Electromagnetic Induction Methods to Assess Nutrient Build-up in Confined Livestock Areas

By

Marcos Renon Cunha Cordeiro

A Thesis

submitted to the Faculty of Graduate Studies

In partial fulfilment of the requirements of the degree of

MASTER OF SCIENCE

Department of Biosystems Engineering

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FACULTY OF GRADUATE STUDIES

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ABSTRACT

Beef cattle feedlot operations can have a negative impact on the environment because feedlots can be sources of several contaminants to soil and water, including microorganism, nutrients, heavy metals, and hormones. Nutrients have been reported as contaminants of major concern, causing problems of eutrophication of water bodies, impairment of the quality of drinking water, and loss of fertility in soils. Therefore, the assessment of nutrients coming from feedlots is quite important to preserve the natural resources. Traditional ways to assess nutrient in soils by coring is tedious and time consuming, which led to the application of alternative techniques such as electromagnetic induction (EMI). This technique is fast and provides useful data set for plotting and interpretation. The general objective of this research was to use electromagnetic induction to describe nutrient distribution. Six feedlot areas were surveyed in Manitoba, samples were acquired using a response surface design and analyzed for electrical conductivity (EC_e), nitrate, and phosphate, and calibration models for EMI readings were built using two different types of multiple linear regression (MLR) – soft and spatial MLR. Soft MLR used "easy-to-acquire" information, while spatial MLR used trend surface parameters. These models were built for simulations by layer and for the whole soil profile (i.e. composite). Models with better prediction capabilities were employed to depict nutrient distribution by mapping modelled readings. Interactions of feedlot and physiographic features were used to propose feedlot design criteria based on nutrient distribution. Comparison of the models showed that both soft and spatial MLR gave similar results because predictors included in the models were the same in most cases. Prediction of electrical conductivity was fairly good in both MLR, but prediction of

nitrate and phosphate was usually poor in this study. However, good prediction of these nutrients by EMI was shown by other studies. Composite methods seemed more appropriate than by layer method for the prediction because they take into account the whole soil profile and overcome the limitation of non-significant depth intervals observed in the by-layer analysis. Models for vertically-weighted profiles gave the best results, but they could only be employed when the whole profile was sampled. Underestimated values were observed when these models were used in partially-sampled profiles. Predictors of major influence were both primary and secondary decorrelated principal component scores (i.e. z1 and z2), derived from EMI readings. The maps created from modelled values of profile-weighted EC_e showed that feedlots 1 through 4 had $EC_e \leq 3.5$ dS m^{-1}, but feedlots 5 and 6 exceeded this threshold and reached maximum values of 5.5 and 7.0 dS m^{-1}, respectively. The distribution of this variable was mainly affected by topography in the field, with low elevations corresponding to high values of EC_e. However, features promoting preferential surface flow (i.e. drainage ditches) strongly affected migration pattern in the field. Also, feedlots located in areas with a rocky layer beneath the soil layer tended to show higher values of this variable probably due to nutrients accumulation. Feedlot design criteria based on the results suggest locating the pens upslope with an impermeable drain to direct runoff into storage or treatment areas. For soils with large hydraulic conductivity, pens should be provided a liner.

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DEDICATION

To my wife and parents.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ASABE: American Society for Agricultural and Biological Engineering

CBIE: Canadian Bureau for International Education

EC_a: apparent electrical conductivity

EC_e: extract electrical conductivity

EMI: electromagnetic induction

EM_H: reading taken with EM-38 conductivity meter in the horizontal position

EM_V: reading taken with EM-38 conductivity meter in the vertical position

GWC: gravimetric water content

LEVEL: micro-elevation

LEVEL: micro-elevation

MLR: multiple linear regression

r^2: coefficient of determination

RMSE: root mean square error

USDA: United States Department of Agriculture

VWC: volumetric water content

z1: primary decorrelated principal component scores

z2: secondary decorrelated principal component scores

LIST OF COPYRIGHTED MATERIAL

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1. INTRODUCTION

Increase in personal income, advances in technology, improvements in international trade, and urbanization have led to the expansion of intensive agricultural production worldwide (FAO 2007a). Agriculture covers 40% of land surface and consumes 70% of global available water resources (FAO 2007b). This expansion has resulted in negative impacts to the environment and led to the recognition of agriculture as a source of pollution (Merrington et al. 2002). In this context, animal production is a concern because animal waste which contain microorganisms (Khaleel et al. 1980; Joergensen et al. 1998; Rasmussen and Casey 2001), nutrients (Koopsman et al. 2002; Makris et al. 2006; Tarkalson et al. 2006), antibiotics, ectoparasiticides, heavy metals and hormones (Khan et al. 2007) can cause environmental problems due to contamination of soil and water.

These risks led some countries to create specific legislation for manure management. Canada published the national geographical profile of manure production for 2001 (Statistics Canada 2006), in which the major producers are described. According to this report, cattle accounted for 86.2% of total manure produced in 2001, of which 36.3% was produced by beef cattle, 13.5% by milk cows, 12.6% by calves, 12.5% by heifers, 9.2% by steers and 2.2 by bulls. These numbers corroborate with the Food and Agriculture Organization of the United Nations, which states that beef is the livestock group that represents a major threat to the environment (FAO 2007c).

Environmental problems caused by beef cattle waste are a direct result of an increase in production, and future prospects are even more alarming as the annual rate of

growth for meat production was estimated to be 1.8% for the period 1993-2020 (Delgado et al. 1999). Notably, 80% of this growth comes from intensive production systems, where a large number of animals are confined in a small area and where the large amount of waste generated is considered a disposal problem (FAO 2007c). The availability of land for manure application is a constraint where animal production is concentrated, and either off-site transportation or alternative utilization strategy is required (Risse et al. 2006). Manure management operations such as collection, transport, storage and handling are expensive due to the high energy cost and can lead to improper manure disposal. Poor waste management results in the accumulation of manure on-site and impact soil and water.

Manure is a source of major nutrients such as nitrogen, phosphorus, and potassium (Risse et al. 2006), but it can also be a source of other minerals such as calcium, manganese, sulfur, iron, arsenic, selenium, copper and zinc (Zhang et al. 2006). Excess nutrients have been linked to a number of environmental problems, but nitrogen and phosphorus are among those of major concern (Webb 2001; Koopsman et al. 2002). These nutrients cause the eutrophication of water bodies with loss of water quality and threat to fish populations, impairment of ground water quality, and loss of soil fertility (Gerber et al. 2005). Thus, the assessment of nutrients accumulation in beef-producing areas is quite important to avoid these problems.

Traditional assessment of nutrients in soils relies on collecting samples at specific sites and performing analysis (Eigenberg et al. 2002), which is laborious and expensive. As a result, new methods for assessing nutrient in soils have been employed, such as electromagnetic induction (EMI), which is becoming more common due to the advances

in instrumentation (Rhoads 1990). This technique uses EMI sensors to measure apparent electrical conductivity of the soil (EC_a), which can be used as a measure of nutrient distribution in the field. Electromagnetic induction method is much faster and less expensive than traditional soil coring; plus, EMI sensors can be coupled with global positioning system (GPS) receivers and their digital output can be exported into geographical information systems (GIS) software for mapping of the georeferenced information. These characteristics have raised EMI to a position of relevance in soil assessment because this method generates affordable, handy, and meaningful information which is easily acquired.

The aim of this research was to use the EMI technique to assess nutrient build-up in feedlot areas in Manitoba. The specific objectives are:

1. To compare calibration models for EMI readings calculated from a reduced number of samples using two different types of multiple linear regression (MLR);
2. To investigate the prediction capabilities of these models for discrete depth intervals and for composite soil profile;
3. To map nutrients using EMI information acquired in the surveyed areas and to identify the major patterns of distribution; and
4. To propose feedlot design criteria based on the interaction between the nutrient accumulation and major physiographic factors of the farms.

The content of this thesis is divided into six chapters. The first chapter presents a brief overview about the beef cattle industry and its environmental interactions, a description of nutrient build-up as an environmental concern, the use of electromagnetic induction as a useful method to assess nutrient in soils, and the objectives of this work. The second chapter presents a more detailed examination of nutrients as an issue, addressing specifically the problem of nitrogen and phosphate under the beef cattle

industry perspective. Chapter two also presents the EMI method, describing soil apparent electrical conductivity (EC_a) and the operation of the conductivity meter. The last section in this chapter discusses the versatility of georeferenced EMI information when exported into a GIS platform. Chapter three covers the research results for objective 1 and 2, presenting the methodology and findings. Similarly, chapter four covers methods and results for objective 3 and 4. It should be noted that chapters 3 and 4 represent papers sent for publication and, thus, they feature the major sections usually present in a paper, such as abstract and introduction. As standalone manuscripts, these chapters also present repetition of material in the introductory sections. Chapter five describes the practical applications of this research. Finally, chapter six summarizes the main conclusions of this study and chapter seven presents some recommendations for future research. References for all the chapters are presented after chapter seven.

2. LITERATURE REVIEW

2.1 Nutrients coming from feedlot waste as an environmental issue

The physical and chemical properties of animal manure, as well its volume, are affected by a number of factors, such as animal characteristics (e.g. species and age), feed ration, water consumption, and the environment (Townshend et al. 1969; Merkel 1981). Although the variability in these factors results in variability of manure composition and impracticability of defining a fixed proportion among its constituents, some approximations have been proposed. Manure is a source of several minerals such as calcium, manganese, sulfur, iron, arsenic, selenium, copper and zinc (Zhang et al. 2006), but its composition is presented in the literature in terms of the major components nitrogen, phosphorus, potassium, and calcium (Merkel 1981; Miner et al. 2000; ASABE 2005). Quantities of these components are presented in Table 2.1 as amount excreted by finished animal and percentage of the total wet weight, but no reports on the quantity of other minerals were identified.

Table 2.1. Quantities of the major minerals on beef cattle manure.

Manure component	Quantity	
	kg/finished animal	% wet weight
Nitrogen	25	0.59
Phosphorus	3.3	0.12
Potassium	17.1	0.30
Calcium	7.7	NA[†]

[†] Not available (Source: adapted from ASABE 2005 and Miner et al. 2000)

The compounds are therefore of major importance in the environmental context because they may represent risk to the natural resources. Excess nutrients have been linked to a number of environmental problems, but nitrogen and phosphorus are among

those of major concern (Webb 2001; Koopsman et al. 2002); hence, these two nutrients are discussed in more details in the following sub-sections.

2.1.1 Nitrogen

Environmental problems associated with nitrogen in animal manure are either due to gaseous emissions, runoff or infiltration into the soil (Moore et al. 2006). These problems are the result of different forms of nitrogen in the manure which undergoes different transformations. A large portion of nitrogen is present in the manure as uric acid and urea (O'Dell et al. 1960), but these compounds are quickly hydrolyzed to ammonia after excretion and, if applied to the soil, ammonia is further converted to nitrate (Moore et al. 2006).

The mobility of nitrogen in the environment varies depending on its forms. Thus, an understanding of the form of the nitrogenous compound in the soil system is quite important to assess its movement. For instance, runoff may have a relatively large amount of nitrogen in its organic form, but little nitrate (Hallberg 1989). This corroborates the results found by Ojeda et al. (2006), who studied the quality of runoff from a sewage sludge-applied field. They found that concentrations of mineral nitrogen in runoff is low, and that relatively high concentrations were only observed after the first rainfall events that took place short time after the sludge application. Conversely, nitrogen movement by leaching takes place mainly as inorganic compounds (i.e. nitrates), which percolate in dissolved form into the aquifer. In fact, nitrate is one of the most important soluble contaminants that go into groundwater (Addiscott et al. 1991 cited by Hillel 1998) and it has been reported to be the groundwater contaminant of major concern in the United States (Fetter 1990; Fig. 2.1).

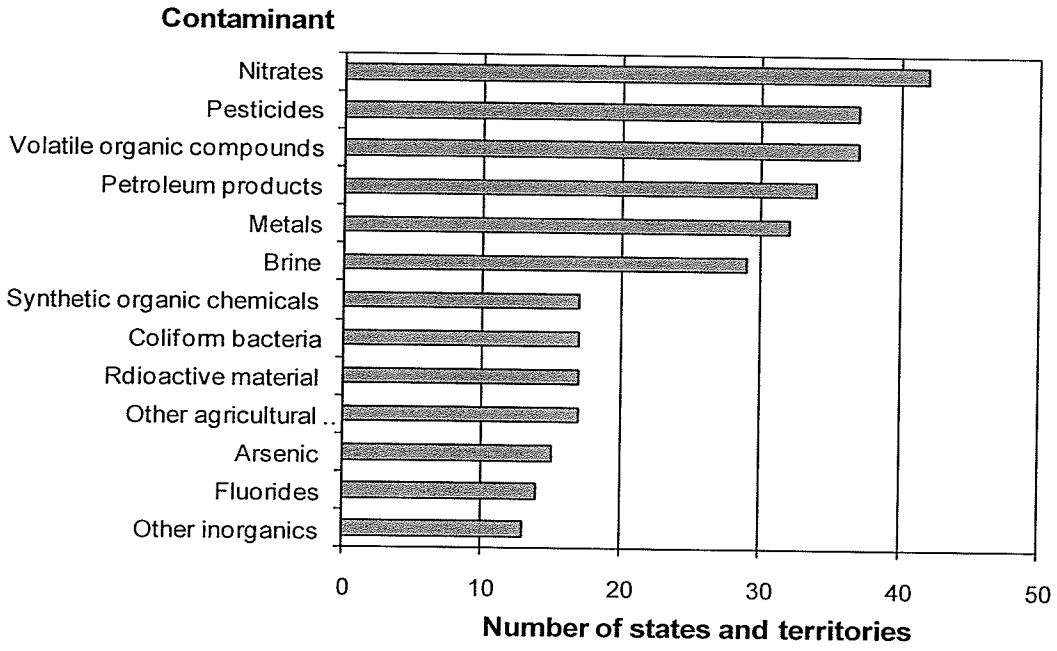

Fig. 2.1 Frequency of various contaminants considered by states and territories of the United States to be a major threat to ground water quality (Fetter 1999).

Nitrate leaching from the root zone to groundwater will only occur if nitrate amount is in excess in the field. That has been the case in some instances, where manure produced in intensive livestock farms is applied to crops in amounts in excess of agronomic requirements. This surplus leads to unutilized nitrogen that is susceptible to leaching (Hooda et al. 2000). Tarkalson et al. (2006) studied the accumulation and movement of nitrates in fields receiving cattle manure, under deficit irrigation, and found that manure applied at twice the recommended rate resulted in greater movement of NO_3. In addition, environmental factors also play a role in this process. Under irrigation deficit, for instance, crop capacity to take up water and nutrients from the soil is decreased, resulting in a relative excess of nutrients. Therefore, measures should be taken to match

fertilizer application to crop requirements. This is not an easy task since this matching depends on precise prediction of seasonal weather patterns (e.g. precipitation).

Another problem with nitrate contamination is that even if the source ceases, nitrate addition to the groundwater may continue for many years (Hillel 1998). That is, the contaminant is already in the soil and moving into groundwater. This scenario may lead to a delayed groundwater contamination, especially if the water table is very deep. That is because the nitrate plume may still be migrating through the soil profile and has not reached the water table; or because the aquifer has a high dilution capacity (Hillel 1998).

Nitrates are of major concern in ground water (Sharpley et al. 1998) mainly due to its potential to cause methemoglobinemia, which impairs the ability of hemoglobin in red blood cells to transport oxygen and carbon dioxide, leading to low levels of oxygen in tissues and, in extreme cases, result in death (Wright et al. 1999). Johnson and Kross (1990) state that this nitrate-induced disease is probably often misdiagnosed and certainly contributes to the infant death rate statistics in the United States. In Canada, nitrate in ground water is also a problem and its concentrations have exceeded the Canadian limit of 10 mg L^{-1} $N\text{-}NO_3^-$ in some places (Savard et al. 2007). Moreover, the rate of production of nitrate in soils of northern regions is faster than believed. Savard et al. (2007), studying nitrification in an agricultural region of Prince Edward Island, Canada, observed that nitrifying activity was found all year long and that nitrate production was high during winter. These findings are contrary to arguments of some authors who state that nitrate production accompanies a variation in temperature and, thus, are low during winter. These health issues arising from increased concentration of nitrate in soil and

ground water have motivated initiatives to investigate the nitrate distribution in the environment.

Some approaches have attempted to investigate nitrate using nitrogen isotopes. Nitrogen occurs as $\delta^{14}N$ and $\delta^{15}N$, whereas the former is by far the most abundant in the atmosphere (Fetter 1999). The relative abundance between these two isotopes (i.e. ratio) is used to predict where nitrate is coming from. The ratio between isotopes in samples from possible sources is compared to the ratio in groundwater samples. When they match, it may be a clue to the origin of the contamination. Widory et al. (2004) used isotopes of nitrogen ($\delta^{15}N$), boron ($\delta^{11}B$), and strontium ($^{87}Sr/\ ^{86}Sr$) coupled with conventional hydrogeologic analysis to determine the main source of nitrate contamination in the Arguenon watershed (Britain, France). The results showed that much of the contamination in this watershed originated from spreading of animal manure. However, due to the non-conservative nature of the isotopes, the identification of the sources was limited. Also, the authors concluded that hydrogeologic characteristics and nitrogen isotopes were not able to distinguish between denitrification process and dilution by unpolluted groundwater. That is, the isotopic approach cannot predict which transformation phenomena take place in the subsurface. In fact, predicting transformation processes that may occur in the subsurface is difficult. Some of these processes result in an effect called retardation. Retardation occurs to solutes dissolved in ground water as they can be sorbed, precipitated, be subject to abiotic or biotic degradation, and participate in oxidation-reduction reactions (Fetter 1999). Consequently, plume movement may be delayed. Particularly, nitrate is only subject to transformations in the

root zone, and once it is well below this zone it may no longer be subject to degradation (Hillel 1998).

2.1.2 Phosphorus

Feedlot manure contains from 0.3 to 0.8% phosphorus (Sweeten 1998), and it is estimated that each finished animal in a beef-finishing operation excretes 3.3 kg of phosphorus during this stage of production (ASABE 2005). Phosphorus is present in manure in both inorganic (30%) and organic forms (70%) (Spellman and Whiting 2007). Nonetheless, organic phosphorus mineralizes as animal waste ages, and the resulting inorganic compounds tend to adhere to soil.

The two forms of phosphorus are subject to mobilization. Organic phosphorus is water soluble and, therefore, passive to leaching and transport by runoff, while inorganic phosphorus can adhere to soil particles and be mobilized by erosion. Extensive attention has been given to qualitative and quantitative aspects of runoff because this is an important mechanism of pollutant transport from feedlots (Miller et al. 2004), including phosphorus. Detectable water pollution from feedlots does not seem to be associated with the number of animals but with conditions that contribute to rapid runoff and sediment movement (Sweeten 1998), such as slope, soil type, and season. The content of different components in runoff is also affected by the physiographic conditions. For example, phosphorus content in pen-floor manure varied significantly ($P \leq 0.05$) with season and bedding material (Miller et al. 2003), which directly affect runoff quality. If conditions favor surface runoff, the phosphorus content from open lots can be very high. Miller et al. (2004), studying quality of runoff from beef cattle feedlots in Alberta, found that

phosphorus concentration would need a 1224-fold dilution to meet the Canadian water quality guidelines for aquatic life or for human consumption.

In addition to feedlots, high phosphorus loads in runoff is also a problem in manure-amended soils. Manure applications are usually based on nitrogen plant requirement, which results in exceeding phosphorus in soils because the ratio of N to P in manure (4:1 to 5:1) is lower than the ratio needed by crops (6:1 to 8:1) (Zhang et al. 2006; Whalen and Chang 2001). This excess of phosphorus can result in greater mobility because movement of phosphorus is related to concentrations in top soil (McDowell et al. 2002). However, manure applications can reduce runoff volume and erosion by changing some of the soil properties (e.g. aggregation, bulk density), thus balancing the increased phosphorus loads. For instance, Gilley and Risse (2000) found that annual application of manure at several locations in the US resulted in a runoff reduction from 2 to 62%, while soil loss decreased from 15% to 65%.

Regardless of the origin, phosphorus-carrying runoff ultimately reaches water bodies. Overall, livestock waste can contribute up to 65% of total phosphorus loads in surface waters (Mulla et al. 1999 cited by Spellman and Whiting 2007). Contemporary interest in the environmental behavior of phosphorus is concentrated on its movement on rivers and lakes because phosphorus is often the biologically limiting factor in freshwaters (Merrington et al. 2002). Phosphorus is a particular concern in oligotrophic and mesotrophic lakes, where it determines the level of biological productivity (Klapper 1991). According to Bronmark and Hansson (1998), the relationship between phosphorus and primary productivity in water bodies was first established during 1950's and 1960's, when many lakes in urban areas and areas with modern agriculture went through a

process called eutrophication, characterized by dense algal blooms, bad odor, and mucky bottom. Eutrophication is described by those authors as a series of processes that begin with an increase in biomass of periphytic (attached) algae and submerged macrophytes as a response to the new phosphorus input. This growth is then prevented by a decrease in water transparency caused by a bloom of phytoplankton, especially cyanobacteria, which results in dead organisms on sediment. Decomposing bacteria mineralize this organic matter available on sediment at the expense of oxygen and, as a consequence, fish kills may happen due to reduced oxygen concentrations. Hence, eutrophication implies considerable ecological changes in the lentic environment with consequences to multiple uses of water such as recreation, fishing, and human consumption.

In Manitoba, eutrophication has been observed in Lake Winnipeg – the 10th largest freshwater lake in the world (Cicek et al. 2006). Unbalanced N:P ratios are involved in this process (North/South Consultants 2006), and nutrient loss from confined livestock areas in over-wintering sites appear in the list of target activities to be approached in order to reverse eutrophication (Lake Winnipeg Stewardship Board 2006). As general measures to prevent nutrient loss from these areas, Lake Winnipeg Stewardship Board recommends the re-direction of drainage into retention basins, use of grassed buffer strips or constructed wetlands, and rotation of holding and wintering areas to prevent a build-up of nutrients in the soil.

Apart from general measures to prevent eutrophication, some people advocate the adoption of more specific measures to assess P losses from intensive crop and livestock farming areas, which may be used to define risk potential. One of these measures is establishing a threshold of phosphorus level in soils from three to four times the level of

phosphorus that would not limit crop production (Daniel et al. 2006). However, this approach is often too simplistic because it does not consider potential runoff and erosion losses, as well as climatic, topographic, and agronomic factors (Sharpley et al. 1996). Thus, a measure called "Phosphorus Index" has been supported by some authors, which incorporates local/regional conditions for assessing and ranking the risk of P losses from individual fields (Lemunyon and Gilbert 1993). When first developed, this index was calculated from a matrix containing a limited number of landform characteristics of the site (Table 2.2; Daniel et al. 2006). Phosphorus loss due to each of these site characteristics would be assigned and multiplied by the respective weighting value, and the P index would be the sum of the contribution from each row in the matrix. The interpretation of the calculated P index would be based on a pre-defined site vulnerability scale, where areas with P index < 8 would have low potential of P loss, areas with P index from 8 to 14 would have medium potential, fields with P index from 15 to 32 would have high potential, and fields with P index > 32 would have very high potential for P losses. Nonetheless, this index is still being developed and its application varies from region to region, despite some evolving consistency among different approaches (Daniel et al. 2006).

Table 2.2. The original P index with additive source and transport factors.

Site Characteristic and (Weighting Factor)	Phosphorus Loss Rating and (Value)				
	None (0)	Low (1)	Medium (2)	High (3)	Very high (4)
Soil erosion (1.5)	NA†	< 5 tons/acre	5 to 10 tons/acre	10 to 15 tons/acre	> 15 tons/acre
Irrigation erosion (1.5)	NA	Infrequent irrigation on well-drained soils	Moderate irrigation on soils with slopes < 5%	Frequent irrigation on soils with slope of 2 to 5%	Frequent irrigation on soils with slope > 5%
Soil runoff class (0.5)	NA	Very low or low	Medium	Optimum	Excessive
Distance from watercourse, feet (1.0)	>1000	1000 to 500	500 to 200	200 to 30	< 30
Soil test P (1.0)	NA	Low	Medium	Optimum	Excessive
P fertilizer application rate, lb P/acre (0.75)	None applied	< 15	16 to 40	41 to 65	> 65
P fertilizer application method (0.5)	None applied	Placed with planter deeper than 2 inches	Incorporated immediately before crop	Incorporated > 3 months before crop or surface applied < 3 months before crop	Surface applied to pasture or applied > 3 months before crop
Organic P source application rate, lb P/acre (1.0)	None applied	< 15	16 to 40	41 to 65	> 65
Organic P source application method (0.5)	None applied	Injected deeper than 2 inches	Incorporated immediately before planting	Incorporated > 3 months before crop or surface applied < 3 months before crop	Surface applied to pasture or applied > 3 months before crop

† Not available

(Source: Daniel et al. 2006)

2.2 Electromagnetic induction for mapping nutrient accumulation in soils

Nutrients can be assessed as salts present in soil, and techniques to measure soil salinity can be used to this end. The conventional way to assess soil salinity comprises sampling the areas to be studied and analyzing samples using the saturated paste extract method (McNeill, 1992). In this method, the sample is saturated with distilled water and mixed using a spatula so that the soluble salts in the sample dissolve. Then, liquid portion is extracted under suction from the sample and the electrical conductivity (EC_e) is measured using a laboratory conductivity meter. This analysis can also be done with no need for extraction with a vacuum pump, where the saturated paste is prepared using one part of soil to two parts of water in a weight basis, and the conductivity of the solution is read using a laboratory conductivity meter. Rhoads (1990) presents a variation of this method that can be applied in the field, where a conductivity cell of $5x10^{-5}$ m^3 (50 cm^3) is filled with saturated soil paste and conductivity of the solution in the cell is read in a battery-powered conductivity meter. In this method, the conductivity of the solution in the cell is back transformed into EC_e using a series of charts.

Regrettably, all of these methods require analysis of a large number of samples to characterize nutrient distribution in the field, a process which involves coring and sample preparation. These constraints led to the application of faster techniques to assess soil salinity, such as electromagnetic induction. This technique has been used in geophysics for decades in the exploration of metallic ore, but only during the last years scientists have fully exploited the power of this technique to detect, locate, and discriminate both metallic and non-metallic objects (Witten 2006). Electromagnetic induction has been applied to several objectives, such as delineation of permafrost, location of gravel,

mapping of saline intrusions, detection of cavities in carbonate rocks, mapping of pollution plumes in groundwater, and mapping of general geological characteristics of terrain (McNeill 1980). It has also been successfully employed to describe soil characteristics by mapping soil apparent electrical conductivity (EC_a). The soil EC_a is a composite property affected by soils characteristics such water content, salinity, clay content and organic matter (Heiniger et al. 2003; Corwin and Lesch 2005). Thus, apparent electrical conductivity will be determined by either dynamic (e.g., salinity) or static (e.g., texture) soil properties. Although EC_a is a product of many factors, in general, only one or two factors will dominate its magnitude and variability (Corwin and Lesch 2005). Several studies report the use of EC_a to describe nutrient build-up (Eigenberg et al. 2002; Eigenberg and Nienaber 2003; Heiniger et al. 2003; Korsaeth 2005), water content (Shumman and Zaman 2003), and salinization (McKenzie et al. 1997; Slavick and Yang 1990).

The EC_a measurements alone do not provide sufficient information to describe other soil properties. Soil samples are required in order to interpret what EC_a measurements mean at a particular site (Corwin and Lesch 2005). The relationship between EC_a and the particular soil property that is being investigated is then assessed by statistical analysis, where correlation has been used as the most practical way (Corwin and Lesch 2003). However, some studies demonstrate that attention should be given to special factors when working with calibration of EC_a measurements. Bronson et al. (2005), for example, state that spatial covariance in EC_a is an important factor to consider. In their study, these authors found that dealing with covariance improved estimation of EC_a in 15 out of 18 cases.

When statistical analysis shows that a good relationship exists between EC_a and a particular soil property, apparent electric conductivity may be used to predict field variations of that property. However, the relationship between soil properties and EC_a may change in the landscape scale and interpretation of EC_a may become difficult. For instance, EC_a readings may be strongly influenced by water content in a portion of a field, but by salinity in another. Due to that variation, EC_a has been recommended to plan sampling design rather than to predict soil properties. Corwin et al. (2003) used EC_a maps to direct soil sampling design, as this technique has the capacity to reduce the number of core samples needed.

Regarding instrumentation for measuring EC_a, Corwin and Lesch (2005) report that the Geonics® EM-31 and EM-38 are the most commonly used EM conductivity meters in soil science. The EM devices induce current loops in the soil, which generate secondary electromagnetic fields. These secondary fields are intercepted by a receiver in the EM meter. The amplitude and phase of the secondary field will differ from those of the primary field as a result of soil properties, device features, and operation (Hendrickx and Kachanoski 2002), and differences between the two fields are used for EC_a calculation. The EM-38 has two operational modes and its response depends on orientation. In the horizontal dipole mode it takes measurements up to 0.75 m deep in the soil profile, while in the vertical dipole mode this depth goes up to 1.5 m. The EM-31 takes measurements at approximately 6 m deep. Due to its operational range, EM-38 is considered more suitable for agricultural purposes (Corwin and Lesch 2005).

2.3 Use of electromagnetic induction with Geographic Information System

Electromagnetic induction (EMI) coupled with Global Positioning System (GPS) has been used as a specific GIS technology in agriculture. It has been used in the last few years for precision agriculture (Bronson et al. 2005; Korsaeth 2005) and environmental impacts assessment (McKenzie et al. 1997; Heiniger et al. 2003). Although conductivity meters are not GIS tools, they can provide useful information for GIS purposes when coupled with Global Positioning System (GPS) because data generated are georeferenced thus allowing for easy mapping. Some authors call this coupling an EM-38 GPS system (Eigenberg and Nienaber 2003. McKenzie et al. (1997) used an EM-38 GPS system to map salinity in western Canada. They employed an improved technique called differential GPS (DGPS) to achieve more accuracy, which consists of using two GPS receivers, with one stationary and the other in motion. According to the authors, horizontal accuracies of a few centimeters can be readily achieved.

A positive aspect of using EM-38 for mapping purposes is that it allows for a large amount of data collection in a short time and repeatability of data collection. McKenzie et al. (1997), in their above cited study of salinity, collected more than 6,000 measurements in a 3-hour period. Data collected two days later had 2,744 common points. These characteristics enable temporal assessment of a particular soil property by successive mapping and improve the quality of interpolation. Greve and Greve (2004) used an EM-38 GPS system to classify the width of soil boundary transition zones. Their 2,500 measurements were interpolated using ordinary kriging (Fig. 2.2). They say that the large number of measurements (i.e. high density) made the prediction method (i.e.

interpolation) of less importance. Due to these characteristics, EM-38 GPS systems are quite suitable to be used with GIS.

The importance of geographical information systems (GIS) to electromagnetic induction technique rests on their capacity to easily manipulate and present data, facilitating analysis. According to Burrough and McDonnell (1998), GIS is a set of tools for collecting, storing, retrieving, transforming, analyzing and displaying spatial data from real world for particular purposes. Therefore, the aim of GIS is not only to create a representation of geophysical phenomena but to provide means of analyzing them. In fact, the ability to analyze data is the distinguishing factor between GIS and cartography (Schuurman 2004). This capability of GIS has made it applicable for many purposes, from waste disposal (Muttiah et al. 1996) to sea farming (Congleton et al. 1999).

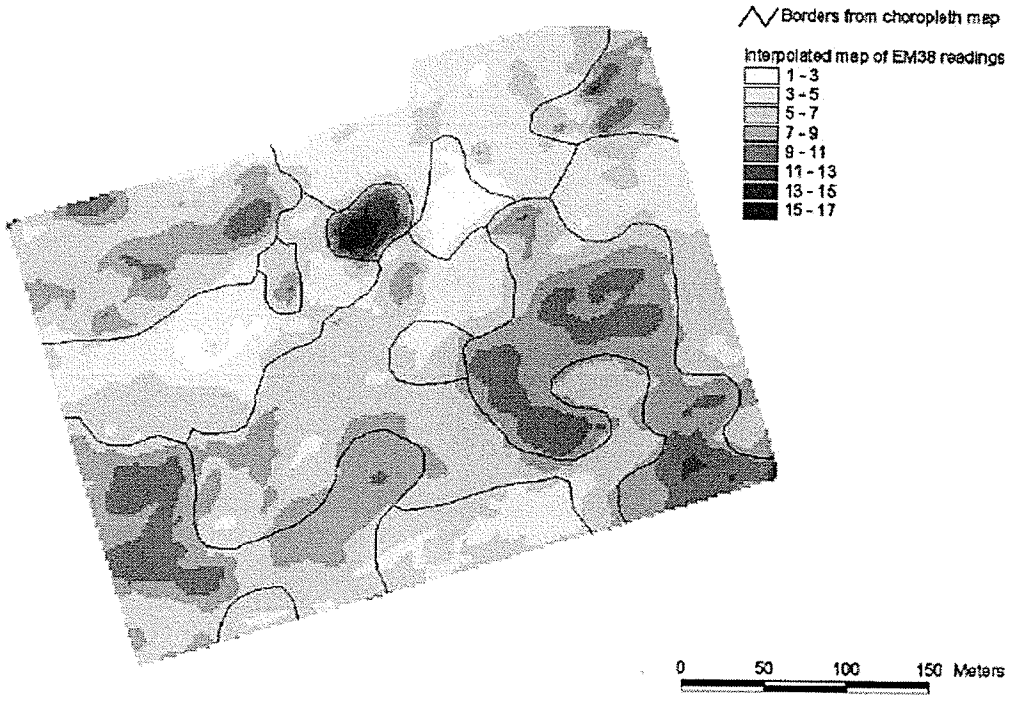

Fig. 2.2 Interpolated map of EC_a from EM-38 readings (Greve and Greve 2004).

Data analysis in GIS may be performed by different operations run for specific entities (e.g. attributes, distance/location, and topology), where modeling is one of them (Burrough and McDonnell 1998). Numerical models have been used to predict future scenarios based on existing data for the present situation, but there are many ways by which such analyses can be done. Schuurman (2004) describe the process as three different steps. In the first, spatial data are represented and organized in GIS. Next, modeling processes are performed outside GIS. Finally, the results are imported back into GIS and analyzed using overlay techniques. In this case, two different environments are used to accomplish the analysis.

There are a myriad of software programs coupled with GIS for performing analysis for different purposes. In environmental studies, such programs have been used for atmospheric (Canepa et al. 2007), oceanographic (Congleton et al. 1999), hydrogeologic (Kolm 1996; Mende et al. 2007) and biological (Baklouti et al. 2006) purposes. Focusing on groundwater management, some studies have been carried out. San Juan and Kolm (1996) used MODFLOW coupled with GIS for groundwater management in northwest Wyoming. Since the numerical model was not designed for groundwater management purposes, they suggest development of a more complex model. Also, Yang et al. (2007) tried the effectiveness of DRAINMOD-N model in simulating nitrate-N movement on an experimental farm in southern Ontario. They assert that DRAINMOD-N was only accurate to predict surface runoff, being less accurate in predicting drain outflow. Singh et al. (2006), using the same model to design subsurface drainage systems in Iowa, found similar results. Marinov et al. (2005) used AMINO (Agricultural-Nutrient-Model) to describe nitrogen movement and transformations in an

experimental arable plot in Bulgaria. They found that simulations showed great divergence with observations. These results led the authors to conclude that future research is necessary to improve the models.

3. CALIBRATION MODELS FOR ELECTROGAMNETIC INDUCTION TO ASSESS NUTRIENT BUILD-UP IN FEEDLOTS

3.1 Abstract

Nutrient build-up caused by animal manure is a potential source of environmental impact. Electromagnetic induction (EMI) has become a practical method to assess nutrient in soils, with multiple linear regression (MLR) as the statistical method often employed to translate EMI readings into nutrient content (i.e. calibration). A particular form of MLR, called spatial MLR, has become common in the last years as a calibration method. This work aimed to compare the performance of MLR models incorporating "easy-to-acquire" information (e.g. micro-elevation) with that of spatial MLR. Six feedlot areas were surveyed with an EM-38 conductivity meter and between 6 and 12 sites at each feedlot were sampled at five depths according to the sample design defined by ESAP–RSSD software. Quantities of extract electrical conductivity (EC_e), nitrate (NO_3^-) and phosphate (PO_4^{3-}) were obtained from samples and used as response variables for both MLR methods. Analyses were performed in two different approaches. First, models were built by layer and, second, a composite analysis was performed using profile-averaged and profile-weighted approaches. The results of both MLR methods were comparable in most instances because the models used only predictors derived from EM-38 readings. Differences in models were more evident when predicting NO_3^- and PO_4^{3-}, even though prediction of these two analytes by either method was generally poor. Composite analysis was more appropriate to assess nutrient build-up because by-layer analysis gave non-significant or poor models in many instances. Averaged-profile was poorer than

weighted-profile analysis, with better results for vertically-weighted MLR. However, the weighted approach can only be used when the whole soil profile can be sampled.

3.2 Introduction

Manure build-up is an inevitable process in the operation of confined livestock areas or feed lots. Consequently, the accumulation of nutrients within the soil below these areas needs to be monitored to assess the potential environmental risk (Eigenberg and Nienaber 2003). Traditional nutrient assessment methods rely on collecting samples at specific sites and performing off-site analysis (Eigenberg et al. 2002), which is tedious and expensive. Alternative methods such as geophysical tools can deliver meaningful data to delineate regions of high nutrient build-up (Eigenberg and Nienaber 2003). Current techniques that apply direct electromagnetic induction (EMI) in the soil have enabled direct measurement and mapping of apparent electrical conductivity (EC_a) (Heiniger et al. 2003).

The EC_a is a composite property influenced by soils properties such as water content and salinity (Heiniger et al. 2003), clay content and organic matter (Corwin and Lesch 2005). Despite EC_a being a product of many factors, in general, only one or two factors will dominate its magnitude and variability (Corwin and Lesch 2005). Several studies report the use of EC_a to describe nutrient build-up (Eigenberg et al. 2002; Eigenberg and Nienaber 2003; Heiniger et al. 2003; Korsaeth 2005), water content (Shumman and Zaman 2003), and salinization (McKenzie et al. 1997; Slavick and Yang 1990). Nonetheless, EC_a measurements alone do not provide sufficient information to quantify these variables. Ground-truth soil samples are required in order to interpret what EC_a measurements mean at a particular site (Corwin and Lesch 2005).

The relationship between EC_a and the particular soil property being investigated is usually assessed by statistical analysis, where correlation has been suggested as the most practical way (Corwin and Lesch 2003). Despite using regression-based procedures, different calibration methods have been devised (Rhoads and Corwin 1981; Wollenhaupt et al. 1986; Rhoads et al. 1989; McKenzie et al. 1989; Slavich and Petterson 1990; Lesch et al. 1992; Rhoads 1992). These methods have incorporated complexities such as spatial covariance in EC_a (Bronson et al. 2005) and differences in salinity profile (Corwin and Rhoads 1990), rendering these models more precise and reliable.

Multiple linear regression (MLR) has been used often as a calibration method. Some recent studies describe the use of this method in different settings (Kaffka et al. 2005; Amezketa 2006; Fitzgerald et al. 2006). The adoption of MLR seems to have intensified since Lesch et al. (1995a,b) i) proved this method gave results as good as interpolation techniques but with the advantage of requiring less samples, and ii) proposed a methodology that optimizes the sampling design to minimize the number of samples. This method was incorporated into ESAP, a software released by the US Department of Agriculture. The ESAP program is often used for EMI calibration (Nogues et al. 2006), adopting an approach known as spatial MLR. This approach uses log-transformed, decorrelated EMI readings, and centered, scaled trend surface parameters for model estimation (Lesch et al. 2000). Decorrelation of EM readings aims to achieve orthogonality (i.e. independence) between predictors and is accomplished by calculation of both primary (z1) and secondary (z2) principal component scores. Similarly, the scaling techniques applied to trend surface parameters (i.e. spatial coordinates x and y) help ensure the matrix inversion techniques used by the regression

modeling algorithm remain stable. Regression-wise, spatial MLR takes advantage of the location information that is available when georeferenced EMI readings are acquired. Incorporation of such information can improve predictability of the models with no impact on cost.

Following this trend, information available from other sources, such as Geographic Information System (GIS) databases, could be incorporated into MLR models. For example, in the Province of Manitoba, Canada, information on soil characteristics is available at Manitoba Land Initiative GIS database and Agriculture and Agri–Food Canada land resources. Such "easy-to-acquire" information (Burrough and McDonnell 1998) can be used to improve prediction capabilities of multiple linear regression models.

The objectives of this paper were i) to assess the impact of "easy-to-acquire" soil information on MLR models for the prediction of nutrient build-up in soils beneath feedlots, and to compare these models with spatial MLR; and ii) to try the performance of these models in two different situations. First, models were built for five discrete depth increments throughout the soil profile; second, a single composite model was calculated for the whole profile. Profile-averaged and profile-weighted methods were compared when calculating the composite models.

3.3 Material and Methods

3.3.1 Data collection in the field

Six feedlot areas were investigated in Southern Manitoba, Canada, in September and October 2007. These areas were coded Farm 1 through 6. Electromagnetic induction

surveys were conducted using EM-38 conductivity meter (accuracy ∓ 5% at 30 mS m^{-1}; Geonics Ltd., Mississauga, ON, Canada), coupled with Allegro CX field PC (Juniper Systems, Inc., Logan, UT, USA) for data logging, and GPSMAP CSx GPS receiver (accuracy ∓ 3 m; Garmin International Inc., Olathe, KS, USA) for position acquiring. In each farm, the georeferenced EMI readings were acquired in between 66 and 226 locations in both vertical (EM_V) and horizontal (EM_H) orientations. It was attempted to follow a regularly spaced grid but this was not always possible due to physical barriers (e.g. hey bales) or metallic objects (e.g. fences, tractor parts) that would affect the EM-38 response. The EMI readings and the GPS positions were uploaded to a laptop PC and combined using DAT38W software (Geonics Ltd., Mississauga, ON, Canada). A detailed description about data upload and GPS position combination can be found in the DAT38W program manual (Geonics, 2002).

After incorporation of GPS positions, files with separated EM_V and EM_H readings were merged together using Microsoft Excel (Microsoft Corp., Redmond, WA, USA) and each pair of readings (i.e. horizontal and vertical) with its respective GPS position had an integer identifier added. These files were then exported into text-format files and used for sampling design calculation, which was accomplished by the ESAP–RSSD software, version 2.35R (USDA–ARS, Riverside, CA, USA). This program uses a response surface design to identify a minimum number of sites from which samples are obtained for calibration of multiple linear regression models (Lesch et al., 1995b). Twelve sites were defined for sampling in all farms but Farm 6, which had 6 sample sites. Geographical coordinates of the sample sites designed by the ESAP–RSSD software were fed into the GPS receiver and located for soil coring. Samples were taken with hand auger at depth

internals 0 – 0.15, 0.15 – 0.30, 0.30 – 0.60, 0.60 – 0.90, and 0.90 – 1.20 m, put in Ziploc bags, and taken to the lab.

Micro-elevations of the surveyed areas, used as "easy-to-acquire" information, were acquired using Rugby 100 construction laser (Leica Geosystems AG, Unterentfelden, Switzerland) and Cyclone laser detector (accuracy ∓ 0.5mm; Apache Technologies, Inc., Dayton, OH, USA). Between 38 and 84 level points were randomly taken in each farm and interpolated in ArcMap version 9.1 (ESRI, Inc., Redlands, CA, USA) using ordinary kriging interpolation technique. Micro-elevations for the sample sites were obtained from these interpolations.

3.3.2 Laboratory procedures

In the laboratory, soil samples were analyzed for gravimetric water content (GWC) within 24 h collection. Two replicates were oven dried at 105°C for 24 h (Black 1965). The remainder of the samples was kept refrigerated at 4°C or less until utilized for further analyses. Soil aliquots of between 50 and120 g were used for saturated-paste extraction method. Sample extracts were analyzed for electrical conductivity (EC_e), nitrate (NO_3^-) and phosphate (PO_4^{3-}) content. Extracts were diluted to increase volume so that aliquots could be taken for quantification of the different analytes. Samples examined for NO_3^- were diluted from 1:30 to 1:45 times and analyzed using a QuickChem 8500 Ion Analyzer (accuracy ∓ 0.5 %; Lachat Instruments, Milwaukee, WI, USA). Samples examined for PO_4^{3-} were diluted from 1:50 to 1:90 times and analyzed with an Ultrospec 4300 spectrophotometer (accuracy ∓ 0.5% at 546 nm; Biochrom Ltd., Cambridge, UK). Determination of EC_e was performed in aliquots diluted from 1:30 to

1:120 times using YSI 32 conductivity meter (accuracy ∓ 1%; YSI, Inc., Yellow Springs, OH, USA).

3.3.3 Preliminary variable calculation

Some variables had to be calculated prior to statistical analysis. Bulk density, also used as "easy-to-acquire" information, was calculated from data available from Manitoba Agriculture database (2006). This database contains soil profile information for the areas surveyed, including sand, silt, and clay contents by depth. Clay content (%C) for each depth was used to calculate the saturation percentage (SP) and bulk density (ρ_b) using the relationships presented by Rhoads (1990):

$$SP = 0.76(\%C) + 27.25 \quad [3.1]$$

and

$$\rho_b = 1.73 - 0.0067(SP). \quad [3.2]$$

Volumetric water content (VWC) was then found by multiplying GWC by ρ_b, assuming water density (ρ_w) equal to 1Mg m^{-3}.

Both EM_V and EM_H were also transformed to be consistent with the spatial MLR methodology proposed by Lesch et al. (2000). De-correlation was achieved by principal component (PC) analysis calculated from log-transformed (i.e. natural log), centered (i.e. subtracted from mean) EM readings. The values of the principal component for each observation (i.e. PC scores) were found using the formula presented by Jolliffe (1986):

$$\mathbf{Z} = \mathbf{XA}, \quad [3.3]$$

where, **Z** is the matrix of principal component scores, **X** is the matrix of original observations (i.e. log-transformed, centered EM_V or EM_H), and **A** is the matrix of

eigenvectors calculated from the original observations. The PC analysis for the calculation of **A** was performed using the multivariate methods in JMP 7.0 (SAS Institute Inc., Cary, NC, USA). Calculation of **Z** was performed in Microsoft Excel using matrix multiplication functions. The new transformed variables were then labeled z1 and z2. As stated in the introduction, these calculations aim to achieve predictos that are orthogonal to each other and, thus, independent.

Centered, scaled spatial coordinates were calculated from originals coordinates using the relationships presented by Lesch et al. (2000):

$$x = [u - \min(u)]/k \qquad [3.4a]$$

and

$$y = [v - \min(v)]/k \qquad [3.4b]$$

where x and y are the centered, scaled spatial coordinates, u and v are the original coordinates, min(u) and min(v) are the minimum values of u and v, respectively, and k is the greater of [max(u) – min(u)] or [max(v) – min(v)].

3.3.4 Calculation of MLR models

Two different MLR analyses were performed for each farm. The first MLR, which uses "easy-to-acquire" data, will therefore be called 'soft MLR'; the second is called 'spatial MLR'. Details about these models are presented in the following subsections. Models were built in two different approaches (Fig. 3.1). First, the analysis was carried out for individual layers (i.e. by depth); second, it was performed for the whole soil profile (i.e. composite). The latter was further separated into profile-averaged and profile-weighted. Finally, the profile-weighted approach was split into vertically and

horizontally weighted approaches. The response variables and predictors which had values for all the depths (e.g. volumetric water content) were weighted according to EM-38 conductivity meter responses. McNeill (1980) presents details about conductivity meter responses and how they vary with vertical or horizontal positioning of the device.

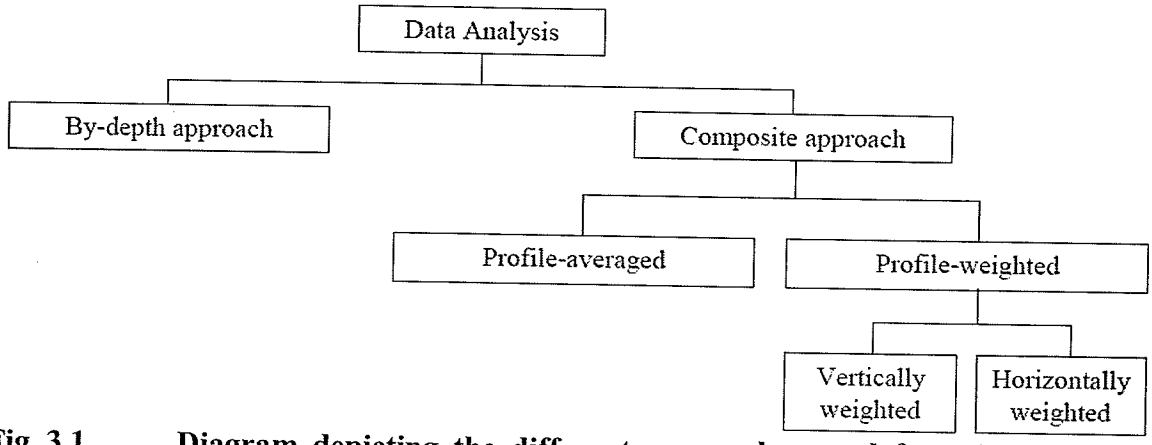

Fig. 3.1 Diagram depicting the different approaches used for calculation of multiple linear regression calibration models.

3.3.4.1 By-depth approach

The response variables used in this analysis were EC_e, NO_3^-, and PO_4^{3-}. However, the method and predictors employed varied according to the type of MLR. Soft MLR was accomplished using a stepwise approach in JMP 7.0, having z1 and z2, volumetric water content (VWC), and micro-elevation (LEVEL) as predictors. Spatial MLR analysis was carried out by ESAP–Calibrate program, version 2.35R (USDA–ARS, Riverside, CA, USA), having z1, z2, x, and y as predictors. The auto-analyze function in ESAP–Calibrate was used because the stepwise regression is not an option in this program. In this case, the "best" model was chosen by the algorithm in ESAP–Calibrate based on the lowest PRESS score. In regression modeling, PRESS score is the sum of jack-knifed prediction errors, and reflects the predictive accuracy of the regression model

(Amezketa 2006). A description about this statistic can be found in Montgomery and Peck (1992). ESAP–Calibrate did not make use of the variables calculated in section 3.3.3 because it calculates its own variables from raw data using the same procedure. Details about this program and how it operates is described by Lesch et al. (2000).

3.3.4.2 Composite approach

This approach used response variables and predictors either averaged or weighted over the entire soil profile, rather than values for discrete depths. In the averaged approach, values of response variables and predictors were profile-averaged (i.e. arithmetic average), except for those measured at the surface only (i.e. z1, z2, LEVEL, x, and y). The response variables in both soft and spatial MLR were aEC_e, aNO_3^-, and aPO_4^{3-} (the prefix 'a' stands for 'averaged'). Predictors for soft MLR were z1, z2, averaged volumetric water content (aVWC), and micro-elevation (LEVEL), while for spatial MLR the predictors were z1, z2, x and y. The soft MLR was accomplished using stepwise approach in JMP 7.0, and spatial MLR was achieved using the auto analyze function in ESAP–Calibrate.

In the weighted approach, weighted responses wEC_e, wNO_3^-, and wPO_4^{3-} (the prefix 'w' stands for 'weighted') were calculated by adding the relative contribution from each depth interval. Two equations were used in this because the response of EM-38 depends on which orientation readings are taken (i.e. either vertical or horizontal). These relationships were adapted from Wollenhaupt et al. (1986) and are shown here for wEC_e:

$$wEC_{eV} = 0.14\ EC_{e,0\text{-}0.30} + 0.22\ EC_{e,0.3\text{-}0.6} + 0.15\ EC_{e,0.6\text{-}0.9} + 0.11\ EC_{e,0.9\text{-}1.2} + 0.08\ EC_{e,1.2\text{-}1.5} + 0.03EC_{e,1.5\text{-}1.8} + 0.27EC_{e>1.8} \quad [3.5a]$$

and

$$wEC_{eH} = 0.43\ EC_{e,0\text{-}0.30} + 0.21\ EC_{e,0.3\text{-}0.6} + 0.10\ EC_{e,0.6\text{-}0.9} + 0.06\ EC_{e,0.9\text{-}1.2} + 0.2\ EC_{e>1.2}, \quad [3.5b]$$

where wEC_{eV} end wEC_{eH} are the weighted EC_e calculated for vertical and horizontal EM readings, respectively; subscripts denote the EC_e for particular depth intervals in meters; and coefficients represent the contribution from depth intervals to weighted EC_e. In fact, Eq. [3.5a] and [3.5b] are designed for weighted EC_a calculations, but they have been used to calculate weighted EC_e because these two variables are highly correlated (Wollenhaupt et al. 1986).

Modifications were done in these equations to incorporate the depth intervals 0 – 0.15 and 0.15 – 0.30 m. Contribution from layer 0 – 0.15 m was calculated using the relationships

$$C_{V,0\text{-}15} = 1 - R_{V(Z)} \quad [3.6a]$$

and

$$C_{H,0\text{-}15} = 1 - R_{H(Z)}, \quad [3.6b]$$

where, $C_{V,0\text{-}15}$ and $C_{H,0\text{-}15}$ are the contributions from the layer 0 – 0.15 m for vertical and horizontal EM readings, respectively; $R_{V(Z)}$ and $R_{H(Z)}$ are the contributions from all the material below the depth z to EC_a; and z is the depth divided by the EM-meter intercoil spacing. As this spacing is 1.0 m for EM-38, z is equal to the depth being calculated, which is 0.15 m in the present case. Mathematical relationships for $R_{V(Z)}$ and $R_{H(Z)}$ are presented by McNeill (1980):

$$R_{V(Z)} = \frac{1}{(4z^2 + 1)^{1/2}} \qquad [3.7a]$$

and

$$R_{H(Z)} = (4z^2 + 1)^{1/2} - 2z, \qquad [3.7b]$$

where, z is defined as before (please note z is not the same as variables z1 and z2). The contribution of layer 0.15 – 0.30 m was then found by subtracting the contribution of layer 0 – 0.15 m found using Eq. [3.6a] and [3.6b] from the contribution from layer 0 – 0.30 m in the Eq. [3.5a] and [3.5b].

One last constraint that had to be overcome was the lack of ground-truth information for the last term in Eq. [3.5b] and the last three terms in Eq. [3.5a]. These terms count for the contribution of depths below 1.2 m, which were not sampled in this study. Thus, EC_e for non-sampled depths was assumed to be equal to that of the layer 0.90 – 1.2 m, and values from this layer were repeated for the layers below in either case. According to Corwin and Rhoads (1990), this assumption will not drastically affect calibration since EM-38 is relatively insensitive to these depths. The fully adapted equations for weighted EC_e were:

$$wEC_{eV} = 0.04\ EC_{e,0\text{-}0.15} + 0.10\ EC_{e,0.15\text{-}0.3} + 0.22\ EC_{e,0.3\text{-}0.6} + 0.15\ EC_{e,0.6\text{-}0.9} + 0.11\ EC_{e,0.9\text{-}1.2} + 0.33 EC_{e>1.2} \qquad [3.8a]$$

and

$$wEC_{eH} = 0.26\ EC_{e,0\text{-}0.15} + 0.17\ EC_{e,0.15\text{-}0.3} + 0.21\ EC_{e,0.3\text{-}0.6} + 0.10\ EC_{e,0.6\text{-}0.9} + 0.06\ EC_{e,0.9\text{-}1.2} + 0.2\ EC_{e>1.2} \qquad [3.8b]$$

Calculation of weighted NO_3^- and weighted PO_4^{3-} was achieved by replacing EC_e with NO_3^- and PO_4^{3-} for all depth intervals in Eq. [3.8a] and [3.8b]. The volumetric water content (VWC), used as a predictor in soft MLR, was also weighted using the above relationships. The whole procedure of weighting variables resulted in two sets (i.e. vertical and horizontal) of three variables (i.e. wEC_e, wNO_3^-, and wPO_4^{3-}), which were then used as responses in the regression analysis. Four predictors were used in soft MLR, namely, z1 and z2, weighted volumetric water content (wVWC), and micro-elevation (LEVEL). For spatial MLR, the predictors were z1, z2, x and y. Again, z1, z2, micro-elevation, x, and y were not weighted because they were surface parameters. Both weighted MLR analyses were performed with JMP 7.0 using stepwise approach because ESAP–Calibrate does not weight variables.

3.4 Results

Farms 4 and 6 could not be sampled at depths below 0.15 and 0.30 m, respectively, due to the shallow soil layer overlying subcrop bedrock. Therefore, results for these farms are not presented below these depths. Also, depth 0.15 – 0.30 m in Farm 6 had only 10 samples collected because of the presence of bedrock at 0.15 m in two sample sites. This mismatch in number of samples between these two layers caused an internal error in ESAP and, because of this, only the 10 samples common to both depths were used in the calculations.

The distribution of the variables throughout the soil profile varied with depth. The larger variability found in electrical conductivity at the farms which had the whole profile sampled was observed in the first layers (Appendix D). Farms 1 and 2 seemed to present a uniform profile with large variability in the first layer, while Farm 2 had inverted

profile also with large variability in the top layer. Characterization of Farm 3 was more difficult because the distribution presented high values of EC_e at top and bottom depths. Distribution in Farm 5 resembles a uniform distribution with large variability. Distribution of nitrate in farms 1 and 5 seemed inverted (dismissing outlier values in farm 5), while it seemed more uniform in farms 2 and 3 if extreme values are dismissed. For phosphate, farms 1, 2, and 5 presented inverted profiles, while distribution in farm 3 was again difficult to be characterized due to high values in both top and bottom layers.

The statistical distribution of the variables was assessed in JMP and differed among farms. Electrical conductivity presented normal distribution in farms 2, 4, and 6 and log-normal distribution in farms 1, 3, and 5. Nitrate presented normal distribution only in farm 1, while phosphate presented normal distribution only in farms 1 and 3. In fact, many soil properties and other materials in soils seem to be approximately log-normally distributed, and skewness is the most common departure from normality (Webster and Oliver 1990). The distribution of variables showed this behavior, and log-transformation was tried; however, transformation was not attained due to internal error in ESAP – Calibrate during model calculation of nitrate (all farms except farm 5) and phosphate (farm 2). Due to that, the variables were not transformed to keep consistency during analysis. Where transformation was possible, models using transformed and orginal variables were compared. The comparisons showed that the capacity of prediction of the models did not vary largely, and characteristics of the models were essentially the same (data not shown).

The stepwise routine in JMP built independent models for each depth interval within a farm. These models are presented in each row of soft MLR tables. The integers

under the predictors show the sequence in which predictors were included in the model (e.g. 1 = first predictor included, 2 = second predictor included). Dashes mean non-inclusion of predictors because they were not statistically significant (α=0.05). Rows containing only dashes mean the model was not significant at all (α=0.05). Coefficient of determination (r^2) and root mean square error (RMSE) are presented after predictors. Conversely, auto-analyze function in ESAP–Calibrate built a single model for all depth intervals. This allowed arranging the results of spatial MLR for all three response variables in a single table, where r^2 and RMSE are presented. The models are presented in the footnote of spatial MLR tables.

3.4.1 By-depth approach

3.4.1.1 Soft MLR

Results of the soft MLR analysis using EC_e as the response variable are shown in Table 3.1. The prediction capability of the models was poor in most cases (i.e. $r^2 < 0.70$), with exceptions at depth 0.90 – 1.20 m in Farm2, depths 0 – 0.15, 0.15 – 0.30 in Farm 3, the single depth in Farm 4, the top three depths in Farm 5, and all two depths in Farm 6. There was no consistent pattern of improvement of prediction with depth. For example, r^2 increased with depth in farms 1 and 6; it also increased in Farm 2, but it decreased in farms 3 and 5. Farm 4 was sampled only at the first depth and, therefore, had no pattern. The results also show that z1 was the only significant predictor in farms 1, 4 and 5. The z2 was the only predictor in the two top layers of Farm 2, but appears as the second predictor in the bottom layer of this farm and in the two depths of Farm 6. The predictors LEVEL and VWC appeared only once. The former was included as the second predictor in the layer 0 – 0.15 m in Farm 3, while the latter appeared as the only predictor at depth 0.15 – 0.30 m in the same farm.

Table 3.1. Predictors, r^2, and RMSE from by-depth soft MLR models having EC_e (dS m^{-1}) as response variable.

Site Farm / Layer (#) (m)	Predictors z1	z2	VWC (%)	LEVEL (cm)	n	r^2	RMSE (dS m^{-1})
Farm 1							
0-0.15	1	–	–	–	12	0.39	3.11
0.15-0.30	1	–	–	–	12	0.53	0.93
0.30-0.60	1	–	–	–	12	0.64	0.37
0.60-0.90	–	–	–	–	–	–	–
0.90-1.20	1	–	–	–	12	0.63	0.41
Farm 2							
0-0.15	–	1	–	–	12	0.52	2.93
0.15-0.30	–	1	–	–	12	0.49	2.50
0.30-0.60	1	–	–	–	12	0.63	0.52
0.60-0.90	1	–	–	–	12	0.44	0.60
0.90-1.20	1	2	–	–	12	0.82	0.49
Farm 3							
0-0.15	1	–	–	2	12	0.74	0.98
0.15-0.30	–	–	1	–	12	0.74	0.82
0.30-0.60	–	–	–	–	–	–	–
0.60-0.90	1	–	–	–	12	0.62	0.34
0.90-1.20	1	–	–	–	12	0.42	0.89
Farm 4							
0-0.15	1	–	–	–	6	0.86	0.49
Farm 5							
0-0.15	1	–	–	–	12	0.80	2.00
0.15-0.30	1	–	–	–	12	0.83	1.95
0.30-0.60	1	–	–	–	12	0.70	1.52
0.60-0.90	1	–	–	–	12	0.61	1.85
0.90-1.20	1	–	–	–	12	0.48	1.46
Farm 6							
0.00-0.15	1	2	–	–	10	0.77	1.38
0.15-0.30	1	2	–	–	10	0.86	1.06

Table 3.2 shows the results of soft MLR for the response variable NO_3^-. In this case, most models were not significant (α=0.05). Models could be built in six cases, out of which only three had $r^2 \geq 0.70$. There was no clear pattern of significance of models with depth, but valid relationships seemed to be restricted to the first three depths, except for Farm1 which presented a significant model at depth 0.90 – 1.20 m. Volumetric water content seemed to be the most important predictor for NO_3^- as it appeared in five of six significant models and was the only regressor in four of them. Likewise, soft MLR models were not significant for PO_4^{3-} in most instances (Table 3.3). Significant models seemed to be restricted to the top layers, except by Farm 2 that had valid models for depths up to 0.90 m. Coefficient of determination was low for most models. The only case where r^2 was over 0.70 occurred at a depth 0.15 – 0.30 m in Farm 2.

Table 3.2. Predictors, r^2, and RMSE from by-depth soft MLR models having NO_3^- (mg 100 g soil^{-1}) as response variable.

Site Farm / Layer (#) (m)	Predictors z1	z2	VWC (%)	LEVEL (cm)	n	r^2	RMSE (mg 100 g soil^{-1})
Farm 1							
0-0.15	–	–	–	–	–	–	–
0.15-0.30	–	–	–	–	–	–	–
0.30-0.60	1	–	2	–	12	0.83	0.14
0.60-0.90	–	–	–	–	–	–	–
0.90-1.20	1	–	–	–	12	0.50	0.14
Farm 2							
0-0.15	–	–	–	–	–	–	–
0.15-0.30	–	–	–	–	–	–	–
0.30-0.60	–	–	–	–	–	–	–
0.60-0.90	–	–	–	–	–	–	–
0.90-1.20	–	–	–	–	–	–	–
Farm 3							
0-0.15	–	–	–	1	12	0.42	0.76
0.15-0.30	–	–	1	–	12	0.74	0.42
0.30-0.60	–	–	–	–	–	–	–
0.60-0.90	–	–	–	–	–	–	–
0.90-1.20	–	–	–	–	–	–	–
Farm 4							
0-0.15	–	–	1	–	6	0.89	0.02
Farm 5							
0-0.15	–	–	–	–	–	–	–
0.15-0.30	–	–	–	–	–	–	–
0.30-0.60	–	–	1	–	12	0.37	0.01
0.60-0.90	–	–	–	–	–	–	–
0.90-1.20	–	–	–	–	–	–	–
Farm 6							
0.00-0.15	–	–	–	–	–	–	–
0.15-0.30	–	–	–	–	–	–	–

Table 3.3. Predictors, r^2, and RMSE from by-depth soft MLR models having PO_4^{3-} (mg 100 g soil^{-1}) as response variable.

Site Farm / Layer (#) (m)	Predictors z1	z2	VWC (%)	LEVEL (cm)	n	r^2	RMSE (mg 100 g soil^{-1})
Farm 1							
0-0.15	1	–	–	–	12	0.38	0.08
0.15-0.30	–	–	–	–	–	–	–
0.30-0.60	–	–	–	–	–	–	–
0.60-0.90	–	–	–	–	–	–	–
0.90-1.20	–	–	–	–	–	–	–
Farm 2							
0-0.15	1	–	–	–	12	0.60	0.02
0.15-0.30	1	–	–	–	12	0.79	<0.01
0.30-0.60	–	–	–	1	12	0.45	<0.01
0.60-0.90	1	–	–	–	12	0.45	<0.01
0.90-1.20	–	–	–	–	–	–	–
Farm 3							
0-0.15	–	–	–	–	–	–	–
0.15-0.30	–	–	–	–	–	–	–
0.30-0.60	–	–	–	–	–	–	–
0.60-0.90	–	–	–	–	–	–	–
0.90-1.20	–	–	–	–	–	–	–
Farm 4							
0-0.15	–	–	–	–	–	–	–
Farm 5							
0-0.15	–	–	–	–	–	–	–
0.15-0.30	–	–	–	1	12	0.50	<0.01
0.30-0.60	–	–	–	1	12	0.57	<0.01
0.60-0.90	–	–	–	–	–	–	–
0.90-1.20	–	–	–	–	–	–	–
Farm 6							
0.00-0.15	–	–	1	–	10	0.38	<0.01
0.15-0.30	–	–	–	–	–	–	–

3.4.1.2 Spatial MLR

Results for spatial MLR analysis are presented in Table 3.4, and the models selected by ESAP–Calibrate are presented at the footnote of this table. Values of r^2 for EC_e were low (< 0.70) in farms 1 and 2, high (≥ 0.70) in farms 4 and 6, and varied with depth in farms 3 and 5. In the latter two farms, r^2 was consistently higher at depths 0 – 0.15, 0.15 – 0.30 m. The z1 was the only predictor in farms 1, 2, 4, and 5, but predictors $z1^2$ and x appeared in Farm 3, and predictor z2 occurred in Farm 6.

For NO_3^-, models were either poor or non-significant in all cases except for depths 0 – 0.15 and 0.15 – 0.30 m in Farm 3. Farms 1, 2 and 5 had z1 as the single predictor. Farm3 had a model with seven predictors, including those of second-order (i.e. $z1^2$, x^2, and y^2) and cross-product (i.e. xy). Models for farms 4 and 6 included y as a trend surface parameter. Regarding PO_4^{3-}, farms 1 and 2 had significant (α=0.05) and good ($r^2 \geq 0.70$) models at depths 0 – 0.15 and 0.15 – 0.30 m, respectively. Significant, good models occurred in Farm 3 at bottom layer and in Farm 5 at both top and bottom layers. Models were non-significant for non-mentioned farms. Predictors varied largely for PO_4^{3-}, with $z1^2$ included in farms 1, 5, and 6, and y included in farms 3 and 4.

Table 3.4. The r^2 and RMSE from by-depth spatial MLR models having EC_e (dS m^{-1}), NO_3^- (mg 100 g $soil^{-1}$), and PO_4^{3-} (mg 100 g $soil^{-1}$) as response variables.

Farm (#)	Site / Layer (m)	n	Response Variable: ECe r^2	ECe RMSE (dS m^{-1})	NO_3^- r^2	NO_3^- RMSE (mg 100g $soil^{-1}$)	PO_4^{3-} r^2	PO_4^{3-} RMSE (mg 100g $soil^{-1}$)
Farm 1								
	0-0.15	12	$0.36^{\dagger}$	3.17	$0.00^{\dagger NS}$	0.99	$0.77^{\ddagger}$	0.05
	0.15-0.30	12	$0.50^{\dagger}$	0.96	$0.14^{\dagger NS}$	0.77	$0.40^{\ddagger NS}$	0.04
	0.30-0.60	12	$0.66^{\dagger}$	0.36	$0.49^{\dagger}$	0.23	$0.18^{\ddagger NS}$	< 0.01
	0.60-0.90	12	$0.31^{\dagger NS}$	0.62	$0.32^{\dagger NS}$	0.26	$0.40^{\ddagger NS}$	< 0.01
	0.90-1.20	12	$0.66^{\dagger}$	0.39	$0.50^{\dagger}$	0.14	$0.06^{\ddagger NS}$	< 0.01
Farm 2								
	0-0.15	12	$0.35^{\dagger}$	3.44	$0.00^{\dagger NS}$	0.41	$0.60^{\dagger}$	0.02
	0.15-0.30	12	$0.31^{\dagger NS}$	2.92	$0.02^{\dagger NS}$	0.49	$0.79^{\dagger}$	< 0.01
	0.30-0.60	12	$0.63^{\dagger}$	0.52	$0.00^{\dagger NS}$	0.17	$0.42^{\dagger}$	< 0.01
	0.60-0.90	12	$0.44^{\dagger}$	0.60	$0.04^{\dagger NS}$	0.23	$0.44^{\dagger}$	< 0.01
	0.90-1.20	12	$0.69^{\dagger}$	0.60	$0.04^{\dagger NS}$	0.36	$0.01^{\dagger NS}$	< 0.01
Farm 3								
	0-0.15	12	$0.79^{\S}$	1.00	$0.93^{\P}$	0.43	$0.03^{\#NS}$	0.02
	0.15-0.30	12	$0.72^{\S}$	1.03	$0.91^{\P}$	0.38	$0.37^{\#NS}$	0.01
	0.30-0.60	12	$0.61^{\S NS}$	0.26	$0.73^{\P NS}$	0.06	$0.38^{\#NS}$	0.01
	0.60-0.90	12	$0.77^{\S}$	0.32	$0.70^{\P NS}$	0.15	$0.42^{\#NS}$	0.01
	0.90-1.20	12	$0.54^{\S NS}$	0.95	$0.90^{\P NS}$	0.30	$0.75^{\#}$	0.01
Farm 4								
	0-0.15	6	$0.96^{\dagger\dagger}$	0.30	$0.66^{\#NS}$	0.03	$0.79^{\#NS}$	< 0.01
Farm 5								
	0-0.15	12	$0.80^{\dagger}$	2.02	$0.02^{\dagger NS}$	0.06	$0.80^{\ddagger\ddagger}$	< 0.01
	0.15-0.30	12	$0.82^{\dagger}$	1.99	$0.00^{\dagger NS}$	0.02	$0.23^{\ddagger\ddagger NS}$	< 0.01
	0.30-0.60	12	$0.68^{\dagger}$	1.56	$0.16^{\dagger NS}$	0.01	$0.26^{\ddagger\ddagger NS}$	< 0.01
	0.60-0.90	12	$0.60^{\dagger}$	1.88	$0.22^{\dagger NS}$	0.03	$0.14^{\ddagger\ddagger NS}$	< 0.01
	0.90-1.20	12	$0.48^{\dagger}$	1.45	$0.12^{\dagger NS}$	0.08	$0.74^{\ddagger\ddagger}$	< 0.01
Farm 6								
	0-0.15	10	$0.83^{\S\S}$	1.30	$0.36^{\P\P NS}$	0.02	$0.28^{\ddagger NS}$	< 0.01
	0.15-0.30	10	$0.86^{\S\S}$	1.06	$0.56^{\P\P NS}$	0.01	$0.54^{\ddagger NS}$	< 0.01

† Calculated using the model $Y = b0 + b1(z_1)$.
‡ Calculated using the model $Y = b0 + b1(z_1) + b2(z_1^2)$.
§ Calculated using the model $Y = b0 + b1(z_1) + b2(z_2) + b3(z_1^2) + b4(x)$.
¶Calculated using the model $Y = b0 + b1(z_1) + b2(z_1^2) + b3(x) + b4(y) + b5(xy) + b6(x^2) + b7(y^2)$.
$^{\#}$ Calculated using the model $Y = b0 + b1(z_1) + b2(y)$.
†† Calculated using the model $Y = b0 + b1(z_1) + b2(x)$.
‡‡Calculated using the model $Y = b0 + b1(z_1) + b2(z_1^2) + b3(y)$.
§§Calculated using the model $Y = b0 + b1(z_1) + b2(z_2)$.
¶¶ Calculated using the model $Y = b0 + b1(z_1) + b2(z_1^2) + b3(y)$
^{NS} Non-significant at $\alpha = 0.05$

3.4.2 Composite approach

3.4.2.1 Averaged soft MLR

In the first composite method, the values of the variables were averaged to the whole soil profile in all farms except for Farm 4, which had only the top layer sampled and could not be averaged. The models predicted the electrical conductivity well ($r^2 \geq$ 0.70) in farms 3, 5 and 6 (Table 3.5). The z1 was included in the models of farms 1, 2, and 5, as the only predictor while predictor z2 appeared as the second predictor in farms 3 and 6, and LEVEL was the first predictor in Farm 3. Soft MLR did not predict nitrate well, with non-significant models in farms 1, 2, 5, and 6 (data not shown). The model for Farm 3 was significant but poor ($r^2 = 0.34$, RMSE = 0.35), and had LEVEL as the only predictor. Phosphate did not present any model with $r^2 \geq 0.70$, even though this variable had more significant models than nitrate (Table 3.6). The z1 appeared as the first predictor in two out of the three significant models, while aVWC was also included in two, and LEVEL in one model.

Table 3.5. Predictors, r^2, and RMSE from averaged soft MLR models having EC_e (dS m^{-1}) as response variable.

Farm	Predictors				n	r^2	RMSE (dS m^{-1})
	z1	z2	aVWC (%)	LEVEL (cm)			
Farm 1	1	–	–	–	12	0.57	0.85
Farm 2	1	–	–	–	12	0.55	1.20
Farm 3	2	–	–	1	12	0.75	0.48
Farm 4†	–	–	–	–	–	–	–
Farm 5	1	–	–	–	12	0.85	1.19
Farm 6	1	2	–	–	10	0.81	1.54

† Model not calculated because only the top layer was sampled

Table 3.6. Predictors, r^2, and RMSE from averaged soft MLR models having PO_4^{3-} (mg 100 g soil^{-1}) as response variable.

Farm	Predictors				n	r^2	RMSE (mg 100g soil^{-1})
	z1	z2	aVWC (%)	LEVEL (cm)			
Farm 1	–	–	–	–	–	–	–
Farm 2	1	–	–	–	12	0.69	< 0.01
Farm 3	1	–	3	2	12	0.59	< 0.01
Farm 4[†]	–	–	–	–	–	–	–
Farm 5	–	–	1	–	12	0.39	< 0.01
Farm 6	–	–	–	–	–	–	–

[†] Model not calculated because only the top layer was sampled

3.4.2.2 Averaged spatial MLR

As for the soft MLR, the models for averaged EC_e had an r^2 over 0.70 for farms 3, 5, and 6 (Table 3.7). However, models for NO_3^- were non-significant in all cases. The variable PO_4^{3-} presented significant models for farms 1 through 3, but all of them had $r^2 <$ 0.70. The models calculated by ESAP–Calibrate for the averaged profile were the same as for by-depth spatial MLR. Thus, comments on predictors for by-layer spatial MLR hold for this approach.

Table 3.7. The r^2 and RMSE from averaged spatial MLR models having EC_e (dS m^{-1}), NO_3^- (mg 100 g soil^{-1}), and PO_4^{3-} (mg 100 g soil^{-1}) as response variables.

Farm	n	Response Variable EC_e		NO_3^-		PO_4^{3-}	
		r^2	RMSE (dS m^{-1})	r^2	RMSE (mg 100g soil^{-1})	r^2	RMSE (mg 100g soil^{-1})
Farm 1	12	0.55[†]	0.87	0.16[†NS]	0.37	0.65[‡]	0.02
Farm 2	12	0.54[†]	1.21	0.01[†NS]	0.41	0.69[†]	< 0.01
Farm 3	12	0.85[§]	0.42	0.91[¶NS]	0.20	0.57[#]	< 0.01
Farm 4[##]	–	–	–	–	–	–	–
Farm 5	12	0.85[†]	1.22	0.07[†NS]	0.03	0.47[‡‡NS]	< 0.01
Farm 6	10	0.88[§§]	1.05	0.48[¶¶ NS]	0.02	0.47[‡NS]	< 0.01

[†, ‡, §, ¶, #, ††, ‡‡, §§, ¶¶] Same as Table 3.4

[##] Model not calculated because only the top layer was sampled

[NS] Non-significant at $\alpha = 0.05$

3.4.2.3 Vertically-weighted soft MLR

The predictability of EC_e using vertically-weighted soft MLR analysis was fairly good ($r^2 \geq 0.70$) for all farms except Farm 6 (Table 3.8). The variable z1 was included as the first predictor in all models, while vertically weighted volumetric water content ($wVWC_V$) was included in farms 1 and 6, and LEVEL was included in Farm 3 as second predictors, respectively. For NO_3^-, only models in farms 1 and 4 were statistically significant (data not shown). The model for Farm 1 presented $r^2 = 0.77$ and RMSE = 0.13, with z1 and $wVWC_V$ as first and second predictors, respectively. The model for Farm 4 had $r^2 = 0.89$ and RMSE < 0.01, with $wVWC_V$ as the only predictor. Models for the variable PO_4^{3-} were significant only in farms 2 and 3 (data not shown). Coefficient of determination and RMSE were 0.67 and < 0.01 for Farm 2, and 0.34 and 0.01 for Farm 3, respectively. The z1 was the only predictor for Farm 2, while $wVWC_V$ was the only predictor for the Farm 3.

Table 3.8. Predictors, r^2, and RMSE from vertically-weighted soft MLR models having EC_e (dS m^{-1}) as response variable.

Farm	Predictors				n	r^2	RMSE (dS m^{-1})
	z1	z2	aVWC (%)	LEVEL (cm)			
Farm 1	1	–	2	–	12	0.81	0.34
Farm 2	1	–	–	–	12	0.78	0.49
Farm 3	1	–	–	2	12	0.72	0.40
Farm 4	1	–	–	–	6	0.86	0.02
Farm 5	1	–	–	–	12	0.82	0.97
Farm 6	1	–	2	–	10	0.67	0.22

3.4.2.4 Horizontally-weighted soft MLR

As for the horizontally-weighted soft MLR, all models were significant for EC_e, but values of r^2 over 0.70 were observed only in farms 3 through 6 (Table 3.9). The variable z1 was included in all models, with z2 included in Farm 6 and LEVEL included in Farm 3 as the second predictor, respectively. Significance for NO_3^- were achieved only in Farm 3 ($r^2 = 0.33$, RMSE = 0.38) and Farm 4 ($r^2 = 0.89$, RMSE < 0.01) (data not shown). The LEVEL was the only predictor for Farm 3 and $wVWC_H$ was the only predictor for Farm4. All the models were poor predictors of PO_4^{3-} (data not shown). Models were significant only in Farm 2 ($r^2 = 0.66$, RMSE < 0.01), Farm 5 ($r^2 = 0.35$, RMSE < 0.01), and Farm 6 ($r^2 = 0.39$, RMSE < 0.01). Models for these farms had single predictors, with z1 for Farm 2, and $wVWC_H$ for farms 5 and 6.

Table 3.9. Predictors, r^2, and RMSE from horizontally-weighted soft MLR models having EC_e (dS m^{-1}) as response variable.

Farm	Predictors				n	r^2	RMSE (dS m^{-1})
	z1	z2	aVWC (%)	LEVEL (cm)			
Farm 1	1	–	–	–	12	0.55	0.98
Farm 2	1	–	–	–	12	0.54	1.29
Farm 3	1	–	–	2	12	0.78	0.65
Farm 4	1	–	–	–	6	0.86	0.13
Farm 5	1	–	–	–	12	0.86	1.14
Farm 6	1	2	–	–	10	0.76	0.56

3.4.2.5 Vertically-weighted spatial MLR

In this approach, all models were significant for electrical conductivity (Table 3.10). Models presented good coefficient of determination ($r^2 \geq 0.70$) in farms 2, 4, and 5. The r^2 value was slightly inferior to the threshold in Farm 1, while it was poor in farms 3

and 6. The z1 was the only predictor included in the models in farms 1, 2, 5, and 6, while x was the only one in farms 3 and 4. This method did not show reasonable prediction of nitrate as five out of six models were not significant (data not shown). The only significant model was for Farm 1 ($r^2 = 0.44$, RMSE = 0.19) and had z1 as single regressor. Prediction of phosphate was better than that for nitrate. The models for this variable were significant in farms 2 through 4, even though r^2 was below 0.70 in Farm 2 (Table 3.11). In this case, the variable y got relative importance as it was included in the model as the first predictor for Farm 3, and it was the only predictor in Farm 4. Again, z1 counted among the predictors included, being the only one included for Farm 2 and the second for Farm 3.

Table 3.10. Predictors, r^2, and RMSE from vertically-weighted spatial MLR models having EC_e (dS m^{-1}) as response variable.

Farm	Predictors				n	r^2	RMSE (dS m^{-1})
	z1	z2	x	y			
Farm 1	1	–	–	–	12	0.69	0.40
Farm 2	1	–	–	–	12	0.78	0.49
Farm 3	–	–	1	–	12	0.59	0.46
Farm 4†	–	–	1	–	6	0.88	0.02
Farm 5	1	–	–	–	12	0.82	0.97
Farm 6	1	–	–	–	10	0.46	0.26

Table 3.11. Predictors, r^2, and RMSE from vertically-weighted spatial MLR models having PO_4^{3-} (mg 100 g soil^{-1}) as response variable.

Farm	Predictors				n	r^2	RMSE (mg 100g soil^{-1})
	z1	z2	x	y			
Farm 1	–	–	–	–	–	–	–
Farm 2	1	–	–	–	12	0.67	< 0.01
Farm 3	2	–	–	1	12	0.74	< 0.01
Farm 4†	–	–	–	1	6	0.78	< 0.01
Farm 5	–	–	–	–	–	–	–
Farm 6	–	–	–	–	–	–	–

3.4.2.6 Horizontally-weighted spatial MLR

In the horizontally-weighted spatial MLR analysis, EC_e was a good predictor (i.e. $r^2 \geq 0.70$) only in farms 4, 5 and 6, despite the models being significant for all farms (Table 3.12). The z1 was the only predictor in farms 1, 2, 3, and 5; the predictor x was the only one in Farm 4; Farm 6 had two predictors, namely, z1 and z2. The NO_3^- was not a significant model predictor (data not shown), while PO_4^{3-} was a significant model predictor in Farm 2 ($r^2 = 0.66$, RMSE < 0.01) and Farm 4 ($r^2 = 0.78$, RMSE < 0.01) (data not shown). Models for these farms had single predictors, with z1 for Farm 2 and y for Farm 4.

Table 3.12. Predictors, r^2, and RMSE from horizontally-weighted spatial MLR models having EC_e (dS m^{-1}) as response variable.

Farm	Predictors				n	r^2	RMSE (dS m^{-1})
	z1	z2	x	y			
Farm 1	1	–	–	–	12	0.55	0.98
Farm 2	1	–	–	–	12	0.54	1.29
Farm 3	1	–	–	–	12	0.54	0.65
Farm 4†	–	–	1	–	6	0.88	0.12
Farm 5	1	–	–	–	12	0.86	1.14
Farm 6	1	2	–	–	10	0.76	0.56

3.5 Discussion

Analysis of outliers was not carried out due to the small calibration dataset of 12 samples and because outliers are likely to occur in regular situations of nutrient assessment. Thus, the analysis presented here corresponds to the worst-case scenario where prediction capabilities of the models were not improved by the statistically permissible exclusion of outliers.

3.5.1 By-depth approach

Comparison of results of by-depth analysis shows that both soft and spatial MLR procedures gave similar outcomes for EC_e in 16 comparisons out of 23. The values of r^2 and occurrence of non-significant models in farms 1, 5, and 6 were essentially the same in both MLR (Tables 1 and 4). Both methods achieved the same result by different ways, i.e., both included the same predictors in the models employing distinctive approaches. The stepwise procedure in soft MLR and the PRESS score criterion in ESAP–Calibrate were equivalent in this case.

In some instances the two methods gave different models, but with similar results. That was the case at depths 0.30 – 0.60 and 0.60 – 0.90 m in Farm 2, where soft MLR selected z1 as the single predictor and spatial MLR worked with a quadratic model, but both had the same r^2 and RMSE. This point highlights an essential difference between the two methodologies because spatial MLR, as calculated by ESAP–Calibrate, can handle models with second order and cross-product predictors (e.g. see models in the footnote of Table 4), while the present soft MLR cannot. In fact, stepwise MLR using quadratic and cross-product predictors was tested in JMP, but it was ignored because the JMP program included these predictors in the models without including first-order predictors. However, the ESAP–Calibrate algorithm does not include higher-order terms before including the lower-order ones (Lesch et al. 2000). Nonetheless, inclusion of quadratic terms in the model did not mean that the model was superior. For example, the first-order soft MLR model at depth 0.90 – 1.20 m in Farm 3 was significant (Table 1), while the quadratic model calculated by spatial MLR was not (Table 4). Higher-order models in ESAP should be closely examined prior to selection as these models can be PRESS-wise similar to first-order models. In fact, model examination is among ESAP developers' recommendations (Lesch et al. 2000), and inspection of depth 0.90 – 1.20 m in Farm 3 proved to be valuable for model selection. In this case, the scaled PRESS score of the auto-selected model [i.e. $Y = b0 + b1(z_1) + b2(z_2) + b3(z_1^2) + b4(x)$] was 1.0, while the scaled PRESS score of the simplest model [i.e. $Y = b0 + b1(z_1)$] was 1.014. Despite the small difference, the latter took the third position in the PRESS score rank calculated by ESAP–Calibrate (data not shown).

Examining the predictors for EC_e models, the soft MLR made use of z1 and z2 in most cases, with VWC and LEVEL appearing in two isolated instances in Farm 3 (Table 3.1); spatial MLR used the single predictor z1 in all cases but Farm 3, where four predictors were used (Table 4). This fact stresses two important points: i) the predominance of EM-derived readings over other predictors, which makes both MLR similar, and ii) the lack of soft information can be overcome with the manipulation of available trend surface information. For example, in Farm 3, surrogate variables were used for both methods because z1 and z2 did not explain variation of EC_e well. Soft MLR used LEVEL as the second predictor and VWC as the only predictor in the two first layers, respectively; spatial MLR met this shortfall by including the second-order and trend surface predictors. In this case, the spatial MLR models again proved to be equivalent to models using "easy-to-acquire" information, with similar r^2 and RMSE. However, the spatial MLR model was not suitable for the bottom layer in Farm 3 because it was non-significant. This aspect emphasizes the versatility of stepwise procedure in JMP over the ESAP–Calibrate. The former can build different models for discrete depth intervals, while the latter builds a single model for all the depths. The stepwise approach is a more tedious and operator-demanding process, but it models tailored to each particular depth, which can improve prediction capability of models built from EMI survey data.

Soft and spatial MLR also gave similar results when dealing with NO_3^-. The pattern of significant/non-significant models was identical in farms 1, 2, 3, and 6, and was slightly different in Farm 5 (i.e. only in depth 0.30 – 0.60 m). The biggest discrepancy occurred in Farm 4, with the soft MLR model showing good predictability

(Table 2) and spatial MLR showing a non-significant model (Table 4). The predictor VWC made the difference in this case. Good predictability of nitrate in Farm 4, different from other farms, was probably due to the shallowness of the soil (i.e. presence of the bedrock at about 0.15 m deep) and the solubility of nitrate, causing its distribution to be similar to that of soil moisture. Differences for nitrate models in terms of r^2 were also observed at the two first depths in Farm 3, where spatial MLR gave high values of r^2 and soft MLR gave low and moderate values. The reason for that may lie on the length of models used in both MLR because spatial MLR calculated a model with seven predictors, including second order and cross-product. Considering the small dataset used (i.e. 12 sample points), it is possible to get a high value of r^2 as a result of only a moderate relationship among response variable and regressors (Dowdy et al. 2004). Thus, examination of parameters such as significance of the model, r^2 and RMSE alone may lead to erroneous conclusions in terms of prediction. More reliable results would require a larger dataset. As the reduction of the number of samples to be collected from the field is one of the main advantages of EMI and response surface design techniques, the reduction of predictors in the model would be advisable. This aspect highlights the need to check the statistics generated by ESAP–Calibrate, and the possibility of manually selecting another model with larger PRESS score. Despite these observations, prediction of NO_3^- in the present context was generally poor in both methods, contradicting some good correlations reported for abandoned manure handling sites (Eigenberg and Nienaber 2003). The low concentrations of nitrate found in the samples made it difficult to find better correlations because variation in EC_a was probably driven by variations in other ions with higher concentrations (e.g. potassium, calcium). According to Korsaeth (2005),

ions with low concentrations have less impact over EC_a than ions with high concentrations. Although nitrogen is the major nutrient in beef cattle manure (ASABE 2005), concentrations of nitrate does not always reflect this fact as the presence of this compound depends on complex processes that take place in the soil (e.g. nitrification), which in turn depend on a number of variables (e.g. aerobic environment, soil microorganisms).

Examining the correlations of PO_4^{3-}, both approaches perfectly matched in terms of significant/non-significant models for farms 1, 2, and 4 (Tables 3 and 4). In terms of r^2, the only cases where spatial MLR made a difference were at the first depth in Farm 1, bottom depth of Farm 3, and at both top and bottom layers in Farm 5 (Table 3 and 4). The prediction of phosphate within the top-most layer was poor probably due to the dominance of other ions. Again, it was not possible to make a deeper assessment in terms of relative importance of several ions because only nitrate and phosphate were specifically analyzed.

3.5.2 Composite approach

3.5.2.1 Averaged profile

From an agronomic standpoint, models calculated from EM-38 data using averaged EC_e profiles are of most interest because these models represent the entire root zone (Amezketa 2006). However, from an environmental perspective, this may not be true because nutrients can migrate to depths below 1.2 m and potentially contaminate groundwater. Nonetheless, composite profiles are very important in the present context

because they represent the source layer for ions and they can depict the general pattern of migration.

As in the by-depth approach, poor relationships in Farm 1 and 2, and the good relationships in farms 5 and 6 were observed for EC_e in both MLR. However, the averaging approach minimized the effects of extremes. In Farm 1, for instance, averaged $r^2 = 0.57$ attenuated the effects of extremes at depths 0 – 0.15 ($r^2 = 0.39$) and 0.30 – 0.60 m ($r^2 = 0.64$) (see Table 1). Moreover, the non-significant relationship in a single layer was masked by the significant relationships obtained by averaging. For example, Farm 3, which had non-significant models for the layer 0.30 – 0.60 m in both soft and spatial MLR, achieved r^2 equal to 0.75 and 0.85 for averaged soft MLR and averaged spatial MLR, respectively. Here again, comparable RMSE for both methods (see Tables 5 and 7), and the lower number of predictors in the soft MLR model made the use of this model or manual selection of another spatial MLR model advisable. For NO_3^-, both soft and spatial MLR showed non-significant models. The prediction of PO_4^{3-} gave similar number of significant models but for different farms (see Tables 6 and 7). For those farms in common (i.e. farms 2 and 3), values of r^2 and RMSE were very similar. Here again, there was predominance of EMI-derived predictors, with secondary regressors gaining relative importance for variables NO_3^- and PO_4^{3-}.

3.5.2.2 Weighted profile

Two factors need to be considered in the weighted profile method. First, this method was not an option in ESAP–Calibrate; consequently, the analysis was carried in JMP 7.0 using stepwise MLR and by employing the variables calculated in section 2.3. As the algorithm of sequential inclusion of first- and second-order predictors was not

available in JMP, only first-order regressors were used because i) these have priority on ESAP–Calibrate and ii) second-order predictors could mean longer models, which should be avoided due to the small size of the dataset (i.e. 12 samples). Second, the analysis was split into vertical and horizontal calculations.

This analysis showed a limitation when working with areas where a shallow bedrock was present (i.e. farms 4 and 6), even though the models could be calculated and presented good prediction indices. In this case, the composite model assumed the contribution of the rock to be zero because this material presents high resistivity, and these nil-contribution layers were accounted for by the model. However, these layers should not be accounted for because they do not contain soil and cannot contribute to nutrient transport. The result of including them was an underestimation of the variables in farms 4 and 6 because they acted like soil layers with no nutrient content. For example, samples in Farm 4 had an EC_e ranging from 0.31 to 3.17 dS m^{-1}, but the vertically-weighted soft MLR modeled the range from 0 to 0.14 dS m^{-1} (data not shown). Similarly, Farm 6 had an EC_e ranging from 0.22 to 9.21 dS m^{-1}, but the modeled values ranged from 0.71 to 2.73 dS m^{-1} (data not shown). An alternative approach in such situations (i.e. shallow bedrock) could be the one presented by Wollenhaupt et al. (1986), where the contribution of resistive layers would be partitioned into the conductive layers. However, working with discrete depth intervals or averaged profiles seems to be more practical for shallow soils.

Apart from this constraint due to the presence of bedrock, the weighted approach worked well for farms that had the whole soil profile sampled. For EC_e, for example, the vertically-weighted approach represented an improvement over the averaged approach

for both soft and spatial MLR. Values of r^2 and RMSE improved or remained somehow stable in all farms sampled to the full depth (i.e. farms 1, 2, 3, and 5) with change in approach from averaged to vertically-weighted (compare Table 5 to Table 8, and Table 7 to Table 10). The only exception to improvement was found for spatial MLR in Farm 3. This improvement was probably due to the down-weighting of the first layer in the vertically-weighted approach, which decreased the effect of large variability of readings in this layer. This down-weighting did not result in misleading values of EC_e. In fact, if EC_e is uniform throughout the soil profile or if values of EC_e are low at the surface, both averaged and vertically-weighted approaches will give similar results. However, the latter approach remains more stable if values at the surface increase and tend to behave as outliers.

For the variable NO_3^-, change in approach did not represent any large improvement, with only minor modifications (i.e. Farm 1 passed to significance in both soft and spatial MLR and Farm 3 lost significance in soft MLR). Vertically-weighted approach gave poorer results than averaged approach for PO_4^{3-}, with loss of significance and decrease of r^2 for both types of MLR. An isolated case of large improvement occurred for spatial MLR in Farm 3 (see Tables 7 and 11).

Horizontally-weighted was somehow inferior to vertically-weighted soft MLR because its outcomes were poorer for EC_e and NO_3^- in both soft and spatial MLR. The only exception was the variable PO_4^{3-}, for which results of vertically- and horizontally-weighted approaches had the same number of significant models for all farms sampled to the full depth and were, therefore, comparable. The dominance of predictors z1 and z2 was once again observed.

3.6 Conclusion

Electromagnetic induction surveys were performed using EM-38 conductivity meter to assess nutrient build-up in beef cattle feedlots in Manitoba, Canada. The EM-38 readings were used to determine the optimum sampling locations using the response surface design. The EM-38 derived readings along with spatial and soil physical properties data were then used as predictors for building calibration models. The performance of two multiple linear regression methods were assessed for calibration of EM-38 readings. The first method, called soft MLR, incorporated "easy-to-acquire" information, while the second method – spatial MLR – incorporated trend surface parameters. Analyses were carried by layer and for composite soil profile using profile-averaged and profile-weighted approaches. Both MLR methods gave similar results in most instances, but soft MLR was more versatile when working by layer because it could build different models for each layer, while spatial MLR, as calculated by ESAP software, built a single model for all depths. For the assessment of nutrient build-up, predictions were good when using EC_e as response variable, but prediction of specific nutrients (i.e. nitrate and phosphate) was poor in most cases probably due to the low concentrations in relation to other ions in the soil (e.g. potassium, calcium). The composite profile approach seemed to be more appropriate to assess nutrient build-up because by-layer analysis gave non-significant or poor models in many instances. Averaged-profile analysis was poorer than weighted-profile, with vertically-averaged MLR giving superior results than horizontally-weighted MLR provided the whole soil profile can be sampled.

4. ASSESSMENT OF NUTRIENT BUILD-UP AND DESIGN CRITERIA FOR FEEDLOTS USING ELECTROMAGNETIC INDUCTION

4.1 Abstract

Electromagnetic induction (EMI) has been used to map soil properties such as salinity, water content. The main objective of this research is to use electromagnetic induction to map the distribution of nutrients around feedlots and relate it to major field features influencing this distribution. Information on these interactions is used to propose better design criteria for feedlots. Feedlot areas located in different physiographic locations were surveyed in Manitoba, Canada, using EM-38 conductivity meter geo-referenced with a GPS receiver. Samples were collected using a response surface design and analyzed for electrical conductivity (EC_e). Multiple linear regression models (MLR) were used for calibration of the EM readings and the modeled values were interpolated using a GIS platform. The results showed that farms 1 through 4 had $EC_e \leq 3.5$ dS m^{-1}, but farms 5 and 6 exceeded this threshold and reached maximum values of 5.5 and 7.0 dS m^{-1}, respectively. Higher values in Farm 6 were probably due to the presence of a rocky layer at 0.3 m depth, leaving a thin soil layer to accumulate the nutrients. Micro-depressions played a major role in salt accumulation with the depressions corresponding to high values of EC_e. The presence of features such as drainage ditches and compacted soils beneath roads strongly affected the direction of the plumes. Based on these results, the elimination of micro-depressions, location of the feedlots on high elevations, and provision to collect the runoff from the feedlot were identified as good design criteria. Highly permeable soils may require a low permeability liner to capture and redirect the deep percolation towards a collection area.

4.2 Introduction

The increased standard of living and the consequent expansion in consumer demand for animal products has led to the "livestock revolution" (Delgado et al. 1999). However, this growth is not globally uniform. According to Gerber et al. (2005), annual growth rate between 1982 and 1994 was 5.4 and 1.1% for developing and developed countries, respectively. The economies of scale have led to the intensification of livestock production in developed countries. For example, the cattle feeding sector in the United States and the United Kingdom has migrated from a semi-intensive to a more intensive scenario based on specialized management since the end of World War II (Mintert 2003; Hooda et al. 2000). The overall animal production has increased in Canada, despite a decline in number of farms during the last decades, leading to the intensification of livestock production (Statistics Canada 2003). Such intensification, with a large number of animals confined in relatively small areas, has been accompanied by a rise in waste concentration in a smaller area, which poses as an environmental risk (Hooda et al. 2000). In this scenario, beef cattle (*Bos taurus*) standout as the main source of livestock waste. In Canada, for instance, 52% of the 132 billion kg of livestock manure produced in 1996 came from beef cattle, followed by dairy cow (19%), hogs (16%), calves (7%), poultry (3%), horses (3%), and sheep (< 1%) (Statistics Canada 2001).

From an economic and environmental standpoint, livestock waste management can play a major role when it comes to sustainability. Economically, waste can represent either a cost or profit depending on the lot capacity because manure can be profitable for moderate and large feedlots if used as fertilizer for crops (Forster 1998). However, the high cost of manure hauling may favor high manure application rates in areas close to

intensive livestock production (Chang and Janzen 1996). This tendency may lead to negative environmental impact with impaired quality of air, soil, and water by chemicals and pathogens (Miller et al. 2003). Significant loads of nitrogen, phosphorus, and some heavy metals from manure are the main concern (Rosen et al. 2004). Nitrogen and phosphorus have been reported as problems to soils and water, causing the eutrophication of surface water bodies, loss of ground water quality, and over-accumulation of nutrients in soils (Gerber et al. 2005). Therefore, an understanding of nutrient build-up and transport from feedlots is important for minimizing environmental damage.

Much attention has been given to nutrient transport by runoff from feedlots. Miller et al. (2004) cite several qualitative and quantitative studies on runoff in Texas, Nebraska, Kansas, southern Ontario, Saskatchewan, and Alberta. Substantial research has also been done on runoff from areas receiving manure application (Gilley et al. 2007). Although a few studies have been conducted on feedlot runoff in northern climate (Miller et al. 2004), no reports were identified on nutrient infiltration from unpaved feedlots with no retention pond. The Province of Alberta, Canada, suggests some measures to avoid seepage of manure nutrients, by avoiding sites on very porous soils (i.e. sands, gravels, shale or sandstone outcroppings), removing manure where it has built up over the winter season, moving feeding sites regularly during the winter to minimize manure buildup, and by providing sufficient areas on porous sites to reduce animal densities (Alberta Agriculture and Rural Development 2008). The province of Manitoba is currently reviewing criteria for feedlot design.

Traditional assessment of nutrients in soils relies on collecting samples at specific sites and performing analysis (Eigenberg et al. 2002), which is laborious and expensive.

As a result, new methods for assessing nutrient in soils have been employed, such as electromagnetic induction (EMI), which is becoming more common due to the advances in instrumentation (Rhoads 1990). Electromagnetic induction method is much faster and less expensive than traditional soil coring; plus, EMI sensors can be coupled with global positioning system (GPS) receivers and their digital output can be exported into geographical information systems (GIS) software for mapping of the georeferenced information.

The objectives of this study were to develop a systematic method to assess nutrient build-up in areas around beef cattle feedlots in southern Manitoba, Canada, using electromagnetic induction, and to suggest design criteria to be implemented based on the interaction between nutrient accumulation and physiographic features. The outcomes of this work can help the design of feedlots that can minimize the negative impact on natural resources.

4.3 Material and Methods

4.3.1 Data and sample collection in the field

During September and October 2007, electromagnetic induction surveys were conducted in six feedlots using an EM-38 conductivity meter (Geonics Ltd., Mississauga, ON, Canada), an Allegro CX field PC (Juniper Systems, Inc., Logan, UT, USA) for data logging, and a GPSMAP CSx GPS receiver (Garmin International Inc., Olathe, KS, USA) for geo-referencing. Both vertical (EM_V) and horizontal (EM_H) EM-38 readings were acquired at locations ranging from 66 to 226 per farm. These readings and their respective GPS positions were combined using DAT38W software (Geonics Ltd., Mississauga, ON, Canada). The georeferenced EM_V and EM_H readings were merged

together into a text file using Microsoft Excel (Microsoft Corp., Redmond, WA, USA) and input into the sampling design program called ESAP–RSSD 2.35R (USDA–ARS, Riverside, CA, USA). The ESAP-RSSD software used the EMI readings from the entire feedlot and identified sampling sites in a non-biased way using the response surface design. In each farm, 12 sampling sites were identified except for Farm 6 where 6 sample sites were identified because the soil was very shallow and did not allow hand augering in all sites. This procedure eliminated human bias in the selection of sampling locations which might lead to improper characterization of the average extent of nutrient accumulation in a feed lot. Sampling site coordinates, as defined by ESAP–RSSD, were fed into the GPS receiver as waypoints and were located for soil coring. Soil at the identified points was hand-augered at depth intervals of 0 – 0.15, 0.15 – 0.30, 0.30 – 0.60, 0.60 – 0.90, and 0.90 – 1.20 m. The classification of the soil at each farm was obtained using the information from Manitoba Land Initiative GIS database (Manitoba Land Initiative 2008) and are presented in table 4.1.

Table 4.1. Dimensions, soil texture, soil series and map scale for the surveyed areas.

Farm	Lengh (m)	Width (m)	Soil texture	Soil series	Map scale
Farm 1	84.42	94.86	sandy and loamy	Long Plain and St. Claude	1:20 000
Farm 2	108.53	54.36	sandy	Willowcrest	1:20 000
Farm 3	37.78	53.82	sandy	Long Plain and Almasippi	1:20 000
Farm 4	72.40	35.84	loamy	Inwood	1:50 000
Farm 5	98.74	68.20	sandy	Long Plain	1:20 000
Farm 6	40.64	57.10	sandy	Caliento, Pelan, and St. Labre	1:50 000

Farms were also surveyed for elevation using Rugby 100 construction laser (Leica Geosystems AG, Unterentfelden, Switzerland) and Cyclone laser detector (Apache Technologies, Inc., Dayton, OH, USA). Elevation maps were constructed in ArcMap 9.1 (ESRI, Inc., Redlands, CA, USA) by interpolating between 38 and 84 elevations taken in each farm using ordinary kriging technique and a spherical variogram model. Micro-elevations for the sample sites were predicted from these interpolation maps using the 'identify' function in ArcMap.

4.3.2 Laboratory procedures

Within 24 h after the samples were collected, two replicates of each soil sample were oven dried at 105°C for 24 h for gravimetric water content (GWC) analysis. The remainder of the samples was kept at 4°C or less until analyzed for electrical conductivity (EC_e). The saturated-paste extraction method (Janzen 1993) was employed to obtain liquid samples out of soil aliquots weighing from 50 to 120 g. Extract volumes examined for EC_e were diluted from 1:30 to 1:120 times and analyzed using YSI 32 conductivity meter (YSI, Inc., Yellow Springs, OH, USA).

4.3.3 Calibration models

Data from soil sample analyses were used to calibrate the EM-38 readings. The calibration models presented in Table 4.2 were used to convert EMI readings into electrical conductivity (EC_e). The rationale for the selection of the models and the methodology used for model construction were presented in chapter 2. This chapter presents the calculations of the models and describes how the variables z1 (primary decorrelated principal component scores calculated from EM-38 readings), z2 (secondary decorrelated principal component scores calculated from EM-38 readings), $wVWC_V$

(vertically-weighted volumetric water content), and LEVEL (micro-elevation) were obtained. Vertically-weighted soft multiple linear regression (Soft MLR) was used for the calibration of EMI readings in farms 1, 2, 3 and 5; by-layer soft MLR was used in Farm 4 because this farm could not have the whole soil profile sampled due to the presence of bedrock at 0.15 m; averaged soft MLR was used in Farm 6 because this farm had only two layers sampled due to a rocky layer at 0.30 m depth.

Table 4.2. Models used for prediction of EC_e (dS m^{-1}) and respective sample size (n), coefficient of determination (r^2), and root mean square error (RMSE).

Farm	Model	MLR model	n	r^2	RMSE
Farm 1	$EC_e = 238.71 + 92.62\ z1 - 630.62\ wVWC_V$	Vertically-weighted	12	0.81	0.34
Farm 2	$EC_e = 245.09 + 103.83\ z1$	Vertically-weighted	12	0.78	0.49
Farm 3	$EC_e = 77.51\ z1 + 889.39\ LEVEL - 88641.91$	Vertically-weighted	12	0.72	0.40
Farm 4	$EC_e = 169.73 + 249.82\ z1$	By-layer	6	0.86	0.02
Farm 5	$EC_e = 207.75 + 203.55\ z1$	Vertically-weighted	12	0.82	0.97
Farm 6	$EC_e = 318.72 + 260.89\ z1 + 657.35\ z2$	Averaged	12	0.81	1.54

In the present study, the water content information available from the 12 locations where soil samples were collected for calibration were used to develop a water content map using inverse distance weighting interpolation technique in ArcMap 9.1, overlaying the interpolated layer over the EM-38 readings, and predicting the values for each reading using the 'identify' function. Inverse distance weighting interpolation was used because it presented smaller Root Mean Square (RMS) values than kriging interpolation did. Similarly, values for the variable LEVEL in the model of Farm 3 were not available for all 67 EMI readings, and this information was obtained from the interpolation calculated for micro-elevation data. After the calculation of these variables, EC_e was modeled for

each farm using Microsoft Excel. The modeled EC_e information was interpolated in ArcMap 9.1 (spherical variogram model) and these maps were used as the actual distribution of nutrients in the surveyed areas, assuming the EC_e maps to be indicators of the spatial distribution of nutrients. This assumption is based on the fact that manure is the only source of ions contribution to an increase in EC_e and that major nutrients (i.e. N, P, K) are among the main constituents of manure.

4.4 Results

Interpolation for EC_e in Farm 1 is shown in Fig. 4.1. This area was around a pen open to the south, where cattle had access to outside the pen and came back frequently for feed and water. The presence of manure was observed with more abundance inside the pen, around the feeder. Cattle were prevented from going to the west and southwest of the pen by an electric fence. However, the presence of manure in some spots indicated this area had been open to cattle some time before. Contours in Fig. 1 show that higher elevations were located on the west side and decreased towards the east side, and that the pen was located in an area of low elevation. The highest EC_e (i.e. 2.0 – 2.5 dS m^{-1}) were found inside the pen, between elevation contours 100.2 and 100.5 m, and in an isolated spot south of the pen (point A), again around contour 100.2 m. The plume is then less concentrated from inside the pen towards the west, showing good agreement with elevation contours. Points B and C show spots of intermediate concentrations (i.e. 1.0 – 1.5 dS m^{-1}) in relation to background concentrations (i.e. 0.0 – 0.5 and 0.5 to 1.0 dS m^{-1}), probably due to manure excretion while cattle had access to this area.

Farm 2 was an area receiving effluents through a drainage tile from a pen located about 170 m southwest (upslope). The duct came from west to east and ended at point A

in Fig. 4.2. The contour lines in this area show higher elevation towards north (i.e. 100.7 m), decreasing towards the south (i.e. 100.1 m), but starting to increase again at the very bottom of the field (i.e. 100.2 m). The lowest elevation of the field is at the centre of Fig. 4.2. The distribution of EC_e shows that the highest concentration of the plume (i.e. 3.0 – 3.5 dS m^{-1}) is being diverted towards the lower elevations in the field with accumulations in two locations along the way. The first is between contours 100.1 and 100.3 (point B) and the second is between contours 100.2 and 100.3 m (point C). The largest portion of the plume has concentration of 2.5 – 3.0 dS m^{-1}, which is distributed within contours 100.2 and 100.3 m. The EC_e seemed to be contained by higher elevations as the plume moved north, and it started reaching the background values further north from contour 100.6 m, showing $EC_e < 1.0$ dS m^{-1} up from contour 100.7 m.

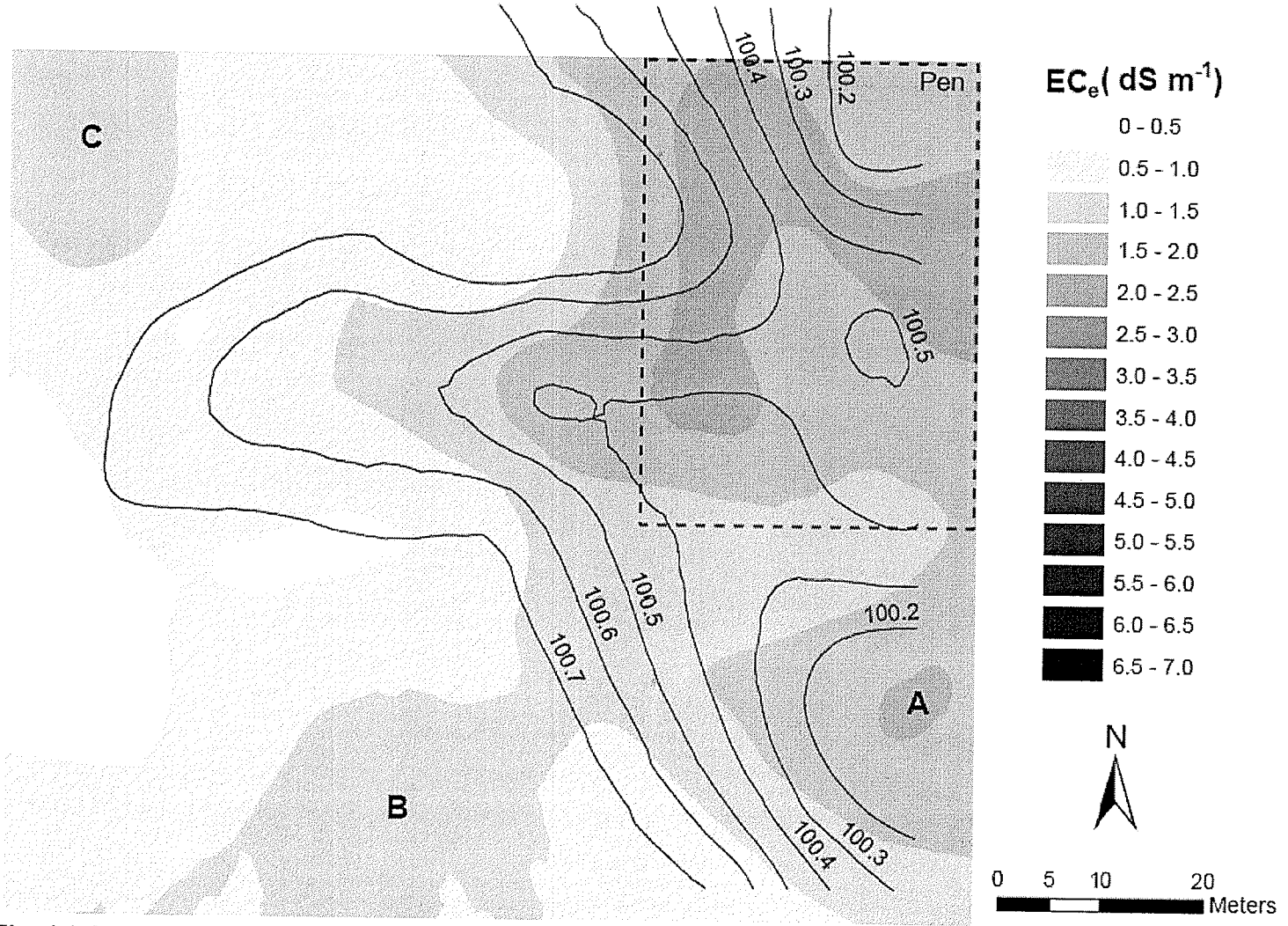

Fig. 4.1. Map of modeled electrical conductivity overlaid by level contours in Farm 1 showing a hotspot (A) and two areas of moderate conductivity within background values (B and C).

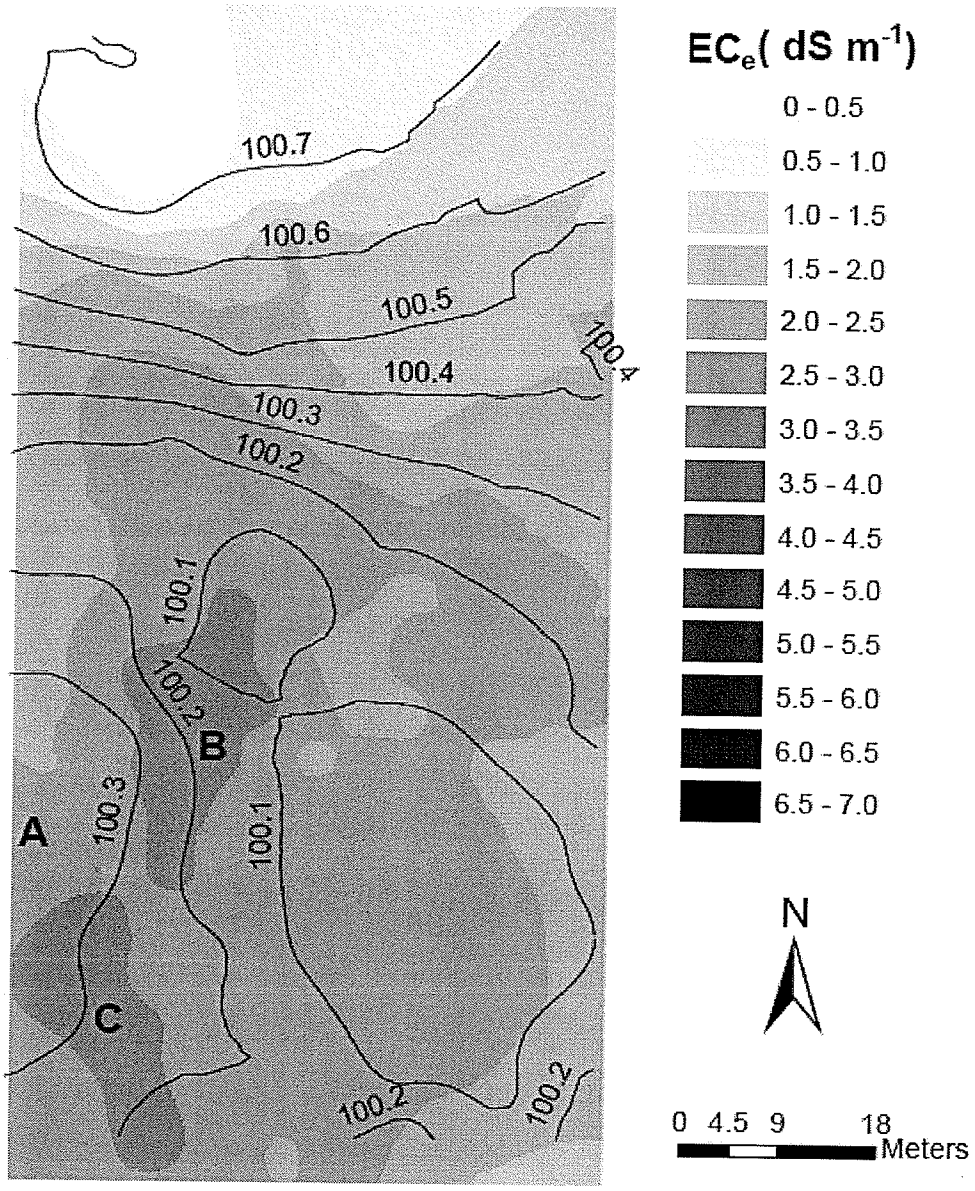

Fig. 4.2. Map of modeled electrical conductivity overlaid by level contours in Farm 2 showing the point where the effluents are released (A) and the points of higher concentration in the plume (B and C).

The area just southeast of the pen was surveyed in Farm 3 (Fig. 4.3). This area was very flat with a slight decrease in elevation from inside the pen (100.3 m) towards the southeast (100.2 m). The EC_e also decreased from inside the pen following the same direction of the contours, where the highest EC_e of 3.0 – 3.5 dS m^{-1} was found to be concentrated on the southeast corner of the pen. There was a strong trend of the plume spreading from the pen straight south (arrow), probably due to the presence of a ditch in that direction. The plume decreased in concentration from the ditch towards the east. The use of finer scale for the contours than showed good agreement between elevation and the EC_e (Fig. 4.4). Two isolated spots with EC_e > 1.5 dS m^{-1} (points A and B) in a background EC_e < 1.5 dS m^{-1} were observed in this farm probably because of some manure found in this area, as cattle had access to the area outside the pen.

Soil in Farm 4 was very shallow (i.e. 0.15 m deep) due to the presence of shallow bedrock. The portion to the north of the pen and the pen itself could not be surveyed (Fig. 4.5). Level contour lines are not visible for this farm because the topography of this area was very flat. A finer contour showed a few lines around level 100.12 m all over the area (Fig. 4.6). The highest values of conductivity (i.e. 2.5 – 3.0 dS m^{-1}) came from northwest of the pen and concentration decreased as the plume spread towards southwest, reaching values from 0.5 to 1.0 dS m^{-1} at southwest part of the field. There was a trend for the plume to spread straight south from the point of higher concentration (point A) along the west edge of the pen (arrow) due to a drainage ditch running to toward the south.

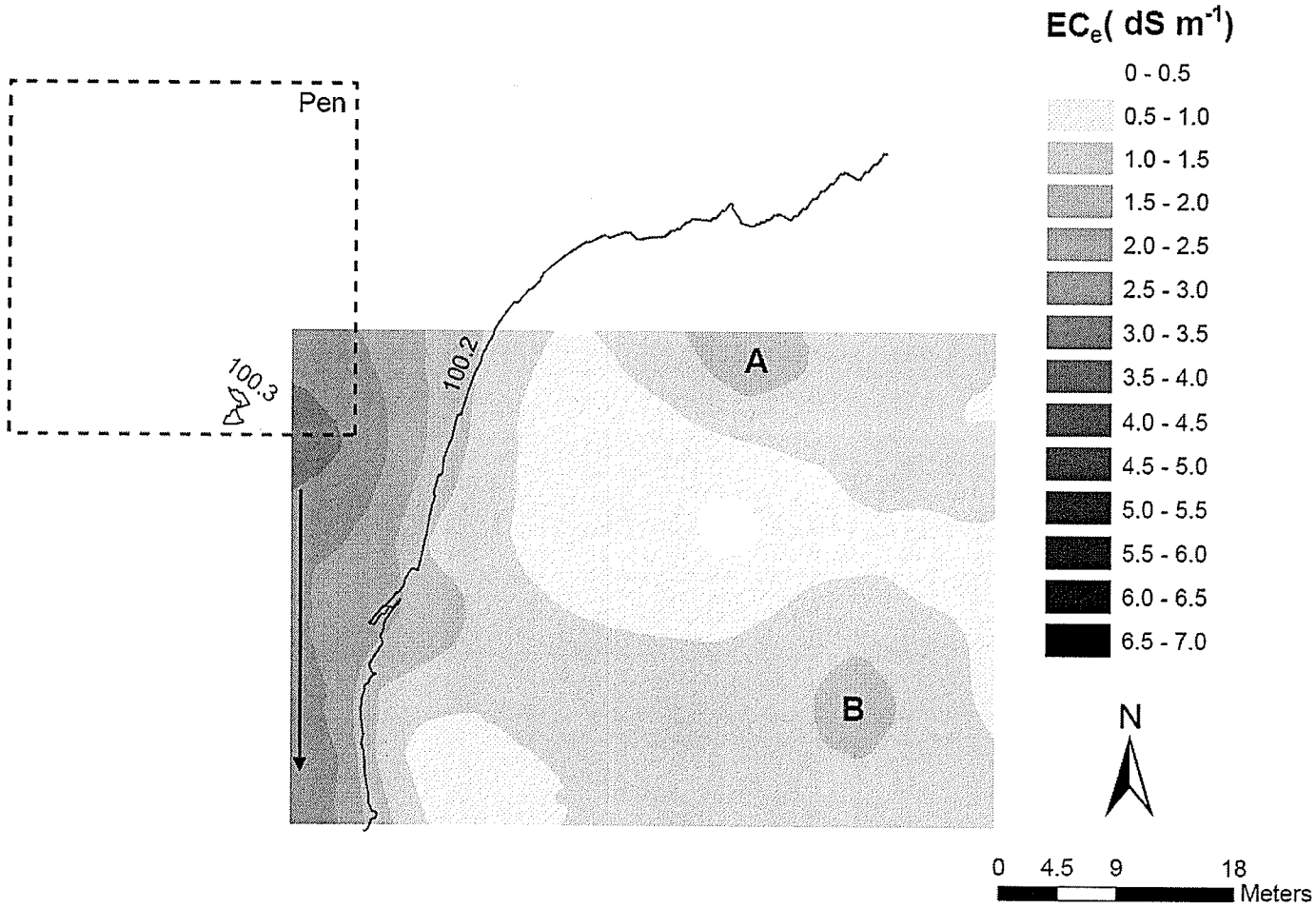

Fig. 4.3. Map of modeled electrical conductivity overlaid by level contours in Farm 3 showing the position and direction of a drainage ditch (arrow) and two areas of moderate conductivity within background values (B and C) .

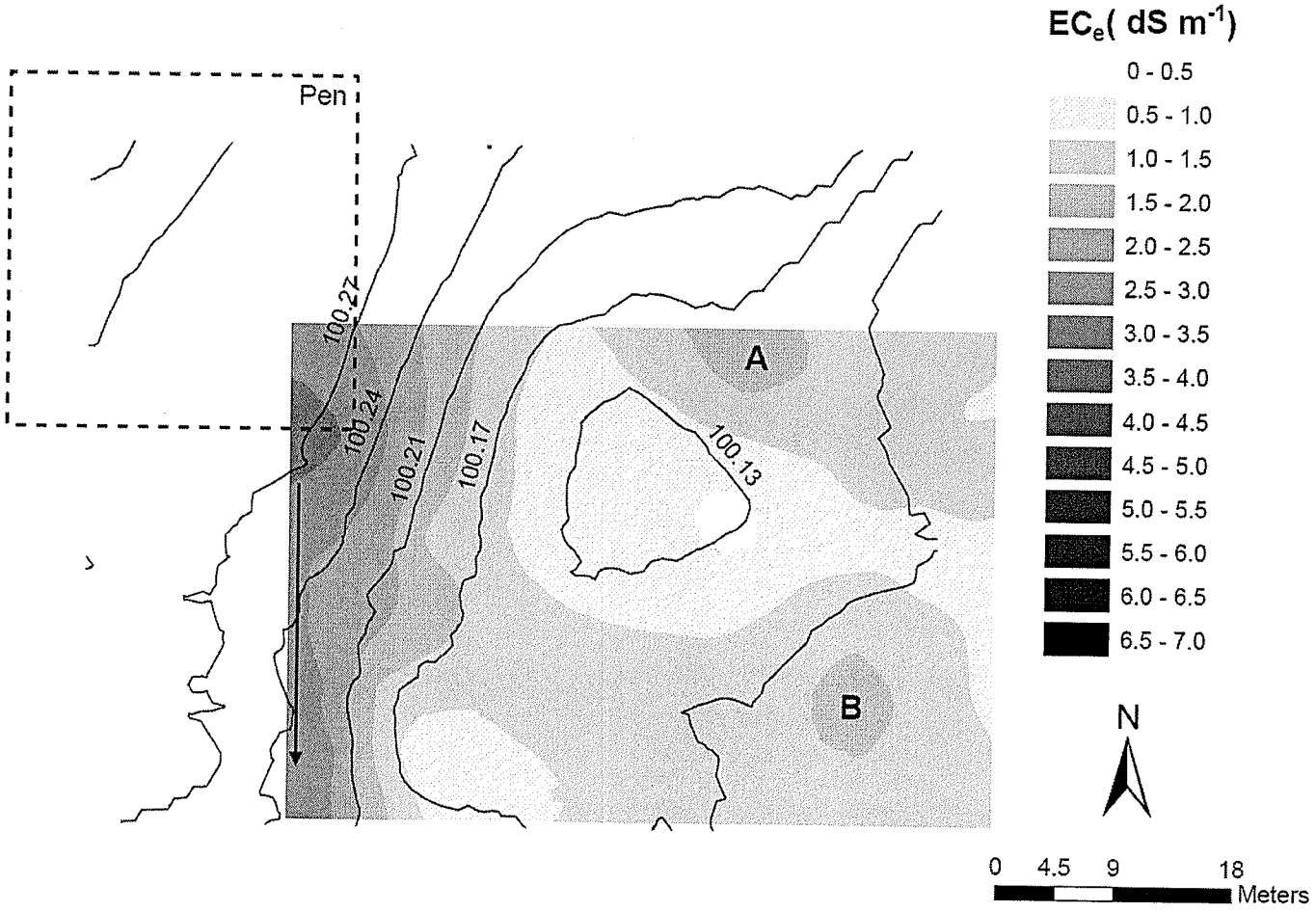

Fig. 4.4. Map of modeled electrical conductivity overlaid by a finer level contours in Farm 3 showing the position and direction of a drainage ditch (arrow) and two areas of moderate conductivity within background values (B and C) .

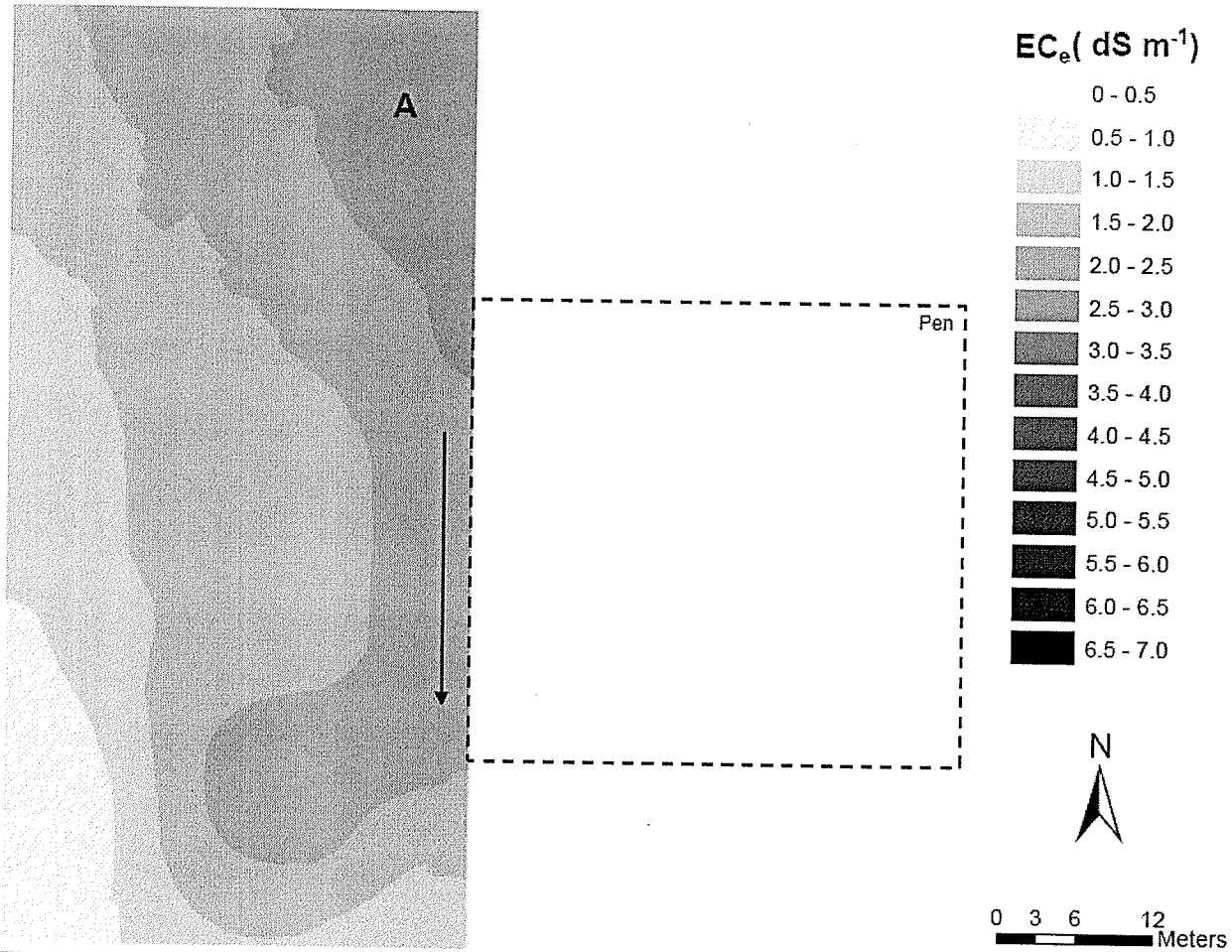

Fig. 4.5. Map of modeled electrical conductivity overlaid by level contours in Farm 4 showing the position and direction of a drainage ditch (arrow) and the area of highest conductivity (A).

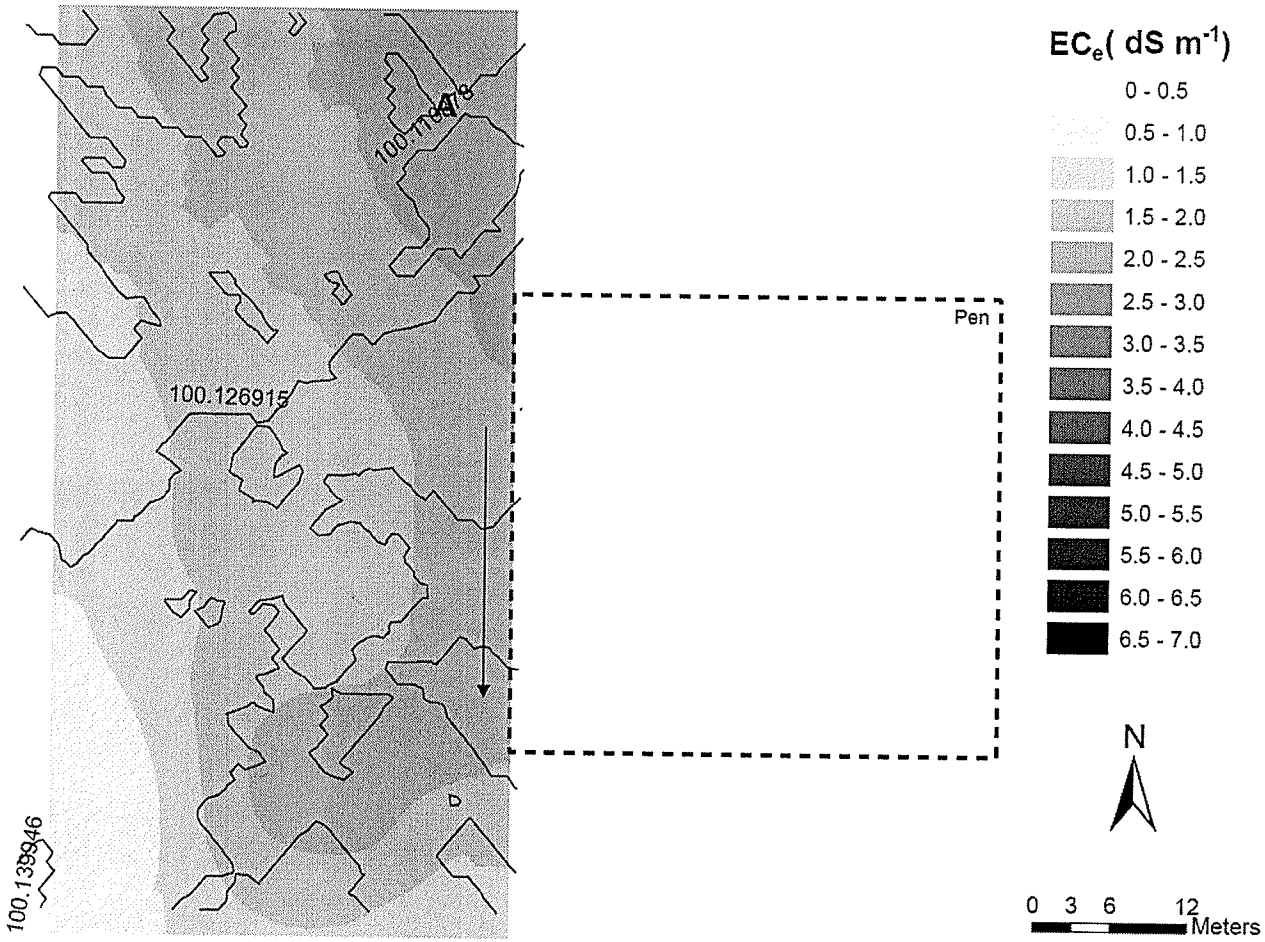

Fig. 4.6. Map of modeled electrical conductivity overlaid by a finer level contours in Farm 4 showing the position and direction of a drainage ditch (arrow) and the area of highest conductivity (A).

Farm 5 was an area down slope from three pens; one located about 110 m west, the second located about 40 m south, and the third located around 65 m southeast. Cattle had access to this field from the pen located on the west side. Animals from the other pens could not get to this field because of an electric fence. Elevation contours show that Farm 5 had the largest variation in elevation among all the farms, ranging from 100.1 to 101.2 m, with contours over 101.3 m observed at northwest corner of the field (data not shown) (Fig. 4.7). The EC_e reached the highest concentrations at points A and B, with EC_e ranging from 4.5 to 5.0 and from 5.0 to 5.5 dS m^{-1}, respectively. The distribution of EC_e was higher to the south of the hotspots than to the west, with background values (i.e. EC_e from 0.0 – 0.5 values dS m^{-1}) around contour 101.1 m. The hotspots (points A and B) did not quite correspond to the lowest levels in the field and were found at south of contour level 100.1 m, but the plume seemed to be moving north towards lower elevations from higher elevations located south and southeast, with some contribution coming from high areas to the west (point C).

Soil in Farm 6 was only 0.30 m deep, with a rocky layer underneath. This area was just south (down slope) of the pen and animals had free access to it. The contours in Fig. 4.8 show a slight variation in topography, with lower elevations towards the south. Point A was located around elevation contours 100.07 and 100.08 m, and levels dropped to 100.03 m towards the south of the field (data not shown). Electrical conductivity in this field was the highest among all farms, with a hotspot just south of the pen (point B; 6.5 – 7.0 dS m^{-1}). Concentrations decreased to 5.0 – 5.5 dS m^{-1} as the plume migrated

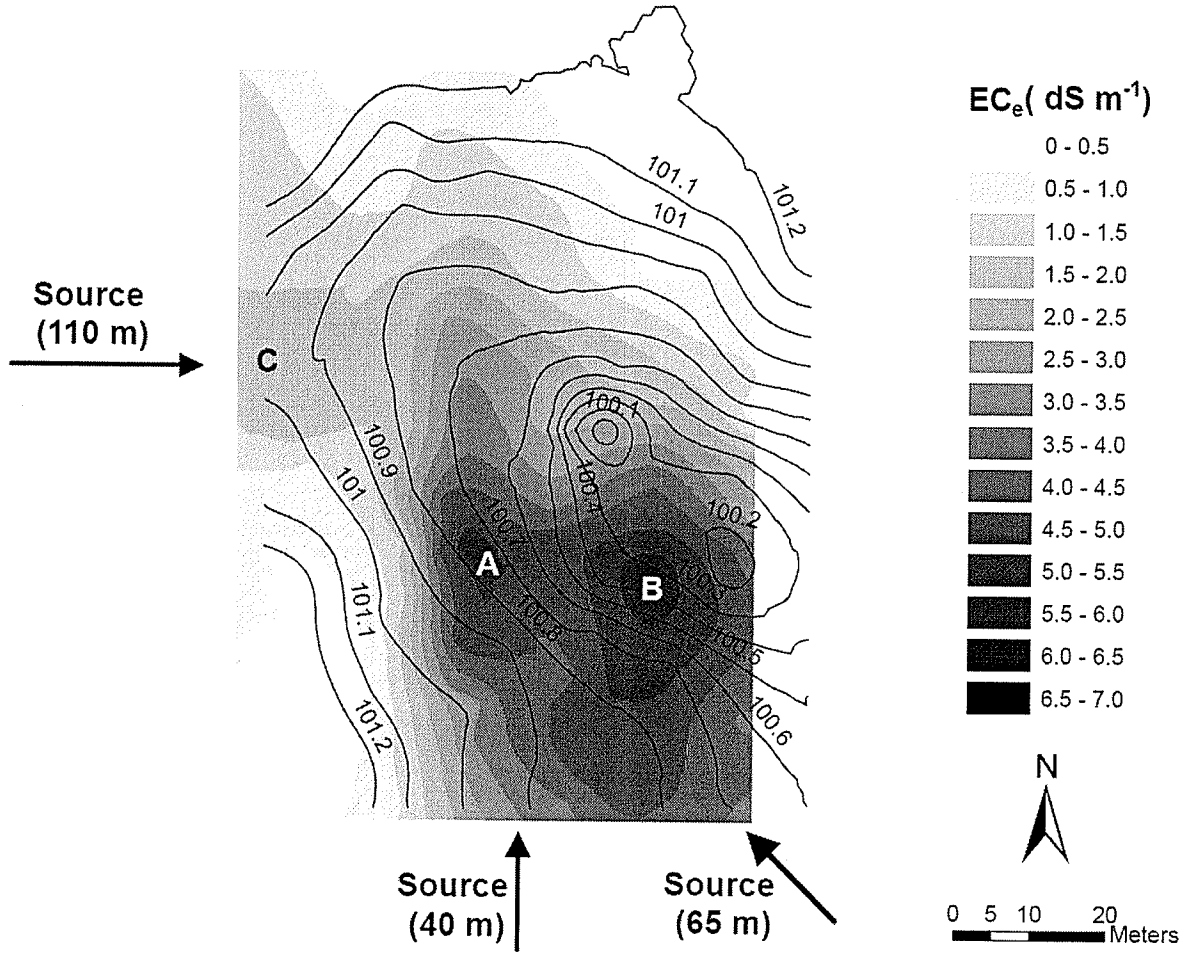

Fig. 4.7. Map of modeled electrical conductivity overlaid by level contours in Farm 5 showing two hotspots (A and B) and area receiving contribution of the pent to west (C).

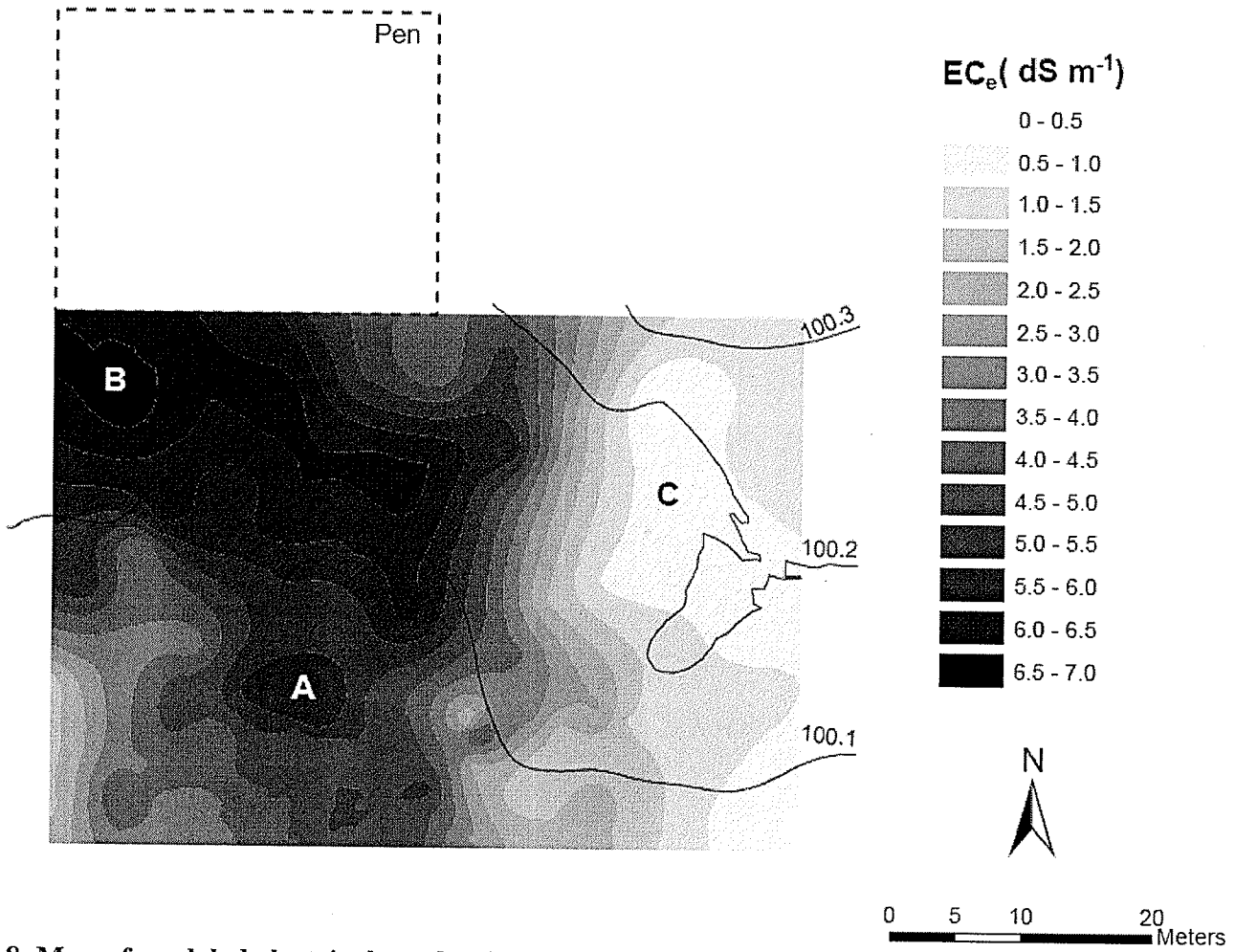

Fig. 4.8. Map of modeled electrical conductivity overlaid by level contours in Farm 6 showing two hotspots (A and B) and area with background values of conductivity (C).

southeast. The plume migrated towards south with concentration dropping to 4.0 – 4.5 dS m^{-1}. This change in direction more or less followed the contour line 100.2 m, an a finer contour (not shown). The lowest electrical conductivity (i.e. 0.5 – 1.0 dS m^{-1}) was found at point C which was inaccessible to the cattle.

4.5 Discussion

4.5.1 Influence of physiographic features on waste distribution

Agri-Maps (Manitoba Agriculture 2008) classify all six farms within non-saline areas with $EC_e < 4.0$ dS m^{-1}. Analysis of the EC_e maps show that farms 1 through 4 are still within this range with maximum values of EC_e ranging from 2.5 to 3.5 dS m^{-1}, but locations at farms 5 and 6 exceeded this threshold and reached maximum values of 5.5 and 7.0 dS m^{-1}, respectively. This change in electrical conductivity indicates an increase in nutrient concentration in the soil profile and possible enrichment by nutrients coming from manure in farms 5 and 6. A trend of accumulation can be observed in farms 1 through 4 as the plumes show a considerable difference from hotspots to background values. In fact, it is not possible to infer from the current analysis if these farms would have reached higher values of EC_e because these areas might be experiencing leaching to deeper layers in the soil profile (except Farm 4 that presents bedrock at 0.15 m depth). This possibility is quite feasible in farms 1, 2, and 3 as these fields contain sandy soil with hay (*Phleum pretense* L.) growing areas. The hydraulic conductivity of sandy soils (10^{-4} to 10^{-5} m sec^{-1}; Hillel 1998) associated with relatively shallow hay root system of about 0.20 m observed in the field support this hypothesis, but further investigation would be necessary to confirm it.

High values of EC_e were often associated with a low elevation, which suggests movement of nutrient driven by surface slope. This pattern was not evident in Farm 1 because the feeder was located in low elevations and manure was more frequently seen around the feeder, which led to higher EC_e in that region. The pattern was more evident in farms 2, 3, 5, and 6, where the plume migrated from higher to lower elevations. Such movement can take place by surface (i.e. runoff) and subsurface (i.e. groundwater) transport mechanisms that tend to direct drainage during rainfall and snowmelt to low spots. For Farm 4, it was not possible to judge the role of elevation on EC_e distribution since elevations changed less than 0.02 m.

Spellman and Whiting (2007) advise that soils with depths of less than 0.5 m are restrictive for land application of manure because this layer prevents plant growth and reduces soil adsorptive capacity for waste. These restrictions hold true for the present case because this feature prevents natural attenuation of manure components, even though manure is not being land-applied. Thus, the bedrock observed in farms 4 and 6 might be contributing to the accumulation of manure constituents in the soil. Although, Farm 4 did not show concentrations above normal in the surveyed area, it could be occurring north of the pen as the interpolation for that farm suggests (point A in Fig. 4). Higher concentrations at that point could be due to the internal drainage of the pen towards the north, which caused accumulation of salts in that region.

Another factor affecting the migration pattern in the surveyed areas was the presence of drainage ditches in farms 3 and 4. These features diverted the migration of the plume. Noticeably, the effect of the ditch seemed not only restricted to the surface but also to the entire depth because the model used for Farm 3 was vertically-weighted for

the whole soil profile and, yet, the plume followed the direction of the ditch. The diversion of the plume towards the south observed on the interpolation for that farm should then be taking place at several soil depths and not only at the surface, process that could be caused by the deep percolation from the ditch to lower depths.

4.5.2 Design of feedlot features

Observations from surveyed farms help to devise some measures to contain the spread of manure constituents from feedlots. The major aspect influencing migration of nutrients in those farms was the elevation contour and therefore the feedlot design should take advantage of the natural elevation in the field. The occurrence of high EC_e in low elevations suggests that the location of feedlot in low spots may contain the spread of nutrient plume. However, the possibility of runoff accumulation in these areas might represent problems to animals and pen operation. Thus, location of pens at higher elevations with some measures to contain the spread of the plume is proposed. In fact, higher elevations represent larger vertical distance from aquifers and longer contact time with soil for contaminants' attenuation (Spellman and Whiting 2007).

When the feedlots are located at higher elevations, drainage ditches could be used to divert the direction of runoff thus containing the migration of the plume. The effect of the drainage ditch on the migration of the plume was evident in farms 3 and 4. The ditches could be designed to drain the runoff from inside the pen to lower areas designated for storage and treatment of effluents. Collection ponds have been proposed to collect and accumulate runoff for future use in irrigation, but vegetative treatment areas (VTA) have also been suggested as an alternative (Koelsch et al. 2006). Both systems present advantages and constraints, and the selection should be based on physical and

management conditions. Design of these systems is out of the scope of this study and can be found in literature.

To avoid the infiltration within the pen itself, areas having soils with high hydraulic conductivity should be provided a liner of low permeability. Compacted soil liners between 0.3 and 0.46 m thick have been used to avoid large seepage rates from animal waste lagoons (Ham 2002), where fine-grained soils present lower permeability than coarse-grained soils (Parker et al. 1999). Geotextile membranes have also been successfully used in beef operations but they require special considerations in some instances (Singh et al. 2008). For areas with underlaying bedrock, installation of liner may not be necessary. Vegetative treatment areas to attenuate the nutrients have been used with suitable plant variety (i.e. growth in shallow soils with certain level of salinity, good nutrient uptake). Harvest of biomass can be employed for nutrient removal and the growth cycle is repeated (Suthersan 1999).

4.6 Conclusion

Six areas around beef cattle feedlots were surveyed in Manitoba, Canada, using electromagnetic induction (EMI) technique, and samples were acquired using a response surface design. Samples were analyzed for electrical conductivity (EC_e) and this information was used as response variable in multiple linear regression models for the calibration of EMI readings. The calibrated EMI readings were assumed to represent nutrients coming from manure produced in these areas, and the EMI readings were interpolated in a GIS platform to assess distribution patterns in the field. Results showed that feedlots are contributing to nutrient accumulation to varying degrees in the soil, with severe accumulation observed in areas with shallow bedrock. Elevation was the major

factor affecting nutrient distribution, with higher EC_e corresponding to lower elevations. However, features that promote preferential flow (i.e. drainage ditches) were shown to considerably affect nutrient distribution. Design criteria based on the present results indicate that pens should be located on higher elevation contours with interceptor drainage ditches to re-direct runoff towards storage or treatment systems. Also, liners should be installed in pens with soils having high hydraulic conductivity to avoid seepage through soil profile. For existing feedlots, the management practices suggested in the introductory sections (e.g. removing manure where it has built up over the winter season, moving feeding sites regularly during the winter, and providing sufficient areas to reduce animal densities) would minimize the impact of feedlot operations.

5. PRACTICAL APPLICATIONS

The research presented in the preceding chapters is useful for nutrient assessment in soils, since the methodology proposed can overcome the cost and complexity of traditional methods by using electromagnetic induction (EMI). Despite the EMI being a well established technology with large commercial and scientific applications, the present work brought new contributions for acquiring, interpreting and presenting EMI information for soil assessment.

The first contribution of this study was the development of the protocol used for field survey and soil sampling. It combines several programs and procedures meant to deliver data tabulation and calculation for sound, statistically-based sampling design. Also, it can be carried out by a single operator, not requiring resources other than the equipment presented in chapter 3. If larger areas are to be studied, the same protocol can be used provided that EMI survey can be sped up (e.g. use of an 'all terrain vehicle' pulling a cart-adapted conductivity meter) and sampling can be optimized (e.g. tractor-mounted soil sampler). Depending on the type of analysis to be performed on soil samples (e.g. electrical conductivity), this method also allows for the appraisal of the field using some of the procedures shown in chapter 2, without an analysis in the lab. This aspect would result in even faster soil assessment.

Calibration of EMI readings is another practical application of the methodology adopted. Vertically-weighted soil profile approach, found to be the method with better results for nutrient assessment in soils, builds on previous knowledge about calibration by incorporating advantageous aspects from other methods presented in the literature. It encompasses features such as weighted contributions from each soil depth interval and

decorrelated predictors calculated from EMI readings, which deliver more reliable predictions. Construction of these models is very practical and can be done quickly, as long as computational tools are available.

The approach used in this thesis also makes use of valuable information that is easy to get either in the field or from the web as well as the soil survey department. Micro-elevation and soil texture, even though not essential for the development and calibration of the model, proved to be useful when assessing salts/nutrient distribution because these factors affect migration pattern on the field. Micro-elevation can be quickly obtained using laser construction level, and soil texture is available from official sources (e.g. Soil Series Descriptions of Manitoba).

Finally, the GIS approach combining both EMI readings and other information (e.g. micro-elevation) is of practical use because it allows for easy handling and presentation of data. Interpolated EC_e maps and contour levels coupled with physical features on the field (e.g. pens and drainage ditches) facilitated the visualization of the raw data and permitted an easier evaluation of field conditions. For being interactive, GIS programs allows for viewing the information in different levels of detail. For instance, micro-elevation was presented in chapter 4 as contour lines of 0.1 m for consistency, but the analysis was done in some cases using a finer contour (i.e. 0.01 m). The GIS also presents modeling capabilities, as shown in chapter 2, which makes prediction of future scenarios feasible.

6. CONCLUSIONS

1. Soft and spatial multiple linear regression (MLR) gave very similar results in most instances. Models calculated using both MLR approaches predicted electrical conductivity (EC_e) well, but the specific compounds nitrate and phosphate were not predicted well in this study probably due to low concentrations of these ions compared to other ions.
2. Models using the composite-profile approach were more suitable for EC_e prediction than models constructed by layer because they overcame limitations presented by the latter approach (i.e. non-significant models among significant models in the soil profile). Profile-weighted approach gave better results than the profile-averaged approach in terms coefficient of determination (r^2) and root mean square error (RMSE), where vertically-weighted approach performed better than the horizontally-weighted. However, profile-weighted models can only be used if the whole soil profile is sampled because profiles partially sampled will results in underestimation of the parameters.
3. Predictors derived from EMI readings were usually included in prediction models, with predictors derived from surface trend parameters and "easy-to-acquire" information having less importance.
4. The accumulation of nutrients is occurring in areas around feedlots, as evidenced by the EC_e maps. Severe accumulation was observed in areas with shallow soil overlaying bedrock. Natural features in the field (e.g. soil texture and vegetative cover) might be contributing to leaching of nutrients deeper in the soil profile, but this possibility has to be investigated.

5. Elevation was the major factor affecting nutrient distribution. Higher EC_e corresponded to lower elevations, and distribution of this variable presented good agreement with level contours. Features that favor surface preferential flow (i.e. drainage ditches) had a large impact on the migration pattern.
6. Design criteria based on EC_e distribution and natural features in the field indicate that pens should be located on higher level contours with some sort of drain duct to direct runoff towards storage or treatment systems. Also, liners should be installed in pens having soils with high hydraulic conductivity to avoid seepage through soil profile.

7. RECOMMENDATIONS FOR FUTURE RESEARCH

The following are recommendations for future research:

1. Undertaking experiments using similar methodology with the number of soil samples increased from 12 to 20 because ESAP – RSSD can generate sample design with up to 20 samples. This increase in the number of samples would not represent a big difference in time and cost for sample analysis but would represent a benefit from the statistical analysis standpoint. Outlier assessment could be performed in the expanded dataset, and deletion of these points could be done without compromising predictability. Also, length of models would not be a constraint, and more predictors could be included.
2. Collection of a second dataset for cross-validation. This approach would help to assess the quality of models in terms of predictability. It would also be important in trying the performance of models across different farms, where models constructed for one farm could be tested in other farms. This procedure would help to assess the applicability of a more general model to be used in different situations.
3. Construction of models for vertically-weighted profiles including both first- and second-order predictors. This approach would give more flexibility to multiple linear regression models, increasing prediction capabilities. However, this possibility is strongly linked to the collection of a larger dataset (e.g. minimum 20 samples).
4. Setting a monitoring scheme using electromagnetic induction and conducting surveys in different seasons. This procedure would help to assess the migration of

nutrients from feedlots under different soil conditions (e.g. water content). It would also assist in evaluating the spatial – temporal variation of nutrients distribution.

5. Repeating this experiment in farms with other soil characteristics and natural features. The study of farms located close to water bodies or streams would help to better understand the interactions of soil and water.

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APPENDICES

Appendix A: Values of electrical conductivity, nitrate, and phosphate used for calculation of multiple linear regression

ECe Farm 1

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (µS)	Dilution	Dillution Corrected Reading (µS)	Cell consant, *k* (100/m) [SI]	ECe (µS/m)	ECe (mS/m)	ECe (dS/m)
F1-16-15cm	12.00	7.63	14.54	30	436.20	100	43,620.00	43.62	0.4362
F1-16-30cm	12.00	7.63	16.28	31	504.68	100	50,468.00	50.47	0.50468
F1-16-60cm	12.00	7.63	7.19	90	647.10	100	64,710.00	64.71	0.6471
F1-16-90cm	12.00	7.63	5.63	120	675.60	100	67,560.00	67.56	0.6756
F1-16-120cm	12.00	7.63	7.84	120	940.80	100	94,080.00	94.08	0.9408
F1-22-15cm	6.75	5.50	60.80	30	1,824.00	100	182,400.00	182.40	1.824
F1-22-30cm	6.75	5.50	36.90	30	1,107.00	100	110,700.00	110.70	1.107
F1-22-60cm	6.75	5.50	12.70	30	381.00	100	38,100.00	38.10	0.381
F1-22-90cm	6.75	5.50	12.20	120	1,464.00	100	146,400.00	146.40	1.464
F1-22-120cm	6.75	5.50	3.02	135	407.70	100	40,770.00	40.77	0.4077
F1-68-15cm	10.25	4.25	8.98	30	269.40	100	26,940.00	26.94	0.2694
F1-68-30cm	10.25	4.25	4.36	60	261.60	100	26,160.00	26.16	0.2616
F1-68-60cm	10.25	4.25	5.63	120	675.60	100	67,560.00	67.56	0.6756
F1-68-90cm	10.25	4.25	6.53	120	783.60	100	78,360.00	78.36	0.7836
F1-68-120cm	10.25	4.25	6.34	120	760.80	100	76,080.00	76.08	0.7608
F1-74-15cm	16.25	9.88	16.72	60	1,003.20	100	100,320.00	100.32	1.0032
F1-74-30cm	16.25	9.88	10.95	90	985.50	100	98,550.00	98.55	0.9855
F1-74-60cm	16.25	9.88	9.01	90	810.90	100	81,090.00	81.09	0.8109
F1-74-90cm	16.25	9.88	8.96	60	537.60	100	53,760.00	53.76	0.5376
F1-74-120cm	16.25	9.88	18.43	30	552.90	100	55,290.00	55.29	0.5529

ECe Farm 1 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (µS)	Dilution	Dillution Corrected Reading (µS)	Cell consant, *k* (100/m) [SI]	ECe (µS/m)	ECe (mS/m)	ECe (dS/m)
F1-135-15cm	14.38	16.88	17.70	30	531.00	100	53,100.00	53.10	0.531
F1-135-30cm	14.38	16.88	6.54	120	784.80	100	78,480.00	78.48	0.7848
F1-135-60cm	14.38	16.88	11.76	45	529.20	100	52,920.00	52.92	0.5292
F1-135-90cm	14.38	16.88	15.80	30	474.00	100	47,400.00	47.40	0.474
F1-135-120cm	14.38	16.88	19.37	30	581.10	100	58,110.00	58.11	0.5811
F1-142-15cm	8.75	4.75	32.60	30	978.00	100	97,800.00	97.80	0.978
F1-142-30cm	8.75	4.75	10.75	30	322.50	100	32,250.00	32.25	0.3225
F1-142-60cm	8.75	4.75	9.24	30	277.20	100	27,720.00	27.72	0.2772
F1-142-90cm	8.75	4.75	4.77	60	286.20	100	28,620.00	28.62	0.2862
F1-142-120cm	8.75	4.75	8.97	30	269.10	100	26,910.00	26.91	0.2691
F1-148-15cm	45.38	41.50	146.10	30	4,383.00	100	438,300.00	438.30	4.383
F1-148-30cm	45.38	41.50	75.30	30	2,259.00	100	225,900.00	225.90	2.259
F1-148-60cm	45.38	41.50	55.00	30	1,650.00	100	165,000.00	165.00	1.65
F1-148-90cm	45.38	41.50	46.00	30	1,380.00	100	138,000.00	138.00	1.38
F1-148-120cm	45.38	41.50	49.90	30	1,497.00	100	149,700.00	149.70	1.497
F1-152-15cm	26.13	12.88	30.00	30	900.00	100	90,000.00	90.00	0.9
F1-152-30cm	26.13	12.88	7.02	105	737.10	100	73,710.00	73.71	0.7371
F1-152-60cm	26.13	12.88	25.20	30	756.00	100	75,600.00	75.60	0.756
F1-152-90cm	26.13	12.88	54.70	30	1,641.00	100	164,100.00	164.10	1.641
F1-152-120cm	26.13	12.88	52.30	30	1,569.00	100	156,900.00	156.90	1.569

ECe Farm 1 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (µS)	Dilution	Dillution Corrected Reading (µS)	Cell consant, *k* (100/m) [SI]	ECe (µS/m)	ECe (mS/m)	ECe (dS/m)
F1-160-15cm	35.25	45.88	155.70	90	14,013.00	100	1,401,300.00	1401.30	14.013
F1-160-30cm	35.25	45.88	162.30	30	4,869.00	100	486,900.00	486.90	4.869
F1-160-60cm	35.25	45.88	53.60	30	1,608.00	100	160,800.00	160.80	1.608
F1-160-90cm	35.25	45.88	17.03	90	1,532.70	100	153,270.00	153.27	1.5327
F1-160-120cm	35.25	45.88	59.20	30	1,776.00	100	177,600.00	177.60	1.776
F1-176-15cm	38.13	25.13	84.80	30	2,544.00	100	254,400.00	254.40	2.544
F1-176-30cm	38.13	25.13	73.80	30	2,214.00	100	221,400.00	221.40	2.214
F1-176-60cm	38.13	25.13	74.40	30	2,232.00	100	223,200.00	223.20	2.232
F1-176-90cm	38.13	25.13	96.70	30	2,901.00	100	290,100.00	290.10	2.901
F1-176-120cm	38.13	25.13	80.40	30	2,412.00	100	241,200.00	241.20	2.412
F1-201-15cm	23.25	18.38	58.30	30	1,749.00	100	174,900.00	174.90	1.749
F1-201-30cm	23.25	18.38	21.60	30	648.00	100	64,800.00	64.80	0.648
F1-201-60cm	23.25	18.38	29.10	30	873.00	100	87,300.00	87.30	0.873
F1-201-90cm	23.25	18.38	35.80	30	1,074.00	100	107,400.00	107.40	1.074
F1-201-120cm	23.25	18.38	37.70	30	1,131.00	100	113,100.00	113.10	1.131
F1-215-15cm	21.50	15.75	69.40	30	2,082.00	100	208,200.00	208.20	2.082
F1-215-30cm	21.50	15.75	32.30	30	969.00	100	96,900.00	96.90	0.969
F1-215-60cm	21.50	15.75	19.04	30	571.20	100	57,120.00	57.12	0.5712
F1-215-90cm	21.50	15.75	30.30	30	909.00	100	90,900.00	90.90	0.909
F1-215-120cm	21.50	15.75	32.20	30	966.00	100	96,600.00	96.60	0.966

NO_3 Farm 1

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	NO3- (mg/100g soil)
F1-16-15cm	12.00	7.63	3.4	30	102.00	8.51	0.00851	70	1.24003
F1-16-30cm	12.00	7.63	0.831	31	25.76	4.30	0.00430	50	0.22154
F1-16-60cm	12.00	7.63	0.532	30	15.96	2.56	0.00256	50	0.08172
F1-16-90cm	12.00	7.63	0.328	30	9.84	1.62	0.00162	50	0.03188
F1-16-120cm	12.00	7.63	0.384	30	11.52	1.70	0.00170	120	0.01632
F1-22-15cm	6.75	5.50	4.73	30	141.90	9.47	0.00947	50	2.68759
F1-22-30cm	6.75	5.50	2.92	30	87.60	7.26	0.00726	50	1.27195
F1-22-60cm	6.75	5.50	0.764	30	22.92	3.40	0.00340	110	0.07084
F1-22-90cm	6.75	5.50	0.206	30	6.18	2.16	0.00216	80	0.01669
F1-22-120cm	6.75	5.50	0.103	45	4.64	1.56	0.00156	80	0.00904
F1-68-15cm	10.25	4.25	0.137	30	4.11	3.72	0.00372	50	0.03058
F1-68-30cm	10.25	4.25	0.228	30	6.84	2.86	0.00286	60	0.03260
F1-68-60cm	10.25	4.25	0.0815	30	2.45	1.70	0.00170	60	0.00693
F1-68-90cm	10.25	4.25	0.0878	30	2.63	1.73	0.00173	80	0.00570
F1-68-120cm	10.25	4.25	0.246	30	7.38	1.33	0.00133	150	0.00654
F1-74-15cm	16.25	9.88	1.45	30	43.50	2.98	0.00298	50	0.25926
F1-74-30cm	16.25	9.88	0.802	45	36.09	1.23	0.00123	60	0.07398
F1-74-60cm	16.25	9.88	0.218	45	9.81	1.20	0.00120	80	0.01472
F1-74-90cm	16.25	9.88	0.476	30	14.28	3.15	0.00315	120	0.03749
F1-74-120cm	16.25	9.88	0.687	30	20.61	5.34	0.00534	150	0.07337

NO_3 Farm 1 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	NO3- (mg/100g soil)
F1-135-15cm	14.38	16.88	0.0981	30	2.94	5.62	0.00562	100	0.01654
F1-135-30cm	14.38	16.88	0.137	30	4.11	1.51	0.00151	60	0.01034
F1-135-60cm	14.38	16.88	0.0402	45	1.81	2.03	0.00203	60	0.00612
F1-135-90cm	14.38	16.88	0.042	30	1.26	4.91	0.00491	120	0.00516
F1-135-120cm	14.38	16.88	0.0528	30	1.58	4.07	0.00407	120	0.00537
F1-142-15cm	8.75	4.75	1.92	30	57.60	4.55	0.00455	50	0.52416
F1-142-30cm	8.75	4.75	0.442	30	13.26	2.57	0.00257	50	0.06816
F1-142-60cm	8.75	4.75	0.0286	30	0.86	2.52	0.00252	80	0.00270
F1-142-90cm	8.75	4.75	0.0103	30	0.31	3.62	0.00362	100	0.00112
F1-142-120cm	8.75	4.75	0.063	30	1.89	3.65	0.00365	100	0.00690
F1-148-15cm	45.38	41.50	0.00471	30	0.14	4.82	0.00482	60	0.00114
F1-148-30cm	45.38	41.50	2.73	30	81.90	3.59	0.00359	60	0.49004
F1-148-60cm	45.38	41.50	1.35	30	40.50	5.16	0.00516	80	0.26123
F1-148-90cm	45.38	41.50	1.02	30	30.60	9.98	0.00998	110	0.27763
F1-148-120cm	45.38	41.50	1.12	30	33.60	9.20	0.00920	110	0.28102
F1-152-15cm	26.13	12.88	1.6	30	48.00	3.19	0.00319	50	0.30624
F1-152-30cm	26.13	12.88	0.682	35	23.87	1.77	0.00177	55	0.07682
F1-152-60cm	26.13	12.88	1.61	30	48.30	3.87	0.00387	60	0.31154
F1-152-90cm	26.13	12.88	3.76	30	112.80	3.84	0.00384	60	0.72192
F1-152-120cm	26.13	12.88	3.25	30	97.50	4.32	0.00432	80	0.52650

NO_3 Farm 1 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	NO3- (mg/100g soil)
F1-160-15cm	35.25	45.88	20.4	30	612.00	2.02	0.00202	50	2.47248
F1-160-30cm	35.25	45.88	9.68	30	290.40	4.68	0.00468	50	2.71814
F1-160-60cm	35.25	45.88	4.42	30	132.60	3.59	0.00359	60	0.79339
F1-160-90cm	35.25	45.88	2.55	30	76.50	2.09	0.00209	80	0.19986
F1-160-120cm	35.25	45.88	2.89	30	86.70	6.69	0.00669	110	0.52729
F1-176-15cm	38.13	25.13	3.14	30	94.20	3.75	0.00375	50	0.70650
F1-176-30cm	38.13	25.13	4.91	30	147.30	2.88	0.00288	60	0.70704
F1-176-60cm	38.13	25.13	5.31	30	159.30	3.78	0.00378	70	0.86022
F1-176-90cm	38.13	25.13	5.64	30	169.20	3.75	0.00375	70	0.90643
F1-176-120cm	38.13	25.13	1.04	30	31.20	6.50	0.00650	110	0.18436
F1-201-15cm	23.25	18.38	1.83	30	54.90	6.42	0.00642	50	0.70492
F1-201-30cm	23.25	18.38	0.583	30	17.49	3.07	0.00307	50	0.10739
F1-201-60cm	23.25	18.38	0.508	30	15.24	5.28	0.00528	70	0.11495
F1-201-90cm	23.25	18.38	0.597	30	17.91	5.92	0.00592	100	0.10603
F1-201-120cm	23.25	18.38	0.801	30	24.03	7.30	0.00730	120	0.14618
F1-215-15cm	21.50	15.75	4.35	30	130.50	6.72	0.00672	50	1.75392
F1-215-30cm	21.50	15.75	1.76	30	52.80	2.72	0.00272	50	0.28723
F1-215-60cm	21.50	15.75	0.491	30	14.73	2.39	0.00239	70	0.05029
F1-215-90cm	21.50	15.75	0.964	30	28.92	5.65	0.00565	100	0.16340
F1-215-120cm	21.50	15.75	0.623	30	18.69	8.39	0.00839	120	0.13067

PO_4 Farm 1

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	PO4- (mg/100g soil)
F1-16-15cm	12.00	7.63	0.05718	62.50	3.57	8.51	0.00851	70	0.04345
F1-16-30cm	12.00	7.63	0.01062	62.50	0.66	4.30	0.00430	50	0.00571
F1-16-60cm	12.00	7.63	0.00638	62.50	0.40	2.56	0.00256	50	0.00204
F1-16-90cm	12.00	7.63	0.00497	62.50	0.31	1.62	0.00162	50	0.00101
F1-16-120cm	12.00	7.63	0.00638	62.50	0.40	1.70	0.00170	120	0.00057
F1-22-15cm	6.75	5.50	0.13479	62.50	8.42	9.47	0.00947	50	0.15956
F1-22-30cm	6.75	5.50	0.10375	62.50	6.48	7.26	0.00726	50	0.09415
F1-22-60cm	6.75	5.50	0.01626	62.50	1.02	3.40	0.00340	110	0.00314
F1-22-90cm	6.75	5.50	0.13197	62.50	8.25	2.16	0.00216	80	0.02227
F1-22-120cm	6.75	5.50	0.01485	93.75	1.39	1.56	0.00156	80	0.00271
F1-68-15cm	10.25	4.25	0.00497	62.50	0.31	3.72	0.00372	50	0.00231
F1-68-30cm	10.25	4.25	0.00356	62.50	0.22	2.86	0.00286	60	0.00106
F1-68-60cm	10.25	4.25	0.01344	62.50	0.84	1.70	0.00170	60	0.00238
F1-68-90cm	10.25	4.25	0.01767	62.50	1.10	1.73	0.00173	80	0.00239
F1-68-120cm	10.25	4.25	0.00356	62.50	0.22	1.33	0.00133	150	0.00020
F1-74-15cm	16.25	9.88	0.11786	62.50	7.37	2.98	0.00298	50	0.04390
F1-74-30cm	16.25	9.88	0.03178	93.75	2.98	1.23	0.00123	60	0.00611
F1-74-60cm	16.25	9.88	0.04448	93.75	4.17	1.20	0.00120	80	0.00626
F1-74-90cm	16.25	9.88	0.03460	62.50	2.16	3.15	0.00315	120	0.00568
F1-74-120cm	16.25	9.88	0.01062	62.50	0.66	5.34	0.00534	150	0.00236

PO_4 Farm 1 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	PO4- (mg/100g soil)
F1-135-15cm	14.38	16.88	0.00497	62.50	0.31	5.62	0.00562	100	0.00175
F1-135-30cm	14.38	16.88	0.00215	93.75	0.20	1.51	0.00151	60	0.00051
F1-135-60cm	14.38	16.88	0.00215	93.75	0.20	2.03	0.00203	60	0.00068
F1-135-90cm	14.38	16.88	0.00920	62.50	0.58	4.91	0.00491	120	0.00235
F1-135-120cm	14.38	16.88	0.00074	62.50	0.05	4.07	0.00407	120	0.00016
F1-142-15cm	8.75	4.75	0.14467	62.50	9.04	4.55	0.00455	50	0.08228
F1-142-30cm	8.75	4.75	0.04025	62.50	2.52	2.57	0.00257	50	0.01293
F1-142-60cm	8.75	4.75	0.03319	62.50	2.07	2.52	0.00252	80	0.00653
F1-142-90cm	8.75	4.75	0.02190	62.50	1.37	3.62	0.00362	100	0.00496
F1-142-120cm	8.75	4.75	0.01344	62.50	0.84	3.65	0.00365	100	0.00307
F1-148-15cm	45.38	41.50	0.44099	62.50	27.56	4.82	0.00482	60	0.22142
F1-148-30cm	45.38	41.50	0.07694	62.50	4.81	3.59	0.00359	60	0.02877
F1-148-60cm	45.38	41.50	0.00497	62.50	0.31	5.16	0.00516	80	0.00200
F1-148-90cm	45.38	41.50	0.01062	62.50	0.66	9.98	0.00998	110	0.00602
F1-148-120cm	45.38	41.50	0.00356	62.50	0.22	9.20	0.00920	110	0.00186
F1-152-15cm	26.13	12.88	0.17571	62.50	10.98	3.19	0.00319	50	0.07006
F1-152-30cm	26.13	12.88	0.02049	62.50	1.28	1.77	0.00177	55	0.00412
F1-152-60cm	26.13	12.88	0.00497	62.50	0.31	3.87	0.00387	60	0.00200
F1-152-90cm	26.13	12.88	0.00638	62.50	0.40	3.84	0.00384	60	0.00255
F1-152-120cm	26.13	12.88	0.00215	62.50	0.13	4.32	0.00432	80	0.00073

PO_4 Farm 1 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	PO4- (mg/100g soil)
F1-160-15cm	35.25	45.88	1.20862	62.50	75.54	2.02	0.00202	50	0.30518
F1-160-30cm	35.25	45.88	0.30130	62.50	18.83	4.68	0.00468	50	0.17626
F1-160-60cm	35.25	45.88	0.00638	62.50	0.40	3.59	0.00359	60	0.00239
F1-160-90cm	35.25	45.88	0.01344	62.50	0.84	2.09	0.00209	80	0.00219
F1-160-120cm	35.25	45.88	0.01203	62.50	0.75	6.69	0.00669	110	0.00457
F1-176-15cm	38.13	25.13	0.49744	62.50	31.09	3.75	0.00375	50	0.23317
F1-176-30cm	38.13	25.13	0.19547	62.50	12.22	2.88	0.00288	60	0.05864
F1-176-60cm	38.13	25.13	0.00779	62.50	0.49	3.78	0.00378	70	0.00263
F1-176-90cm	38.13	25.13	0.00215	62.50	0.13	3.75	0.00375	70	0.00072
F1-176-120cm	38.13	25.13	0.00920	62.50	0.58	6.50	0.00650	110	0.00340
F1-201-15cm	23.25	18.38	0.02755	62.50	1.72	6.42	0.00642	50	0.02211
F1-201-30cm	23.25	18.38	0.00779	62.50	0.49	3.07	0.00307	50	0.00299
F1-201-60cm	23.25	18.38	0.00497	62.50	0.31	5.28	0.00528	70	0.00234
F1-201-90cm	23.25	18.38	0.00215	62.50	0.13	5.92	0.00592	100	0.00080
F1-201-120cm	23.25	18.38	0.00638	62.50	0.40	7.30	0.00730	120	0.00243
F1-215-15cm	21.50	15.75	0.11645	62.50	7.28	6.72	0.00672	50	0.09781
F1-215-30cm	21.50	15.75	0.10375	62.50	6.48	2.72	0.00272	50	0.03527
F1-215-60cm	21.50	15.75	0.00779	62.50	0.49	2.39	0.00239	70	0.00166
F1-215-90cm	21.50	15.75	0.00779	62.50	0.49	5.65	0.00565	100	0.00275
F1-215-120cm	21.50	15.75	0.02473	62.50	1.55	8.39	0.00839	120	0.01081

ECe Farm 2

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (µS)	Dilution	Dillution Corrected Reading (µS)	Cell consant, *k* (100/m) [SI]	ECe (µS/m)	ECe (mS/m)	ECe (dS/m)
F2-02-15cm	42.50	36.13	58.1	30.00	1,743.00	100	174,300	174.30	1.743
F2-02-30cm	42.50	36.13	36.8	30.00	1,104.00	100	110,400	110.40	1.104
F2-02-60cm	42.50	36.13	12.7	30.00	381.00	100	38,100	38.10	0.381
F2-02-90cm	42.50	36.13	16.5	30.00	495.00	100	49,500	49.50	0.495
F2-02-120cm	42.50	36.13	76.3	30.00	2,289.00	100	228,900	228.90	2.289
F2-08-15cm	90.75	92.50	194.6	30.00	5,838.00	100	583,800	583.80	5.838
F2-08-30cm	90.75	92.50	144.2	30.00	4,326.00	100	432,600	432.60	4.326
F2-08-60cm	90.75	92.50	103.4	30.00	3,102.00	100	310,200	310.20	3.102
F2-08-90cm	90.75	92.50	94.7	30.00	2,841.00	100	284,100	284.10	2.841
F2-08-120cm	90.75	92.50	117.5	30.00	3,525.00	100	352,500	352.50	3.525
F2-21-15cm	53.00	46.88	220	30.00	6,600.00	100	660,000	660.00	6.6
F2-21-30cm	53.00	46.88	136.8	30.00	4,104.00	100	410,400	410.40	4.104
F2-21-60cm	53.00	46.88	62	30.00	1,860.00	100	186,000	186.00	1.86
F2-21-90cm	53.00	46.88	84.1	30.00	2,523.00	100	252,300	252.30	2.523
F2-21-120cm	53.00	46.88	117	30.00	3,510.00	100	351,000	351.00	3.51
F2-28-15cm	73.00	81.00	261	30.00	7,830.00	100	783,000	783.00	7.83
F2-28-30cm	73.00	81.00	251	30.00	7,530.00	100	753,000	753.00	7.53
F2-28-60cm	73.00	81.00	56.9	30.00	1,707.00	100	170,700	170.70	1.707
F2-28-90cm	73.00	81.00	55.3	30.00	1,659.00	100	165,900	165.90	1.659
F2-28-120cm	73.00	81.00	74.7	30.00	2,241.00	100	224,100	224.10	2.241

ECe Farm 2 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (μS)	Dilution	Dillution Corrected Reading (μS)	Cell consant, *k* (100/m) [SI]	ECe (μS/m)	ECe (mS/m)	ECe (dS/m)
F2-43-15cm	78.63	75.63	211	30.00	6,330.00	100	633,000	633.00	6.33
F2-43-30cm	78.63	75.63	65.3	30.00	1,959.00	100	195,900	195.90	1.959
F2-43-60cm	78.63	75.63	88.4	30.00	2,652.00	100	265,200	265.20	2.652
F2-43-90cm	78.63	75.63	72.6	30.00	2,178.00	100	217,800	217.80	2.178
F2-43-120cm	78.63	75.63	90.1	30.00	2,703.00	100	270,300	270.30	2.703
F2-50-15cm	71.75	51.50	236	30.00	7,080.00	100	708,000	708.00	7.08
F2-50-30cm	71.75	51.50	179.7	30.00	5,391.00	100	539,100	539.10	5.391
F2-50-60cm	71.75	51.50	77.6	30.00	2,328.00	100	232,800	232.80	2.328
F2-50-90cm	71.75	51.50	59.2	45.00	2,664.00	100	266,400	266.40	2.664
F2-50-120cm	71.75	51.50	106.8	30.00	3,204.00	100	320,400	320.40	3.204
F2-79-15cm	63.75	78.25	505	30.00	15,150.00	100	1,515,000	1515.00	15.15
F2-79-30cm	63.75	78.25	401	30.00	12,030.00	100	1,203,000	1203.00	12.03
F2-79-60cm	63.75	78.25	76.6	30.00	2,298.00	100	229,800	229.80	2.298
F2-79-90cm	63.75	78.25	70.8	30.00	2,124.00	100	212,400	212.40	2.124
F2-79-120cm	63.75	78.25	91.4	30.00	2,742.00	100	274,200	274.20	2.742
F2-103-15cm	57.50	51.00	70.3	30.00	2,109.00	100	210,900	210.90	2.109
F2-103-30cm	57.50	51.00	233	30.00	6,990.00	100	699,000	699.00	6.99
F2-103-60cm	57.50	51.00	65	30.00	1,950.00	100	195,000	195.00	1.95
F2-103-90cm	57.50	51.00	70.2	30.00	2,106.00	100	210,600	210.60	2.106
F2-103-120cm	57.50	51.00	79.9	30.00	2,397.00	100	239,700	239.70	2.397

ECe Farm 2 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (μS)	Dilution	Dillution Corrected Reading (μS)	Cell consant, *k* (100/m) [SI]	ECe (μS/m)	ECe (mS/m)	ECe (dS/m)
F2-106-15cm	39.88	39.00	110	30.00	3,300.00	100	330,000	330.00	3.3
F2-106-30cm	39.88	39.00	104.9	30.00	3,147.00	100	314,700	314.70	3.147
F2-106-60cm	39.88	39.00	59.4	30.00	1,782.00	100	178,200	178.20	1.782
F2-106-90cm	39.88	39.00	50.4	45.00	2,268.00	100	226,800	226.80	2.268
F2-106-120cm	39.88	39.00	46.6	30.00	1,398.00	100	139,800	139.80	1.398
F2-112-15cm	18.00	12.63	23.9	30.00	717.00	100	71,700	71.70	0.717
F2-112-30cm	18.00	12.63	9.49	60.00	569.40	100	56,940	56.94	0.5694
F2-112-60cm	18.00	12.63	11.86	60.00	711.60	100	71,160	71.16	0.7116
F2-112-90cm	18.00	12.63	11.2	135.00	1,512.00	100	151,200	151.20	1.512
F2-112-120cm	18.00	12.63	6.35	135.00	857.25	100	85,725	85.73	0.85725
F2-122-15cm	22.63	14.63	22.8	30.00	684.00	100	68,400	68.40	0.684
F2-122-30cm	22.63	14.63	7.49	90.00	674.10	100	67,410	67.41	0.6741
F2-122-60cm	22.63	14.63	9.25	90.00	832.50	100	83,250	83.25	0.8325
F2-122-90cm	22.63	14.63	14.5	60.00	870.00	100	87,000	87.00	0.87
F2-122-120cm	22.63	14.63	13.4	90.00	1,206.00	100	120,600	120.60	1.206
F2-138-15cm	109.13	90.00	125.9	30.00	3,777.00	100	377,700	377.70	3.777
F2-138-30cm	109.13	90.00	123.9	30.00	3,717.00	100	371,700	371.70	3.717
F2-138-60cm	109.13	90.00	69.4	30.00	2,082.00	100	208,200	208.20	2.082
F2-138-90cm	109.13	90.00	99.7	30.00	2,991.00	100	299,100	299.10	2.991
F2-138-120cm	109.13	90.00	146.4	30.00	4,392.00	100	439,200	439.20	4.392

NO_3 Farm 2

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	NO3- (mg/100g soil)
F2-02-15cm	42.50	36.13	0.263	30.00	7.89	5.25	0.00525	50	0.08285
F2-02-30cm	42.50	36.13	0.258	30.00	7.74	3.06	0.00306	60	0.03947
F2-02-60cm	42.50	36.13	0.0697	30.00	2.09	3.37	0.00337	80	0.00881
F2-02-90cm	42.50	36.13	0.0353	30.00	1.06	4.21	0.00421	100	0.00446
F2-02-120cm	42.50	36.13	0.0523	30.00	1.57	8.58	0.00858	100	0.01346
F2-08-15cm	90.75	92.50	0.293	30.00	0.09	3.69	0.00369	50	0.00063
F2-08-30cm	90.75	92.50	0.0681	30.00	0.00	4.92	0.00492	60	0.00004
F2-08-60cm	90.75	92.50	0.0731	30.00	0.01	5.14	0.00514	80	0.00003
F2-08-90cm	90.75	92.50	0.114	30.00	0.01	7.87	0.00787	100	0.00010
F2-08-120cm	90.75	92.50	0.295	30.00	0.09	8.04	0.00804	120	0.00058
F2-21-15cm	53.00	46.88	0.333	30.00	9.99	4.07	0.00407	50	0.08132
F2-21-30cm	53.00	46.88	0.341	30.00	10.23	3.29	0.00329	60	0.05609
F2-21-60cm	53.00	46.88	0.0743	30.00	2.23	7.24	0.00724	90	0.01793
F2-21-90cm	53.00	46.88	0.304	30.00	9.12	9.88	0.00988	100	0.09011
F2-21-120cm	53.00	46.88	0.545	30.00	16.35	11.28	0.01128	100	0.18443
F2-28-15cm	73.00	81.00	0.5	30.00	0.25	4.34	0.00434	50	0.00217
F2-28-30cm	73.00	81.00	1.47	30.00	2.16	7.18	0.00718	60	0.02586
F2-28-60cm	73.00	81.00	1.38	30.00	1.90	5.37	0.00537	80	0.01278
F2-28-90cm	73.00	81.00	1.47	30.00	2.16	8.32	0.00832	80	0.02247
F2-28-120cm	73.00	81.00	1.87	30.00	3.50	7.05	0.00705	80	0.03082

NO_3 Farm 2 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	NO3- (mg/100g soil)
F2-43-15cm	78.63	75.63	0.584	30.00	17.52	3.37	0.00337	50	0.11808
F2-43-30cm	78.63	75.63	1.51	30.00	45.30	3.85	0.00385	60	0.29068
F2-43-60cm	78.63	75.63	0.716	30.00	21.48	3.86	0.00386	80	0.10364
F2-43-90cm	78.63	75.63	2.02	30.00	60.60	7.53	0.00753	80	0.57040
F2-43-120cm	78.63	75.63	2.4	30.00	72.00	9.11	0.00911	80	0.81990
F2-50-15cm	71.75	51.50	5.85	30.00	175.50	3.28	0.00328	50	1.15128
F2-50-30cm	71.75	51.50	7.77	30.00	233.10	4.21	0.00421	60	1.63559
F2-50-60cm	71.75	51.50	3.63	30.00	108.90	4	0.004	80	0.54450
F2-50-90cm	71.75	51.50	2.65	45.00	119.25	4.14	0.00414	80	0.61712
F2-50-120cm	71.75	51.50	5.04	30.00	151.20	5.31	0.00531	80	1.00359
F2-79-15cm	63.75	78.25	0.0458	30.00	1.37	4.32	0.00432	50	0.01187
F2-79-30cm	63.75	78.25	0.0579	30.00	1.74	4.68	0.00468	60	0.01355
F2-79-60cm	63.75	78.25	0.0003	30.00	0.01	8.17	0.00817	80	0.00009
F2-79-90cm	63.75	78.25	0.0003	30.00	0.01	8.07	0.00807	80	0.00009
F2-79-120cm	63.75	78.25	0.0472	30.00	1.42	5.63	0.00563	90	0.00886
F2-103-15cm	57.50	51.00	0.0468	30.00	1.40	2.15	0.00215	50	0.00604
F2-103-30cm	57.50	51.00	0.0003	30.00	0.01	4.34	0.00434	60	0.00007
F2-103-60cm	57.50	51.00	0.0003	30.00	0.01	4.52	0.00452	80	0.00005
F2-103-90cm	57.50	51.00	0.0115	30.00	0.35	6.78	0.00678	80	0.00292
F2-103-120cm	57.50	51.00	0.00904	30.00	0.27	7.64	0.00764	80	0.00259

NO_3 Farm 2 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	NO3- (mg/100g soil)
F2-106-15cm	39.88	39.00	4.99	30.00	149.70	3.23	0.00323	50	0.96706
F2-106-30cm	39.88	39.00	2.68	30.00	80.40	4.26	0.00426	60	0.57084
F2-106-60cm	39.88	39.00	1.85	30.00	55.50	4.06	0.00406	80	0.28166
F2-106-90cm	39.88	39.00	1.75	45.00	78.75	1.82	0.00182	80	0.17916
F2-106-120cm	39.88	39.00	1.89	30.00	56.70	4.28	0.00428	80	0.30335
F2-112-15cm	18.00	12.63	0.468	30.00	14.04	4.64	0.00464	50	0.13029
F2-112-30cm	18.00	12.63	0.192	30.00	5.76	1.72	0.00172	50	0.01981
F2-112-60cm	18.00	12.63	0.119	30.00	3.57	1.73	0.00173	60	0.01029
F2-112-90cm	18.00	12.63	0.119	45.00	5.36	1.08	0.00108	60	0.00964
F2-112-120cm	18.00	12.63	0.0561	45.00	2.52	1.23	0.00123	80	0.00388
F2-122-15cm	22.63	14.63	1.07	30.00	32.10	3.85	0.00385	60	0.20598
F2-122-30cm	22.63	14.63	0.199	45.00	8.96	1.58	0.00158	60	0.02358
F2-122-60cm	22.63	14.63	0.105	45.00	4.73	1.63	0.00163	100	0.00770
F2-122-90cm	22.63	14.63	0.291	30.00	8.73	2.13	0.00213	100	0.01859
F2-122-120cm	22.63	14.63	0.285	45.00	12.83	1.28	0.00128	100	0.01642
F2-138-15cm	109.13	90.00	1.48	30.00	44.40	4.11	0.00411	60	0.30414
F2-138-30cm	109.13	90.00	0.938	30.00	28.14	4.88	0.00488	60	0.22887
F2-138-60cm	109.13	90.00	0.0611	30.00	1.83	7.69	0.00769	80	0.01762
F2-138-90cm	109.13	90.00	0.02	30.00	0.60	8.56	0.00856	80	0.00642
F2-138-120cm	109.13	90.00	0.0317	30.00	0.95	11.09	0.01109	100	0.01055

PO_4 Farm 2

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	PO4- (mg/100g soil)
F2-02-15cm	42.50	36.13	0.14692	50.00	7.35	5.25	0.00525	50	0.07713
F2-02-30cm	42.50	36.13	0.06075	50.00	3.04	3.06	0.00306	60	0.01549
F2-02-60cm	42.50	36.13	0.00425	50.00	0.21	3.37	0.00337	80	0.00089
F2-02-90cm	42.50	36.13	0.00566	50.00	0.28	4.21	0.00421	100	0.00119
F2-02-120cm	42.50	36.13	0.00566	50.00	0.28	8.58	0.00858	100	0.00243
F2-08-15cm	90.75	92.50	0.02544	50.00	1.27	3.69	0.00369	50	0.00939
F2-08-30cm	90.75	92.50	0.00566	75.00	0.42	4.92	0.00492	60	0.00348
F2-08-60cm	90.75	92.50	0.00425	50.00	0.21	5.14	0.00514	80	0.00136
F2-08-90cm	90.75	92.50	0.00284	50.00	0.14	7.87	0.00787	100	0.00112
F2-08-120cm	90.75	92.50	0.00284	50.00	0.14	8.04	0.00804	120	0.00095
F2-21-15cm	53.00	46.88	0.02261	75.00	1.70	4.07	0.00407	50	0.01380
F2-21-30cm	53.00	46.88	0.00707	50.00	0.35	3.29	0.00329	60	0.00194
F2-21-60cm	53.00	46.88	0.00142	50.00	0.07	7.24	0.00724	90	0.00057
F2-21-90cm	53.00	46.88	0.00284	50.00	0.14	9.88	0.00988	100	0.00140
F2-21-120cm	53.00	46.88	0.00142	50.00	0.07	11.28	0.01128	100	0.00080
F2-28-15cm	73.00	81.00	0.01131	50.00	0.57	4.34	0.00434	50	0.00491
F2-28-30cm	73.00	81.00	0.00707	50.00	0.35	7.18	0.00718	60	0.00423
F2-28-60cm	73.00	81.00	0.00001	50.00	0.00	5.37	0.00537	80	0.00000
F2-28-90cm	73.00	81.00	0.00142	50.00	0.07	8.32	0.00832	80	0.00074
F2-28-120cm	73.00	81.00	0.00142	50.00	0.07	7.05	0.00705	80	0.00063

PO_4 Farm 2 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	PO4- (mg/100g soil)
F2-43-15cm	78.63	75.63	0.03532	50.00	1.77	3.37	0.00337	50	0.01190
F2-43-30cm	78.63	75.63	0.00566	50.00	0.28	3.85	0.00385	60	0.00182
F2-43-60cm	78.63	75.63	0.00425	50.00	0.21	3.86	0.00386	80	0.00102
F2-43-90cm	78.63	75.63	0.00284	50.00	0.14	7.53	0.00753	80	0.00133
F2-43-120cm	78.63	75.63	0.00425	50.00	0.21	9.11	0.00911	80	0.00242
F2-50-15cm	71.75	51.50	0.01414	50.00	0.71	3.28	0.00328	50	0.00464
F2-50-30cm	71.75	51.50	0.00142	50.00	0.07	4.21	0.00421	60	0.00050
F2-50-60cm	71.75	51.50	0.00001	50.00	0.00	4	0.00400	80	0.00000
F2-50-90cm	71.75	51.50	0.00142	75.00	0.11	4.14	0.00414	80	0.00055
F2-50-120cm	71.75	51.50	0.00142	50.00	0.07	5.31	0.00531	80	0.00047
F2-79-15cm	63.75	78.25	0.02685	50.00	1.34	4.32	0.00432	50	0.01160
F2-79-30cm	63.75	78.25	0.00284	50.00	0.14	4.68	0.00468	60	0.00111
F2-79-60cm	63.75	78.25	0.00001	50.00	0.00	8.17	0.00817	80	0.00001
F2-79-90cm	63.75	78.25	0.00001	50.00	0.00	8.07	0.00807	80	0.00001
F2-79-120cm	63.75	78.25	0.00425	50.00	0.21	5.63	0.00563	90	0.00133
F2-103-15cm	57.50	51.00	0.03391	50.00	1.70	2.15	0.00215	50	0.00729
F2-103-30cm	57.50	51.00	0.00284	50.00	0.14	4.34	0.00434	60	0.00103
F2-103-60cm	57.50	51.00	0.00142	75.00	0.11	4.52	0.00452	80	0.00060
F2-103-90cm	57.50	51.00	0.00284	50.00	0.14	6.78	0.00678	80	0.00120
F2-103-120cm	57.50	51.00	0.00142	50.00	0.07	7.64	0.00764	80	0.00068

PO_4 Farm 2 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	PO4- (mg/100g soil)
F2-106-15cm	39.88	39.00	0.04662	50.00	2.33	3.23	0.00323	50	0.01506
F2-106-30cm	39.88	39.00	0.01272	50.00	0.64	4.26	0.00426	60	0.00452
F2-106-60cm	39.88	39.00	0.00284	50.00	0.14	4.06	0.00406	80	0.00072
F2-106-90cm	39.88	39.00	0.00425	75.00	0.32	1.82	0.00182	80	0.00072
F2-106-120cm	39.88	39.00	0.00566	75.00	0.42	4.28	0.00428	80	0.00227
F2-112-15cm	18.00	12.63	0.12714	50.00	6.36	4.64	0.00464	50	0.05899
F2-112-30cm	18.00	12.63	0.12149	75.00	9.11	1.72	0.00172	50	0.03134
F2-112-60cm	18.00	12.63	0.03956	75.00	2.97	1.73	0.00173	60	0.00856
F2-112-90cm	18.00	12.63	0.01414	75.00	1.06	1.08	0.00108	60	0.00191
F2-112-120cm	18.00	12.63	0.01131	75.00	0.85	1.23	0.00123	80	0.00130
F2-122-15cm	22.63	14.63	0.25851	50.00	12.93	3.85	0.00385	60	0.08294
F2-122-30cm	22.63	14.63	0.12149	75.00	9.11	1.58	0.00158	60	0.02399
F2-122-60cm	22.63	14.63	0.01131	75.00	0.85	1.63	0.00163	100	0.00138
F2-122-90cm	22.63	14.63	0.01696	50.00	0.85	2.13	0.00213	100	0.00181
F2-122-120cm	22.63	14.63	0.01837	75.00	1.38	1.28	0.00128	100	0.00176
F2-138-15cm	109.13	90.00	0.05651	50.00	2.83	4.11	0.00411	60	0.01936
F2-138-30cm	109.13	90.00	0.00707	50.00	0.35	4.88	0.00488	60	0.00288
F2-138-60cm	109.13	90.00	0.00284	50.00	0.14	7.69	0.00769	80	0.00136
F2-138-90cm	109.13	90.00	0.00142	50.00	0.07	8.56	0.00856	80	0.00076
F2-138-120cm	109.13	90.00	0.00707	50.00	0.35	11.09	0.01109	100	0.00392

ECe Farm 3

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (μS)	Dilution	Dillution Corrected Reading (μS)	Cell consant, *k* (100/m) [SI]	ECe (μS/m)	ECe (mS/m)	ECe (dS/m)
F3-01-15cm	55.13	50.00	152.6	30.00	4,578	100	457,800	457.80	4.578
F3-01-30cm	55.13	50.00	104.8	30.00	3,144	100	314,400	314.40	3.144
F3-01-60cm	55.13	50.00	30.4	30.00	912	100	91,200	91.20	0.912
F3-01-90cm	55.13	50.00	34.5	30.00	1,035	100	103,500	103.50	1.035
F3-01-120cm	55.13	50.00	55.2	30.00	1,656	100	165,600	165.60	1.656
F3-08-15cm	64.38	62.38	227	30.00	6,810	100	681,000	681.00	6.81
F3-08-30cm	64.38	62.38	189.3	30.00	5,679	100	567,900	567.90	5.679
F3-08-60cm	64.38	62.38	53.7	30.00	1,611	100	161,100	161.10	1.611
F3-08-90cm	64.38	62.38	80	30.00	2,400	100	240,000	240.00	2.4
F3-08-120cm	64.38	62.38	100.8	30.00	3,024	100	302,400	302.40	3.024
F3-11-15cm	46.25	54.50	51	60.00	3,060	100	306,000	306.00	3.06
F3-11-30cm	46.25	54.50	14.9	60.00	894	100	89,400	89.40	0.894
F3-11-60cm	46.25	54.50	14.5	60.00	870	100	87,000	87.00	0.87
F3-11-90cm	46.25	54.50	56.1	30.00	1,683	100	168,300	168.30	1.683
F3-11-120cm	46.25	54.50	147.5	30.00	4,425	100	442,500	442.50	4.425
F3-15-15cm	45.75	28.88	16.8	90.00	1,512	100	151,200	151.20	1.512
F3-15-30cm	45.75	28.88	9.83	90.00	885	100	88,470	88.47	0.8847
F3-15-60cm	45.75	28.88	11.62	90.00	1,046	100	104,580	104.58	1.0458
F3-15-90cm	45.75	28.88	40.6	30.00	1,218	100	121,800	121.80	1.218
F3-15-120cm	45.75	28.88	88.5	30.00	2,655	100	265,500	265.50	2.655

ECe Farm 3 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (µS)	Dilution	Dillution Corrected Reading (µS)	Cell consant, *k* (100/m) [SI]	ECe (µS/m)	ECe (mS/m)	ECe (dS/m)
F3-22-15cm	45.88	43.25	51.7	30.00	1,551	100	155,100	155.10	1.551
F3-22-30cm	45.88	43.25	10.1	60.00	606	100	60,600	60.60	0.606
F3-22-60cm	45.88	43.25	15.8	60.00	948	100	94,800	94.80	0.948
F3-22-90cm	45.88	43.25	37.6	30.00	1,128	100	112,800	112.80	1.128
F3-22-120cm	45.88	43.25	56.5	30.00	1,695	100	169,500	169.50	1.695
F3-26-15cm	34.63	44.13	90.4	30.00	2,712	100	271,200	271.20	2.712
F3-26-30cm	34.63	44.13	54.1	30.00	1,623	100	162,300	162.30	1.623
F3-26-60cm	34.63	44.13	14.7	60.00	882	100	88,200	88.20	0.882
F3-26-90cm	34.63	44.13	33.2	30.00	996	100	99,600	99.60	0.996
F3-26-120cm	34.63	44.13	37.3	30.00	1,119	100	111,900	111.90	1.119
F3-32-15cm	36.38	36.50	74.6	30.00	2,238	100	223,800	223.80	2.238
F3-32-30cm	36.38	36.50	21.2	30.00	636	100	63,600	63.60	0.636
F3-32-60cm	36.38	36.50	9.35	90.00	842	100	84,150	84.15	0.8415
F3-32-90cm	36.38	36.50	15.28	60.00	917	100	91,680	91.68	0.9168
F3-32-120cm	36.38	36.50	22.5	60.00	1,350	100	135,000	135.00	1.35
F3-44-15cm	44.63	39.00	129.2	30.00	3,876	100	387,600	387.60	3.876
F3-44-30cm	44.63	39.00	105.2	30.00	3,156	100	315,600	315.60	3.156
F3-44-60cm	44.63	39.00	44.4	30.00	1,332	100	133,200	133.20	1.332
F3-44-90cm	44.63	39.00	29.8	30.00	894	100	89,400	89.40	0.894
F3-44-120cm	44.63	39.00	32.6	30.00	978	100	97,800	97.80	0.978

ECe Farm 3 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (μS)	Dilution	Dillution Corrected Reading (μS)	Cell consant, *k* (100/m) [SI]	ECe (μS/m)	ECe (mS/m)	ECe (dS/m)
F3-48-15cm	34.25	26.63	13.5	60.00	810	100	81,000	81.00	0.81
F3-48-30cm	34.25	26.63	8.35	60.00	501	100	50,100	50.10	0.501
F3-48-60cm	34.25	26.63	16.2	30.00	486	100	48,600	48.60	0.486
F3-48-90cm	34.25	26.63	8.6	60.00	516	100	51,600	51.60	0.516
F3-48-120cm	34.25	26.63	42.3	30.00	1,269	100	126,900	126.90	1.269
F3-50-15cm	30.50	18.75	38.7	60.00	2,322	100	232,200	232.20	2.322
F3-50-30cm	30.50	18.75	83.5	30.00	2,505	100	250,500	250.50	2.505
F3-50-60cm	30.50	18.75	31.6	30.00	948	100	94,800	94.80	0.948
F3-50-90cm	30.50	18.75	25.7	30.00	771	100	77,100	77.10	0.771
F3-50-120cm	30.50	18.75	29.4	30.00	882	100	88,200	88.20	0.882
F3-63-15cm	27.75	30.50	19.4	60.00	1,164	100	116,400	116.40	1.164
F3-63-30cm	27.75	30.50	7.41	90.00	667	100	66,690	66.69	0.6669
F3-63-60cm	27.75	30.50	7.58	60.00	455	100	45,480	45.48	0.4548
F3-63-90cm	27.75	30.50	23.4	30.00	702	100	70,200	70.20	0.702
F3-63-120cm	27.75	30.50	40.3	30.00	1,209	100	120,900	120.90	1.209
F3-67-15cm	20.13	13.75	36.1	30.00	1,083	100	108,300	108.30	1.083
F3-67-30cm	20.13	13.75	64	30.00	1,920	100	192,000	192.00	1.92
F3-67-60cm	20.13	13.75	42.1	30.00	1,263	100	126,300	126.30	1.263
F3-67-90cm	20.13	13.75	14.6	30.00	438	100	43,800	43.80	0.438
F3-67-120cm	20.13	13.75	18.2	30.00	546	100	54,600	54.60	0.546

NO_3 Farm 3

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	NO3- (mg/100g soil)
F3-01-15cm	55.13	50.00	1.46	30.00	43.80	5.05	0.00505	60	0.36865
F3-01-30cm	55.13	50.00	1.5	30.00	45.00	5.29	0.00529	60	0.39675
F3-01-60cm	55.13	50.00	0.14	30.00	4.20	3.87	0.00387	80	0.02032
F3-01-90cm	55.13	50.00	0.09	30.00	2.70	3.16	0.00316	80	0.01067
F3-01-120cm	55.13	50.00	0.36	30.00	10.80	4.13	0.00413	80	0.05576
F3-08-15cm	64.38	62.38	17.8	30.00	534.00	3.21	0.00321	50	3.42828
F3-08-30cm	64.38	62.38	10.5	30.00	315.00	4.32	0.00432	50	2.72160
F3-08-60cm	64.38	62.38	1.79	30.00	53.70	3.5	0.0035	80	0.23494
F3-08-90cm	64.38	62.38	3.84	30.00	115.20	3.58	0.00358	80	0.51552
F3-08-120cm	64.38	62.38	4.76	30.00	142.80	4.02	0.00402	80	0.71757
F3-11-15cm	46.25	54.50	2.77	30.00	83.10	2.97	0.00297	50	0.49361
F3-11-30cm	46.25	54.50	0.49	30.00	14.70	1.85	0.00185	60	0.04533
F3-11-60cm	46.25	54.50	0.21	30.00	6.30	2.51	0.00251	80	0.01977
F3-11-90cm	46.25	54.50	0.39	30.00	11.70	4.2	0.0042	80	0.06143
F3-11-120cm	46.25	54.50	0.96	30.00	28.80	7.59	0.00759	90	0.24288
F3-15-15cm	45.75	28.88	0.22	30.00	6.60	1.8	0.0018	60	0.01980
F3-15-30cm	45.75	28.88	0.15	30.00	4.50	2.19	0.00219	70	0.01408
F3-15-60cm	45.75	28.88	0.19	30.00	5.70	1.74	0.00174	80	0.01240
F3-15-90cm	45.75	28.88	0.44	30.00	13.20	3.31	0.00331	90	0.04855
F3-15-120cm	45.75	28.88	0.86	30.00	25.80	6.59	0.00659	90	0.18891

NO_3 Farm 3 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	NO3- (mg/100g soil)
F3-22-15cm	45.88	43.25	2.16	30.00	64.80	3.2	0.0032	60	0.34560
F3-22-30cm	45.88	43.25	0.43	30.00	12.90	2.9	0.0029	80	0.04676
F3-22-60cm	45.88	43.25	0.52	30.00	15.60	2.22	0.00222	80	0.04329
F3-22-90cm	45.88	43.25	1.15	30.00	34.50	4.71	0.00471	80	0.20312
F3-22-120cm	45.88	43.25	0.65	30.00	19.50	6.73	0.00673	100	0.13124
F3-26-15cm	34.63	44.13	1.99	30.00	59.70	3.58	0.00358	60	0.35621
F3-26-30cm	34.63	44.13	0.7	30.00	21.00	3.71	0.00371	70	0.11130
F3-26-60cm	34.63	44.13	0.35	30.00	10.50	2.23	0.00223	80	0.02927
F3-26-90cm	34.63	44.13	0.57	30.00	17.10	3.47	0.00347	80	0.07417
F3-26-120cm	34.63	44.13	0.79	30.00	23.70	5.98	0.00598	90	0.15747
F3-32-15cm	36.38	36.50	1.73	30.00	51.90	3.92	0.00392	70	0.29064
F3-32-30cm	36.38	36.50	0.39	30.00	11.70	2.91	0.00291	80	0.04256
F3-32-60cm	36.38	36.50	0.2	45.00	9.00	1.45	0.00145	80	0.01631
F3-32-90cm	36.38	36.50	0.26	30.00	7.80	2.46	0.00246	80	0.02399
F3-32-120cm	36.38	36.50	0.25	30.00	7.50	10.04	0.01004	100	0.07530
F3-44-15cm	44.63	39.00	8.59	30.00	257.70	4.88	0.00488	60	2.09596
F3-44-30cm	44.63	39.00	1.98	30.00	59.40	4.73	0.00473	60	0.46827
F3-44-60cm	44.63	39.00	0.19	30.00	5.70	5.48	0.00548	80	0.03905
F3-44-90cm	44.63	39.00	0.21	30.00	6.30	4.78	0.00478	80	0.03764
F3-44-120cm	44.63	39.00	0.26	30.00	7.80	4.96	0.00496	80	0.04836

NO_3 Farm 3 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	NO3- (mg/100g soil)
F3-48-15cm	34.25	26.63	0.24	30.00	7.20	2.42	0.00242	60	0.02904
F3-48-30cm	34.25	26.63	0.13	30.00	3.90	2.12	0.00212	70	0.01181
F3-48-60cm	34.25	26.63	0.13	30.00	3.90	3.12	0.00312	80	0.01521
F3-48-90cm	34.25	26.63	0.16	30.00	4.80	2.43	0.00243	80	0.01458
F3-48-120cm	34.25	26.63	1.3	30.00	39.00	6.74	0.00674	80	0.32858
F3-50-15cm	30.50	18.75	2.49	30.00	74.70	2.35	0.00235	60	0.29258
F3-50-30cm	30.50	18.75	1.76	30.00	52.80	3.57	0.00357	60	0.31416
F3-50-60cm	30.50	18.75	0.48	30.00	14.40	3.53	0.00353	80	0.06354
F3-50-90cm	30.50	18.75	0.32	30.00	9.60	3.58	0.00358	80	0.04296
F3-50-120cm	30.50	18.75	0.3	30.00	9.00	4.87	0.00487	80	0.05479
F3-63-15cm	27.75	30.50	0.52	30.00	15.60	1.91	0.00191	60	0.04966
F3-63-30cm	27.75	30.50	0.18	45.00	8.10	1.43	0.00143	70	0.01655
F3-63-60cm	27.75	30.50	0.24	30.00	7.20	1.91	0.00191	80	0.01719
F3-63-90cm	27.75	30.50	0.55	30.00	16.50	3.66	0.00366	80	0.07549
F3-63-120cm	27.75	30.50	1.58	30.00	47.40	6.74	0.00674	80	0.39935
F3-67-15cm	20.13	13.75	1.14	30.00	34.20	5.45	0.00545	60	0.31065
F3-67-30cm	20.13	13.75	0.26	30.00	7.80	6.14	0.00614	70	0.06842
F3-67-60cm	20.13	13.75	0.06	30.00	1.80	4.33	0.00433	80	0.00974
F3-67-90cm	20.13	13.75	0.06	30.00	1.80	3.12	0.00312	80	0.00702
F3-67-120cm	20.13	13.75	0.04	30.00	1.20	3.28	0.00328	80	0.00492

PO_4 Farm 3

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	PO4- (mg/100g soil)
F3-01-15cm	55.13	50.00	0.09035	50.00	4.52	5.05	0.00505	60	0.03802
F3-01-30cm	55.13	50.00	0.03425	50.00	1.71	5.29	0.00529	60	0.01510
F3-01-60cm	55.13	50.00	0.02303	50.00	1.15	3.87	0.00387	80	0.00557
F3-01-90cm	55.13	50.00	0.00339	50.00	0.17	3.16	0.00316	80	0.00067
F3-01-120cm	55.13	50.00	0.00620	50.00	0.31	4.13	0.00413	80	0.00160
F3-08-15cm	64.38	62.38	0.04547	50.00	2.27	3.21	0.00321	50	0.01460
F3-08-30cm	64.38	62.38	0.08053	50.00	4.03	4.32	0.00432	50	0.03479
F3-08-60cm	64.38	62.38	0.02723	50.00	1.36	3.5	0.00350	80	0.00596
F3-08-90cm	64.38	62.38	0.00339	50.00	0.17	3.58	0.00358	80	0.00076
F3-08-120cm	64.38	62.38	0.21097	50.00	10.55	4.02	0.00402	80	0.05301
F3-11-15cm	46.25	54.50	0.07212	50.00	3.61	2.97	0.00297	50	0.02142
F3-11-30cm	46.25	54.50	0.07913	75.00	5.93	1.85	0.00185	60	0.01830
F3-11-60cm	46.25	54.50	0.13243	50.00	6.62	2.51	0.00251	80	0.02077
F3-11-90cm	46.25	54.50	0.06510	50.00	3.26	4.2	0.00420	80	0.01709
F3-11-120cm	46.25	54.50	0.02443	50.00	1.22	7.59	0.00759	90	0.01030
F3-15-15cm	45.75	28.88	0.07632	50.00	3.82	1.8	0.00180	60	0.01145
F3-15-30cm	45.75	28.88	0.02583	50.00	1.29	2.19	0.00219	70	0.00404
F3-15-60cm	45.75	28.88	0.00479	75.00	0.36	1.74	0.00174	80	0.00078
F3-15-90cm	45.75	28.88	0.00620	50.00	0.31	3.31	0.00331	90	0.00114
F3-15-120cm	45.75	28.88	0.00339	50.00	0.17	6.59	0.00659	90	0.00124

PO_4 Farm 3 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	PO4- (mg/100g soil)
F3-22-15cm	45.88	43.25	0.20536	50.00	10.27	3.2	0.00320	60	0.05476
F3-22-30cm	45.88	43.25	0.20957	50.00	10.48	2.9	0.00290	80	0.03798
F3-22-60cm	45.88	43.25	0.12261	50.00	6.13	2.22	0.00222	80	0.01701
F3-22-90cm	45.88	43.25	0.15206	50.00	7.60	4.71	0.00471	80	0.04476
F3-22-120cm	45.88	43.25	0.20676	50.00	10.34	6.73	0.00673	100	0.06957
F3-26-15cm	34.63	44.13	0.25024	50.00	12.51	3.58	0.00358	60	0.07465
F3-26-30cm	34.63	44.13	0.07492	50.00	3.75	3.71	0.00371	70	0.01985
F3-26-60cm	34.63	44.13	0.01601	50.00	0.80	2.23	0.00223	80	0.00223
F3-26-90cm	34.63	44.13	0.00760	50.00	0.38	3.47	0.00347	80	0.00165
F3-26-120cm	34.63	44.13	0.00199	50.00	0.10	5.98	0.00598	90	0.00066
F3-32-15cm	36.38	36.50	0.10998	50.00	5.50	3.92	0.00392	70	0.03080
F3-32-30cm	36.38	36.50	0.10858	75.00	8.14	2.91	0.00291	80	0.02962
F3-32-60cm	36.38	36.50	0.08053	75.00	6.04	1.45	0.00145	80	0.01095
F3-32-90cm	36.38	36.50	0.15346	50.00	7.67	2.46	0.00246	80	0.02360
F3-32-120cm	36.38	36.50	0.10017	50.00	5.01	10.04	0.01004	100	0.05028
F3-44-15cm	44.63	39.00	0.08474	50.00	4.24	4.88	0.00488	60	0.03446
F3-44-30cm	44.63	39.00	0.05669	50.00	2.83	4.73	0.00473	60	0.02234
F3-44-60cm	44.63	39.00	0.10578	50.00	5.29	5.48	0.00548	80	0.03623
F3-44-90cm	44.63	39.00	0.13383	50.00	6.69	4.78	0.00478	80	0.03998
F3-44-120cm	44.63	39.00	0.11279	50.00	5.64	4.96	0.00496	80	0.03496

PO_4 Farm 3 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	PO4- (mg/100g soil)
F3-48-15cm	34.25	26.63	0.08193	50.00	4.10	2.42	0.00242	60	0.01652
F3-48-30cm	34.25	26.63	0.08614	50.00	4.31	2.12	0.00212	70	0.01304
F3-48-60cm	34.25	26.63	0.01882	50.00	0.94	3.12	0.00312	80	0.00367
F3-48-90cm	34.25	26.63	0.00900	50.00	0.45	2.43	0.00243	80	0.00137
F3-48-120cm	34.25	26.63	0.00479	50.00	0.24	6.74	0.00674	80	0.00202
F3-50-15cm	30.50	18.75	0.13944	50.00	6.97	2.35	0.00235	60	0.02731
F3-50-30cm	30.50	18.75	0.10718	50.00	5.36	3.57	0.00357	60	0.03189
F3-50-60cm	30.50	18.75	0.01461	50.00	0.73	3.53	0.00353	80	0.00322
F3-50-90cm	30.50	18.75	0.00479	50.00	0.24	3.58	0.00358	80	0.00107
F3-50-120cm	30.50	18.75	0.00199	50.00	0.10	4.87	0.00487	80	0.00061
F3-63-15cm	27.75	30.50	0.07212	75.00	5.41	1.91	0.00191	60	0.01722
F3-63-30cm	27.75	30.50	0.06791	75.00	5.09	1.43	0.00143	70	0.01040
F3-63-60cm	27.75	30.50	0.03986	75.00	2.99	1.91	0.00191	80	0.00714
F3-63-90cm	27.75	30.50	0.01040	50.00	0.52	3.66	0.00366	80	0.00238
F3-63-120cm	27.75	30.50	0.00199	50.00	0.10	6.74	0.00674	80	0.00084
F3-67-15cm	20.13	13.75	0.04687	50.00	2.34	5.45	0.00545	60	0.02129
F3-67-30cm	20.13	13.75	0.03004	50.00	1.50	6.14	0.00614	70	0.01317
F3-67-60cm	20.13	13.75	0.03284	50.00	1.64	4.33	0.00433	80	0.00889
F3-67-90cm	20.13	13.75	0.00760	50.00	0.38	3.12	0.00312	80	0.00148
F3-67-120cm	20.13	13.75	0.00900	50.00	0.45	3.28	0.00328	80	0.00185

ECe Farm 4

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (μS)	Dilution	Dillution Corrected Reading (μS)	Cell consant, *k* (100/m) [SI]	ECe (μS/m)	ECe (mS/m)	ECe (dS/m)
F4-02-15cm	15.50	16.88	43.6	45.00	1,962	100	196,200	196.20	1.96200
F4-06-15cm	32.13	24.88	70.4	45.00	3,168	100	316,800	316.80	3.16800
F4-011-15cm	21.00	28.63	65.3	45.00	2,939	100	293,850	293.85	2.93850
F4-38-15cm	17.38	18.88	22.8	45.00	1,026	100	102,600	102.60	1.02600
F4-59-15cm	11.38	14.50	6.97	45.00	314	100	31,365	31.37	0.31365
F4-67-15cm	16.25	12.25	17.24	45.00	776	100	77,580	77.58	0.77580

NO_3 Farm 4

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	NO3- (mg/100g soil)
F4-02-15cm	15.50	16.88	0.13	45.00	5.85	2.9	0.00290	60.00	0.02828
F4-06-15cm	32.13	24.88	0.37	45.00	16.65	4.49	0.00449	60.00	0.12460
F4-011-15cm	21.00	28.63	0.01	45.00	0.45	6.01	0.00601	60.00	0.00451
F4-38-15cm	17.38	18.88	0.03	45.00	1.35	3.72	0.00372	50.00	0.01004
F4-59-15cm	11.38	14.50	0.02	45.00	0.90	4.87	0.00487	50.00	0.00877
F4-67-15cm	16.25	12.25	0.04	45.00	1.80	2.79	0.00279	50.00	0.01004

PO_4 Farm 4

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	PO4- (mg/100g soil)
F4-02-15cm	15.50	16.88	0.05313	75.00	3.98	2.9	0.00290	60.00	0.01926
F4-06-15cm	32.13	24.88	0.00320	75.00	0.24	4.49	0.00449	60.00	0.00180
F4-011-15cm	21.00	28.63	0.00042	75.00	0.03	6.01	0.00601	60.00	0.00032
F4-38-15cm	17.38	18.88	0.00459	75.00	0.34	3.72	0.00372	50.00	0.00256
F4-59-15cm	11.38	14.50	0.01429	75.00	1.07	4.87	0.00487	50.00	0.01044
F4-67-15cm	16.25	12.25	0.00320	75.00	0.24	2.79	0.00279	50.00	0.00134

ECe Farm 5

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (μS)	Dilution	Dillution Corrected Reading (μS)	Cell consant, *k* (100/m) [SI]	ECe (μS/m)	ECe (mS/m)	ECe (dS/m)
F5-05-15cm	13.25	8.88	13.33	30.00	400.00	100	40,000	40.00	0.40
F5-05-30cm	13.25	8.88	7.71	30.00	231.30	100	23,130	23.13	0.2313
F5-05-60cm	13.25	8.88	5.07	60.00	304.20	100	30,420	30.42	0.3042
F5-05-90cm	13.25	8.88	5.74	60.00	344.40	100	34,440	34.44	0.3444
F5-05-120cm	13.25	8.88	6.63	60.00	397.80	100	39,780	39.78	0.3978
F5-13-15cm	26.25	20.00	27.1	30.00	813.00	100	81,300	81.30	0.813
F5-13-30cm	26.25	20.00	19.1	30.00	573.00	100	57,300	57.30	0.573
F5-13-60cm	26.25	20.00	34.4	30.00	1,032.00	100	103,200	103.20	1.032
F5-13-90cm	26.25	20.00	14.3	30.00	429.00	100	42,900	42.90	0.429
F5-13-120cm	26.25	20.00	15.9	30.00	477.00	100	47,700	47.70	0.477
F5-18-15cm	25.63	14.50	8.5	30.00	255.00	100	25,500	25.50	0.255
F5-18-30cm	25.63	14.50	9.19	30.00	275.70	100	27,570	27.57	0.2757
F5-18-60cm	25.63	14.50	4.41	60.00	264.60	100	26,460	26.46	0.2646
F5-18-90cm	25.63	14.50	4.9	90.00	441.00	100	44,100	44.10	0.441
F5-18-120cm	25.63	14.50	135.9	30.00	4,077.00	100	407,700	407.70	4.077
F5-27-15cm	23.88	23.00	227	30.00	6,810.00	100	681,000	681.00	6.81
F5-27-30cm	23.88	23.00	179	30.00	5,370.00	100	537,000	537.00	5.37
F5-27-60cm	23.88	23.00	82.9	30.00	2,487.00	100	248,700	248.70	2.487
F5-27-90cm	23.88	23.00	52.6	30.00	1,578.00	100	157,800	157.80	1.578
F5-27-120cm	23.88	23.00	57.1	30.00	1,713.00	100	171,300	171.30	1.713

ECe Farm 5 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (μS)	Dilution	Dillution Corrected Reading (μS)	Cell consant, *k* (100/m) [SI]	ECe (μS/m)	ECe (mS/m)	ECe (dS/m)
F5-34-15cm	13.38	11.88	14.2	30.00	426.00	100	42,600	42.60	0.426
F5-34-30cm	13.38	11.88	6.53	60.00	391.80	100	39,180	39.18	0.3918
F5-34-60cm	13.38	11.88	9.19	30.00	275.70	100	27,570	27.57	0.2757
F5-34-90cm	13.38	11.88	11.59	30.00	347.70	100	34,770	34.77	0.3477
F5-34-120cm	13.38	11.88	15.46	30.00	463.80	100	46,380	46.38	0.4638
F5-40-15cm	51.00	64.88	239	30.00	7,170.00	100	717,000	717.00	7.17
F5-40-30cm	51.00	64.88	358	30.00	10,740.00	100	1,074,000	1074.00	10.74
F5-40-60cm	51.00	64.88	280	30.00	8,400.00	100	840,000	840.00	8.4
F5-40-90cm	51.00	64.88	258	31.00	7,998.00	100	799,800	799.80	7.998
F5-40-120cm	51.00	64.88	65.6	30.00	1,968.00	100	196,800	196.80	1.968
F5-52-15cm	20.00	13.63	5.54	60.00	332.40	100	33,240	33.24	0.3324
F5-52-30cm	20.00	13.63	3.68	90.00	331.20	100	33,120	33.12	0.3312
F5-52-60cm	20.00	13.63	4.29	90.00	386.10	100	38,610	38.61	0.3861
F5-52-90cm	20.00	13.63	35.9	30.00	1,077.00	100	107,700	107.70	1.077
F5-52-120cm	20.00	13.63	42.6	30.00	1,278.00	100	127,800	127.80	1.278
F5-71-15cm	69.63	55.38	344	30.00	10,320.00	100	1,032,000	1032.00	10.32
F5-71-30cm	69.63	55.38	376	30.00	11,280.00	100	1,128,000	1128.00	11.28
F5-71-60cm	69.63	55.38	128.1	30.00	3,843.00	100	384,300	384.30	3.843
F5-71-90cm	69.63	55.38	66.3	30.00	1,989.00	100	198,900	198.90	1.989
F5-71-120cm	69.63	55.38	95.5	30.00	2,865.00	100	286,500	286.50	2.865

ECe Farm 5 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (µS)	Dilution	Dillution Corrected Reading (µS)	Cell consant, *k* (100/m) [SI]	ECe (µS/m)	ECe (mS/m)	ECe (dS/m)
F5-75-15cm	84.25	93.50	386	30.00	11,580.00	100	1,158,000	1158.00	11.58
F5-75-30cm	84.25	93.50	310	30.00	9,300.00	100	930,000	930.00	9.3
F5-75-60cm	84.25	93.50	191	30.00	5,730.00	100	573,000	573.00	5.73
F5-75-90cm	84.25	93.50	259	30.00	7,770.00	100	777,000	777.00	7.77
F5-75-120cm	84.25	93.50	224	30.00	6,720.00	100	672,000	672.00	6.72
F5-80-15cm	25.13	20.00	21.6	30.00	648.00	100	64,800	64.80	0.648
F5-80-30cm	25.13	20.00	19.7	30.00	591.00	100	59,100	59.10	0.591
F5-80-60cm	25.13	20.00	10.49	30.00	314.70	100	31,470	31.47	0.3147
F5-80-90cm	25.13	20.00	11.96	30.00	358.80	100	35,880	35.88	0.3588
F5-80-120cm	25.13	20.00	16.82	30.00	504.60	100	50,460	50.46	0.5046
F5-86-15cm	19.25	10.50	4.29	60.00	257.40	100	25,740	25.74	0.2574
F5-86-30cm	19.25	10.50	5.35	60.00	321.00	100	32,100	32.10	0.321
F5-86-60cm	19.25	10.50	4.76	90.00	428.40	100	42,840	42.84	0.4284
F5-86-90cm	19.25	10.50	5.44	60.00	326.40	100	32,640	32.64	0.3264
F5-86-120cm	19.25	10.50	8.95	30.00	268.50	100	26,850	26.85	0.2685
F5-100-15cm	43.13	37.00	131	30.00	3,930.00	100	393,000	393.00	3.93
F5-100-30cm	43.13	37.00	172.7	30.00	5,181.00	100	518,100	518.10	5.181
F5-100-60cm	43.13	37.00	57.1	30.00	1,713.00	100	171,300	171.30	1.713
F5-100-90cm	43.13	37.00	31.4	30.00	942.00	100	94,200	94.20	0.942
F5-100-120cm	43.13	37.00	41.8	30.00	1,254.00	100	125,400	125.40	1.254

NO_3 Farm 5

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	NO3- (mg/100g soil)
F5-05-15cm	13.25	8.88	0.65	30.00	19.50	4.31	0.00431	60	0.13998
F5-05-30cm	13.25	8.88	0.14	30.00	4.20	3.36	0.00336	60	0.02352
F5-05-60cm	13.25	8.88	0.07	30.00	2.10	2.65	0.00265	60	0.00928
F5-05-90cm	13.25	8.88	0.08	30.00	2.40	2.1	0.00210	80	0.00630
F5-05-120cm	13.25	8.88	0.1	30.00	3.00	2.56	0.00256	80	0.00960
F5-13-15cm	26.25	20.00	0.85	30.00	25.50	5.84	0.00584	60	0.24820
F5-13-30cm	26.25	20.00	0.22	30.00	6.60	4.61	0.00461	60	0.05071
F5-13-60cm	26.25	20.00	0.1	30.00	3.00	9.63	0.00963	80	0.03611
F5-13-90cm	26.25	20.00	0.06	30.00	1.80	5.62	0.00562	80	0.01265
F5-13-120cm	26.25	20.00	0.04	30.00	1.20	5.61	0.00561	80	0.00842
F5-18-15cm	25.63	14.50	0.3	30.00	9.00	4.19	0.00419	60	0.06285
F5-18-30cm	25.63	14.50	0.23	30.00	6.90	3.37	0.00337	60	0.03876
F5-18-60cm	25.63	14.50	0.14	30.00	4.20	2.55	0.00255	60	0.01785
F5-18-90cm	25.63	14.50	0.1	45.00	4.50	1.53	0.00153	80	0.00861
F5-18-120cm	25.63	14.50	0.1	30.00	3.00	8.59	0.00859	80	0.03221
F5-27-15cm	23.88	23.00	0.13	30.00	3.90	8.67	0.00867	60	0.05636
F5-27-30cm	23.88	23.00	0.04	30.00	1.20	6.1	0.00610	60	0.01220
F5-27-60cm	23.88	23.00	0.06	30.00	1.80	7.47	0.00747	60	0.02241
F5-27-90cm	23.88	23.00	0.06	30.00	1.80	8.59	0.00859	80	0.01933
F5-27-120cm	23.88	23.00	0.05	30.00	1.50	5.12	0.00512	80	0.00960

NO_3 Farm 5 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	NO3- (mg/100g soil)
F5-34-15cm	13.38	11.88	0.36	30.00	10.80	4	0.00400	60	0.07200
F5-34-30cm	13.38	11.88	0.23	30.00	6.90	2.69	0.00269	60	0.03094
F5-34-60cm	13.38	11.88	0.09	30.00	2.70	3.36	0.00336	60	0.01512
F5-34-90cm	13.38	11.88	0.09	30.00	2.70	3.87	0.00387	70	0.01493
F5-34-120cm	13.38	11.88	0.36	30.00	10.80	4.77	0.00477	70	0.07359
F5-40-15cm	51.00	64.88	0.07	30.00	2.10	9.02	0.00902	60	0.03157
F5-40-30cm	51.00	64.88	0.08	30.00	2.40	5.67	0.00567	60	0.02268
F5-40-60cm	51.00	64.88	0.06	30.00	1.80	7.43	0.00743	70	0.01911
F5-40-90cm	51.00	64.88	0.03	31.00	0.93	8.01	0.00801	70	0.01064
F5-40-120cm	51.00	64.88	0.02	30.00	0.60	5.85	0.00585	60	0.00585
F5-52-15cm	20.00	13.63	0.27	30.00	8.10	2.72	0.00272	60	0.03672
F5-52-30cm	20.00	13.63	0.11	45.00	4.95	1.83	0.00183	60	0.01510
F5-52-60cm	20.00	13.63	0.09	45.00	4.05	1.54	0.00154	60	0.01040
F5-52-90cm	20.00	13.63	0.07	30.00	2.10	7.27	0.00727	70	0.02181
F5-52-120cm	20.00	13.63	0.06	30.00	1.80	6.95	0.00695	80	0.01564
F5-71-15cm	69.63	55.38	0.2	30.00	6.00	8.25	0.00825	60	0.08250
F5-71-30cm	69.63	55.38	0.1	30.00	3.00	7.7	0.00770	70	0.03300
F5-71-60cm	69.63	55.38	0.09	30.00	2.70	8.83	0.00883	70	0.03406
F5-71-90cm	69.63	55.38	0.4	30.00	12.00	7.24	0.00724	70	0.12411
F5-71-120cm	69.63	55.38	0.84	30.00	25.20	7.98	0.00798	70	0.28728

NO_3 Farm 5 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	NO3- (mg/100g soil)
F5-75-15cm	84.25	93.50	0.22	30.00	6.60	6.2	0.00620	50	0.08184
F5-75-30cm	84.25	93.50	0.1	30.00	3.00	4.46	0.00446	50	0.02676
F5-75-60cm	84.25	93.50	0.07	30.00	2.10	3.75	0.00375	50	0.01575
F5-75-90cm	84.25	93.50	0.05	30.00	1.50	6.41	0.00641	60	0.01603
F5-75-120cm	84.25	93.50	0.05	30.00	1.50	8.22	0.00822	90	0.01370
F5-80-15cm	25.13	20.00	0.31	30.00	9.30	3.74	0.00374	50	0.06956
F5-80-30cm	25.13	20.00	0.37	30.00	11.10	3.23	0.00323	50	0.07171
F5-80-60cm	25.13	20.00	0.09	30.00	2.70	4.35	0.00435	50	0.02349
F5-80-90cm	25.13	20.00	0.05	30.00	1.50	3.48	0.00348	50	0.01044
F5-80-120cm	25.13	20.00	0.05	30.00	1.50	3.97	0.00397	60	0.00993
F5-86-15cm	19.25	10.50	0.15	30.00	4.50	1.96	0.00196	50	0.01764
F5-86-30cm	19.25	10.50	0.1	30.00	3.00	1.84	0.00184	50	0.01104
F5-86-60cm	19.25	10.50	0.08	45.00	3.60	1.6	0.00160	60	0.00960
F5-86-90cm	19.25	10.50	0.11	30.00	3.30	2.92	0.00292	100	0.00964
F5-86-120cm	19.25	10.50	0.09	30.00	2.70	3.66	0.00366	100	0.00988
F5-100-15cm	43.13	37.00	0.12	30.00	3.60	7.35	0.00735	60	0.04410
F5-100-30cm	43.13	37.00	0.1	30.00	3.00	3.41	0.00341	60	0.01705
F5-100-60cm	43.13	37.00	0.08	30.00	2.40	6.21	0.00621	80	0.01863
F5-100-90cm	43.13	37.00	0.06	30.00	1.80	8.36	0.00836	80	0.01881
F5-100-120cm	43.13	37.00	0.11	30.00	3.30	8.39	0.00839	80	0.03461

PO_4 Farm 5									
Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	PO4- (mg/100g soil)
F5-05-15cm	13.25	8.88	0.06489	50.00	3.24	4.31	0.00431	60	0.02329
F5-05-30cm	13.25	8.88	0.01716	50.00	0.86	3.36	0.00336	60	0.00480
F5-05-60cm	13.25	8.88	0.01716	50.00	0.86	2.65	0.00265	60	0.00379
F5-05-90cm	13.25	8.88	0.01716	50.00	0.86	2.1	0.00210	80	0.00225
F5-05-120cm	13.25	8.88	0.00874	50.00	0.44	2.56	0.00256	80	0.00140
F5-13-15cm	26.25	20.00	0.01014	50.00	0.51	5.84	0.00584	60	0.00493
F5-13-30cm	26.25	20.00	0.00452	50.00	0.23	4.61	0.00461	60	0.00174
F5-13-60cm	26.25	20.00	0.00031	50.00	0.02	9.63	0.00963	80	0.00019
F5-13-90cm	26.25	20.00	0.00312	50.00	0.16	5.62	0.00562	80	0.00110
F5-13-120cm	26.25	20.00	0.00172	50.00	0.09	5.61	0.00561	80	0.00060
F5-18-15cm	25.63	14.50	0.02979	50.00	1.49	4.19	0.00419	60	0.01040
F5-18-30cm	25.63	14.50	0.04804	50.00	2.40	3.37	0.00337	60	0.01349
F5-18-60cm	25.63	14.50	0.02558	50.00	1.28	2.55	0.00255	60	0.00544
F5-18-90cm	25.63	14.50	0.02277	75.00	1.71	1.53	0.00153	80	0.00327
F5-18-120cm	25.63	14.50	0.00593	50.00	0.30	8.59	0.00859	80	0.00318
F5-27-15cm	23.88	23.00	0.00312	50.00	0.16	8.67	0.00867	60	0.00225
F5-27-30cm	23.88	23.00	0.00452	50.00	0.23	6.1	0.00610	60	0.00230
F5-27-60cm	23.88	23.00	0.00172	50.00	0.09	7.47	0.00747	60	0.00107
F5-27-90cm	23.88	23.00	0.00172	50.00	0.09	8.59	0.00859	80	0.00092
F5-27-120cm	23.88	23.00	0.00031	50.00	0.02	5.12	0.00512	80	0.00010

PO_4 Farm 5 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	PO4- (mg/100g soil)
F5-34-15cm	13.38	11.88	0.07612	50.00	3.81	4	0.00400	60	0.02537
F5-34-30cm	13.38	11.88	0.01716	50.00	0.86	2.69	0.00269	60	0.00385
F5-34-60cm	13.38	11.88	0.01154	50.00	0.58	3.36	0.00336	60	0.00323
F5-34-90cm	13.38	11.88	0.00312	50.00	0.16	3.87	0.00387	70	0.00086
F5-34-120cm	13.38	11.88	0.00312	50.00	0.16	4.77	0.00477	70	0.00106
F5-40-15cm	51.00	64.88	0.00031	50.00	0.02	9.02	0.00902	60	0.00024
F5-40-30cm	51.00	64.88	0.00312	50.00	0.16	5.67	0.00567	60	0.00147
F5-40-60cm	51.00	64.88	0.00452	50.00	0.23	7.43	0.00743	70	0.00240
F5-40-90cm	51.00	64.88	0.00312	50.00	0.16	8.01	0.00801	70	0.00179
F5-40-120cm	51.00	64.88	0.00312	50.00	0.16	5.85	0.00585	60	0.00152
F5-52-15cm	20.00	13.63	0.00452	50.00	0.23	2.72	0.00272	60	0.00103
F5-52-30cm	20.00	13.63	0.00733	75.00	0.55	1.83	0.00183	60	0.00168
F5-52-60cm	20.00	13.63	0.01154	75.00	0.87	1.54	0.00154	60	0.00222
F5-52-90cm	20.00	13.63	0.00031	50.00	0.02	7.27	0.00727	70	0.00016
F5-52-120cm	20.00	13.63	0.00031	50.00	0.02	6.95	0.00695	80	0.00014
F5-71-15cm	69.63	55.38	0.01014	50.00	0.51	8.25	0.00825	60	0.00697
F5-71-30cm	69.63	55.38	0.00172	50.00	0.09	7.7	0.00770	70	0.00094
F5-71-60cm	69.63	55.38	0.00172	50.00	0.09	8.83	0.00883	70	0.00108
F5-71-90cm	69.63	55.38	0.00031	50.00	0.02	7.24	0.00724	70	0.00016
F5-71-120cm	69.63	55.38	0.00172	50.00	0.09	7.98	0.00798	70	0.00098

PO_4 Farm 5 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	PO4- (mg/100g soil)
F5-75-15cm	84.25	93.50	0.00312	50.00	0.16	6.2	0.00620	50	0.00193
F5-75-30cm	84.25	93.50	0.00172	50.00	0.09	4.46	0.00446	50	0.00077
F5-75-60cm	84.25	93.50	0.00172	50.00	0.09	3.75	0.00375	50	0.00064
F5-75-90cm	84.25	93.50	0.00172	50.00	0.09	6.41	0.00641	60	0.00092
F5-75-120cm	84.25	93.50	0.01716	50.00	0.86	8.22	0.00822	90	0.00784
F5-80-15cm	25.13	20.00	0.00312	50.00	0.16	3.74	0.00374	50	0.00117
F5-80-30cm	25.13	20.00	0.00172	50.00	0.09	3.23	0.00323	50	0.00055
F5-80-60cm	25.13	20.00	0.00312	50.00	0.16	4.35	0.00435	50	0.00136
F5-80-90cm	25.13	20.00	0.00312	50.00	0.16	3.48	0.00348	50	0.00109
F5-80-120cm	25.13	20.00	0.00452	50.00	0.23	3.97	0.00397	60	0.00150
F5-86-15cm	19.25	10.50	0.01014	75.00	0.76	1.96	0.00196	50	0.00298
F5-86-30cm	19.25	10.50	0.01295	75.00	0.97	1.84	0.00184	50	0.00357
F5-86-60cm	19.25	10.50	0.00733	75.00	0.55	1.6	0.00160	60	0.00147
F5-86-90cm	19.25	10.50	0.01154	50.00	0.58	2.92	0.00292	100	0.00169
F5-86-120cm	19.25	10.50	0.01014	50.00	0.51	3.66	0.00366	100	0.00186
F5-100-15cm	43.13	37.00	0.01154	50.00	0.58	7.35	0.00735	60	0.00707
F5-100-30cm	43.13	37.00	0.00593	50.00	0.30	3.41	0.00341	60	0.00168
F5-100-60cm	43.13	37.00	0.00312	50.00	0.16	6.21	0.00621	80	0.00121
F5-100-90cm	43.13	37.00	0.00874	50.00	0.44	8.36	0.00836	80	0.00456
F5-100-120cm	43.13	37.00	0.00031	50.00	0.02	8.39	0.00839	80	0.00016

ECe Farm 6

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (µS)	Dilution	Dillution Corrected Reading (µS)	Cell consant, *k* (100/m) [SI]	ECe (µS/m)	ECe (mS/m)	ECe (dS/m)
F6-02-15cm	45.88	62.75	307	30.00	9,210	100	921,000	921.00	9.21
F6-02-30cm	45.88	62.75	253	30.00	7,590	100	759,000	759.00	7.59
F6-04-15cm	54.13	63.13	185	30.00	5,550	100	555,000	555.00	5.55
F6-04-30cm	54.13	63.13	209	30.00	6,270	100	627,000	627.00	6.27
F6-06-15cm	47.50	38.25	29.6	60.00	1,776	100	177,600	177.60	1.776
F6-06-30cm	47.50	38.25	98.9	30.00	2,967	100	296,700	296.70	2.967
F6-11-15cm	12.25	11.25	7.56	30.00	227	100	22,680	22.68	0.2268
F6-11-30cm	12.25	11.25	5.1	60.00	306	100	30,600	30.60	0.306
F6-21-15cm	26.50	37.75	144.5	30.00	4,335	100	433,500	433.50	4.335
F6-21-30cm	26.50	37.75	153.6	30.00	4,608	100	460,800	460.80	4.608
F6-28-15cm	24.38	26.50	89.9	30.00	2,697	100	269,700	269.70	2.697
F6-28-30cm	24.38	26.50	156.6	30.00	4,698	100	469,800	469.80	4.698
F6-37-15cm	37.50	41.75	96.6	30.00	2,898	100	289,800	289.80	2.898
F6-37-30cm	***	***	***	***	***	100	***	***	***
F6-49-15cm	13.38	17.63	39.3	30.00	1,179	100	117,900	117.90	1.179
F6-49-30cm	13.38	17.63	69.9	30.00	2,097	100	209,700	209.70	2.097

ECe Farm 6 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (μS)	Dilution	Dillution Corrected Reading (μS)	Cell consant, *k* (100/m) [SI]	ECe (μS/m)	ECe (mS/m)	ECe (dS/m)
F6-58-15cm	41.38	28.50	68.3	30.00	2,049	100	204,900	204.90	2.049
F6-58-30cm	41.38	28.50	67.3	30.00	2,019	100	201,900	201.90	2.019
F6-64-15cm	19.00	21.38	41.3	30.00	1,239	100	123,900	123.90	1.239
F6-64-30cm	19.00	21.38	20.9	30.00	627	100	62,700	62.70	0.627
F6-76-15cm	12.38	14.25	14.93	30.00	448	100	44,790	44.79	0.4479
F6-76-30cm	12.38	14.25	14.18	30.00	425	100	42,540	42.54	0.4254
F6-83-15cm	36.38	36.00	173	30.00	5,190	100	519,000	519.00	5.19
F6-83-30cm	***	***	***	***	***	100	***	***	***

NO_3 Farm 6

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	NO3- (mg/100g soil)
F6-02-15cm	45.88	62.75	0.05	30.00	1.50	6.35	0.00635	60	0.015875
F6-02-30cm	45.88	62.75	0.07	30.00	2.10	6.21	0.00621	70	0.01863
F6-04-15cm	54.13	63.13	0.19	30.00	5.70	5.61	0.00561	50	0.063954
F6-04-30cm	54.13	63.13	0.13	30.00	3.90	4.61	0.00461	50	0.035958
F6-06-15cm	47.50	38.25	0.15	30.00	4.50	2.45	0.00245	50	0.02205
F6-06-30cm	47.50	38.25	0.08	30.00	2.40	4.58	0.00458	50	0.021984
F6-11-15cm	12.25	11.25	0.15	30.00	4.50	3.49	0.00349	60	0.026175
F6-11-30cm	12.25	11.25	0.08	30.00	2.40	2.2	0.0022	60	0.0088
F6-21-15cm	26.50	37.75	0.03	30.00	0.90	7.73	0.00773	50	0.013914
F6-21-30cm	26.50	37.75	0.05	30.00	1.50	6.65	0.00665	50	0.01995
F6-28-15cm	24.38	26.50	0.1	30.00	3.00	5.34	0.00534	60	0.0267
F6-28-30cm	24.38	26.50	0.02	30.00	0.60	6.74	0.00674	60	0.00674
F6-37-15cm	37.50	41.75	0.15	30.00	4.50	5.64	0.00564	50	0.05076
F6-37-30cm	***	***	***	***	***	***	***	***	***
F6-49-15cm	13.38	17.63	0.02	30.00	0.60	3.96	0.00396	50	0.004752
F6-49-30cm	13.38	17.63	0.03	30.00	0.90	5.61	0.00561	50	0.010098

NO_3 Farm 6 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	NO3- (mg/100g soil)
F6-58-15cm	41.38	28.50	0.1	30.00	3.00	4.64	0.00464	50	0.02784
F6-58-30cm	41.38	28.50	0.07	30.00	2.10	5.29	0.00529	50	0.022218
F6-64-15cm	19.00	21.38	0.13	30.00	3.90	5.73	0.00573	50	0.044694
F6-64-30cm	19.00	21.38	0.05	30.00	1.50	4.87	0.00487	50	0.01461
F6-76-15cm	12.38	14.25	0.21	30.00	6.30	5.11	0.00511	50	0.064386
F6-76-30cm	12.38	14.25	0.17	30.00	5.10	4.54	0.00454	60	0.03859
F6-83-15cm	36.38	36.00	0.16	30.00	4.80	5.62	0.00562	50	0.053952
F6-83-30cm	***	***	***	***	***	***	***	***	***

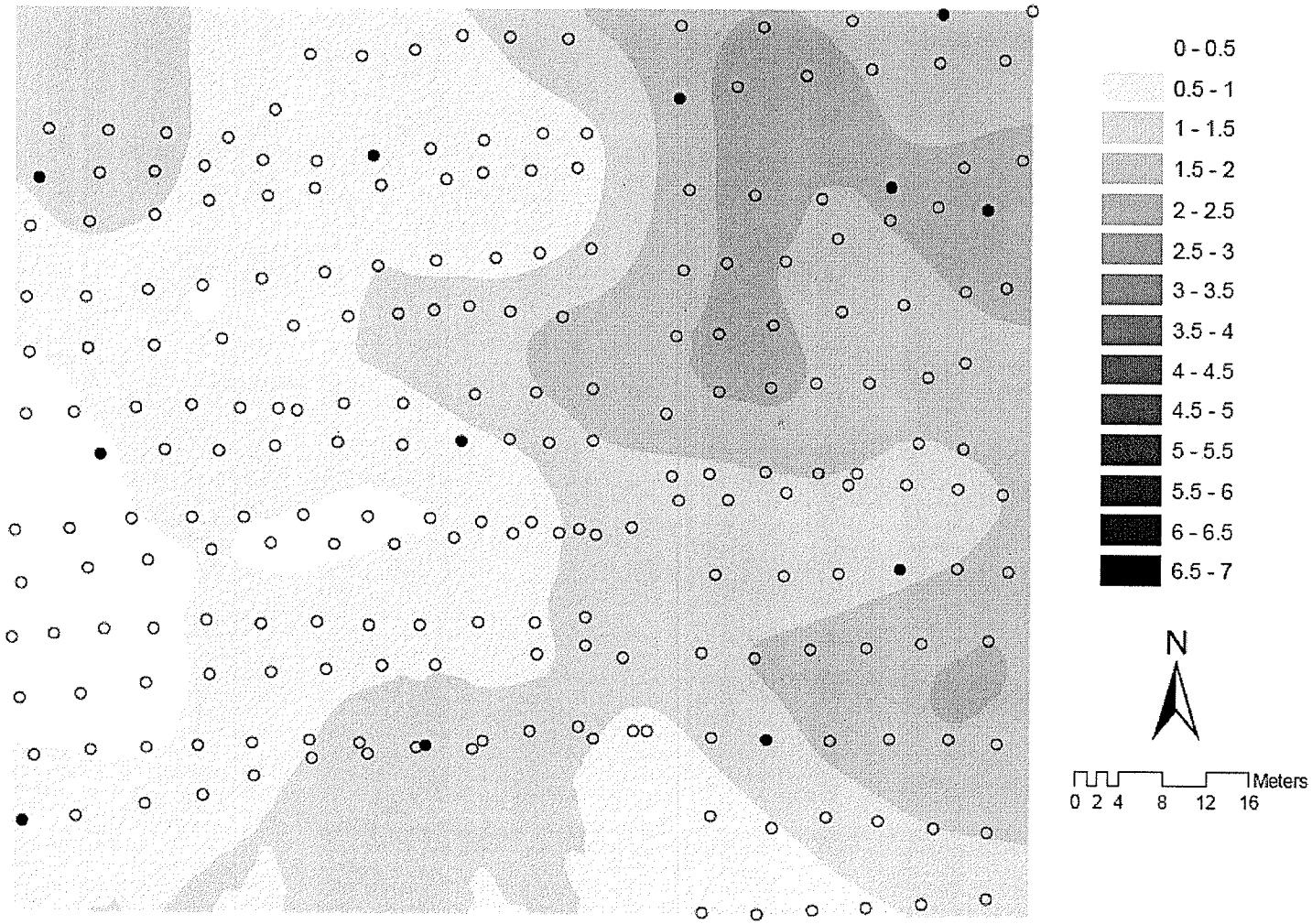
PO_4 Farm 6

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	PO4- (mg/100g soil)
F6-02-15cm	45.88	62.75	0.00320	50.00	0.16	6.35	0.00635	60	0.00169
F6-02-30cm	45.88	62.75	0.00181	50.00	0.09	6.21	0.00621	70	0.00080
F6-04-15cm	54.13	63.13	0.00320	50.00	0.16	5.61	0.00561	50	0.00179
F6-04-30cm	54.13	63.13	0.00736	15.63	0.11	4.61	0.00461	50	0.00106
F6-06-15cm	47.50	38.25	0.00181	50.00	0.09	2.45	0.00245	50	0.00044
F6-06-30cm	47.50	38.25	0.00459	50.00	0.23	4.58	0.00458	50	0.00210
F6-11-15cm	12.25	11.25	0.00320	50.00	0.16	3.49	0.00349	60	0.00093
F6-11-30cm	12.25	11.25	0.00459	50.00	0.23	2.2	0.00220	60	0.00084
F6-21-15cm	26.50	37.75	0.00181	50.00	0.09	7.73	0.00773	50	0.00140
F6-21-30cm	26.50	37.75	0.00736	50.00	0.37	6.65	0.00665	50	0.00489
F6-28-15cm	24.38	26.50	0.00181	50.00	0.09	5.34	0.00534	60	0.00081
F6-28-30cm	24.38	26.50	0.00459	50.00	0.23	6.74	0.00674	60	0.00258
F6-37-15cm	37.50	41.75	0.00042	50.00	0.02	5.64	0.00564	50	0.00024
F6-37-30cm	***	***	***	***	***	***	***	***	***
F6-49-15cm	13.38	17.63	0.00042	50.00	0.02	3.96	0.00396	50	0.00017
F6-49-30cm	13.38	17.63	0.00181	50.00	0.09	5.61	0.00561	50	0.00102

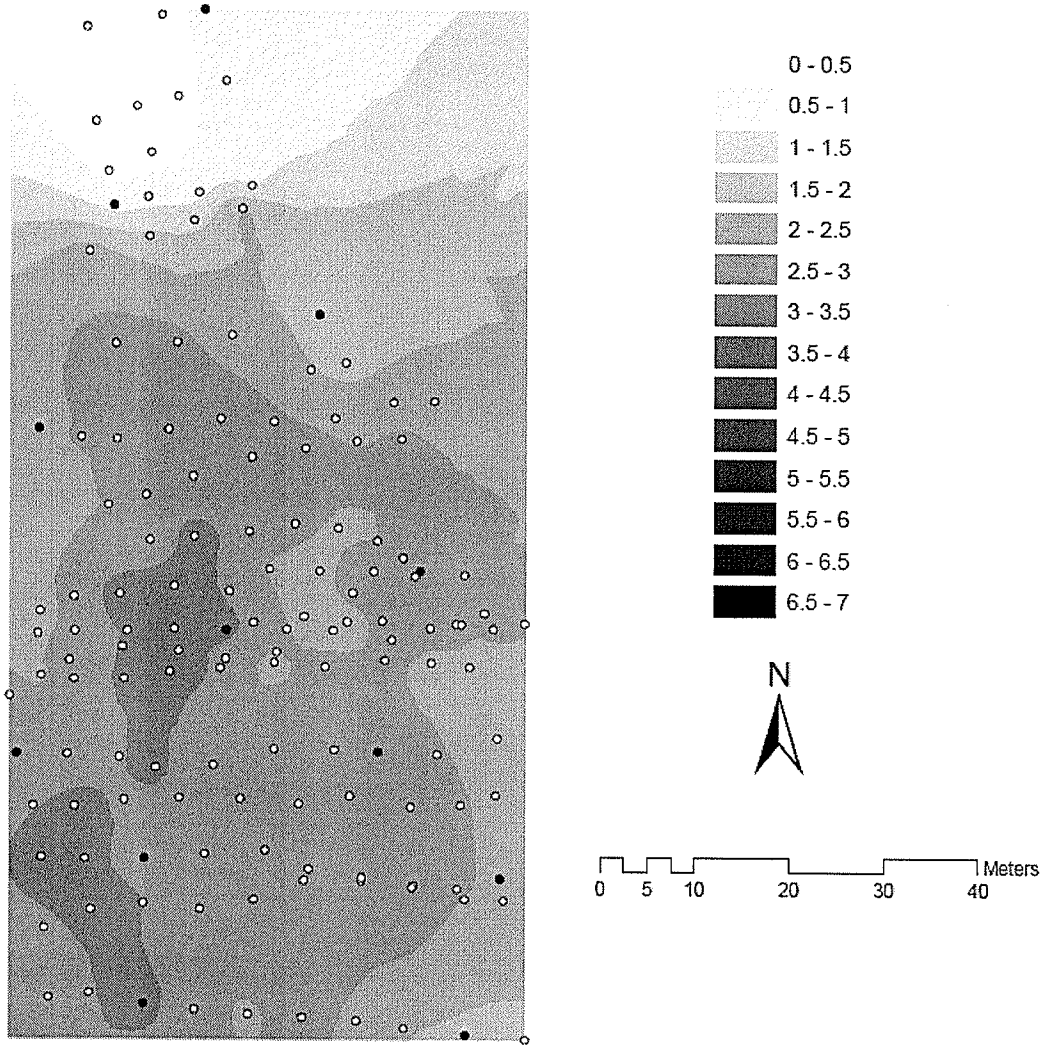
PO_4 Farm 6 (cont'd)

Farm/Site/Depth	EM Vertical	EM Horizontal	Raw Reading (mg/L)	Dilution	Dillution Corrected Reading (mg/L)	Volume of Extract (mL)	Volume of Extract (L)	Sample Weight (g)	PO4- (mg/100g soil)
F6-58-15cm	41.38	28.50	0.00320	50.00	0.16	4.64	0.00464	50	0.00148
F6-58-30cm	41.38	28.50	0.00459	50.00	0.23	5.29	0.00529	50	0.00243
F6-64-15cm	19.00	21.38	0.00181	75.00	0.14	5.73	0.00573	50	0.00156
F6-64-30cm	19.00	21.38	0.00320	50.00	0.16	4.87	0.00487	50	0.00156
F6-76-15cm	12.38	14.25	0.00181	50.00	0.09	5.11	0.00511	50	0.00093
F6-76-30cm	12.38	14.25	0.00320	50.00	0.16	4.54	0.00454	60	0.00121
F6-83-15cm	36.38	36.00	0.00042	50.00	0.02	5.62	0.00562	50	0.00024
F6-83-30cm	***	***	***	***	***	***	***	***	***

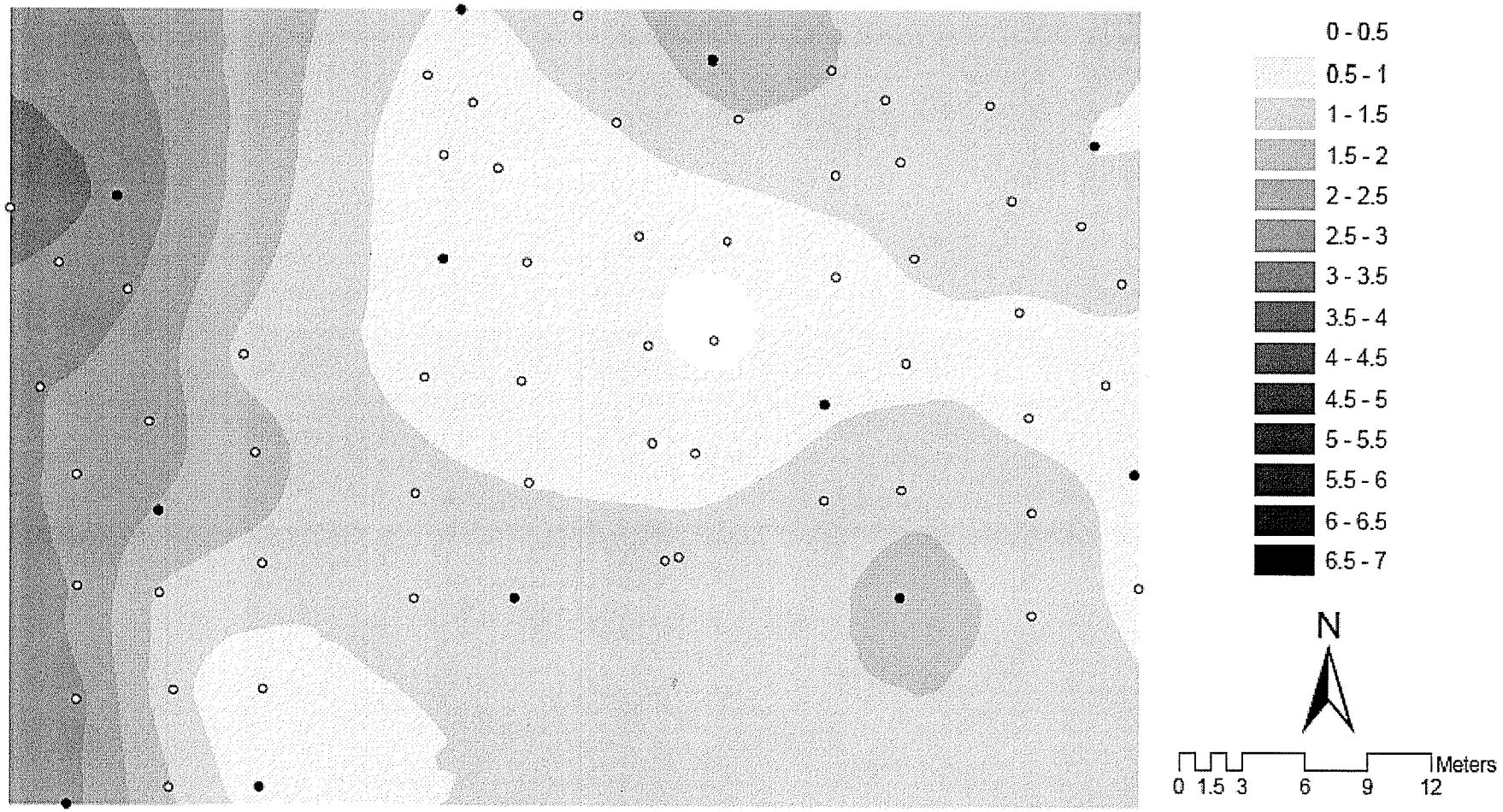
Appendix B: Interpolated maps of EC_e overlaid by data points used for interpolation



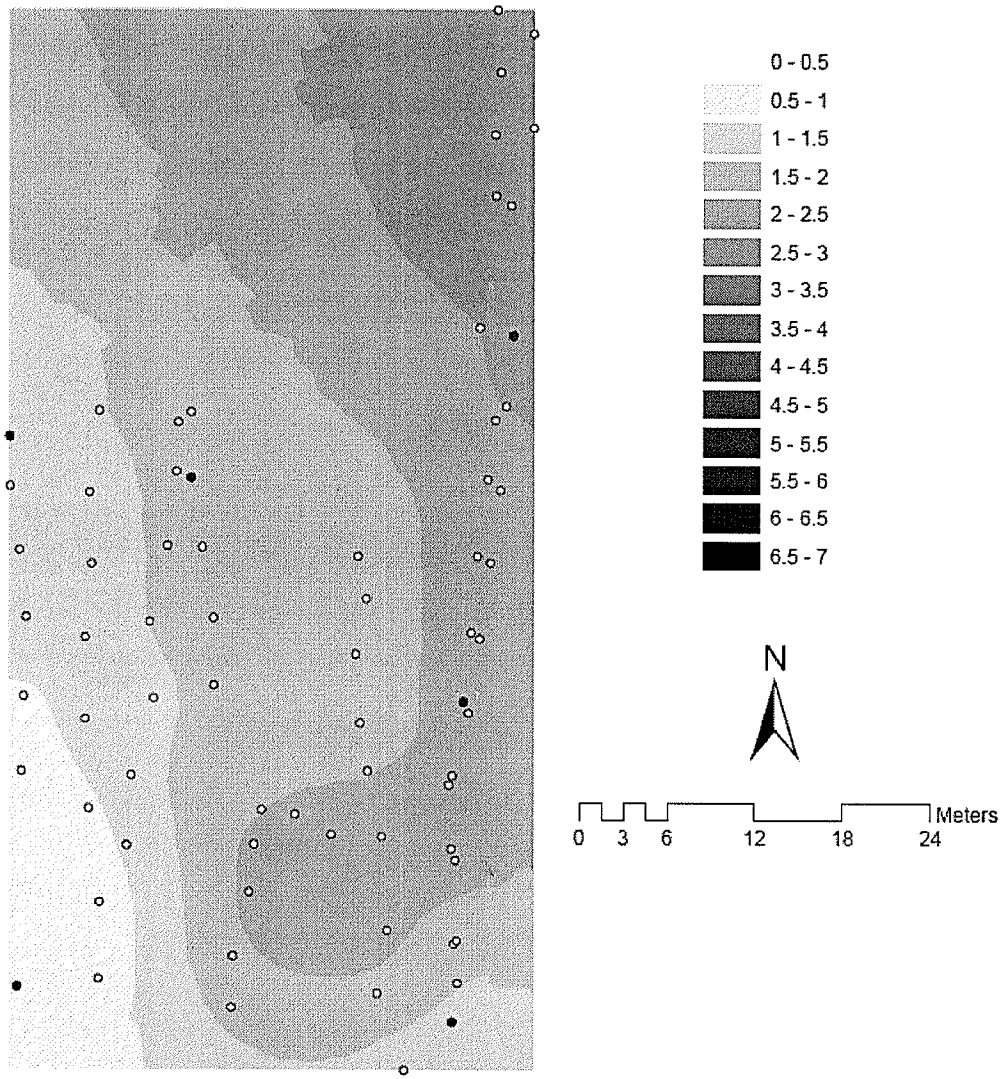
Interpolated map of EC_e (dS m^{-1}) overlaid by data points used for interpolation (white dots) and sample locations (black dots) in Farm 1



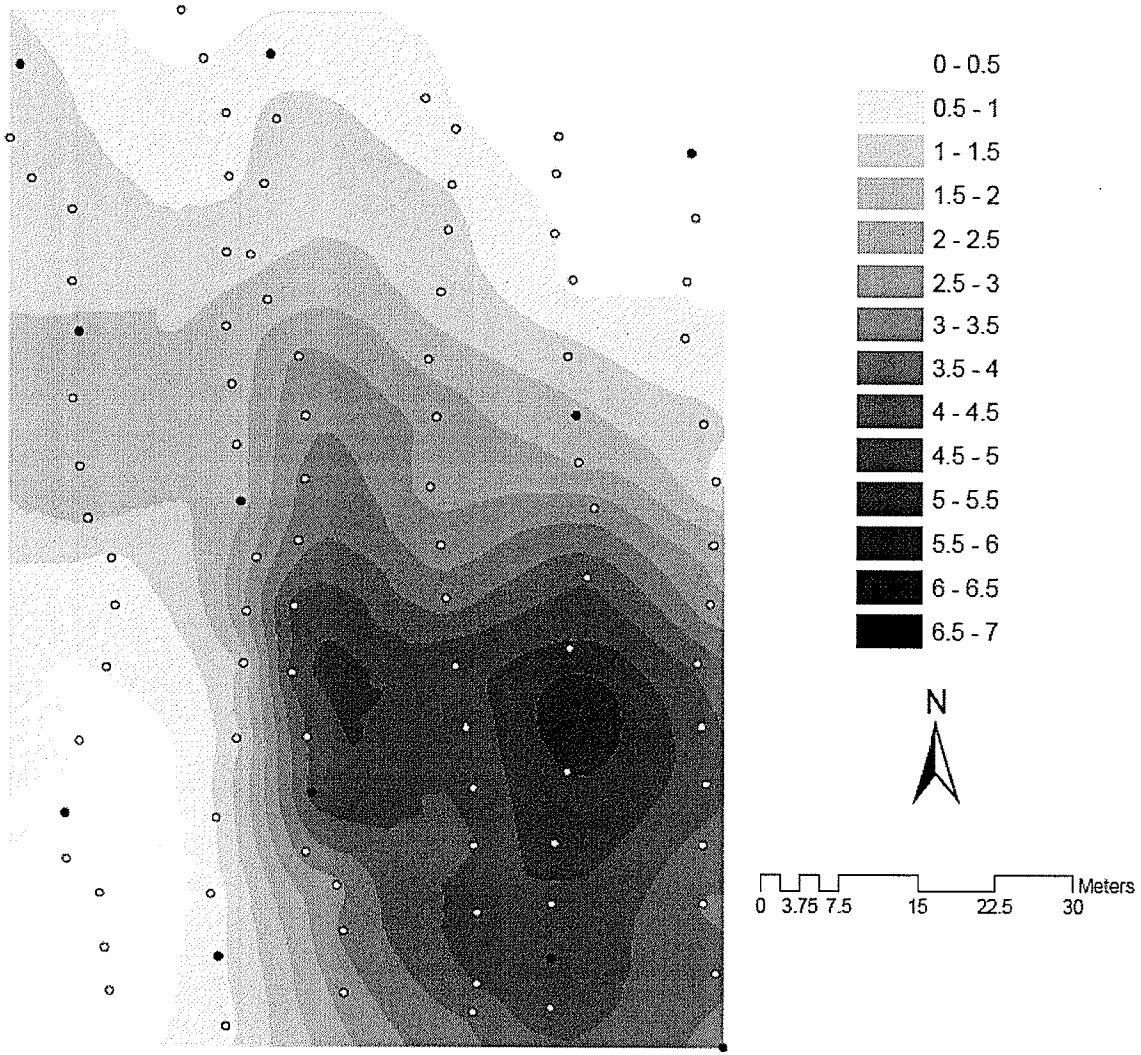
Interpolated map of EC_e (dS m^{-1}) overlaid by data points used for interpolation (white dots) and sample locations (black dots) in Farm 2



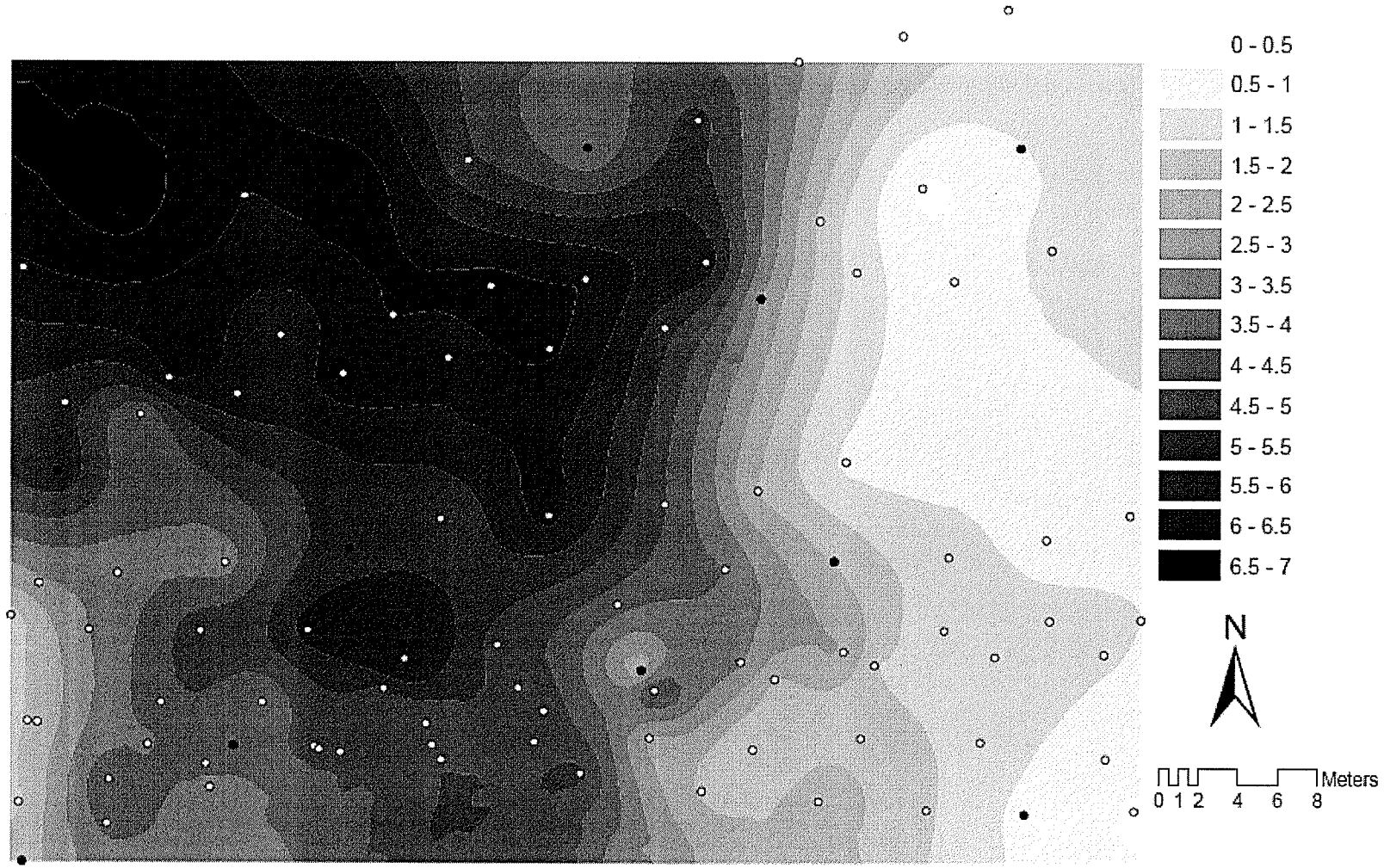
Interpolated map of EC_e (dS m^{-1}) overlaid by data points used for interpolation (white dots) and sample locations (black dots) in Farm 3



Interpolated map of EC_e (dS m^{-1}) overlaid by data points used for interpolation (white dots) and sample locations (black dots) in Farm 4

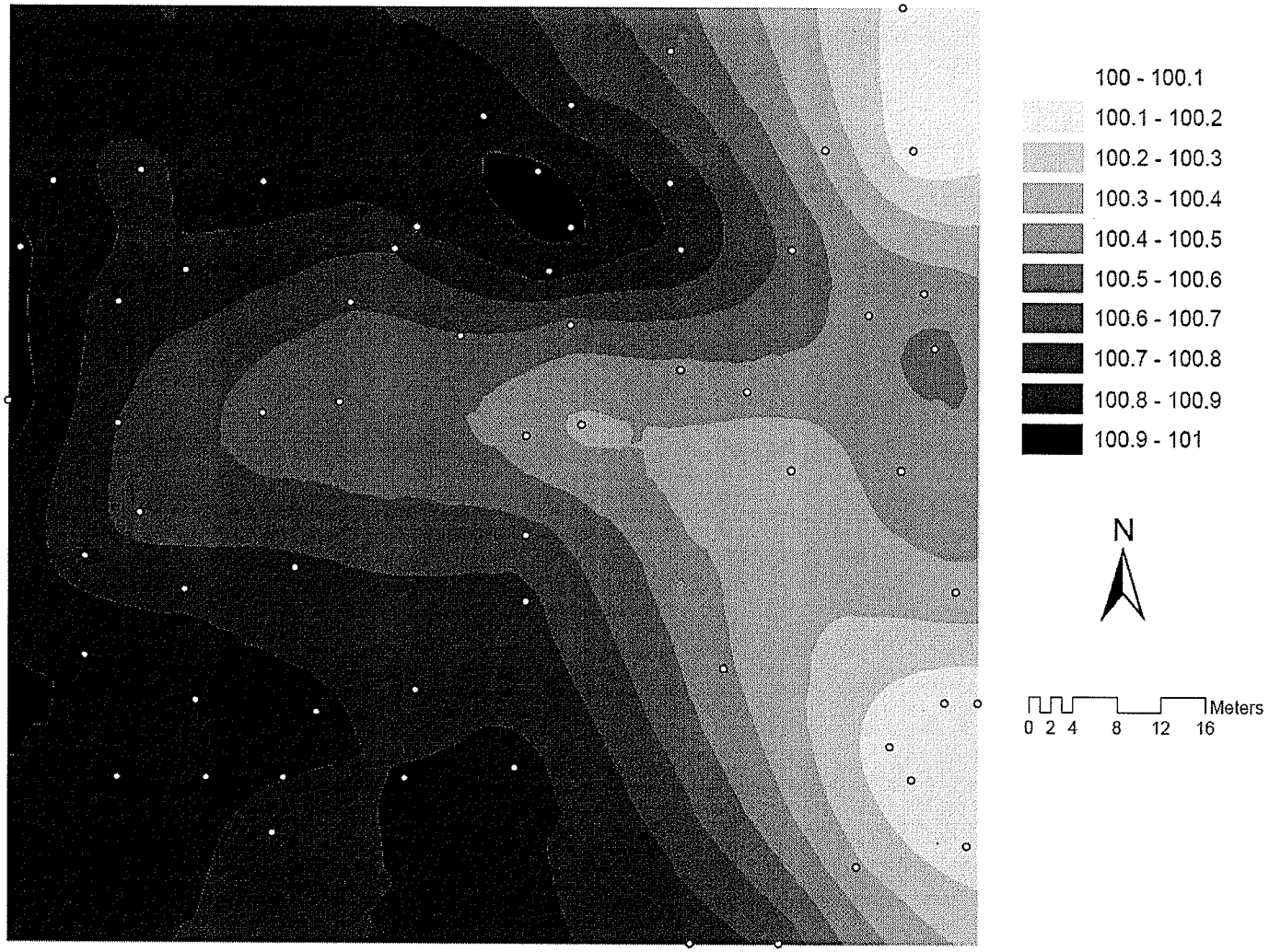


Interpolated map of EC_e (dS m^{-1}) overlaid by data points used for interpolation (white dots) and sample locations (black dots) in Farm 5

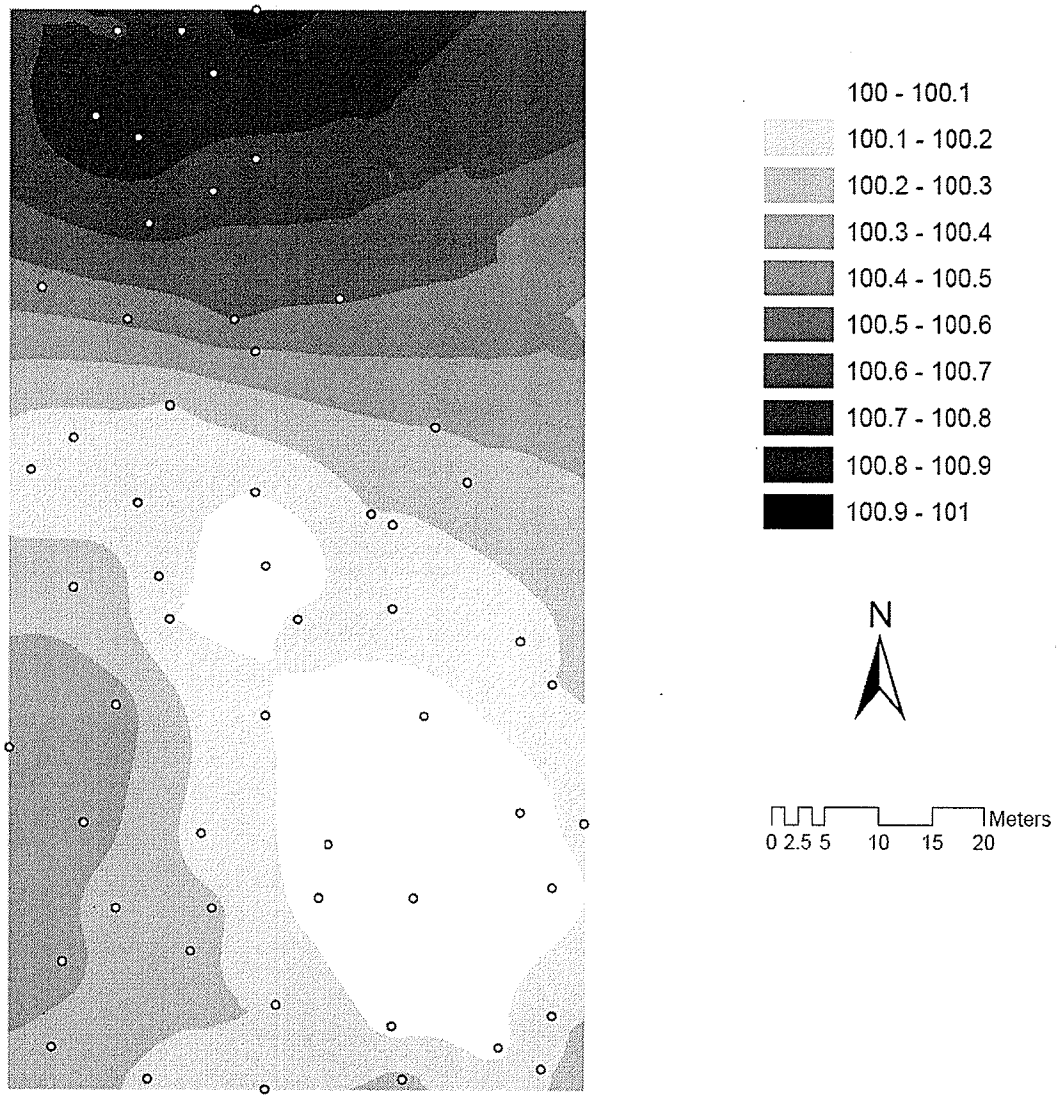


Interpolated map of EC_e (dS m^{-1}) overlaid by data points used for interpolation (white dots) and sample locations (black dots) in Farm 6

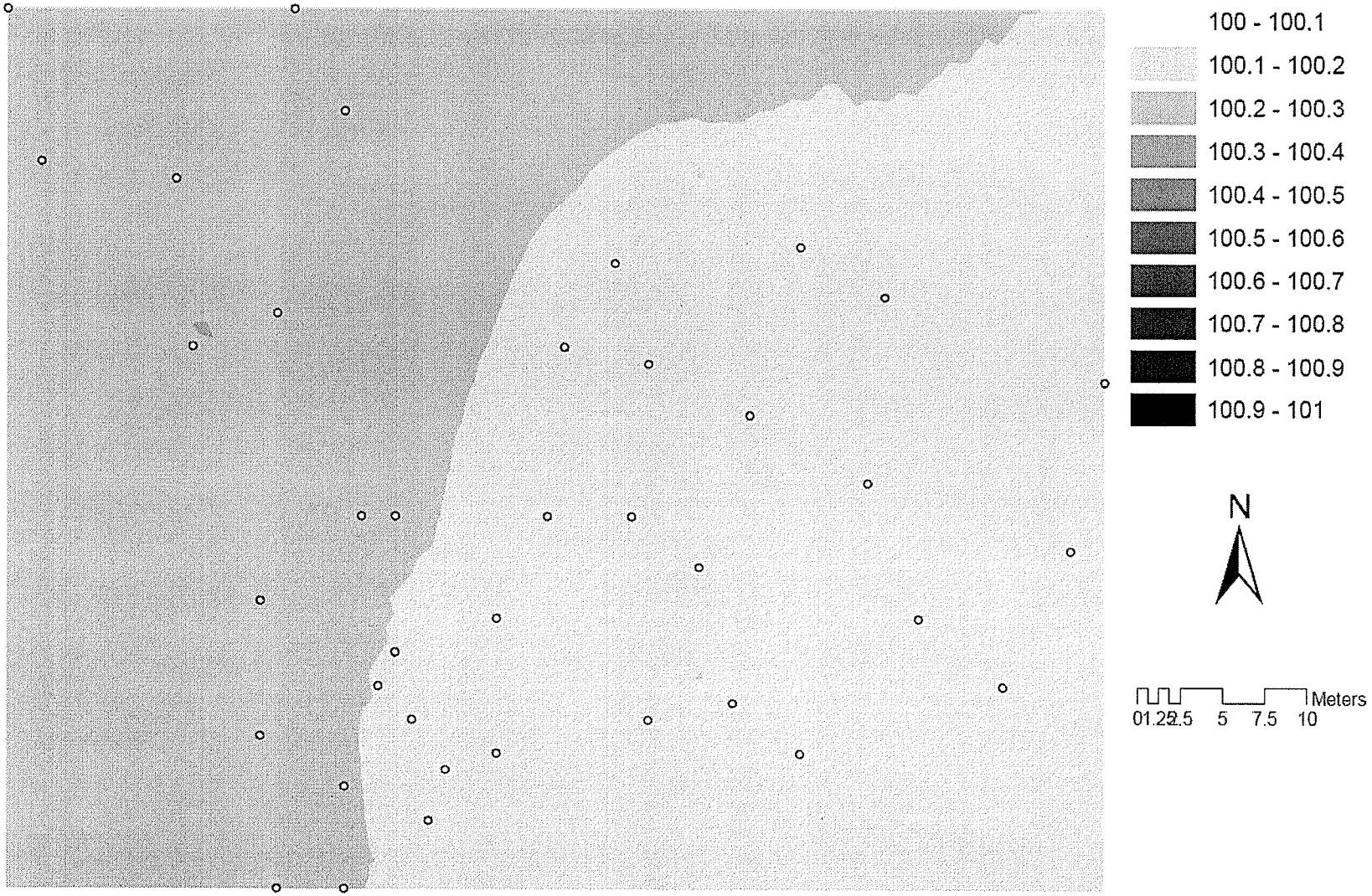
Appendix C: Interpolated maps of elevation overlaid by data points used for interpolation



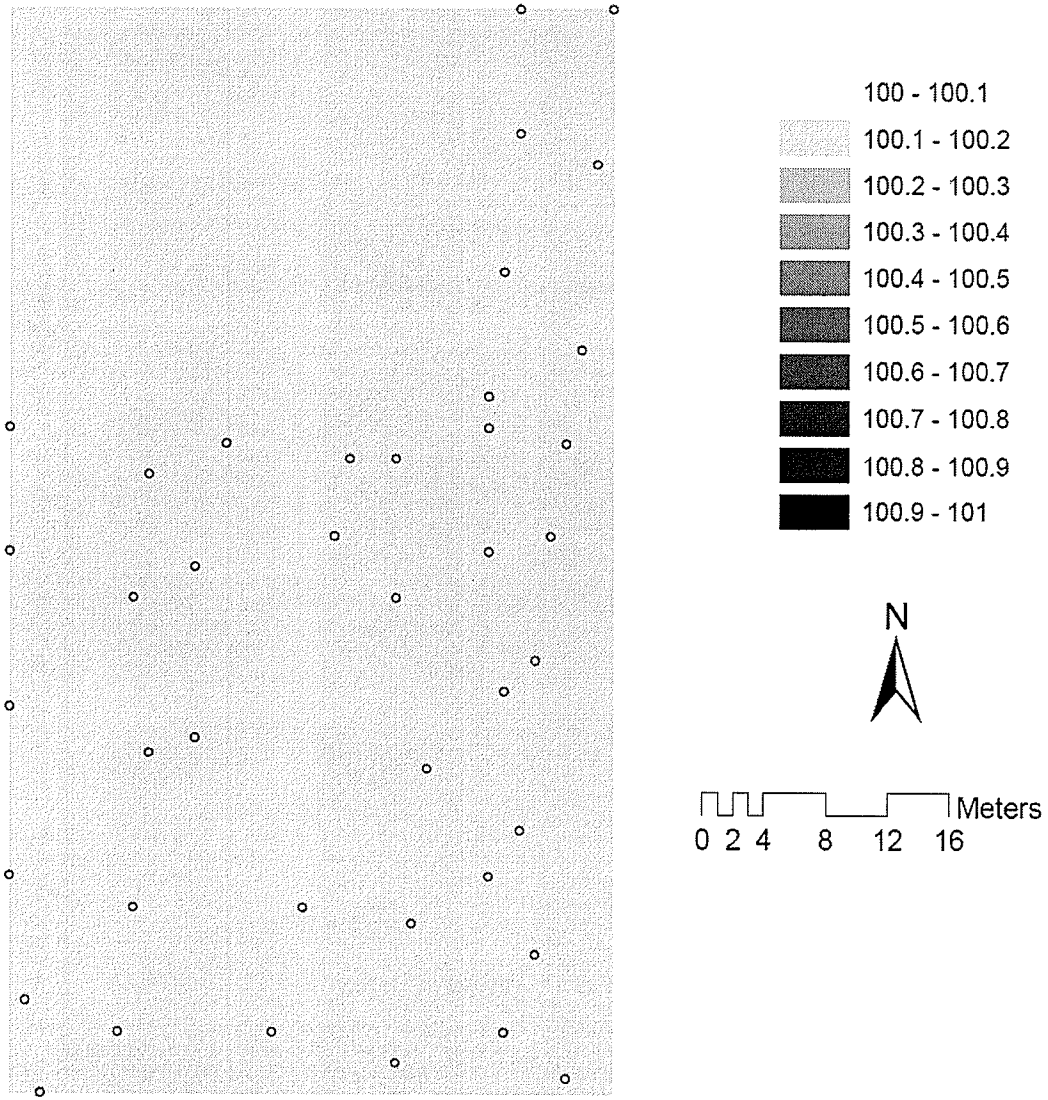
Interpolated map of elevation (m) overlaid by data points used for interpolation in Farm 1



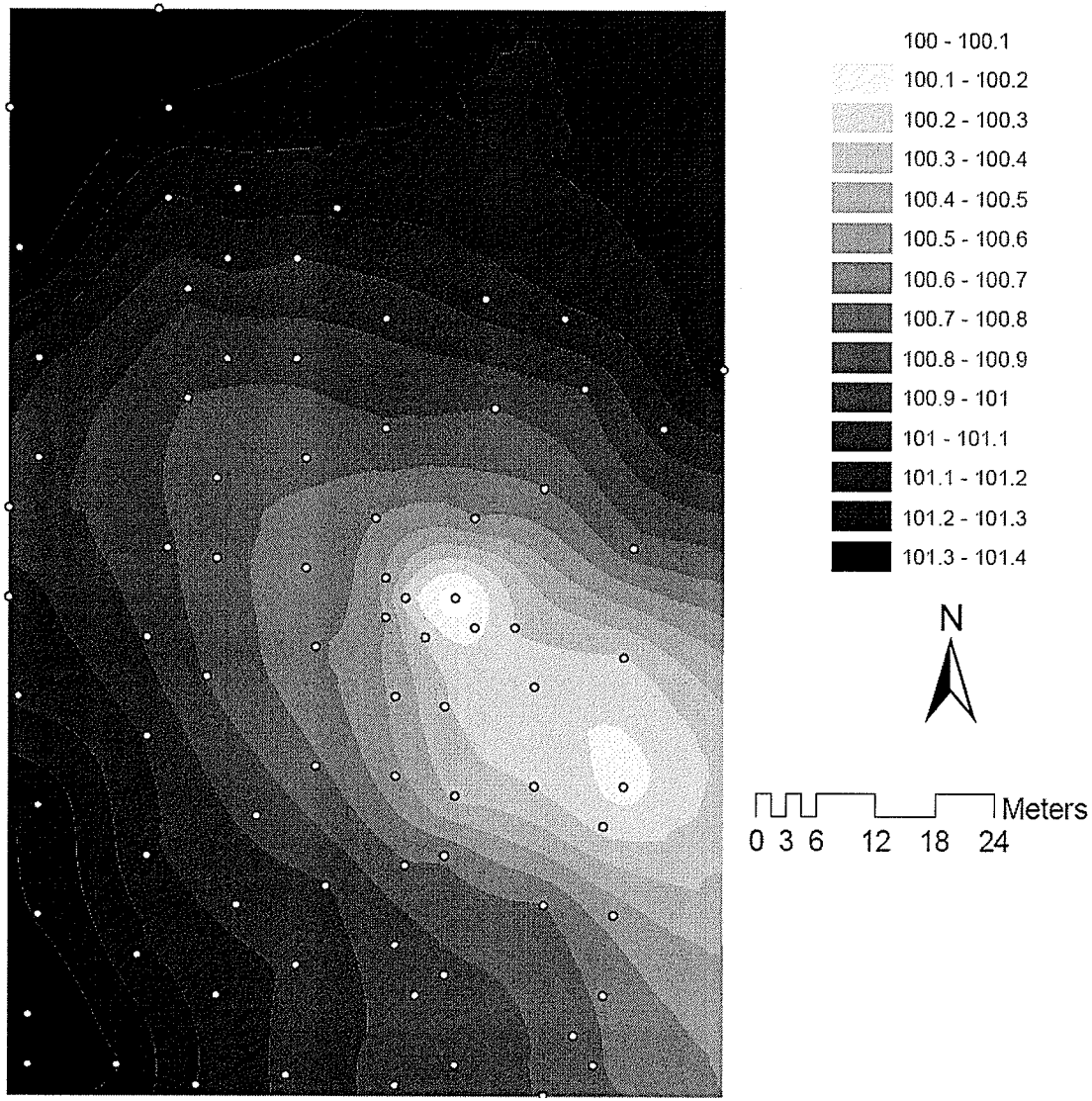
Interpolated map of elevation (m) overlaid by data points used for interpolation in Farm 2



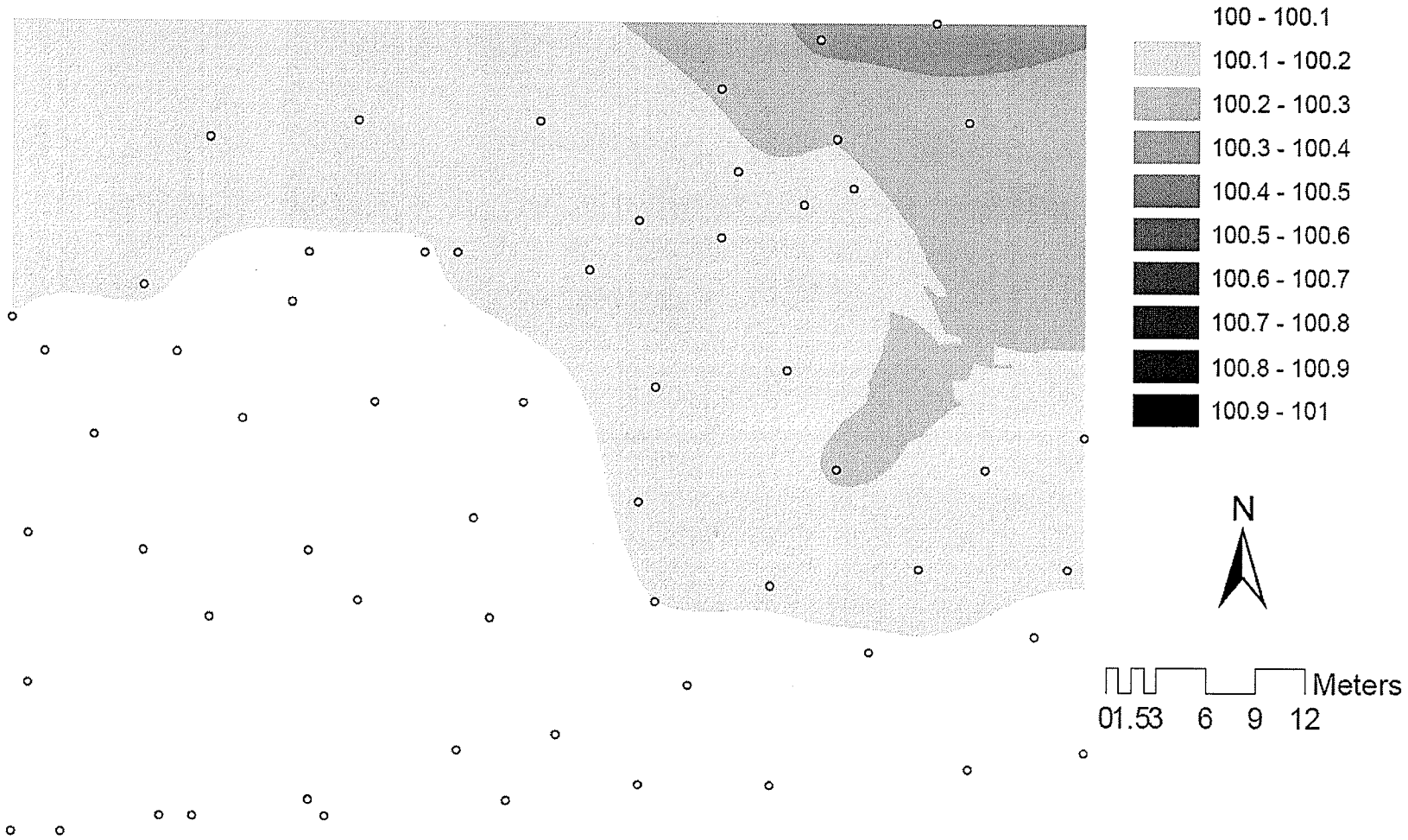
Interpolated map of elevation (m) overlaid by data points used for interpolation in Farm 3



Interpolated map of elevation (m) overlaid by data points used for interpolation in Farm 4

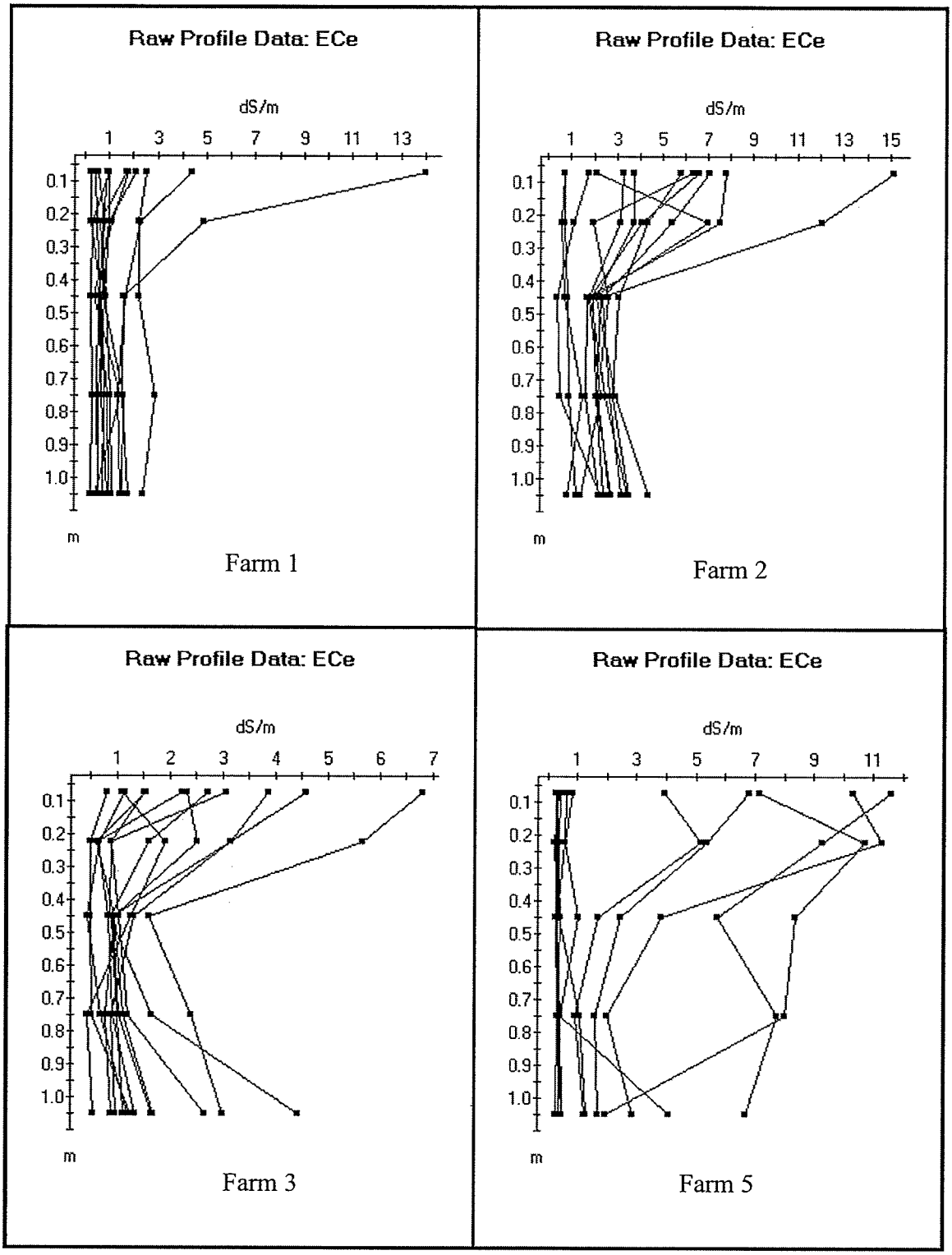


Interpolated map of elevation (m) overlaid by data points used for interpolation in Farm 5

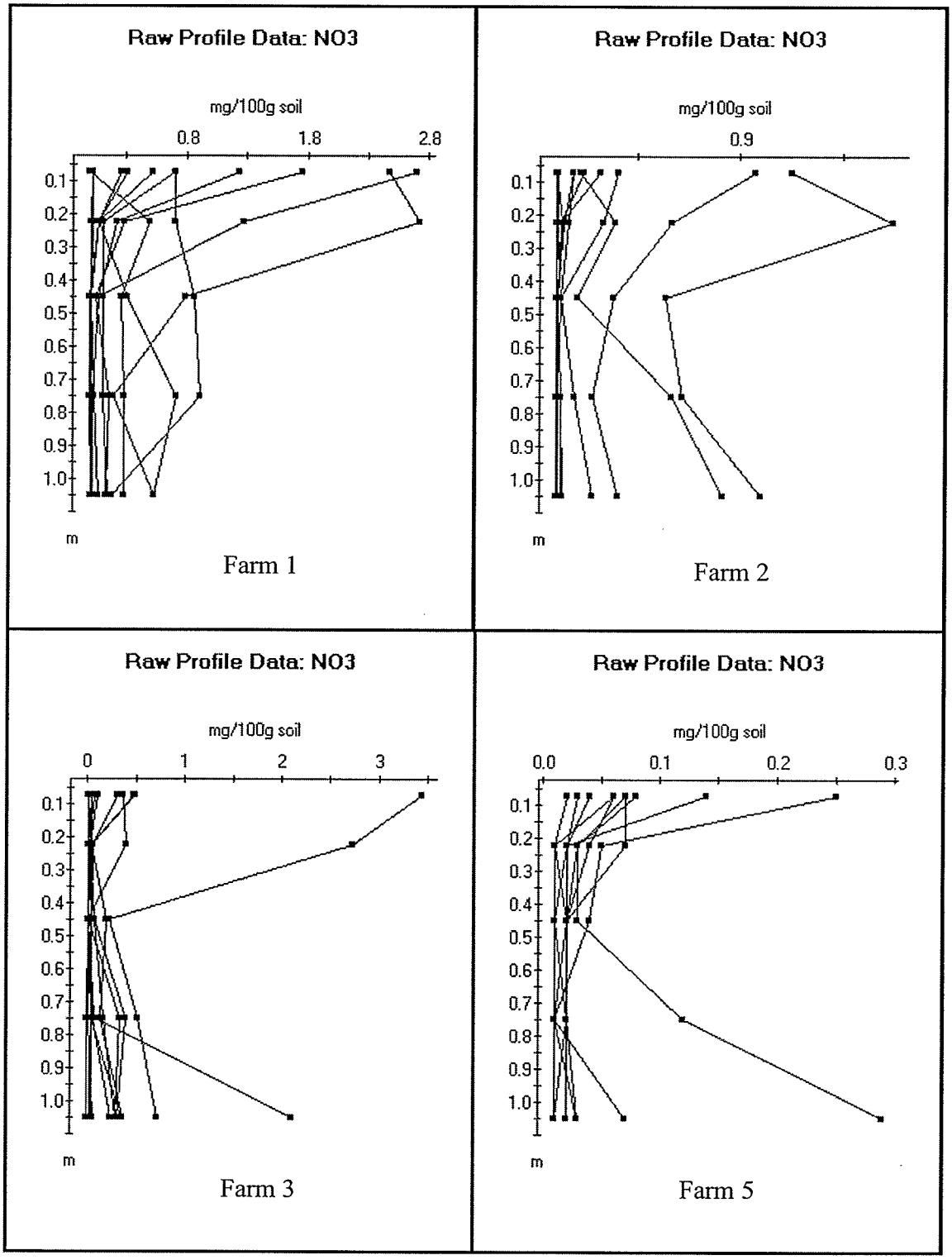


Interpolated map of elevation (m) overlaid by data points used for interpolation in Farm 6

Appendix D: Profile plots of EC_e for farms which had the whole soil profile sampled



Appendix E: Profile plots of NO_3^- for farms which had the whole soil profile sampled



Appendix F: Profile plots of PO_4^{3-} for farms which had the whole soil profile sampled