (1): 1501-1511.

Chang, J., D. E. Clay, C. G. Carlson, C. L. Reese, S. A. Clay, and M. M. Ellsbury. 2004. Defining yield goals and management zones to minimize yield and nitrogen and phosphorus fertilizer recommendation errors. *Agron. J.* 96(3): 825-831.

Cemek, B., M. Guler, K. Kilic, Y. Demir, and H. Arslan. 2007. Assessment of spatial variability in some soil properties as related to soil salinity and alkalinity in Bafra Plain in northern Turkey. *Envir. Monit. Assess.* 124(1-3): 223-234.

Cox, M. S., P. D. Gerard, M. C. Wardlaw, and M. J. Abshire. 2003. Variability of selected soil properties and their relationships with soybean yield. *Soil Sci. Soc. America J.* 67(4): 1296-1302.

Davies, B. E. 1974. Loss-on-ignition as an estimate of soil organic matter. *Soil Sci. Soc. America Proc.* 38(1): 150-151.

Day, P. R. 1965. Part 1: Particle fractionation and particle-size analysis. In *Methods of Soil Analysis,* 545-567. C. A. Black, ed. Madison, Wis.: ASA.

Doerge, T. A. 1999. Management zone concepts. Available at: ppifar.org/ssmg. Accessed 04 February 2010.

Eaton, L. J. 1988. Nitrogen cycling in lowbush blueberry stands. Ph.D. diss. Nova Scotia, Canada: Dalhousie University.

Ferguson, R. B., R. M. Lark, and G. P. Slater. 2003. Approaches to management zone definition for use of nitrification inhibitors. *Soil Sci. Soc. America J.* 67(3): 937-947.

Kerry, R., and M. A. Oliver. 2003. Variograms of ancillary data to aid sampling for soil surveys. *Precis. Agric.* 4(3): 261-278.

Li, Y., Z. Shi, C. F. Wu, H. Y. Li, and F. Li. 2008. Determination of potential management zones from soil electrical conductivity, yield and crop data. *J. Zhejiang Univ. Sci.* 9(1): 68-76.

Mann, K. K., A. W. Schumann, T. A. Obreza, W. G. Harris, and S. Shukla. 2010. Spatial variability of soil physical properties affecting Florida citrus production. *Soil Sci.* 175(10): 487-499.

McBratney, A. B., and M. J. Pringle. 1999. Estimating average and proportional variograms of soil properties and their potential use in precision agriculture. *Preci. Agric.* 1(2): 125-152.

McLean, E. O. 1982. Part II: Soil pH and lime requirement. In *Methods of Soil Analysis,* 199-223. A. L. Page et al., eds. Madison, Wis.: ASA, CSSA, and SSSA.

Oliver, M. 1987. Geostatistics and its application to soil science. *Soil Use Manage.* 3(1): 8-20.

Parkin, T. B., and J. A. Robinson. 1992. Analysis of lognormal data. *Adv. Soil Sci.* 20: 193-235.

Percival, D. C., and K. R. Sanderson. 2004. Main and interactive effects of vegetative year applications of nitrogen, phosphorous and potassium fertilizer. *Small Fruits Review* 3(1-2): 105-122.

Ping, J., C. Green, K. Bronson, R. Zartman, and A. Dobermann. 2005. Delineating potential management zones for cotton based on yields and soil properties. *Soil Sci.* 170(5): 371-377.

Pocknee, S., B. C. Boydell, H. M. Green, D. J. Waters, and C. K. Kvien. 1996. Directed soil sampling. In *Proc. of the 3rd Intl. Conf. on Precision Agriculture,,* 159-168. Minneapolis, Minn.: ASA, CSSA, SSSA.

Rhoades, J. D. 1982. Part II: Soluble salts. In *Methods of Soil Analysis*, 167-178. L. Page et al., eds. Madison, Wis.: ASA, CSSA, and SSSA.

Schueller, J. K., J. Whitney, T. Wheaton, W. Miller, and A. Turner. 1999. Low-cost automatic yield mapping in hand-harvested citrus. *Computers and Electronics in Agric.* 23(1999): 145-153.

Schumann, A., A. Fares, A. K. Alva, and S. Paramasivam. 2003. Response of 'Hamlin' orange to fertilizer source, rate and irrigated area. *Proc. Fla. State Hort. Soc.* 116: 256-260.

Sudduth, K. A., S. T. Drummond, and N. R. Kitchen. 2000. Measuring and interpreting soil electrical conductivity for precision agriculture. In *Proc. Intl. Conf. Geospatial Information in Agriculture and Forestry,* 144-148. Ann Arbor, Mich.: ERIM International, Inc.

Technicon Industrial Systems. 1973. Ammonia in water and wastewater. Industrial Method No. 98-70W. Tarrytown, N.Y.: Technicon Industrial Systems.

Technicon Industrial Systems. 1978. Nitrate and nitrite in water and wastewater. Method No. 98-70W. Tarrytown, N.Y.: Technicon Industrial Systems.

Trevett, M. F. 1962. Nutrition and Growth of the Lowbush Blueberry. Maine Agricultural Research Station. Bulletin No. 605. Orono, Maine.

Webb, K. T., and D. R. Langille. 1996. Soils of Fiddes and Brookside, Colchester County – Revised. Truro, Nova Scotia: Agriculture and Agri-Food Canada Research Branch.

Wilding, L. 1985. Spatial variability: Its documentation, accommodation and implication to soil surveys. In *Soil Spatial Variability,* 166-189. D.R. Nielsen and J. Bouma, eds. *Proc. of a workshop of ISSS and SSA.* Pudoc Wageningen, the Netherlands: Ctr for Agr. Publishing and Documentation.

Wibawa, W., D. Dludlu, L. J. Swenson, D. Hopkins, and W. Dahnke. 1993. Variable fertilizer application based on yield goal, soil fertility, and soil map unit. *J. Prod. Agric.* 6(2): 255-261.

Wong, M. T. F., and S. Asseng. 2006. Determining the causes of spatial and temporal variability of wheat yields at sub-field scale using a new method of upscaling a crop model. *Plant Soil* 283(1-2): 209-221.

Yarborough, D. E. 2009. Wild Blueberry. Orono, Maine: University of Maine Cooperative Extension. Available at: www.wildblueberries.maine.edu/.

Zaman, Q. U., and A.W. Schumann. 2006. Nutrient management zones for citrus based on variation in soil properties and tree performance. *Precis. Agric.* 7(1): 45-63.

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

Zaman, Q. U., K. C. Swain, A. W. Schumann, and D. C. Percival. 2010a. Automated, low-cost yield mapping of wild blueberry fruit. *Appli. Eng. in Agric.* 26(2): 225-232.

Zaman, Q. U., A. W. Schumann, and D. C. Percival. 2010b. An automated slope measurement and mapping system. *Hort. Tech.* 20(2): 431-437.