GEOGRAPHIC INFORMATION SYSTEMS IN THE APPLICATION OF PRECISION AGRICULTURE FOR SUSTAINABLE SUGARCANE PRODUCTION IN THE REPUBLIC OF PANAMA

by

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ABSTRACT

Geographic Information Systems (GIS) have revolutionized the development of the sophisticated resource management method known as Precision Agriculture (PA). PA involves the wise management of agricultural inputs based on knowledge of soil and plant health heterogeneity over a field, in order to minimize environmental impact and increase economic efficiency. A GIS platform was created as the basis of PA implementation at Azucarera Nacional sugarcane plantation in Panama. Field data collection took place over two years, from 2005 to 2006. A digital map of Mangote plantation was created and linked to production records. Detailed field sampling was also conducted on seven parcels of Mangote plantation, including soil conductivity monitoring and plant chlorophyll monitoring. Data was spatially interpolated to create raster coverages.

Soil salinity variation within some parcels studied justifies the creation of soil salinity management zones. Salinity zones were found to be relatively stable over the study period and in general conductivity at a depth was higher than at the surface. The root mean square errors obtained using Inverse Distance Weighting as opposed to Ordinary Kriging did not vary greatly, and hence it is recommended to use the simpler method (IDW) at the study site. Plant chlorophyll profiles revealed nitrogen deficiencies in some study parcels. Plant chlorophyll also showed within parcel variability as well as variability over the study period. No direct spatial correlation was found between conductivity readings and plant chlorophyll readings, although parcels with extreme salinity showed depressed chlorophyll values. The ground-based chlorophyll sampling showed no correlation with NDVI, however the NDVI coverages were deemed useful for the visual identification of plant stress. In general, GIS based management shows promise in improving Azucarera Nacional's agricultural efficiency.

RÉSUMÉ

Les systèmes d'information géographiques (SIG) a révolutionné l'élaboration de la méthode sophistiquée de gestion connue sous le nom d'agriculture de précision (AP). L'AP implique la gestion sage des entrées agricoles basées sur la connaissance de l'hétérogénéité de santé de sol et des récoltes dans un champ, afin de réduire au minimum les impactes sur l'environnement et augmenter l'efficacité économique. Une plateforme de SIG a été créée comme base d'exécution de AP à la plantation de canne à sucre d'Azucarera Nacional au Panama. La collection de données a eu lieu sur deux ans, de 2005 à 2006. Une carte digitale de la plantation Mangote a été créée et liée aux dossiers de production. Le prélèvement de données dans le champ a été conduit sur sept champs particuliers de la plantation Mangote, quel incluse une enquête de conductivité de sol et des mesures de chlorophylle. Des données ont été interpolées pour créer des surfaces continues.

La variation considérable de salinité de sol dans quelques champs étudiés justifie la création des zones de gestion de salinité de sol. Des zones de gestion de salinité sont relativement stables au cours de la période d'étude et en général la conductivité à une profondeur est plus haute que sur la surface. Les erreurs quadratiques moyenne obtenues en utilisant IDW, en comparaison avec OK, n'ont pas changé considérablement et par conséquent on lui recommande l'IDW comme l'option le plus simple. Les profils de chlorophylle ont indiquées insuffisances d'azote pour quelques champs. Les profiles de chlorophylle ont également montrée la variabilité dedans les champs, aussi bien que la variabilité au cours de la période d'étude. Aucune corrélation directe n'a été trouvé entre les lectures de conductivité et les lectures de chlorophylle bien qu'en général les champs avec la salinité extrême aient montré des valeurs diminuées de chlorophylle. Le système de prélèvement pour surveillance du contenu de chlorophylle n'a montré aucune corrélation avec NDVI, toutefois le NDVI est considérée utiles pour l'identification visuelle de santé végétale. Généralement l'intégration de SIG est prometteuse en améliorant l'efficacité agricole d'Azucarera Nacional.

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LIST OF ACRONYMS AND SYMBOLS

CSIRO	Commonwealth Scientific and Industrial Research Organization
ESRI	Environmental Systems Research Institute
DGPS	differential global positioning system
GIS	Geographic Information Systems
GPS	Global Positioning Systems
ha	hectare
IDW	inverse distance weighting
IRSS	Indian Remote Sensing Satellite
m	meter
MSAVI	modified soil adjusted vegetation index
NDVI	normalized difference vegetation index
NSERC	natural science and engineering research council

OK	Ordinary Kriging
OKTR	Ordinary Kriging with trend removed
PA	precision agriculture
R	correlation coefficient
RMSE	root mean square error
RS	remote sensing
SASA	South African Sugarcane Association
SAVI	soil-adjusted vegetation index
SPAD	specialty products agricultural division, Minolta Corporation
VRT	variable rate technology

CHAPTER 1 INTRODUCTION

"There is no global challenge facing humanity that is more important than managing the earth's environment to assure that it can sustain life in all its forms" (FAO 2007).

1.1 Motivation

There exists an important and pressing need to ensure food security as global population increases (USAID, 2007). Furthermore, not only ample but *sustainable* crop production is crucial to relieve the tremendous pressure on natural resources that corresponds to this increase (FAO, 2006). The importance of wise management of freshwater resources, prudent use of pesticides and fertilizers, and the mitigation of soil erosion are prime concerns, not only for the agricultural sector, but also for the global community (GEF, 2006). Cutting-edge spatial information technologies such as Geographic Information System (GIS), Global Positioning System (GPS), satellite remote sensing (SRS), and digital image processing (DIP) are invaluable tools in the accomplishment of these goals and provide a backbone for the burgeoning field of precision agriculture (PA) (Brisco et al., 1998).

Precision agriculture, also known as site-specific farming, is a management scheme which aims to *optimize* crop land use by increasing production, while decreasing agricultural inputs. This dual goal addresses the issue of human subsistence while accounting for the environmental repercussions of agriculture which are derived mainly from its inputs; that is, the excessive use of freshwater and agro-chemicals which effect surrounding ecosystems. Although the theory supporting PA has been around for centuries, the enlargement of fields and intensive mechanization that are the hallmarks of modern agriculture, have made sophisticated 'on-the-go' site-specific management unrealistic without an accompanying revolutionary development in technologies (Zhang et al., 2002). These spatial information technologies, particularly SRS and GIS, have begun to play an increasingly important role in environmental monitoring and resource management activities in general, and are at the heart of PA implementation.

Although the acceptance and growth of PA has been rapid, some fundamental requirements are needed to help fully develop and implement this technology on a larger scale (Brisco et al., 1998). Not only is there a need for further research into the various technical aspects of PA, but a paradigm shift must also occur in agricultural production towards sustainability. Not surprisingly, countries of the global south often face additional challenges in regards to PA implementation. Despite the on-going development of PA related tools for tropical crops such as sugarcane in Brazil, Australia and South Africa, widespread dissemination remains largely unrealized. Unfortunately, issues related to lack of access to appropriate resources, and the current capital cost and delayed return on investment associated with PA implementation are the greatest deterrents to developing countries that would potentially derive the greatest benefits from adoption (Cook et al., 2003).

In order to overcome the barriers mentioned above, certain key developments must occur:

1) Place emphasis on the economic value of information gathering and environmental externalities
2) Develop and implement training and technology transfer programs to accelerate the acceptance of this technology for the agribusiness sector, especially in developing countries
3) Increase access to satellite imagery and develop straightforward methods of satellite image analysis for practical crop management purposes

Contributing to a solution for the problems listed above, in the particular regional context of the Panamanian sugarcane industry by establishing a platform GIS, is the principle motivation for this project. With agricultural activities as the primary economic activity in Latin America (FAO, 2005) and the presence of some of the world's largest cane producers (Brazil, Cuba etc.) often subjected to limited or no environmental regulations, the project was initiated in the hopes of promoting regional development of sustainable agricultural practices by developing a practical tool and generating thematic maps to help farmers improve:

1) Irrigation management to mitigate salinization
2) Fertilizer management to mitigate waste.

With the participation of the Universidad Tecnológica de Panamá, this project was carried out as a consultation contract with Azucarera Nacional and the accompanying dissertation was prepared under the Neotropical Environment Option offered jointly by McGill University and the Smithsonian Tropical Research Institute (STRI).

1.2 Background

1.2.1 Sugarcane

The Latin America and the Caribbean region has undergone significant land use changes in the past few decades, with tremendous expansion of cultivated area of three principal crops: soybeans, corn and sugarcane (Tejo and Nagel, 2002). Concurrently, Panamanian farm production has undergone a major change in the last few decades, with predominant agricultural activities such as banana cultivation declining and crops such as coffee and sugarcane increasing their share of the total agricultural GDP (Tejo and Nagel, 2002). Sugarcane producers however, have had to contend with the cut on import quotas that the United States has imposed on Panama, making profitable sugarcane production an increasingly difficult task (Tejo and Nagel, 2002). In addition to this, all sugar industries are being exposed to the low world price for sugar or are otherwise facing reduced income from sugar exports and hence are feeling the pressure of reduced viability (Milford, 2005). In order for the Panamanian sugar industry to survive and compete on the international market in the face of these pressures, measures must be taken to increase production efficiency and stay abreast with modern agricultural developments.

Sugarcane is an extremely valuable agricultural resource from which sugar and a variety of by-products are derived. The sugar industry processes sugarcane and sugar beet to manufacture edible sugar, with over 60% of the world's sugar production coming from sugarcane cultivation. (World Bank Group, 1998). Sugarcane is a member of the plant family *Graminae* of which only the species *Saccharum officinarum* L. is grown commercially. Economically, the most important part of the sugar cane plant is the stalk containing sucrose. The plant is harvested and processed to extract the final product sugar. Sugarcane is commonly propagated asexually, whereby mature cane is cut, producing new shoots and root systems from the underground part of the stalk. The new plant emerging after the first cut is known as the first ratoon, and successive generations are named accordingly. The sucrose content of the sugarcane plant decreases with increasing number of ratoons, and the amount of decrease depends on regionally varying environmental conditions and the variety of sugarcane grown. Consequently, the number of ratoons common in commercial sugarcane farming varies greatly from region to region. Most varieties of cane grown at Santa Rosa are harvested up to approximately 12 ratoons.

Certain properties of the sugarcane plant with regard to commercial sugarcane farming are of major importance from the economical and social point of view. First of all, sugarcane is a perennial grass, and hence, is normally not integrated into a rotation system; it is commonly carried out as a monoculture and requires inputs of freshwater, pesticides and fertilizers. Furthermore, the fact that sugarcane is harvested by cutting the stalk and removing the leaves and tops which, if harvesting is not mechanized, is very labor-intensive. High sucrose content levels, which are attained at full maturity, only last for a relatively short period; therefore cane must be harvested within a limited period of time, making harvest labor-intensive and seasonal. Sugarcane agriculture, as with most other crops, is controlled by a complex system of environmental determinants such as climate, landform and soil. Farmers experience severe environmental constraints with regard to natural hazards that cause damage to the plant and often result in heavy yield loses. These characteristics, and the prevailing economic conditions under which sugarcane agriculture is carried out, make sustainable and optimal farming practices a particular necessity.

1.2.2 Study area: Azucarera Nacional, Republic of Panama

The project site, and ultimate beneficiary of PA implementation, is Panamanian company Azucarera Nacional, the oldest and largest sugarcane producer in Panama and an important player in Panama's agricultural sector. Azucarera Nacional was founded by Mr. David Delvalle in 1884, an entrepreneur motivated by a governmental initiative promoting economic development who took the opportunity to establish the plantation in an area of the province of Coclé known as El Roble, in the Republic of Panama. The original machinery and equipment were transported in boats to the Port of Aguadulce and then in ox-carts to Santa Rosa. In 1913, the Santa Rosa plantation realized its first zafra (sugarcane harvest), thereby starting the Panamanian national sugar industry.

The current land holdings of Azucarera Nacional span over 15,000 hectares in the provinces of Coclé and Herrera. The plantation is also situated in the heart of the Santa Maria watershed and uses water from the Santa Maria River for irrigation during the dry season which goes from December to April and rain-fed irrigation during the remainder of the year. The company holdings are comprised of five farms: Santa Rosa, Panela, Mangote, Los Canelos and San Jose. Small independent sugarcane producers or Colonos also provide a significant portion of the cane that is processed by the on-site sugar mill. Each farm is composed of smaller parcels of land which range in size from just a few hectares to over 30 hectares. The parcels are the functional production units for each farm, and all agricultural inputs are applied on a parcel basis. For the purposes of this project, mapping was restricted to the Mangote farm and detailed studies were carried out on several individual production units, or parcels, on Mangote. Implementation of PA at this site represents an important step in the Panamanian governmental mandate to increase efficiency and sustainability in agriculture and also represents an important step in the dissemination of PA technologies in the region.

1.3 Hypothesis

The current project is based on the assumption that GIS is an important tool in site-specific management and that such a management scheme can greatly contribute to the sustainability of agricultural activities. Furthermore, it is based on the assumption that soil conductivity heterogeneity and plant chlorophyll heterogeneity over a field are important parameters to monitor to optimize agricultural inputs. The hypothesis is that using GIS and creating maps which display soil and plant health properties, by using spatial interpolation to predict values at un-sampled locations, in conjunction with remote sensing information, is expected to result is more complete estimation of in-field heterogeneity and that this information can be used to optimize farm operations.

1.4 Objectives

The principal objective of this project is to establish a platform GIS in order to initiate a PA management scheme at Azucarera Nacional. In order to fulfill this objective, it is necessary to first build a digital cartographic base and then add information to the system that can eventually be used for analysis of conditions in individual fields, or parcels and for optimization of opertions. Finally, capacity-building in data collection and GIS analysis, as well as effective technology transfer, are significant priorities of this project. The specific objectives are:

1. Create an annotated digital land holdings map for the Mangote plantation of Azucarera Nacional.
2. Create descriptive maps of Mangote based on variations between individual parcels of the following parameters:
    i) Production
    ii) Ratoon number
3. Create maps of individual study parcels of Mangote using ground-truth and soil sample analysis data describing variations in:
    i) Soil conductivity and changes over time and with depth
    ii) Plant chlorophyll
4. Compare the performance of inverse distance weighting and ordinary kriging for predicting the spatial variability of soil properties
5. Investigate the utility of multispectral high-resolution satellite imagery in the visual identification of plant stress and correlation of NDVI with SPAD meter plant chlorophyll measurements

In order to meet these general and specific objectives information from aerial photography and hard copy maps were integrated to create a digital map of Mangote plantation of Azucarera Nacional in Panama. This was carried out in conjunction with extensive field scale studies of seven individual study parcels of Mangote over two consecutive years (2005 and 2006). Remote sensing data was also acquired from the Quickbird satellite for the 2006 growing season. The methodology used to fulfill these objectives is described in the following chapters.

1.5 Scope

It is important to note that the implementation of a GIS and the requisite data collection are subject to various economic and physical constraints and the extent and style of PA implementation should be tailored to the specific geographic context. Also, because crop growth and soil conditions are influenced by numerous variable factors, application of the field methods used in this study is limited to the field and atmospheric conditions encountered during data acquisition. Most importantly, this project is intended to be a practical exercise in establishing a spatial management system for a company and integrating already existing data, as well as gathering field data specific to the context of the company and their land holdings. The conclusions made in regards to interpolation techniques as well as correlations between measured properties should be validated under a variety of field and atmospheric conditions, and under more controlled experimental settings. Therefore, any extrapolation of the results to other sites and environmental conditions should be carried out with due diligence.

1.6 Thesis Organization

This thesis is organized into five chapters, which provide a background for the current project, describe its objectives and how they were achieved. Chapter 2 provides a global literature review of work that has been carried out in the field of precision agriculture, as well specific studies related to soil salinity and plant chlorophyll determination and related remote sensing methods. Chapter 3 gives a detailed description of the methodology used for field work, as well as the methodology used for subsequent spatial and statistical analysis. Chapter 4 presents the results of the creation of the geographic information system: thematic maps of the Mangote plantation, as well as maps of individual study parcels displaying variations in soil conductivity and crop leaf chlorophyll content, are presented and discussed. Issues related to the spatial interpolation models used to generate the individual parcels maps are also discussed in Chapter 4, and the results of correlations between soil conductivity measurements (EM38), plant chlorophyll measurements (SPAD) and NDVI values derived from satellite imagery are presented and discussed. Chapter 5 provides a summary and conclusions based on the results, as well as providing recommendations for further study.

CHAPTER 2 LITERATURE REVIEW

This chapter reviews the literature relevant to the development and application of Precision agriculture (PA) by looking at the history of its development and scope of adoption. The role of Geographic Information Systems in PA implementation is then described. The following section describes the characterization of soil salinity and moisture, as well as crop nitrogen status, using 'on-the ground' field methods and remote sensing. The last section describes how information collected in the field can be spatially interpolated using Geostatistical techniques to create continuous surfaces from discrete data.

2.1 Precision Agriculture

Agriculture, as humankind's most important life-sustaining activity, has had a tremendous global impact; the extent of agricultural land use and its environmental and social significance are enormous. With global population at over 6 billion, commercial agriculture and its impacts are continuously under expansion and reverberate through all aspects of our biosphere. Not only do agricultural activities, which account for 75% of global freshwater withdrawals, play a central role in global water scarcity issues, they also have repercussions on biodiversity and climate change (FAO 2007). These environmental impacts, along with the continued reality of world hunger, make agricultural productivity and sustainability the key problem of the coming century. In order to solve this problem we must cross the "principle remaining agricultural frontier...land productivity – coaxing more production from each parcel of cropland" (Postel, 1999). More importantly however, we must encourage increased production through the effective use of agricultural inputs; that is, by optimizing agricultural production in order to ensure sustainability.

Traditionally the individual production unit, for example a field that is often hectares in size, is treated uniformly. Agricultural inputs such as fertilizers, herbicides, insecticides, fungicides as well as irrigation water are uniformly applied. However, crops obviously respond to major environmental and soil variables varying on a much finer scale. The discrepancy between the uniformity of crop treatments and the uniqueness of individual plants' physiological responses implies that a significant portion of the farmers' costs is going to waste. This waste not only represents a financial loss, but also often represents a negative impact on the surrounding environment. Precision agriculture therefore seeks to retain the benefits of large-scale mechanization while accounting for this local in-field variation.

The principle behind PA is simple: The environment is heterogeneous and should be managed accordingly. Ignoring environmental heterogeneity represents a loss in efficiency that we simply cannot afford. In order to accomplish this, we must undertake both descriptive activities in order to *characterize* environmental heterogeneity, and prescriptive activities to *respond* to it. Modern technological advances have made these activities of description and prescription possible with unprecedented sophistication and precision. Geographic Information Systems allow us to catalogue and analyze the vast amounts of information required to operate large-scale farms, by drawing upon and synthesizing information from a variety of sources and capitalizing on their spatial location. Remotely sensed information from earth observation satellites, in conjunction with information collected on the ground, also provides an important source of information for a GIS, and allows us to partake in descriptive activities in ways which greatly surpass traditional methods in ease, time commitment and detail. By using 'on-the ground' sensors and remote sensing to characterize spatially variable environmental parameters in great detail, and GIS to manage this information and respond to the information, PA has the potential to increase production efficiency and lower production costs, while at the same time promoting environmentally sustainable crop management. These technologies and their use in PA represent "a great leap forward for agricultural production" (Jhoty and Autrey,1998)

2.1.1 History and Scope

The concept of PA, although present in some form for centuries, was formulated formally in 1986 in a seminal paper written by Fairchild (Fairchild 1994). Since its theoretical inception PA has been explored widely, although it has been applied mainly in Europe and the United States, where farm sizes are large and landowners are willing to make larger capital investments in PA technology (Pederson et al., 2001). Accordingly, many significant PA developments took place in the US, Canada, Australia and Western Europe in the mid-to-late 1980s (Zhang et al., 2002) with principle areas of PA development taking place in regards to high yield crops such as wheat, barley, corn and soybean. (Jhoty and Autrey, 1998). Regardless, PA management has experienced considerable attention from researchers worldwide and has become a prominent issue in modern agriculture, with PA related experiments reported in recent literature from China, Korea, Indonesia, Bangladesh, Sri Lanka, Turkey, Saudi Arabia, Australia, Brazil, Argentina, Chile, Uruguay, Russia, Italy, The Netherlands, Germany, France, UK, United States and Canada (Zhang et al., 2002). All of these experiments with various aspects of PA practice have occurred in parallel with the development of spatial database management and environmental monitoring tools, and the literature explores a range of issues from general PA implementation guidelines to specific indices for the analysis of crop spectral information (Barnes et al., 1996; Atherton et al., 1999). Excellent reviews are available of its development and myriad aspects from leaders in the PA field (Moran, Inoue et al. 1997; Plant 2001).

In comparison to high yield crops however, PA application to sugarcane is still in its infancy. Regardless, important advancements have occurred in sugarcane PA in countries such as Australia and South Africa, with research groups such as South African Sugarcane Association (SASA) and Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) having carried out multiple studies regarding PA and its application to sugarcane cultivation (Blackmer and White 1998; Cook and Bramley 1998; Rossel and McBratney 1998; Schmidt et al., 2001; Gers 2003). Sugarcane PA has also seen significant contribution from Brazil which, with over 6 million hectares of planted cane, harbors the world's largest sugarcane industry (Magalhaes and Cerri 2007). Large scale projects have been initiated to design a sugarcane yield monitor, which remains commercially unavailable at the time of writing, and to map physical and chemical soil attributes, with the aim of furthering the implementation of PA in sugarcane crop in Brazil (Cerri and Magalhaes 2003).

PA for sugarcane has also been explored in Asia, with extensive land and soil cover monitoring made possible by the Indian Remote Sensing Satellite (IRS-1). The most significant contributions have come from India, Japan and Thailand (Chakraborti et al., 2002; Shanwad et al., 2004; Saravanan et al., 2005; Ueno et al., 2005). A great source of motivation for this sugarcane PA development comes from the fact that the sugar industry relies strongly on agricultural inputs to increase yield and instead of treating specific high-infested or nutrient deficient areas, large areas are often uniformly treated with herbicides and fertilizers(Simoes et al., 2005).

In spite of these myriad developments and widespread interest, some studies suggest that adoption of PA related technologies, such as yield monitoring, is not as widespread as initially forecasted (Zhang et al., 1997; Lowenberg-DeBoer 2003). Although there are many complex sociological and economic reasons for this, most studies reveal that the greatest barrier to PA adoption is the substantial initial capital investment required, and the fact that the most significant benefits of PA usually come after the accumulation of many years of detailed soil and plant variability data. (Blackmore et al., 1994; Pederson et al., 2001; Sevier and Lee 2003; McBratney et al., 2004; Adrian et al., 2005). Unfortunately, this barrier may seem even greater in a developing country context, where profitability in agriculture is often even lower (Cook et al. 2003). Despite this uncertainty, PA has been shown to be profitable in both a developed and developing country context (Stombaugh et al. 2001; Godwin et al., 2002; Bongiovanni and Lowenberg-Deboer 2004) and a survey of economic studies related to PA concludes that the majority of PA management schemes show positive net returns (Lambert and Lowenberg-DeBoer 2000). In general, there is also strong correlation between PA profitability and farm size and even farms of just over 200 ha, can expect profits and an amelioration of product quality by implementing PA (Stombaugh, et al., 2001; Godwin et al., 2002). Although smaller farm sizes and land tenure may be an issue in the global south, the existence of landowners with large landholdings such as Azucarera Nacional in Panama, provides strong cause for PA implementation in the developing country context, where optimization of production is most pressing.

It is important to note that as sustainable development becomes economically valued, the benefits of PA implementation will accordingly become increasingly apparent. That is, when reduced environmental burdens are recognized and evaluated and become part of the ultimate reward, PA will gain increased importance in the agricultural sphere (Auernhammer 2001). Currently very few economic models used to determine the optimal number of PA management units within a given field, pay express attention to environmental externalities (Ancev et al., 2004). For example, Danish farmers see greater economic benefits in taking action based on knowledge of field heterogeneity, as opposed to simply gathering information, than do producers in the United States and UK; this can be attributed to restrictions on N rates below the economic optimum in Denmark, as well as substantial taxation on the use of pesticides.

Similar environmental laws are being implemented throughout continental Europe to limit N fertilization on arable land, especially to protect drinking water areas.(Link et al., 2006) . European Union legislation has accordingly prompted certain local governments to pass laws which further reduce the loss of N to groundwater from agricultural sources, greatly motivating management systems which encourage the efficient use of N input. Furthermore, a case-study of variable-rate application of nitrogen on an Argentinean farm, which shows how profitability can be maintained while reducing the application of nitrogen, demonstrates how PA works for both environment and development goals (Bongiovanni and Lowenberg-Deboer 2004). Using a wide range of hypothetical government restrictions on N application levels, a sensitivity analysis shows that precision agriculture is a modestly more profitable alternative to traditional whole field management (Bongiovanni and Lowenberg-Deboer 2004). These results imply that appropriate environmental policy reforms by local governments worldwide will be pivotal in encouraging the use of precision farming and that such management schemes encourage economic *and* environmental optimization.

2.2 Geographic Information Systems

Geographic Information Systems (GIS) are a cutting-edge technology that allows the unprecedented manipulation and analysis of geographic information. In practical terms, a GIS simply consists of computer software, hardware and data, and personnel to help manipulate, analyze and present information that is tied to spatial location. A GIS can provide farm managers an effective method to visualize, manipulate, analyze and display spatial data, providing the backbone of a PA system.

There are two principal ways to input and visualize data in a GIS:

1) **Raster data:** consists of information in a grid, composed of pixels, where each pixel represents a location and has a certain value. Data obtained from remote sensing, such as satellite imagery and aerial photography are in this format. Discrete point data obtained from field sampling can also be interpolated to create continuous raster coverages of the sampled properties (Crosier et al., 1999).

2) **Vector data:** consists of linear, rather than grid, information and is composed of points, lines and polygons. Geographic features such as buildings, bodies of water and boundaries of fields and agricultural management units etc. are in vector format. One can attach attributes such a size, type and length, among other properties to vector data (Crosier et al., 1999).

The information that can be integrated into a GIS is many and varied, contributing to the flexibility and adaptability of GIS to many applications. In general these in information sources consist of digitized and scanned maps, tables of attribute data, spatial data gathered using a GPS device, as well as data gathered using remote sensing devices such as satellites. What makes GIS a crucial part of PA systems is that they ultimately involve a high level of data integration between positioning and sensing technologies and control systems (Earl et al., 2000). GIS is therefore able to provide the necessary platform for complex information flows, which include spatial and temporal components, and to facilitate the use of expert knowledge already held by farmers, to synthesize information into a scheme for optimal crop management (ESRI, 2007). Once digital maps are created of agricultural holdings and linked to relevant attribute information, query and analysis are the key functions of a GIS system used for decision support. Strengthening the system with continued input of field data, a GIS can be used for site-specific management involving the mapping of yield variability and the identification of limiting factors by combined analysis of soil, nutrients, slope and weather information along with field data and remotely sensed data. Visual displays of how properties are changing over a field are extremely useful for farm managers to manage inputs using management zones (Plant, 2001).

Creating a GIS is the first step in PA implementation (Jhoty and Autrey, 1998) and it is a becoming a commonplace information technology tool for agricultural production applications (ESRI, 2007). GIS has been applied to sugarcane PA in particular, for the spatial analysis of soils, and to catalogue land use, weather and slope in order to derive areas suitable for new cane planting (Saravanan et al., 2005). Several studies using GIS for mapping in agriculture have been produced in Thailand (Sah et al., 1995). Sah (2000) focused on developing a methodology to classify the salt-affected soils using remote sensing and GIS. They found that ground truth combined with remotely sensed data was effective in classifying the extremely and moderately saline areas and that the integration of GIS was found effective in classifying low and potentially saline areas. The authors concluded that the integration of GIS with digital image processing was very effective for classifying and monitoring saline soils (Sukchan and Yamamoto 2000).

Saravan et. al (2005) also recognized the importance of building farm information systems for the Thai sugar industry. A mapping project was initiated in order to map cane fields and other land uses using the Indian Remote Sensing (IRS) - 1D satellite, as well as to build a farm record system with links to the map and finally to analyze this information using GIS software (Saravanan et al., 2005). The study concluded that GIS was a powerful tool that allowed for interpretation, analysis and decision making for sustainable and profitable farming. The maps generated and field data gathered for this study were used for monitoring cane area, delivering inputs and planning for locating new potential areas for planting. Japanese efforts to implement sustainable sugarcane production also relied on the integration of RS with GIS; these tools were used to evaluate cane growth conditions and prepare field maps and resulted in improved management practices on individual farms (Ueno et al., 2005)

GIS is not only an important tool to input and analyze crop management information, it can also be used in conjunction with GPS and variable rate technology (VRT) to directly control agricultural inputs once information is gathered. Small-scale variations in site-quality can be detected using GIS and related PA technology and this information can then be translated into valid crop management guidelines (Jarfe and Werner. 2000). German researchers initiated a field-based project where management guidelines were designed and then transformed into software modules to allow farmers to adjust cropping measures to respective management zones in a field (Jarfe and Werner, 2000) . They were able to successfully apply a decision support system based on

ArcView using if-then rules, for calculating site specific and agronomic optimal sowing rates. Many similar projects have been realized using GIS in conjunction with variable rate controllers for site specific application of fertilizer (Seidl et al., 2001 ; Miller et al., 2005), herbicides (Al-Gaadi and Ayers 1999) and irrigation water (Perry et al., 2002)

In light of these studies, it was decided to build a farm level GIS for the Azucarera Nacional sugarcane plantation using the Environmental Systems Research Institute (ESRI) ArcGIS 9.0 software. The GIS was established to optimally manage the vast amounts of production data with a spatial component, used at the plantation. The GIS will also provide a basis for site-specific input management at the plantation through the use of soil and plant health maps generated from detailed sampling on the individual parcels that make up each farm. The priorities for detailed sampling were identified according to the most pressing needs for crop management at the plantation and the limited resources available at the site. Soil conductivity monitoring was carried out because salinity was the most pressing challenge for soil management at the plantation. For plant chlorophyll assessment the SPAD meter was used for whole-field crop monitoring to manage nitrogen applications. Spatial interpolation was used to create continuous coverage maps from this data. Finally, remote sensing was explored as a qualitative tool for assessing crop health. Literature relevant to these topics is reviewed in the following sections.

2.3 Determination of soil and plant properties in precision agriculture

Traditionally, the determination of soil and plant properties over a field has been limited to direct methods of analysis such as gravimetric and chemical analysis of soil samples taken with an auger or foliar analysis in a laboratory to determine plant health characteristics. These methods, although direct, are extremely labor, time and cost intensive, and therefore field sampling is often carried out at a coarse resolution. These limitations have prompted the development of ground-based and remote sensing methods that can be used to determine relevant soil and plant properties with much greater ease and at a much higher spatial resolution.

2.3.1 Soil salinity assessment

In dry areas soil salinity is a frequent consequence of irrigation, and soil salinity has significant implications for crop health. In fact, early detection of saline areas can be used to enact preventive measures before a crop is significantly damaged (Jackson 1986). It has been shown that in high-salinity conditions with high vapor pressure deficits which is common in irrigated areas, plant stress exists, limiting the plant from achieving optimal growth (Howell et al., 1984).

In order to account for the adverse effects of soil salinity and soil moisture deficits, bulk soil electrical conductivity (EC) can serve as an indirect indicator of important soil physical properties. The traditional method of obtaining soil salinity by determining the conductance of the soil solution extract is too labor, time, and cost intensive to be practical for field-scale applications (Rhoades et al., 1999). Apparent soil electrical conductivity, which can easily be measured using an EC sensor, can serve as surrogate measure for salinity, clay content, clay mineralogy, soil pore size and distribution, soil moisture content and temperature (Rhoades et al., 1999).

In order to determine apparent soil electrical conductivity (EC), two basic designs of EC sensors are now commercially available. One is an electrode-based sensor requiring soil contact, and the other is a non-invasive electromagnetic induction (EM) sensor. The EM38-DD (dual-dipole), the most popular of such sensors, is a conductance meter which allows collection of on-the-go simultaneous collection of GPS referenced horizontal and vertical EM38 signal data (Barnes et al., 1996). Electromagnetic induction methods are most appropriate for the determination of soil salinity in precision agriculture applications because the volume of measurement is larger than traditional point soil sampling for chemical analysis, and it is much less labor, cost and time intensive (Rhoades et al., 1999). The EM has therefore become the first choice for measuring soil salinity in a geospatial context for the following reasons (Corwin and Lesch 2003):

(i) Measurements can be taken as quickly as one can move from one location to the next.

(ii) The reading represents the mean of a large volume of soil and hence reduces problems with point sampling.

(iii) Measurements in relatively dry or stony soils are possible because no contact is necessary between the soil and the EM sensor.

In areas of salt-affected soils, most of the EC signal is related to concentration of soluble salts. However, in non-saline soils, EC variations are primarily a function of soil texture, organic matter, moisture content and cation exchange capacity (Rhoades et al., 1999). Several studies have shown that bulk soil electrical conductivity serves as an effective proxy for soil texture and soil salinity (Rhoades et al., 1989) Soil physical properties such as soil texture have a direct effect on water-holding capacity, cation-exchange capacity, crop yield, production capability and nitrogen loss variations within a field (Lund et al., 2001). Furthermore, case studies of site-specific N applications based on EC maps that have proven to be effective (Lund et al., 2001).

Fortunately, multiple measurements of soil EC have been shown to correspond when taken at the same time of the year (Sudduth et al., 2001). This implies that soil EC patterns stay relatively constant and that detailed soil EC maps created from systematic measurements can be used in multiple years. It is important to note however that soil moisture and temperature differences across measurements dates can have a significant effect on EC measurements, and this should ideally be taken into account when creating soil EC coverages (Sudduth et al., 2005) EC values mapped across fields sometimes show weak temporal associations due precisely to variation in soil moisture contents, which depends on climatic conditions and irrigation schedule (McCutcheon et al., 2006).

One study evaluates field-scale apparent electrical conductivity mapping for delineating soil properties correlated with productivity and ecological properties (Johnson et al. 2001). After EC mapping 250 ha of contiguous farmland, using a geo-referenced soil-sampling scheme separating each field into four EC classes that were sampled in triplicate (0- to 7.5 and 7.5-30-cm depth), soil physical and chemical parameters were characterized for each of the classes. Physical parameters investigated included bulk density, moisture content and percentage clay and chemical properties studied were organic matter, total C and N, extractable P, laboratory-measured electrical conductivity and pH. Investigated properties showed significant differences among EC classes ($P < 0.06$) at one or both depths. Positive correlation was found between bulk density, percentage clay, EC and pH and negative correlation was found for all other soil parameters. Potential uses of this study include assessing temporal impacts of soil condition management and site-specific soil nutrient management (Johnson et al., 2001).

Similarly, Sudduth (2005) related EC data to measured soil properties across a wide range of soil types, management practices and climatic conditions (Sudduth, Kitchen et al. 2005). They found that correlations of EC with clay content and cation exchange capacity (CEC) were generally highest and persistent across all fields. Other soil properties (soil moisture, silt, sand, organic C) were strongly related to EC in some study fields but not in others.

A study carried out in Turkey used GIS and remote sensing to estimate the effect of salinity on crop yield (Cullu 2003). GIS media was used to combine and analyze an EC map created from soil sampling, land use maps, a soil map and results showed that increasing EC values up to 14.4 dS/m caused decreases in cotton and wheat of respectively. In general, increases in salinity above the threshold for cotton and wheat resulted in a linear decrease in crop yield (Cullu 2003).

Monitoring plant water availability is an important step in optimizing irrigation systems to maximize yield and this is directly affected by the salinity level of the soil (Neumann 1997). As soil moisture content, not only soluble salts, has an effect on the measured soil conductivity, it is necessary to take soil conductivity measurements under uniform soil moisture conditions (ideally at field capacity) in order to isolate the effects of soil salinity on soil conductivity measurements (Sudduth et al., 2001). As it is not always possible to take conductivity measurements under uniform moisture condition, soil moisture or volumetric soil water content (VWC) can also be monitored in conjunction with soil conductivity using a variety of commercially available instruments as well as basic gravimetric techniques. As a method for assessing field VWC, Time domain reflectometry (TDR) is widely recognized as the best electronic method available (Chandler et al., 2004).

Based on the above, it was decided to use the Geonics EM-38 sensor to conduct soil conductivity surveys for the purposes of this project. Soil moisture measurements were also taken using the FieldScout TDR 300 soil moisture meter.

2.3.2 Plant chlorophyll estimation

Plants are subject to a wide variety of biotic and abiotic limits to growth such as disease, adverse climatic conditions and most commonly a deficit of water or nutrients (Jackson 1986). Plant 'stress' can be defined as any such limit that adversely influences growth, and whose limitation results in higher plant yield (Jackson, 1986). A goal for good agricultural production then becomes the early detection of plant stress in order to minimize the adverse effects of stress on plant growth. This must be balanced by the fact that over application of nitrogen fertilizer for crop production has important environmental consequences, most significantly on water quality, and hence the use of N fertilizer should also be mitigated (Ahmad et al., 1999).

Nitrogen (N) is an essential nutrient for plant growth and is most frequently the limiting nutrient in agricultural soils. Consequently, nitrogen is the most commonly applied nutrient in agricultural systems and its economic and environmental management is of paramount importance to farmers and regulators. A uniform application of Nitrogen (N) to varying soils results in a wide range of N availability to the crop. Nitrogen applied in excess of the crop usage results in waste of the grower's input expense and a potential negative effect on the environment. Conversely, inadequate N levels represent a lost opportunity for crop yield and profit (Lund et al., 2001).

Traditional methods of assessing spatial variability of N over large fields, such as tissue analysis and soil testing are both labor and cost intensive and require many point samples. The need to develop sensors which identify areas of a field requiring specific inputs in specific quantities has led to the development of the handheld chlorophyll meter, introduced by the Minolta Corporation, known as the SPAD 502. The fact that handheld chlorophyll absorbance meters are quick, non-destructive and can be used in the field have made them a popular tool in crop nitrogen assessment (Richardson et al., 2002).

One major limitation of the chlorophyll meter in determining crop nitrogen status is that the readings are affected by many factors including varietal differences, growth stages, nutrient deficiencies other than N, environmental conditions and measurement positions on leaves (Wu et al., 2007). Furthermore, chlorophyll meter readings are generally taken at a limited number of locations in the field and therefore these results often provide little information concerning the nitrogen status across the entire field (Han et al., 2002). As such, chlorophyll meters, by themselves, are not considered practical tools to characterize crop nitrogen status on a whole–field basis (Han et al., 2002). Regardless, in light of the fact that taking chlorophyll meter readings presents a significant time, cost and labor advantage over foliar analysis on a field scale, it was decided for the purposes of this study to assess the SPAD 502 meter as field mapping tool for N.

2.3.2.1 Remote sensing in plant chlorophyll estimation

The power of remote sensing as an important tool for the improvement of world agricultural production has been recognized for over almost three decades (Buffalano and Kochanowski 1979). Remote sensing provides a primary source of input data for GIS and many PA applications. Remote sensing applications explored in the literature include pre-growth soil fertility and moisture analyses, crop growth monitoring and yield forecasting (Brisco et al., 1998).

Fortunately, due to the close correlation between leaf chlorophyll and leaf N concentration, remote sensing provides a 'one-shot' opportunity to evaluate N variability over large fields (Daughtry et al., 2000). Numerous studies have investigated the correlation between spectral response and leaf chlorophyll concentration and have concluded that spectral responses in the visible and NIR wavelengths, and vegetation indices calculated from the spectral values, are a measure of the amount of photosynthetically active tissue in plant canopies (Wiegand et al., 1996). Blackburn (1999) found that reflectance of narrow wavebands with the visible region was moderately related to chlorophyll concentrations, while ratio indices, employing wavebands in the near infrared and visible region were more successful. Also, one of the first studies on the spectral response of sugarcane to nutrient and water deficiencies found that infrared/red ratios measured over plots with adequate nitrogen, potassium and water were significantly higher then those with nutrient deficiencies (Jackson et al., 1981). Another important finding of this study was that although irradiance values varied considerably depending on cloud cover, the changes in infrared/red ratio were minimal, indicating that the ratio could be adequately measured for sugarcane irrespective of cloud cover variance (Jackson, 1986).

Multispectral reflectance data can be used to compute a variety of indices that are well correlated to plant biophysical parameters related to photosynthetic activity and plant productivity (Jackson 1986; Pinter and Moran 1994; Wiegand, Anderson et al. 1996; Blackburn 1999). One of the most commonly used spectral indices for the analysis of crop parameters using remote sensing is the Normalized Difference Vegetation Index (NDVI), developed almost 30 years ago by a NASA scientist (Tucker 1979). Tucker (1979) found in his seminal paper that the IR-red difference divided by the sum was or the *normalized* vegetation index, was sensitive to the amount of photosynthetically active vegetation. Since its conception, NDVI has become a well established method of assessing plant health and is calculated as follows:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

The NDVI, which varies between -1 and +1, quantifies the relative difference between the near infrared reflectance 'peak' and the red reflectance 'trough' in the spectral signature; the NDVI value for highly vegetated targets will be close to unity and non-vegetated targets will be close to zero, with negative values rarely occurring for natural targets (Lamb 2000). Calculating the NDVI and reducing the multiple waveband data at each image pixel to a single numerical value (index) is a way to produce images that give an excellent visual indication of plant stress by highlighting changes in vegetation health, or more specifically plant nitrogen status (Lamb, 2000).

It is important to note that the straightforward use of NDVI for detection of various crop canopies has some important limitations due to its sensitivity to soil background and atmospheric effects; background reflectance as well as Leaf Area Index (LAI) have been found to confound the detection of relatively subtle differences in canopy reflectance caused by changes in leaf chlorophyll concentration (Daughtry, Walthall et al. 2000). Several indices, such as the Soil Adjusted Vegetation Index (SAVI) (Huete, 1988) and the Modified Soil Adjusted Vegetation Index (MSAVI) (Wu et al., 2007) have been developed to account for the impact of soil brightness, however these effects are less relevant for crops with dense canopies such as sugarcane (Noble and

Crowe, 2001). The current project makes use of a high resolution Quickbird satellite image to create NDVI coverages of the fields under study. These images are used for both visual interpretation of plant health, and their relationship with coverages derived from SPAD chlorophyll meter sampling is also briefly examined.

2.4 Spatial Analysis

Spatial variability of soil physical and chemical properties is a result of various superimposed processes acting at different spatial scales and over time periods, including soil and crop management practices as well as naturally occurring structure and texture of soil (Castrignano et al., 2000). In order to characterize and predict this variability spatial prediction or interpolation is used. Spatial prediction is a wide-ranging subject and has many obvious applications in GIS and remote sensing: GIS programs integrate methods of spatial interpolation, in order to allow the creation of coverages, once point data has been collected in the field.

Statistical tools such autocorrelation function; semivariograms and state-space have all been used to evaluate the structure of spatial distributions of soil properties; unlike 'classical statistics' that presuppose the independence among observations and disregard their location intra-field, they take advantage of the spatial dependence of observations and make use of the location of each observation to predict the values of un-sampled locations (Dourado-Neto et al., 1999). The Geostatistical analyst extension of ArcGIS provides various deterministic and stochastic Geostatistical methods for the creation of continuous surfaces from discrete data. Two of the most well-established and commonly used spatial interpolation methods, Inverse Distance Weighting and Kriging, are described below (Johnston et al., 2001).

Inverse Distance Weighting (IDW) is a deterministic interpolation method. Deterministic methods are used to create a surface from measured points based on the extent of similarity and forces the resulting surface to pass through the data values, a method which is know as exact interpolation (Johnston et al., 2001). IDW implements the basic assumption of Geostatistics that points located close to one another are more similar than points located farther apart; in order to predict the value of a point at an unmeasured location, IDW uses the measured values of the points around the prediction location

(Johnston et al., 2001). As the name implies, IDW assumes that that the influence of measured points diminishes with distance and hence gives closer points greater weight in the final prediction than points located farther away. A drawback of IDW however is that there is no way to characterize the error in the model and no a priori method of estimating the optimal exponent or the number of the closest neighbor (Kravchenko and Bullock 1999).

Kriging is a commonly applied statistical method employed by soil scientists used to estimate values of soil properties at unsampled sites (Castrignano et al., 2000). It is a method of interpolation based on regionalized variable theory and depends on expressing spatial variation of the property in terms of the variogram, while minimizing prediction errors that are themselves estimated (Oliver and Webster 1990). Similar to IDW, it relies on a weighting scheme where sample locations closer to the sample have a greater impact then those farther out, and has found extensive applications in soil science (Gotway et al., 1996; Bishop and McBratney 2001).

Robinson and Metternicht (2006) compared the accuracy of Ordinary Kriging, IDW and splines for interpolating soil properties including pH, electrical conductivity and organic matter; they found that overall all of the methods gave similar root mean square error (RMSE) values. Geostatistical tools were also used by Douaik (2005) to identify the spatio-temporal variability of soil salinity using both field and laboratory measurements and found that Kriging produced reliable estimates of soil salinity at unobserved spatial locations (Douaik et al., 2005). The current study compares IDW and Ordinary Kriging as methods to create interpolated surfaces from discrete field data.

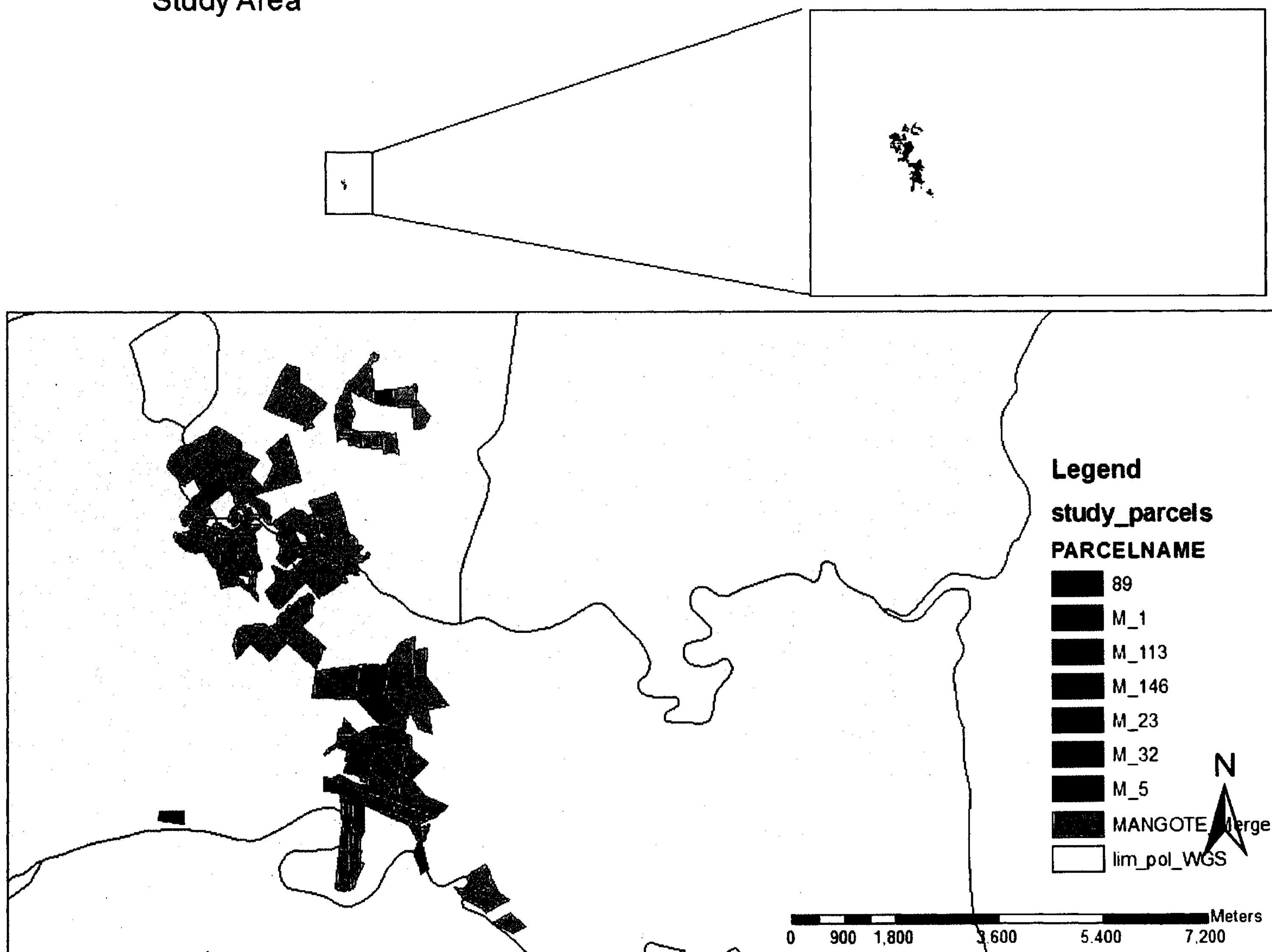
CHAPTER 3 METHODOLOGY

3.1 Study area

The study area is located in the heavily-deforested Azuero peninsula region of Panama where most land is dedicated to cropping and cattle ranching. The area spans the provinces of Cocle and Herrera in an area of the peninsula known as the "arco seco" (dry arc). The land holdings of Azucarera Nacional span over 15,000 hectares of primarily agricultural land, devoted to sugarcane cultivation with a small area covered with primary and secondary forest. The agricultural area, located closest to the township of El Roble, in the district of Aguadulce, is divided into five plantations: Santa Rosa, Mangote, San Jose, Los Canelos and Panela.

For the purposes of this study, digital map creation and the detailed field sampling and links to production information used to create a database, were limited to the Mangote plantation centered at approximately 80°35′W, 8°10′N. This plantation was chosen because of the wide range of soil chemical and physical conditions. Also, some parcels show persistent soil salinity problems, due to proximity to the Pacific Ocean. Parcel boundary mapping and database creation for the purpose of establishing a GIS platform focused on the entire Mangote plantation. Detailed sampling of soil and plant properties however, was focused on seven of the over 150 individual parcels that make up the Mangote plantation. The study area is shown in Figure 3.1.

Study Area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M_113
M_146
M_23
M_32
M_5
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0 900 1,800 3,600 5,400 7,200

3.2 Field Methods

3.2.1 Sampling methodology

On the Mangote plantation of Azucarera Nacional,, seven study sites (parcels of land) were chosen for detailed sampling, where data was obtained over the course of two years. The seven study parcels were chosen according to a variety of factors, including availability of aerial photos of the parcel, occurrence of mechanical harvesting on each parcel to account for the possibility of future yield monitoring, and representative soil classes (see Table 3.1). The parcels varied in size from 7 to 25 hectares. In most cases, due to the size of the parcels, field data collection for a single parcel would take several days. Field data was collected at 5 different times during 2005 and 2006, spanning both the wet and dry seasons as well as several stages of cane maturation, from the early growth to pre-harvest.

Table 3.1 Soil classes of study parcels

	Soil Class
Parcel 1	highly fertile
Parcel 5	highly fertile
Parcel 23	persistent salinity problems
Parcel 32	persistent salinity problems
Parcel 89	highly fertile
Parcel 113	persistent salinity problems
Parcel 146	average

The first two field collection runs (hereafter referred to as EM38 I and EM38 II) were used to collect 'data bundles' consisting of; soil samples and soil conductivity readings with the Geonics Limited EM-38 soil conductivity meter. The remaining three data bundle collection runs (hereafter referred to as Field Data Run (FDR) 1, 2 and 3 respectively) were used to collect soil conductivity readings with the EM38, plant chlorophyll readings with a hand-held Minolta SPAD 502 chlorophyll meter and soil moisture readings using a Spectrum Technologies Field Scout TDR 300. All field data was spatially referenced using a hand-held Trimble GPS unit. The name and area of each study parcel, as well as the start dates of each data bundle are listed below in Table 3.

1. The first two field collection runs were limited to soil sampling and soil conductivity readings because only the soil conductivity meter was available at that time. The remaining three data bundle collection runs were carried out upon acquisition of the remaining sampling equipment.

Table 3.2: Field data collection locations, dates and type of data bundle collected.

	Area (Ha)	Soil Samples	EM38 I	EM38 II	FDR1	FDR2	FDR3
Parcel 1	11.52	05-Jul-05	05-Jul-05	19-Jul-05	14-Oct-05	13-Feb-06	24-May-06
Parcel 5	7.95	17-Jun-05	17-Jun-05	13-Jul-05	04-Oct-05	19-Jan-06	11-May-06
Parcel 23	20.66	13-Jun-05	13-Jun-05	08-Jul-05	06-Dec-05	25-Jan-06	02-May-06
Parcel 32	25.32	28-Jul-05	28-Jul-05	12-Aug-05	24-Oct-05	04-Mar-06	31-May-06
Parcel 89	8.1	23-Jun-05	23-Jun-05	17-Jul-05	25-Nov-05	08-Feb-06	15-May-06
Parcel 113	7.2	27-Jun-05	27-Jun-05	15-Jul-05	14-Nov-05	01-Dec-05	NA
Parcel146	11.2	20-Jul-05	20-Jul-05	17-Aug-05	21-Nov-05	06-Mar-06	16-May-06

It is common in Panama for a parcel to be divided into *decimos*, which is approximately equal a tenth of a hectare, or ~1000 m^2. The exact dimensions of a decimo are dictated by the overall shape of the parcel and the dimensions of the spacing between 'surcos' (irrigation furrows) that run between the rows of cane, and hence *decimo* dimensions may slightly vary, but in general are ~ 30m x 30m. The decimo divisions were the most convenient markers to use for navigation within the fields and hence were used to guide the sampling density.

A soil sample was taken once, roughly in the centre of each decimo. Spad, TDR, EM38 instrument readings were taken all together at three locations per decimo: at the first or second row (~2.5 m from the edge of the decimo), in the middle of the *decimo* and at the edge of the next *decimo*, or approximately, on average, every 10 m. The position along the row was approximated near the centre of the decimo, so that samples were taken on a ore or less evenly spaced grid. At each sampling location a reading was taken with a handheld GPS device, and the coordinates recorded were given at least 10 minutes to stabilize. Readings from each instrument were recorded by hand in a field notebook and subsequently entered into a spreadsheet. Figure 3.3 shown below gives a schematic of the sampling locations within the boundaries of a decimo.

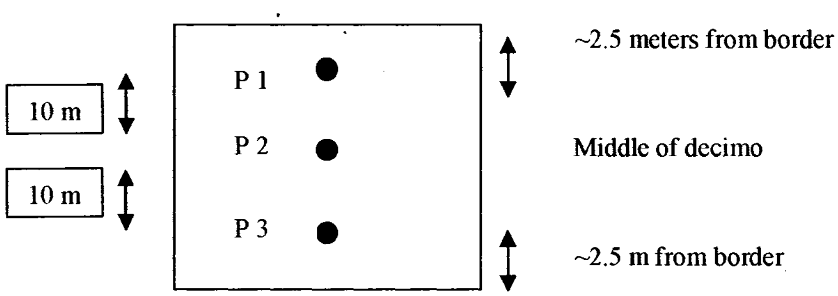


Figure 3.2: Sampling locations within decimo boundary.

The following sections provide more detail in regards to the theory and sampling procedures related to the specific plant and soil properties sampled.(Konica_Minolta 2003)

3.2.2 Soil conductivity determination

Soil conductivity measurements were taken using the Geonics Limited EM-38 soil conductivity meter. The instrument works by inducing circular eddy-current loops in the soil, whereby the magnitude of the loops is directly proportional to the EC of the soil in the vicinity of that loop. The current loops generate secondary electromagnetic fields that are proportional to the value of the current flowing within the loops. The secondary induced electromagnetic field from each loop is then intercepted by the receiver coil of the instrument, forming the output voltage which is proportional to the apparent electrical conductivity (Corwin and Lesch 2003). This is a result of the fact that the properties of the secondary field differ from the primary field because of soil properties such as clay content, water content and salinity (Corwin and Lesch 2003). In order to obtain conductivity measurements, the instrument was calibrated at the beginning of every field measurement run in the morning at the same location following the manufacturer's procedure and a reading was taken at that location at the end of each field run in order to check for instrument drift. Measurements were taken in both the horizontal and vertical dipole modes which provide an indication of the ground conductivity to a depth of 0.75m and 1.5m respectively, as indicated by the manufacturer's manual. Readings were recorded at the highest point at the sample site (at the top of the furrow rather than between planted rows) in order to avoid 3D electrical field profile of surrounding soil and great care was taken to avoid electrical interference from any nearby metal objects (Sharma and Gupta 2000).

3.2.3 Plant chlorophyll determination

Leaf health measurements were obtained using a SPAD 502 chlorophyll meter, an instrument that measures leaf chlorophyll content, which is correlated to the amount of nitrogen content of the plant (Konica_Minolta, 2003). The values measured by the meter correspond to the amount of chlorophyll present in the plant leaf which is calculated based on the amount of light transmitted by the leaf in two wavelength bands between which the absorbance of chlorophyll is different. The SPAD meter uses the red area, where absorbance is high and unaffected by carotene, and the infrared area, where absorbance is extremely low, as the basis of its measurements (Konica_Minolta, 2003). The SPAD 502 has a $0.06cm^2$ measurement area and calculates an index in 'SPAD units' based on absorbance at 650 and 940nm, with a claimed accuracy of +/- 1.0 SPAD unit (Richardson et al., 2002). In the immediate area of the soil sample site, three leaves at breast height were chosen for sampling. Three recordings, spaced 10 cm apart where taken on each leaf (see Fig 3.3). The arithmetic mean of the nine recordings was then used for all subsequent analyses (Peterson et al., 1993).

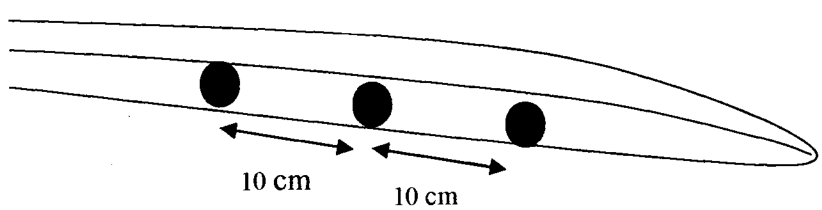


Figure 3.3: Sampling locations on a leaf

3.2.4 Soil moisture determination

Soil moisture readings were taken using a Field Scout ™ TDR 300 soil moisture meter obtained from Spectrum Technologies Inc. The instrument takes volumetric soil moisture readings based on time domain reflectometry. The volumetric water content of the soil is the ratio of the volume of water in a given volume of soil to the total volume of soil. The saturation value therefore depends on the total pore space of the soil, which is equal to the percent volumetric water content when soil saturation is reached. Because the dielectric permittivity (ε) of soil minerals is considerably lower than that of water (typically 3-5ε as opposed to 80ε) the bulk permittivity of the soil is governed mostly by the soil moisture content. The Field Scout uses this property to determine the in situ volumetric soil moisture content (Spectrum_Technologies, 2000). It is accepted that the relationship between apparent dielectric permittivity and volumetric water content is independent of soil type, density, temperature and soluble salts content (Nadler et al., 1999). Although it is recognized that salinity affects TDR functionality in measuring volumetric soil moisture by increasing the attenuation of the TDR signal and hence reducing its accuracy, reports in the literature are conflicting as to whether this leads to over or under estimation of the measured parameter and at field capacity, salinity is shown to have no detectable effect on the readings (Nadler et al., 1999).

The instrument consists of a shaft mounted probe with two attached rods that act as wave-guides. A wave is sent down the rods and after traveling their length, is partially reflected at the interface between the tips of the rods and the soil. The received signal is transformed into a square wave output with a frequency proportional to the volumetric water content. The volume range that is being measured by the instrument is an elliptical cylinder extending, radially, 3 cm from the rods with a length equal to the length of the rods (Spectrum_Technologies, 2000). The instrument, equipped with 20cm rods was fully inserted into the soil at three locations spaced approximately 20 cm apart at the soil sampling site and volumetric soil moisture readings were recorded and the arithmetic mean of these three readings was used for all subsequent analysis.

Soil moisture measurements were also obtained by traditional gravimetric methods when it was not possible to obtain TDR soil moisture probe readings. This was necessary for FDR 2 and 3 due to the fact that the TDR instrument was damaged. All soil gravimetric analysis was carried out in the Azucarera Nacional soil and plant analysis laboratory using standard methods (Gardner, 1986).

3.2.5 Soil sampling

Soil samples were collected using a spiral auger inserted to a depth of 60 cm. Soil removed from the auger was placed in a plastic bag containing a tag identifying the parcel number, decimo number and geographic coordinate taken with the GPS device. Each sample was mixed for uniformity and sealed in a plastic bag. Soil sampling resolution for chemical analysis was lower than the sampling resolution used for other crop and soil properties due to the labour and cost involved in soil sample collection and analysis. All soil chemical analyses were carried out at the Instituto de Investigacion Agropecuaria de Panama (IDIAP) laboratory. Samples were analyzed using standard methods, for soil organic content, moisture, electrical conductivity of saturated paste extract, bulk density as well as mineral composition. All soil texture analysis was carried out using the standard Boyoucous hydrometer method (Sheldrick and Wang, 1993).

3.3 Spatial analysis and statistical methods

3.3.1 Digital map creation

As the first step for creating a crop information database and for the purposes of carrying out subsequent GIS analysis, a digital map was created of the Mangote plantation. As the only available hardcopy maps of the land holdings were those created by traditional cartographic methods in 1977 and considerable changes in parcel boundaries had occurred since that time, aerial imagery, obtained from aerial surveys conducted in 2002, was acquired and used in order to more accurately demarcate parcel borders on each farm. Digital orthophotographs (planimetrically corrected aerial photographs) were chosen based on the fact that analytical photogrammetry is used on such photos to remove relief and camera angle tilt displacement, thus ensuring maximum accuracy of boundary lines. Fourty-two such aerial orthophotographs were acquired from Tommy Guardia cartographic institute, located in Panama city, Panama.

The orthorectified aerial images were imported into ESRI's ArcGIS 9.0 as images (*.tiff) and referenced under the NAD 27 projection system and then re-projected into WGS 1984 using the geographic transformation utility of ArcGIS 9.0 found in ArcToolbox. Using these high-resolution photographs, and the historical hard-copy maps to identify features and parcel numbers, parcel boundaries were traced using a mouse and each stored as a vector file. These final 'shapefiles' were than merged using the "Data Management" tool "Join" operation of ArcToolbox.

Each parcel of land, representing the operational production units of the plantation, was assigned a unique identifier in the attribute data table associated with the shapefile encompassing all the parcels of Mangote plantation. The identifiers were used to link the parcel map with the plantation's production information, contained in the Oracle database used to store and manage Azucarera Nacional's production information. This database management innovation was implemented at the company in 2004. Creating the link between the shapefile containing the parcel boundaries and the production information was undertaken in two ways:

1) Using ArcCatalogue a spatial database connection was created with the geographic data stored in the relational database system of the plantation's Oracle database. The link created a real-time spatially referenced information system where the digital maps created in ArcINFO had access to the plantations's historical production records. This was created for the purposes of future onsite GIS analysis

2) The Oracle database information was also extracted as .dbf files and was than linked directly to the digital map of Mangote. These files were used for the analysis purposes of the current dissertation project.

3.3.2 Spatial analysis

Ground-based data is typically composed of discrete points that generally require spatial data analysis to be interpolated to a continuous grid. These continuous data layers are often revealing of the spatial patterns of heterogeneity in soil and plant health conditions, and hence can be very useful to farmers as management tools (ESRI 2007), Creating such continuous data layers (hereafter referred to as "coverages") of important soil and plant properties, for use in input management, is the major goal at this stage of PA implementation. Using the Geostatistical Analyst and Spatial Analyst extensions of ArcINFO 9.2, it was possible to create these coverages from the discrete field data collected.

3.3.2.1 Creating XY shapefiles

Creating XY shapefiles, based on the field data gathered, is the first stage in creating continuous raster coverages in ArcGIS. Once the raw field data was transcribed into spreadsheets and saved as database files (.dbf) (which is the format accessible to ArcCatalogue) the data was thoroughly reviewed visually and via sort functions for obvious value outliers and outliers due to transcription errors. This was an extremely labor intensive process considering the size and number of datasets to be reviewed (hundreds of individual data points for the 40 datasets listed in Table 3.1). Once the datasets were reviewed, they were mapped in ArcCatalogue and XY shapefiles were created using the 'Create Feature Class from XY Table' command in ArcCatalogue.

Shapefiles were displayed in ArcMap and projected to the WGS 1984 coordinate system. These shapefiles were then reexamined for both spatial and value outliers, as once this step was completed it became possible to view the spatial distribution of the data. In order to process spatial outliers, coordinates were examined for expected position in the sequence of points (based on the fact that decimos within parcels were sampled sequentially) and when the transcription error was not obvious, simple interpolation was used to place point samples in the expected position. Decisions regarding global value outliers were based on judgment and field experience. This stage of data processing is very important when creating coverages from point data because outliers can have dramatic effects on the final output surface.

3.3.2.2 Creating Geostatistical analyst layers

There are several interpolation methods available in ArcGIS to create continuous raster coverages from discrete data. Among the various methods available, IDW and two methods of applying Ordinary Kriging were chosen and compared based on their ease of use and relative accuracy. The interpolation methods examined are described below.

A) Inverse distance weighting (IDW)

The Geostatistical Analyst extension of ESRI's ArcInfo 9.1 was used to create all interpolated surfaces. Using IDW, it is possible to specify the level of significance that surrounding known points have on the interpolated values. A higher power places more emphasis on the nearest points leading to a more detailed surface (less smooth) whereas decreasing the power gives more influence to points farther away (ESRI 2006). Therefore, in order to create a coverage using this method, one must specify the power used to calculate interpolated values.

Test surfaces were created using both the first power, which has shown promise in soil surface interpolation applications (Robinson and Metternicht 2006), the second power which is the most commonly used power and provided as the default value setting, as well as the "Optimize Power" option provided by Geostatistical Analyst, which finds the power that results in the lowest RMSE. The associated RMSE values for surfaces created were then examined and in light of the fact that resulting differences in RMSE were very small and all surfaces created were visually very similar, a power of '2' was chosen to create all subsequent surfaces. This option was chosen over the auto RMSE minimizing approach so that the method was consistent among surfaces created with IDW, in order to achieve a better comparison with other methods. The IDW method also requires that the user input the number of neighbors considered in the interpolation. Similar trial and error examination led to the use of the default value setting of '15', which means that up to 15 of the nearest data points are considered when calculating the interpolated value (the number of points may be less than 15 depending on the geometry of the situation and the search radius).

B) Ordinary Kriging

Unlike IDW which is a deterministic interpolation method based directly on the surrounding measured values, Ordinary Kriging (OK) is a geostatistical interpolation method, which is based on a statistical model that includes autocorrelation, or the statistical relationship between the measured points. Kriging is most appropriate when it is known that there is a spatially correlated distance or directional bias in the data, and therefore it is commonly used in soil science (ESRI 2006). Although this provides the user creating the surface with more information regarding the measure of uncertainty or accuracy regarding the prediction, which is not possible with deterministic interpolators such as IDW, it also requires estimation of more input parameters. Creating coverages using OK is therefore a much more involved process than IDW and requires thorough exploration of the data.

Unfortunately, there is no a priori method of determining what parameters will produce the best prediction surface and the chosen model and input parameters varies according to the characteristics of each particular data set, and often achieving the best model by adjusting the semivariogram characteristics is a process of trial and error. For the purposes of this project, the principle goal was to keep the creation of the coverages as 'user-friendly' and straightforward as possible in order to make the creation of soil maps as accessible as possible to the largest number of users, regardless of training. In order to accomplish this, two sets of coverages were created using OK interpolation. The first set involved the least amount of input from the user as possible and the second set involved the estimation of parameters based on the particular dataset. The two methods of coverage creation using OK are described below:

1) Coverages were created using all of the default values provided in the Ordinary Kriging module of Geostatistical Analyst. All data distributions were assumed to be normal and no transformations were applied to the initial datasets and no trend removal occurred. The partial sill, nugget, lag size and number of lags were all left unchanged from the default values provided for the dataset by Geostatistical analyst. Coverages using this method are hereby referred to as "OK" coverages.

2) Coverages were also created by considering results of a more detailed exploration of the source data, which involved removing spatial trends and applying systematic transformations to the raw data values. Using the "Explore Data" tool available through the Geostatistical Analyst menu, the following sequence of steps was followed for each coverage:

i) The histogram of the data was examined to check for normality. When the data was skewed, a lognormal transformation was attempted. If the lognormal transformation pushed the data distribution towards normality it was applied and if it had either no effect on the distribution, it was not applied.

ii) Spatial trends in the data were then examined using the "Trend Analysis" tool of Geostatistical Analyst. The trend analysis tool creates a three-dimensional surface of the study area, projecting the sampled points to the height attribute value. This surface is then projected onto planes that are perpendicular to the map plane, and a polynomial is fit to each projection (ESRI 2006). If there was an observable trend (the projection was not a straight line with zero slope), a first order trend was removed from the data (the lowest order of trend removal is recommended). (ArcGIS manual)

iii) When necessary, the lag distance was adjusted so that the lag distance multiplied by the number of lags was equal to less than half the largest distance between points in the set.

This process was carried out to create coverages for the "Horizontal" attribute of the EM38 I and EM38 II datasets. Coverages using this method are hereby referred to as "OKTR" coverages. The parameters used to create the OKTR coverages are given below in Table 3.3.

Table 3.3 Parameters used in creating OKTR coverages

		Parcel and date	Transformation	Trend removal	Lag distance (m)
EM38	Horizontal	1_jul19	NA	first	NA
		1_july5	NA	first	35
		5_july13	log	first	NA
		5_june17	log	first	NA
		23_july8	log	first	37
		23_june13	log	first	NA
		32_july28	NA	first	39
		32_aug12	log	NA	39
		89_july17	log	first	23
		89_june23	log	first	23
		113_jul15	NA	first	18
		113_jun13	NA	first	18
		146_aug17	log	first	NA
		146_july20	NA	first	NA

3.3.3 Satellite image analysis

3.3.1 Satellite image selection and processing

A high resolution satellite image was obtained from the Quickbird satellite. The Quickbird Bundle Standard Orthoready Geotiff DVD format was chosen among available products, with 8K tiling and a 60 cm spatial resolution for the panchromatic image and a 2.44m resolution for the, multispectral image. Standard imagery is radiometrically corrected, sensor corrected and mapped to a cartographic projection (WGS84 UTM).The orthoready format was chosen so that ground control points could be applied for georectification. Ground control points (GCPs) were taken in the field at the corners of each study parcel as well as at easily identifiable points near the edge of the image capture region.

The "Georeferencing" module of IDRISI Andes software was used to georeference the original image using ground control points; the resulting spectral response of the adjusted image varied considerably in the NDVI values produced from the raw image, due to the "rubber sheeting" process used to georectify the image.

"Rubber sheeting" causes the satellite image pixels to be recalculated, thus no longer providing a true representation of the spectral response. Upon examination of the georectified satellite image in comparison to the raw image, it was decided to accept the original image with basic georectification; this, in order to save accuracy of the spectral response. Regardless, overlaying of the original satellite image with the digital boundaries of parcels created using aerial photography, showed excellent visual agreement. Discrepancies between the spatial accuracy of the original satellite image when overlaid with the digitized parcel boundaries were on the order of less than 1m and hence no additional georectification was deemed acceptable.

3.3.3.2 NDVI

Spectral analysis of the remotely sensed imagery obtained from the Quickbird satellite was carried out in the IDRISI Andes Edition software. In order to create NDVI coverages from the raw multispectral bands provided, the "Raster Calculator" module of IDRISI was used. The software calculates the value for each pixel of a new raster using the algebraic combination of the red (Band 3) and near infrared (Band 4) which corresponds to the formula for NDVI (see Chapter 2) which was input into the raster calculator. In order to create NDVI coverage maps of individual parcels, the following sequence of steps was followed for each study parcel:

1) Import ArcGIS parcel outline vector file into IDRISI.

2) Create an initial raster which takes the dimensions of the vector file to create a blank image (Blank image is a binary raster that has a pixel value of '1' for all pixels located within the borders of the parcel and a pixel value of '0' for all pixels outside the border).

3) Multiply the raster coverage created for the whole scene by the initial raster for the parcel

4) Re-digitize the borders of the individual parcels' coverages, cutting just within the borders of the parcels (one to two pixel widths) to remove any bare soil and edge effects.

3.3.4 Statistical comparisons

In addition to the surfaces created using Geostatistical methods, the relationship between individual soil and plant properties collected in the field were also compared using traditional statistical methods. The correlation between different properties was examined by plotting variables in excel and using simple linear regression to find the best fit line. The degree of correlation was reported as the coefficient of determination (R^2), the square of the commonly used Pearson's product-moment correlation coefficient (R) which gives an estimate of the colinearity between the observed and model simulated values (Legates and McCabe 1999).

In order to undertake comparisons between data collected on the field with spectral data in the form of NDVI values for each pixel, two approaches were undertaken. The first approach exploited the fact that once the discrete data collected on the ground was interpolated to raster form, with a resolution similar to that of the remotely sensed images (where the spectral response is averaged over an area in a pixel) the surfaces could be compared pixel by pixel (Pinter, Hatfield et al. 2003).

In order to do this the first step was to obtain a regression data set for NDVI values. ASCII files were therefore generated containing the NDVI reflectance value for each individual pixel of the raster coverage in IDRSI. Files were exported from IDRISI format into ASCII format and saved in .csv format, after which they were manipulated with a text editor in order to generate a continuous data field. Raster coverages created in ArcGIS of SPAD values for example were similarly converted into ASCII format. These two data sets were then used as the two variables in the simple regression function of 'R' statistical software, available as open access user software. Unfortunately, this approach generated extremely large datasets and led to processing difficulties and hence an alternative approach had to be explored.

Rather than using all interpolated values for regression purposes NDVI values corresponding to the coordinates at which the field data was collected was extracted in ArcGIS using the "Extract by Point" command under the General menu of ArcToolbox. The NDVI values, calculated by interpolating the value of the pixels immediately surrounding the specified point, were appended as a new field to the attribute data table for each individual dataset. Rather than using the interpolated values derived in

Geostatistical Analyst, the data points collected in the field were then compared to these NDVI values.

The EM38 horizontal dipole orientation readings (hereby referred to as EM38 horizontal) were chosen for regression comparison with SPAD and NDVI readings because it was expected that if there was to be a correlation to be found between such parameters it would occur more strongly with shallow conductivity rather than deeper soil profile vertical conductivity readings.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Annotated digital land holdings maps

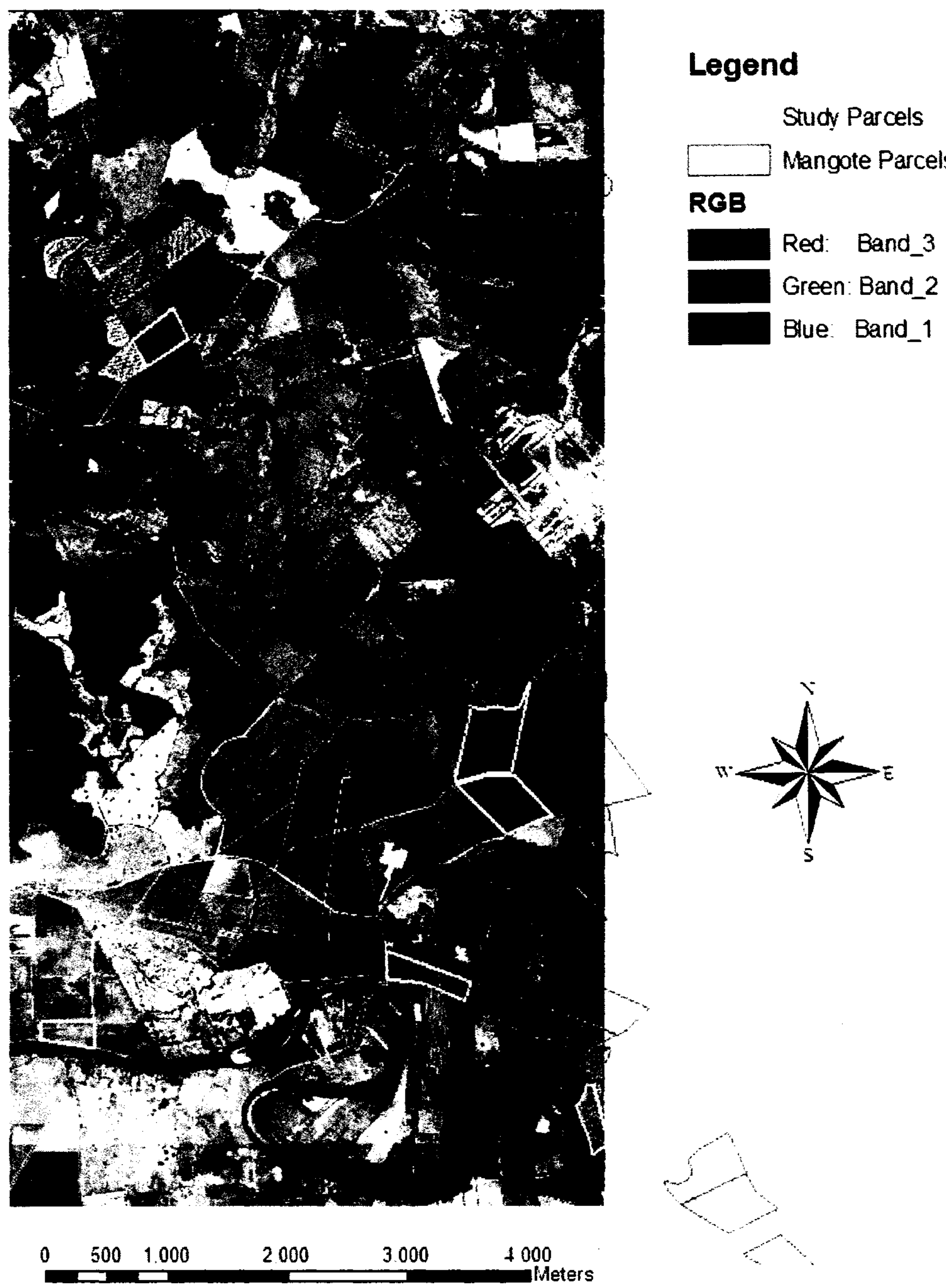
Setting up the Geographic Information System, with an annotated digital land holdings map as its basis, and training users to add information to the system and undertake spatial analysis are the first steps towards sustainable input management implementation (Gonsalves, T. Becker et al. 2005). Up-to-date knowledge of exact parcel boundaries and the ability to view important crop characteristics on a parcel by parcel basis is the first necessary step towards the directed management of inputs at Azucarera Nacional. In light of the fact that the company's land holding span such a large area and are also comprised of units belonging to smaller private landowners known as Colonos, having a visual, interactive platform containing all information relevant to the condition of each parcel would be most helpful for centralized resource management.

The digital map created of Mangote plantation is comprised of various data layers. As part of the project, ArcGIS was installed on one central computer in the main office where the team devoted to cartography and field investigations was put in charge of managing the GIS. Operators were given basic training in GIS principles and shown how to add data, in order to create maps and undertake analysis. Furthermore an important component of the project was to train staff at the company in data collection methods, in addition to basic software skills. This ensures that proper and complete field data collection is continued and further crop and soil information is added to the system.

Figure 4.1 shows a map file (.mxd) created of Mangote plantation with a true color composite of the Quickbird satellite image as its first layer, overlain by the parcel boundaries digitized from the aerial photographs. The satellite image provides striking detail of the terrain and important geographic features of the plantation are clearly visible; the river running through the southernmost portion of the image is the water body from which irrigation water is pumped in the dry season, and the area-under-cane is clearly distinguishable from those areas devoted to other land uses, such as shrimp farming (the white blocks of land visible at the center-east edge of the image).

Figure 4.1: True color composite with parcel polygons

Derived from QuickBird Satellite Imagery Bands: 1,2,3



The attribute data table for the Mangote maps is shown as a screen capture of the ArcGIS software in Figure 4.2. Data concerning the type of soil, the variety of planted cane, the date the cane was planted , as well as numbers related to the expected and actual harvest are all provided in the table. Similar attribute tables have also been linked to the map for the 2004 and 2005 harvest seasons; 2004 being the first year that the Oracle database was put in place and the plantation shifted from paper to electronic record keeping. The hope is to continue to input historical records into the system, as the accumulation of data provides the opportunity for increasingly sophisticated and informative analysis. Additional data layers which will be including in the system in the coming year include digital elevations models (DEMs) of each parcel, as well as an infestation record for each parcel, which is in the process of being included in the Oracle database.

Figure 4.2: Attribute Table, Mangote Harvest 2006

ParcelName	ParcelCode	OID	FarmCode	Code	Year	Variety	Seed	Soil Type	Area	Row Length	Planting date	Rows
M_10	10	9	7	10	2006	1	3	A1	11	53	08/03/200	0
M_102	102	73	7	102	2006	33	3	B3	13	53	05/04/200	1615
M_103	103	74	7	103	2006	9	3	B2	5	57	30/07/200	609
M_104	104	75	7	104	2006	33	3	B2	9	57	28/04/200	1025
M_105	105	76	7	105	2006	45	3	B2	8	57	06/08/200	931
M_108	108	77	7	108	2006	1	3	B3	8	29	01/06/200	1950
M_11	11	10	7	11	2006	9	2	A3	13	57	31/01/200	0
M_110	110	78	7	110	2006	33	3	B3	13	29	05/06/200	3024
M_113	113	108	7	113	2006	30	3	B3	5	29	29/03/199	1112
M_115	115	80	7	115	2006	1	3	B3	9	57	08/04/200	1084
M_116	116	81	7	116	2006	1	3	B2	18	29	27/08/200	4110
M_116	116	81	7	116	2006	1	3	B2	18	29	27/08/200	4110
M_118	118	82	7	118	2006	22	3	B3	10	29	12/07/200	2379
M_119	119	83	7	119	2006	33	5	B4	12	57	19/08/200	1392
M_120	120	84	7	120	2006	44	3	B4	13	29	23/05/200	3062
M_121	121	85	7	121	2006	33	3	B3	16	29	07/05/200	3745
M_127	127	109	7	127	2006	22	3	B2	6	29	13/06/200	1514
M_128	128	86	7	128	2006	1	3	B1	4	53	25/04/200	553
M_128	128	86	7	128	2006	1	3	B1	4	53	25/04/200	563
M_128	128	86	7	128	2006	1	3	B1	4	53	25/04/200	553
M_129	129	87	7	129	2006	1	3	B1	9	53	15/04/200	1100
M_130	130	88	7	130	2006	30	3	B1	5	29	23/08/199	1063
M_131	131	89	7	131	2006	50	3	B1	5	29	30/03/200	1075
M_132	132	90	7	132	2006	9	3	A1	10	29	20/03/199	2410
M_133	133	91	7	133	2006	9	3	A1	14	29	13/04/199	3379
M_135	135	111	7	135	2006	1	3	A1	5	29	05/04/199	1169
M_136	136	92	7	136	2006	44	3	A1	12	29	25/03/199	2818
M_14	14	13	7	14	2006	9	2	A1	22	57	09/02/200	0
M_141	141	94	7	141	2006	9	3	A2	12	29	07/02/199	2891
M_143	143	96	7	143	2006	9	3	A2	7	29	02/03/199	1607
M_144	144	97	7	144	2006	9	3	A2	3	29	09/02/199	788
M_146	146	99	7	146	2006	9	2	A2	10	57	16/03/200	0
M_147	147	100	7	147	2006	9	3	A2	10	29	09/03/199	2431
M_148	148	101	7	148	2006	9	3	A2	11	29	16/03/199	2611
M_149	149	102	7	149	2006	9	3	A2	9	29	12/03/199	2215
M_15	15	14	7	15	2006	9	3	A1	32	57	03/04/200	0
M_150	150	103	7	150	2006	45	3	A2	7	29	13/03/200	1676
M_151	151	104	7	151	2006	9	3	A2	9	29	06/08/200	2163
M_152	152	105	7	152	2006	56	3	A2	11	29	04/03/200	2577
M_153	153	106	7	153	2006	33	3	A2	15	29	07/03/200	3500

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4.2 Thematic maps

Using the information contained in the attribute data tables, which are linked to the digital map of Mangote plantation it is possible to create a variety of thematic maps, highlighting selected attributes of particular parcels. An example of a thematic map that can be created for management purposes is shown in Figure 4.3 which displays the ratoon number (number of years cane has been perennially harvested from original planting) of each parcel on Mangote farm. This is important for farm management because sugarcane yield tends to decrease with an increasing number of ratoons, and depending on the variety of cane, there is a point at which further harvesting becomes unprofitable and the parcel must be re-seeded (Verma 2002). Although it is possible to identify which parcels have been planted the longest directly from hardcopy lists and individual knowledge of parcel performance from farm managers, a visual display of parcels that require reseeding among the hundreds of planted parcels, greatly facilitatesthe management process. More importantly, the ability to query production values in conjunction with ratoon number allows farm managers to assess whether it is in fact necessary to reseed a particular parcel when expected, or conversely if a parcel is in need or reseeding before the expected timeframe due to prematurely declining productivity.

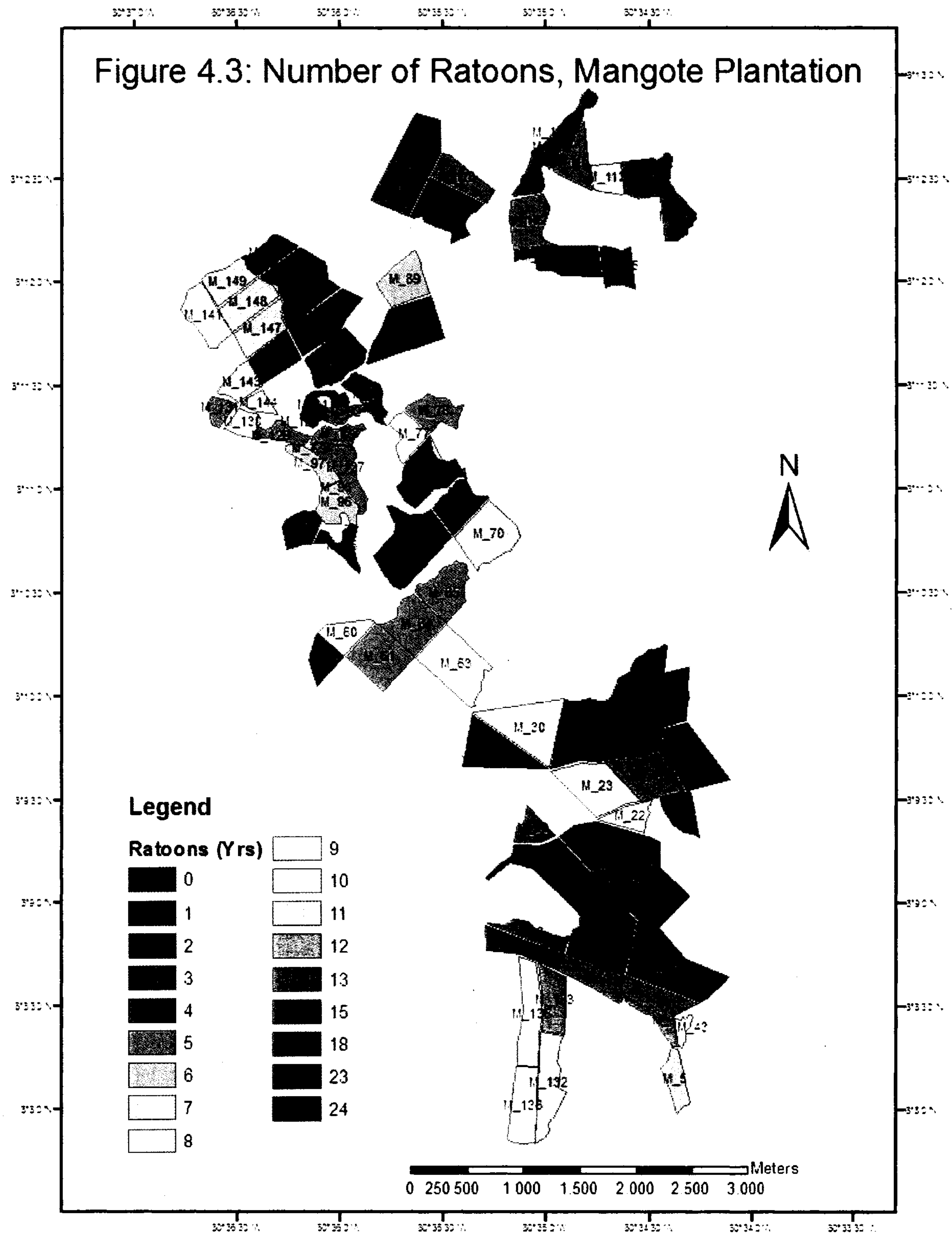
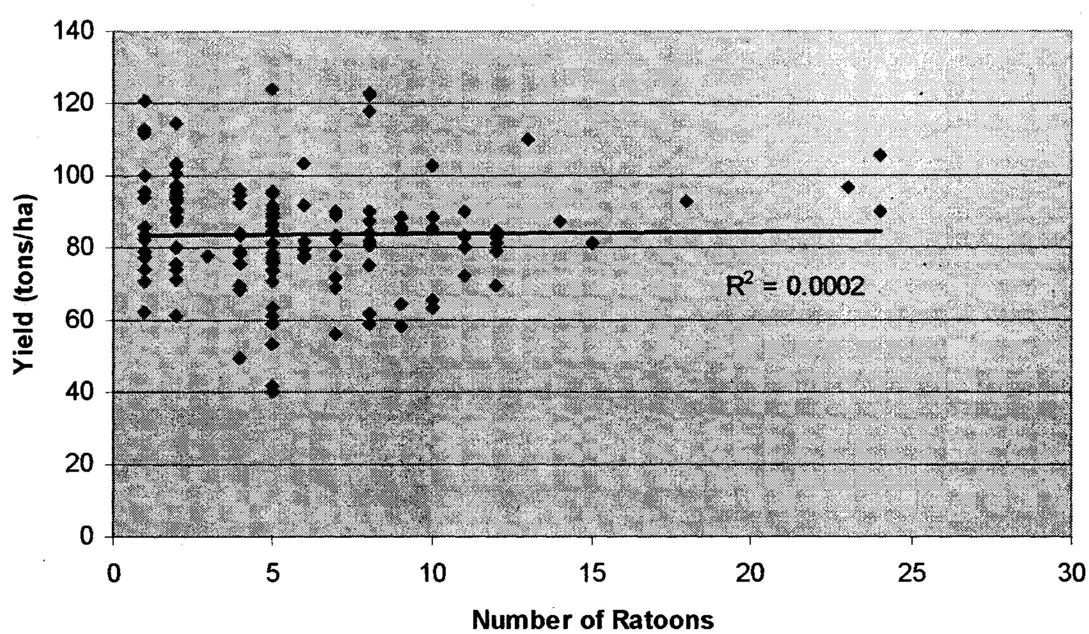


Figure 4.3: Number of Ratoons, Mangote Plantation
Legend
Ratoons (Yrs)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
15
18
23
24
N
Meters
0 250 500 1 000 1 500 2 000 2 500 3 000
M_149
M_148
M_147
M_89
M_143
M_144
M_70
M_60
M_20
M_23
M_22
M_132

Figure 4.4, based on collected field data, demonstrates that yield decline is far from a linear process and that in practice it is a much more erratic "noisy" process, which concurs with other results found in literature (Simmonds and Walker 1986). Factors that influence the rate of yield decline include the cane variety, soil type and fertility, history of pest and fungal infestations, as well as management practices (Garside 2005). The analytical capabilities of ArcGIS can be used in this instance to isolate such contributing factors, in order to optimize yield.

Figure 4.4: Number of Ratoons vs. Yield



Finally, introducing breaks (fallow periods) and rotations into sugarcane crop production, which is traditionally carried out as a monoculture, has been shown to increase cane yield (Bell, Garside et al. 2001). According to the FAO:

> "In their natural state, many soils, in particular in the tropics, cannot be continuously cultivated without undergoing degradation. Such degradation is marked by a decrease in crop yields and a deterioration of soil structure, nutrient status and other physical, chemical and biological attributes. Under traditional low input farming systems, this deterioration is kept in check by alternating some years of cultivation with periods of fallow. The length of the necessary rest period is dependent on inputs applied, soil and climate conditions, and crops. Hence, the

main reason for incorporating fallow into crop rotations is to enhance sustainability of production through maintenance of soil fertility." (FAO, 2000)

Introducing new crops however is not straightforward and the costs associated with building the expertise and technical capacity to rotate other crops with sugarcane must be balanced against the potential gains in yield and the environmental benefits. ArcGIS can be used to model different break and rotation scenarios, allowing farm managers to explore the practical repercussions of introducing practices that may increase sustainability, while ideally increasing returns.

Finally, Figure 4.5 shows a map of the production of cane harvested from each parcel (standardized by dividing by the area of each parcel) for the 2006 harvest season. The map of production in terms of tons of cane per hectare is perhaps the thematic map of greatest economic importance. This map shows that production of cane varies considerably over the spatial extent of the farm and using this map one is able to identify those parcels where yield values are exceptionally low or high. A GIS user can also use the 'Query' function to identify those parcels where the actual production varies considerably from expected production and those parcels which have historically low production values. Furthermore, it is possible to examine the synergistic effects of soil type, cane variety and input parameters in order to identify parcels that require special management attention.

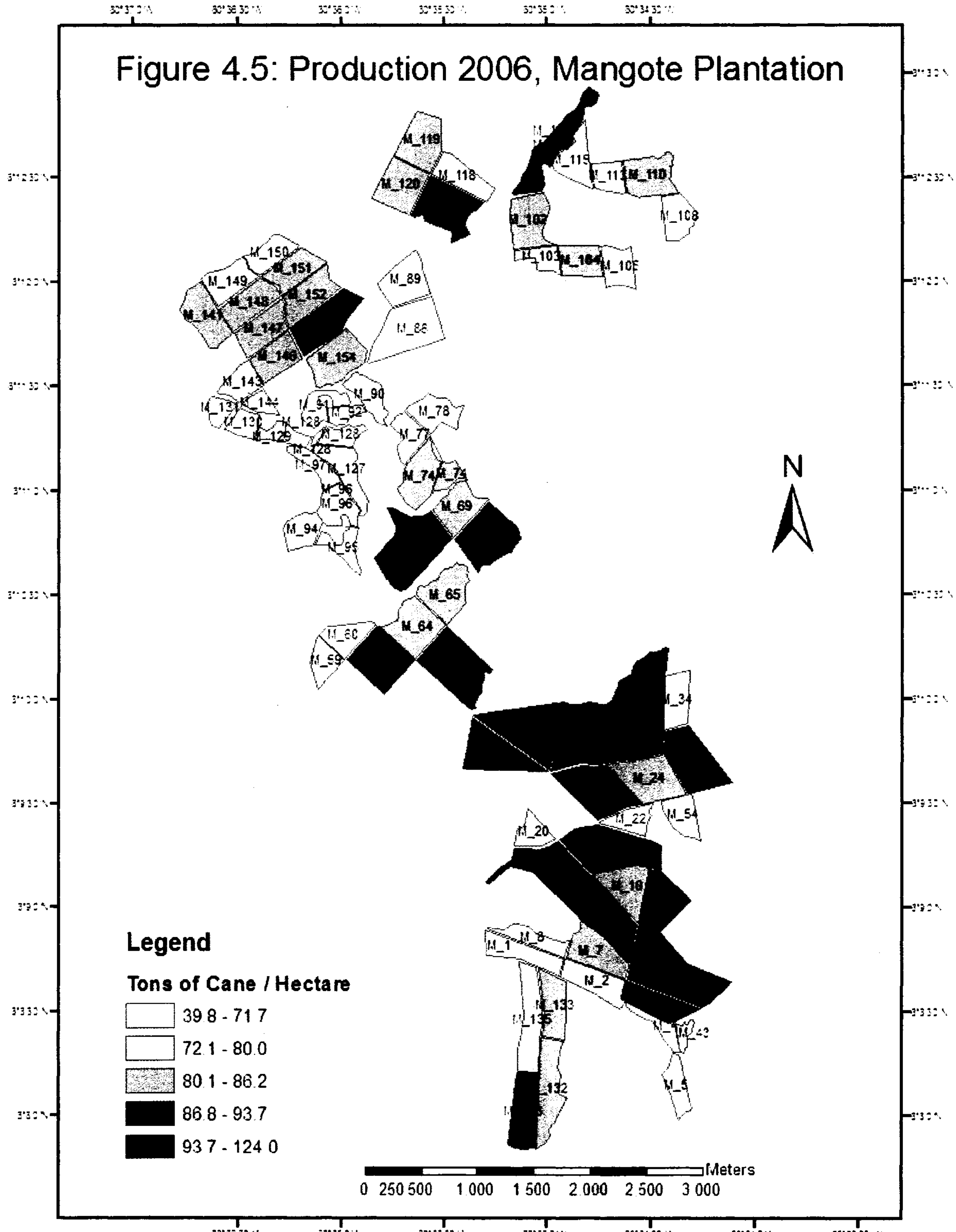


Figure 4.5: Production 2006, Mangote Plantation
Legend
Tons of Cane / Hectare
39 8 - 71 7
72 1 - 80.0
80 1 - 86 2
86 8 - 93 7
93 7 - 124 0
N
Meters
0 250 500 1 000 1 500 2 000 2 500 3 000

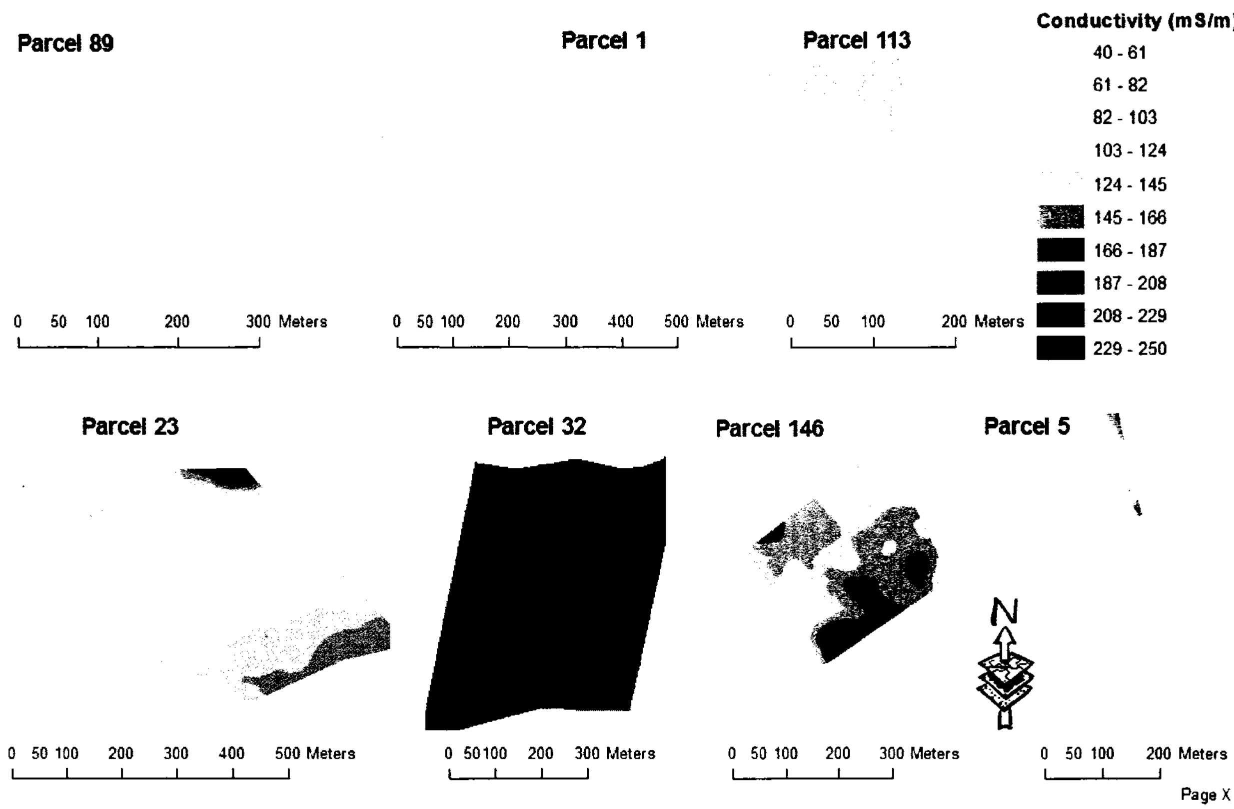
4.3 Soil conductivity mapping

4.3.1 Conductivity zones

Extensive soil electrical conductivity mapping was undertaken in order to create maps of the soil conductivity profile of individual parcels. As discussed in previous chapters, soil conductivity is a composite measure of various important soil properties, with the greatest contribution coming from soil moisture and soil salinity (Veris 2006). The purpose of conductivity mapping with an EM38 conductivity meter was to assess naturally occurring soil moisture profiles within each study parcel. It was also used to identify salinity zones under consistent soil moisture conditions.

Figure 4.6 shows the soil conductivity profiles of the seven chosen study parcels during the first field data collection campaign (EM38 I – June-July 2005). Conductivity readings taken with the EM 38 device are presented here in the standard units used to express bulk soil conductivity: milliSiemens per meter (mS/m). A Siemen is a measurement of a material's conductivity and expressing the value in mS/m makes the measurement independent of volume (Veris 2006).The coverages have also all been standardized to the same scale, shown in the legend for Figure 4.6. In some parcels, conductivity readings were obtained below and above the limits shown in the legend (40mS/m and 250mS/m respectively). That is, anything above 250 mS/m was cut back to 250 mS/m and values below 40 mS/m were shown as 40 mS/m. The maximum salinity value obtained was 344 mS/m and the minimum value obtained was 11 mS/m. However the legend was designed to give a reasonable indication of the range of conductivity readings obtained, and outlying values beyond the limits shown make up less than 1% of the data obtained.

Figure 4.6: Soil Conductivity, EM38 I Horizontal



Ideally, for salinity measurements, all recordings should be taken in the shortest time period that practical limitations (such as manpower) allow, and soil moisture conditions should be constant among all fields and across dates of samplings . To attain these conditions a common approach is to carry out measurements 24 hours after a rainfall (one sufficient to fill the soil profile); soil at field-capacity. A challenge encountered during practical field conductivity mapping however, is the time required to gather data at the chosen sampling resolution and the inability to arrange manpower to be available 24 hours after such a rainfall. Although soil conductivity sampling with an EM38 offers vast time improvements over the collection and analysis of individual soil samples, rapid and complete soil conductivity assessment is only truly possible with an on-the-go sensor. As most field data collection runs span several days it is impossible to control absolutely for soil moisture conditions, and precipitation events between sampling times can cause discontinuities in the conductivity profiles obtained. One way to rigorously account for these changes would be to determine the field capacity of the soil belonging to major regions within the parcels in conjunction with logging climatic data from a weather station in order to quantify whether the soil was always at field capacity when readings were taken. In absence of this data, it was deemed adequate to ensure that the field was never far from field capacity by taking recordings as close to the ideal soil moisture condition (field capacity) as possible.

Furthermore, regardless of whether there is an overall increase in conductivity readings with an increased level of soil moisture, the relative values within the field remain constant and localized rainfall differences within a field typically do not cause enough of a difference in the overall soil profile moisture to affect conductivity readings, (Veris 2006). Given that all soil conductivity surveys conducted in the EM38 I field run were done within 24 hours of a precipitation event in the rainy season when the humidity is consistently above 80%, the soil conductivity profiles displayed in Figure 4.6 can be said to provide a good indication of the relative levels of soil salinity found amongst the seven parcels.

From Figure 4.6, it is evident that Parcel 32 has greatly elevated soil salinity in comparison to other parcels and that Parcels 23, 113 and 146 generally show higher soil salinity levels than Parcels 1, 5 and 89. This corresponds to the hands-on knowledge of soil fertility held by farm managers of Mangote; Parcel 1, 5 and 89 are all located at the edge of the river, and are considered to be among the most fertile parcels of the farm, whereas Parcels 23, 32 and 113 were all chosen for persistent salinity problems. According to Table 4.1 which provides a classification of salinity levels based on EM38 readings, parcels 1, 5 and 89 can generally be considered non-saline to slightly saline (with the exception of the north-easternmost portion of Parcel 5). Parcels 23, 32, 113 and 146 however all exhibit areas of moderate to extremely high salinity.

Table 4.1 Salinity classes for plants (DAFWA 2006)

	EM38 horizontal (mS/m)
Non-saline	<50
Slightly	50-100
Moderately	100-150
Very	150-200
Extremely	>200

Figure 4.6 reveals that in most cases there are definite zones of elevated soil conductivity, which may be due to underlying soil conditions, suggesting the potential benefits to be derived from management zone delineation . The creation of management zones is the second major step in implementing site-specific management, once a descriptive map database has been created. In particular, parcels with elevated salinity levels such as parcels 23, 32, 113, 146 and even parcel 5, which shows a problematic region in its northeast corner, should be subdivided into management zones in which targeted and specific salinity control measures can be implemented. Such measures can include biological or structural controls, depending on the type of saline seep that is occurring and usually consist of appropriate surface water management (Cathcart, 2000).

In making use of this information it is also important to note that the salt tolerance of plants is not only affected by the actual soil salinity but also issues such as waterlogging, soil type, sodicity, depth to water table, salinity of the water table, and rainfall, among other factors (DAFWA 2006). Water and soil management measures that attempt to combat soil salinity should also take these factors into account. Possible salinity control measures include supplying decreased amounts of saline irrigation water to designated parts of the field and undertaking measures to improve surface or subsurface drainage in the required areas (Tanji and Kielen 2002). In the case where variable rate technology is not being used to target fine-scale differences, as is the current situation at Azucarera Nacional, it is easier to implement management methods for larger contiguous areas. Therefore salinity control measures are most easily implemented and necessary for large parcels such as Parcels 23 and 32, both of which span areas over 20 hectares. These parcels can easily be subdivided into regions of common salinity levels, where irrigation and fertilizer management can be adjusted accordingly.

4.3.2 Conductivity changes over time

When creating management zones for salinity management purposes, it is important to understand how soil conductivity may change in a parcel over time. Identifying zones that stay relatively stable is an important prerequisite for delineating zones for long-term site-specific management of soil.

Figure 4.7, which shows the soil conductivity profiles for Parcel 23, demonstrates that general soil conductivity zones are relatively constant, over the study period. This is an extremely promising result for the creation of management zones. Despite differences in the absolute values of conductivity over the field, from Figure 4.7 it is evident that the regions of elevated and depressed values within the parcel remain relatively constant. The north-east and south-east portions of the Parcel 23 seem to display much higher conductivity values, indicating a concentration of salts. This is also in agreement with the fact the northern portion of Parcel 23 is almost contiguous with Parcel 32 which also shows elevated soil salinity.

Figure 4.7 Conductivity zones at different times, Parcel 23, Mangote plantation

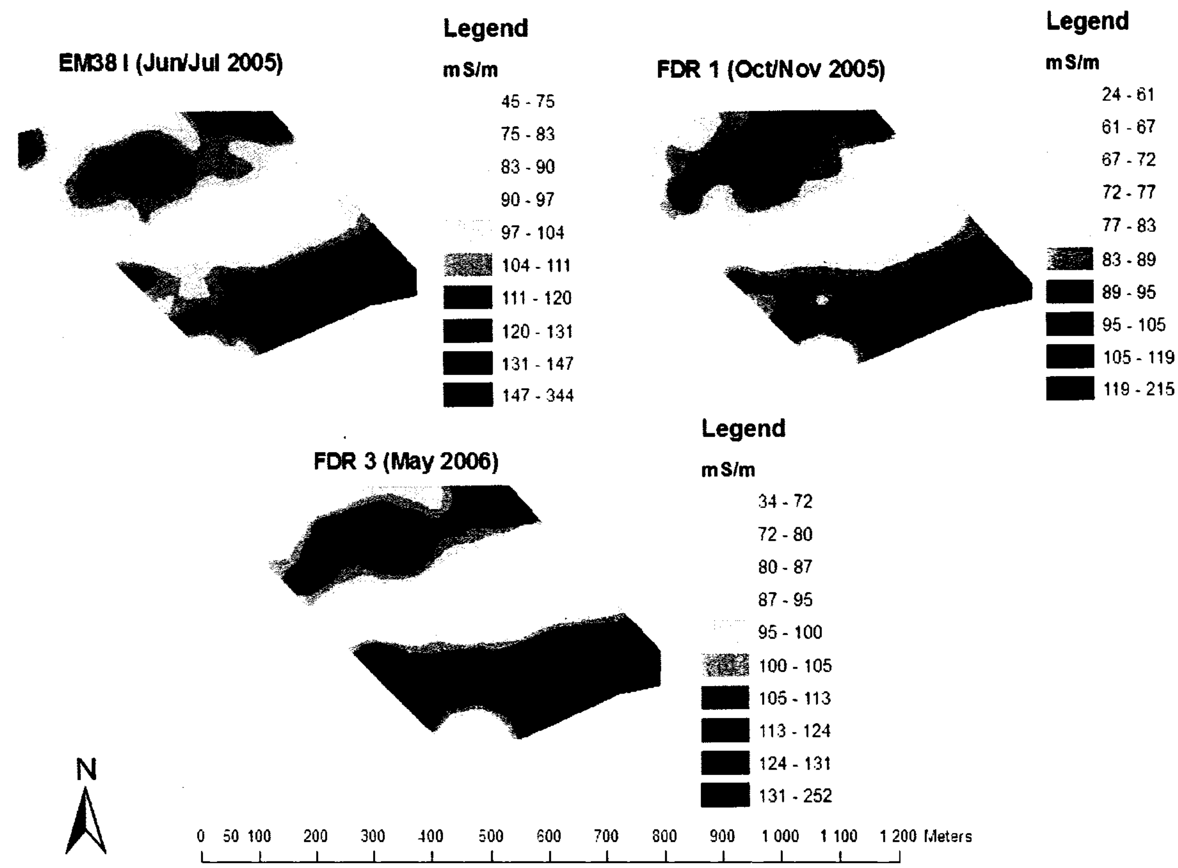
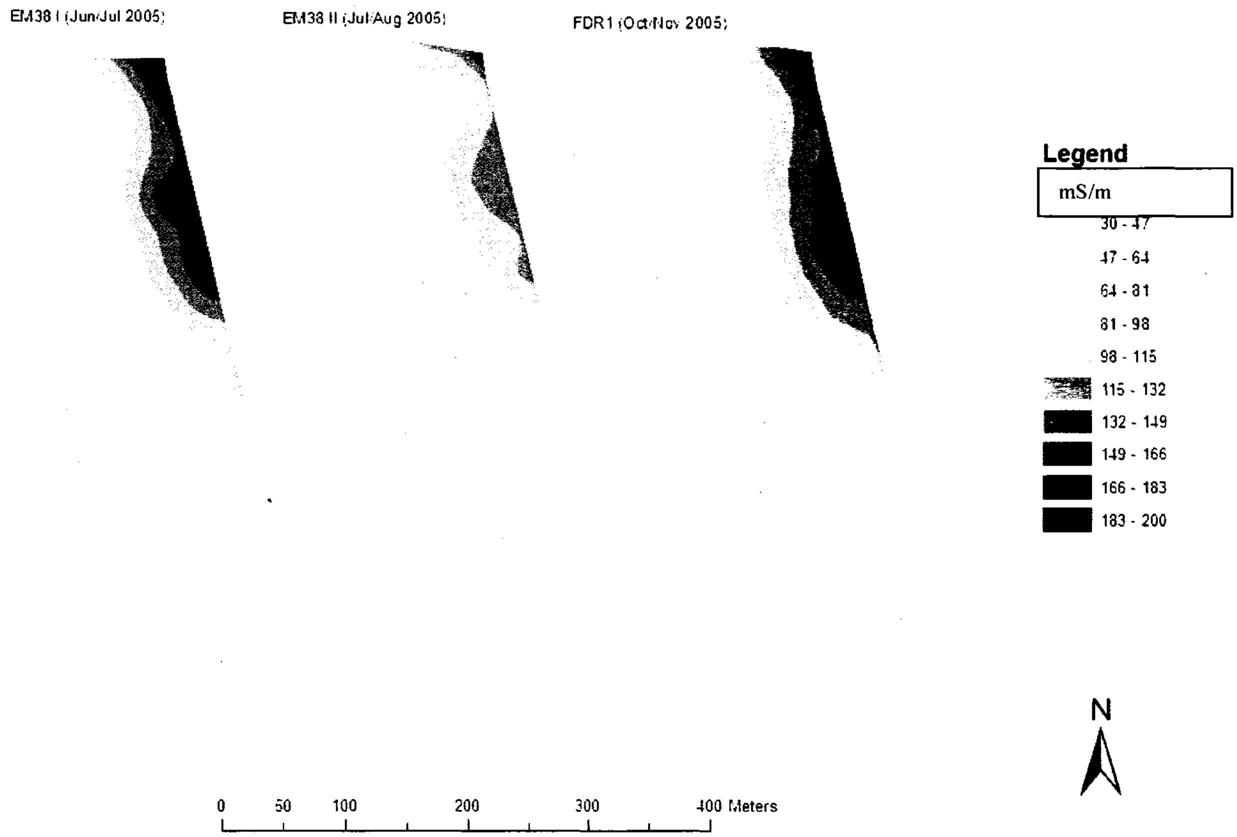


Figure 4.8, which shows how the absolute conductivity of Parcel 5 changes over time, also corroborates these results. As demonstrated by Figure 4.7 it is evident that the areas in which soil conductivity is high remain relatively constant over the field season, however an examination of Figure 4.8 shows that changes in the absolute values of the readings may occur. The principle reasons for these changes in conductivity over time are likely due to soil moisture changes, the leaching of solutes by rainfall or build-up of salinity from irrigation water.

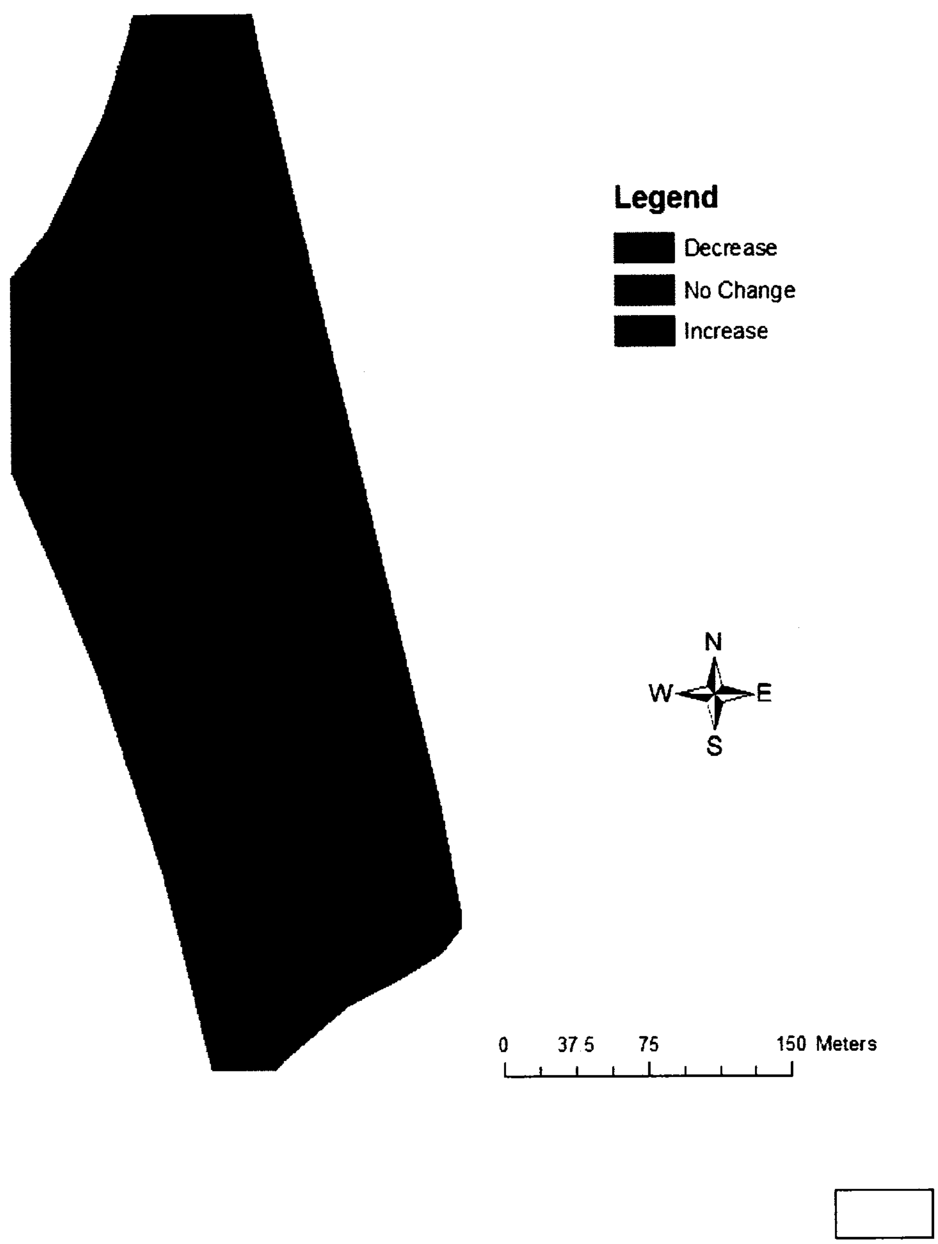
Figure 4.8: Conductivity change over time, Parcel 5, Mangote plantation



Another way to examine the data is to use the spatial analysis tools available with the ArcGIS platform. Using the Spatial Analyst extension, a GIS user can create a raster of the soil conductivity profile at two different times and then using the 'Raster Calculator' utility of Spatial Analyst, produce a surface which is the difference of the two original rasters. Such a raster is shown in Figure 4.9, which highlights the areas which have increased soil conductivity values and those that have decreased in conductivity during the time period separating the field runs. The input rasters used to create the raster difference shown in Figure 4.9 were taken during the EM38 I (June-July 2005) and EM 38 II (July-August 2005) field runs, and hence are taken 3 weeks apart. Figure 4.8 quantifies the areas of conductivity change and clearly displays those areas where salt may be accumulating on the surface of the parcel over the three week period (areas of conductivity increase). These areas can be identified and monitored over time, and appropriate measures taken if accumulation reaches an unacceptable level.

Although soil conductivity profiles were only constructed for the seven parcels shown above, this is just a preliminary step in the incremental addition of data to the GIS. The ultimate goal is to create similar maps for all parcels of the Mangote plantation, and eventually for the all the parcels on all farms of Azucarera Nacional. Creating such coverages over several years would allow managers to identify areas of consistent change, thereby identifying where there were management issues. It was also allow farm managers to identify those areas where EC levels were harmful to sugarcane production.

Figure 4.9: Conductivity change over time
Raster difference, Parcel 5, Mangote Plantation



4.3.3 Conductivity changes over depth

Another useful pattern to examine when creating soil conductivity maps is the difference between conductivity profiles from the surface to the root zone. Soil conductivity data was collected in both the horizontal and vertical dipole modes for all field data runs. As discussed in previous chapters, the horizontal readings give an indication of the surface soil profile, to a depth of 0.6m and vertical readings provide an indication of soil conductivity at a greater depth, giving an average of the conductivity up to 1.75m. Comparing the horizontal dipole with the vertical dipole gives the most effective indication of whether salt is moving upward or downward in the soil profile, and how well the processes of leaching and drainage are occurring in the field. When the surface profile shows generally lower values than the profile at a depth, than it is an indication that sufficient leaching is occurring and that salt is not moving up through the soil profile.

Figure 4.10 reveals that in general the conductivity at a depth (vertical dipole readings) for Parcels 23, 32 and 113 is higher than at the surface. This indicates that in general salts are being leached downward (either by rainfall or irrigation waters). Closer examination of the conductivity profile for Parcel 5, once again using the 'Raster Calculator' to obtain the difference between two rasters, reveals that there are areas in which the horizontal readings are in fact greater than the vertical readings (see Figure 4.11). It is important to monitor such regions for trends over the long term in order to identify soil salinization and implement mitigating measures before there is a strong decline of productivity.

Figure 4.10: Conductivity change over depth
FDR2 Horizontal vs. Vertical

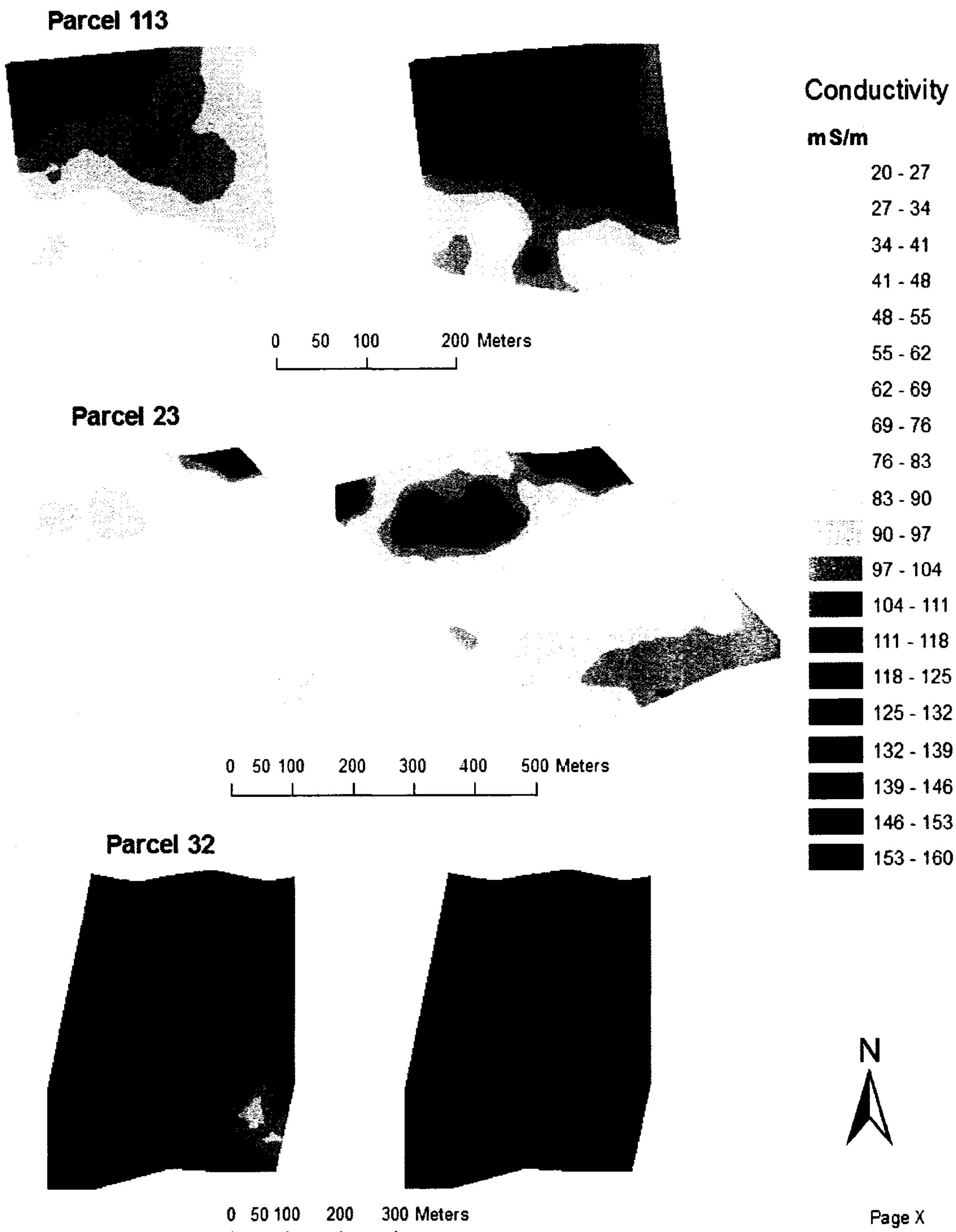
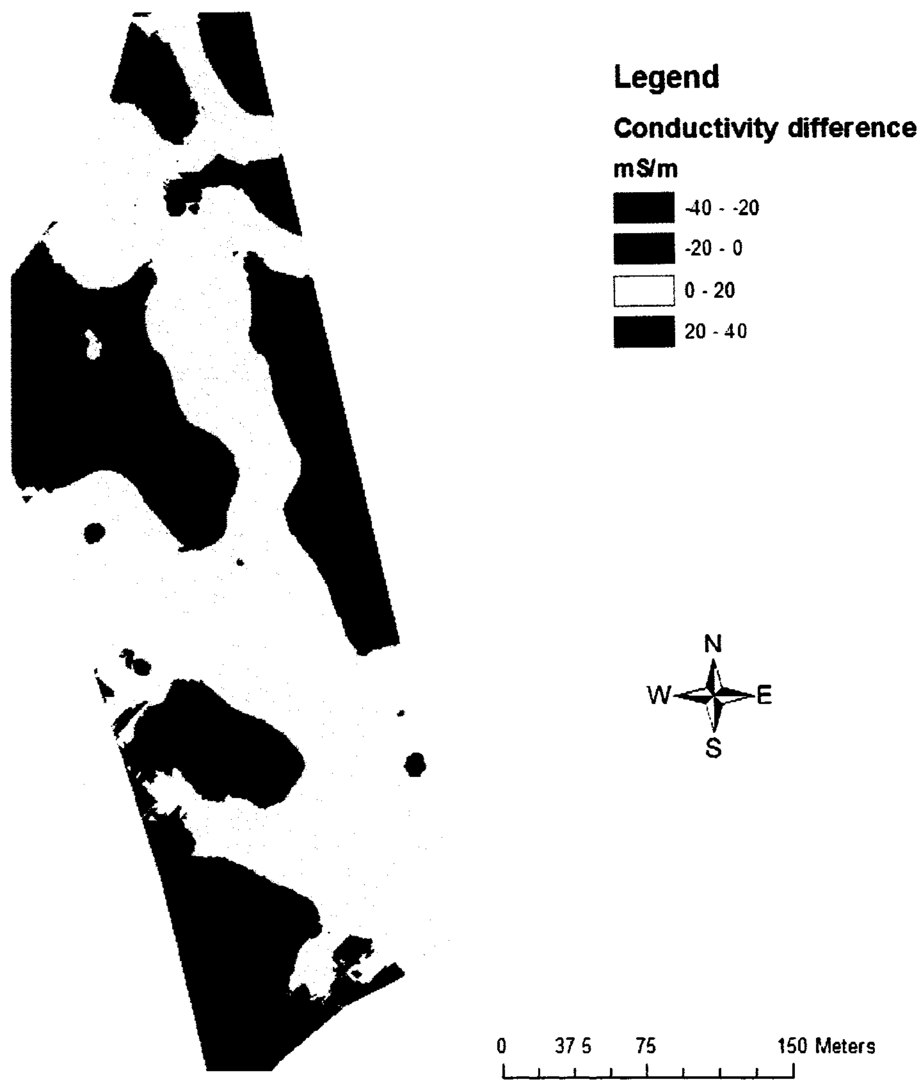


Figure 4.11: Conductivity change over depth Raster difference, Parcel 5, Mangote plantation



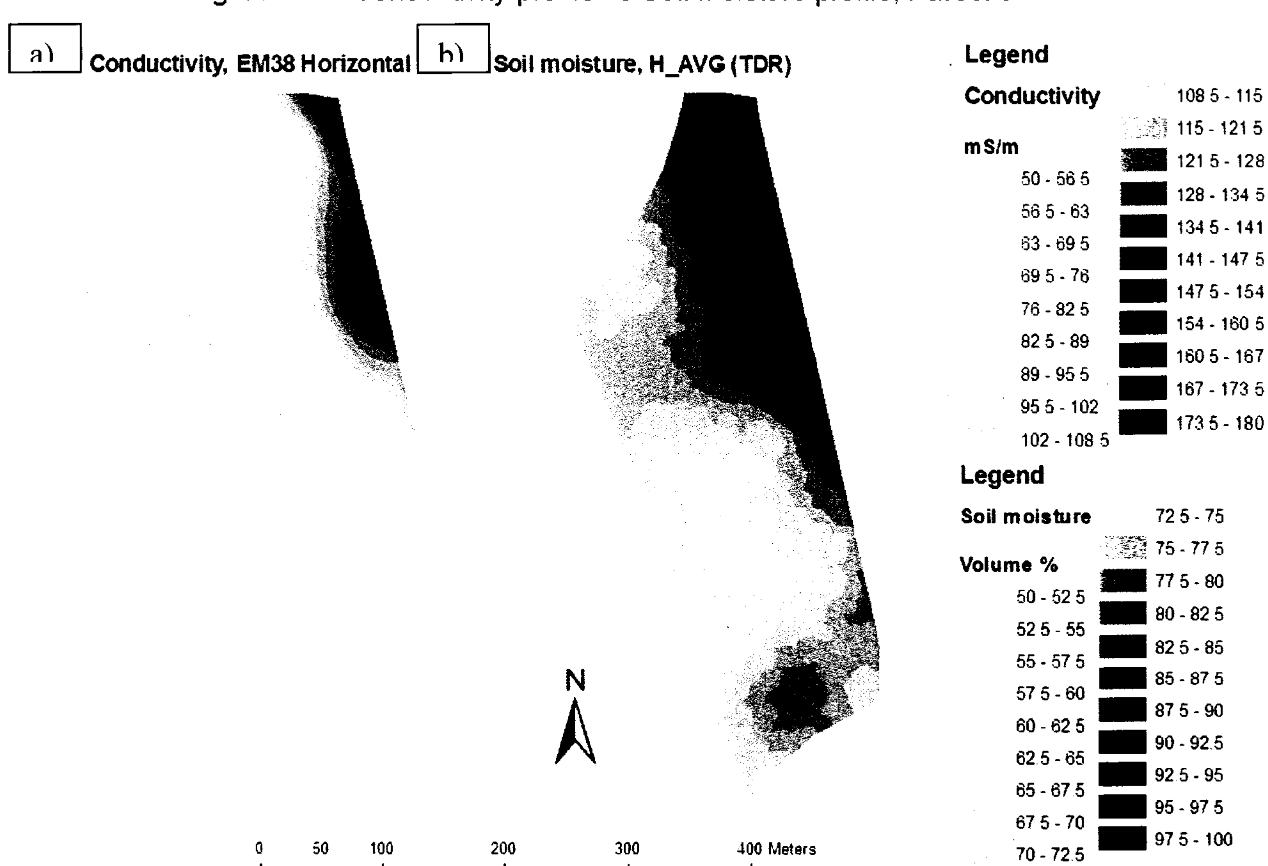
Data used: EM38 I Parcel 5, Horizontal - Vertical

4.3.4 Correlation of soil conductivity with moisture

a) Soil moisture

As discussed previously, soil conductivity readings are primarily a composite measure of soil moisture and salinity when the soil texture is constant. During the dry season, when the parcels are irrigated, the EM 38 instrument can also serve as a tool for identification of areas of high and low soil moisture; particularly in parcels that are know to be uniform in salinity. These measurements can be used in order to adjust irrigation water application, decreasing freshwater input where the soil is sufficiently irrigated. In order to assess the efficacy of the EM38 as a soil moisture measurement tool, soil conductivity readings were taken during the dry season in conjunction with independent soil moisture readings using a TDR300 soil moisture probe. The TDR readings give an indication of the relative soil moisture values over the field. The results of this field data collection were then interpolated and are shown in Figure 4.12.

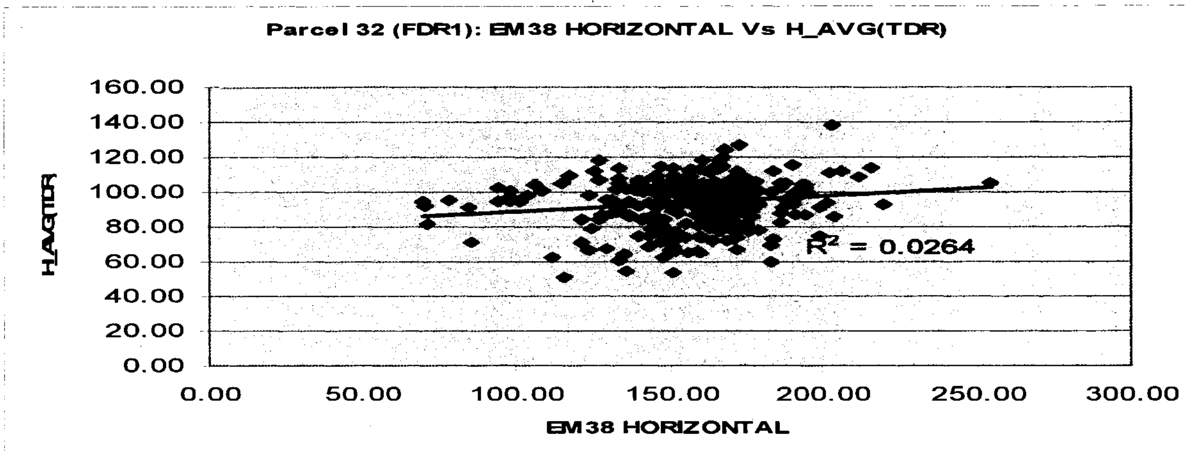
Figure 4.12: Conductivity profile vs Soil moisture profile, Parcel 5

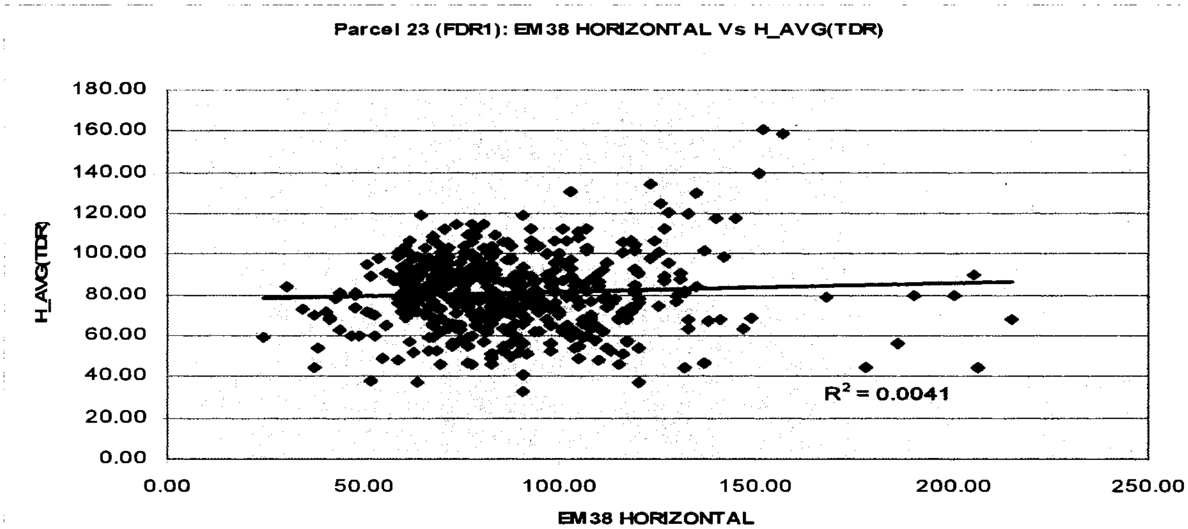


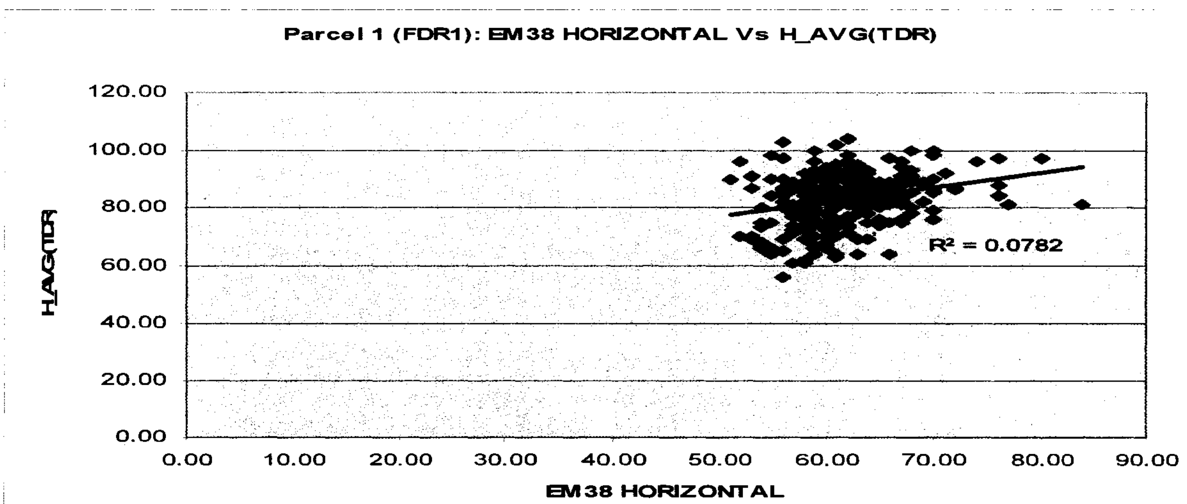
Upon examination of Figure 4.12, similar trends are observed between the conductivity profile and the TDR soil moisture profile. Although there are areas of elevated soil moisture and soil conductivity along the northeast edge of the field which correspond, the variation in the southern portion of the field, in particular a circular area of elevated moisture at the bottom center of the soil moisture profile does not show an accompanying peak in soil conductivity values in 4.12 a. This discrepancy between the soil moisture and soil salinity profiles is most likely due to an underlying property of the soil such as texture which influences both the soil moisture profile and the salinity of the soil. A soil texture change, such as elevated clay content, would not only increase the water holding capacity of soil but its salt content as well, which has been shown to linearly increase with clay content (Bajwa, Hira et al. 1983).

A simple linear regression between the soil conductivity readings and the soil moisture TDR readings also imply that in this case, only a very small percentage of the variation in the conductivity values can be explained by variation in moisture. Figure 4.13 below shows that R^2 values for regression of the conductivity readings taken by the EM38 in the horizontal dipole mode versus soil moisture readings taken with the TDR 300 soil moisture probe show values which indicate that less than 10% of the variation in soil conductivity can be explained by variations in soil moisture. The correlation between these two properties was not expected to be as low as the R^2 values displayed in the graphs of Fig 4.13 reveal, however this lack of correlation may be due to a variety of factors. One important consideration is that the soil moisture readings taken with the TDR may not be capturing the true spatial variability of this property in the field. That is soil moisture readings taken within only centimeters of each other may vary due to pockets of air present in the soil and the method by which the probes are inserted for example. However the primary reason that it is difficult to make a direct comparison between EM-38 and TDR 300 readings is the fact that the EM-38 gives an indication of the average conductivity of a much larger volume of soil then does the TDR 300 moisture probe. This is compounded by the fact that R^2 values are notoriously sensitive to outliers (Quan, 1988) and hence the correlation between soil conductivity and soil moisture may actually be higher than suggested by Figure 4.13.

Figure 4.13 Correlation of Conductivity (EM38 hor) with Soil Moisture (TDR)







4.3.5 Comparison of interpolation methods

Three different interpolation methods were tested for their relative accuracy in creating soil property coverages. As the main goal of this project was to provide a practical tool for the examination of field conditions using maps in GIS, it was considered interesting to examine the difference between the accuracy and ease of use of the interpolation methods available through the Geostatistical Analyst extension of ArcGIS. As described in earlier sections, producing maps using a deterministic interpolator such as IDW is a relatively straightforward method in comparison to OK, which requires a more in depth understanding of the spatial variability of the data. Therefore three different surfaces were generated using the same data set for the first two field runs for all seven study parcels (14 data sets in total).

From Figure 4.14 it is evident that the IDW, OK and OKTR methods (Please refer to Chapter 3 for an explanation of how these surfaces were created) give very similar results in regards to the general pattern produced in the final surface, as expected. The only major visual difference in the coverages is that IDW produces coverages that are less "smooth" than those produced by OK and OKTR. That is, the coverages made using IDW display the "bull's eye" effect surrounding individual data points; This is not considered an important limitation of the method and has little to no effect for the purposes of delineating management zones. The RMSE's values for the various methods are displayed in Table 4.2. Considering these results, and the fact that RMSE's values for the three methods do not differ by more than 3%, the author suggests that creating coverages with the ordinary kriging method without removing trends in the data or applying transformations(as in OKTR) , is the most practical option for GIS users at the plantation.

Figure 4.14: Geostatistical Interpolation Method Comparison, Parcel 5

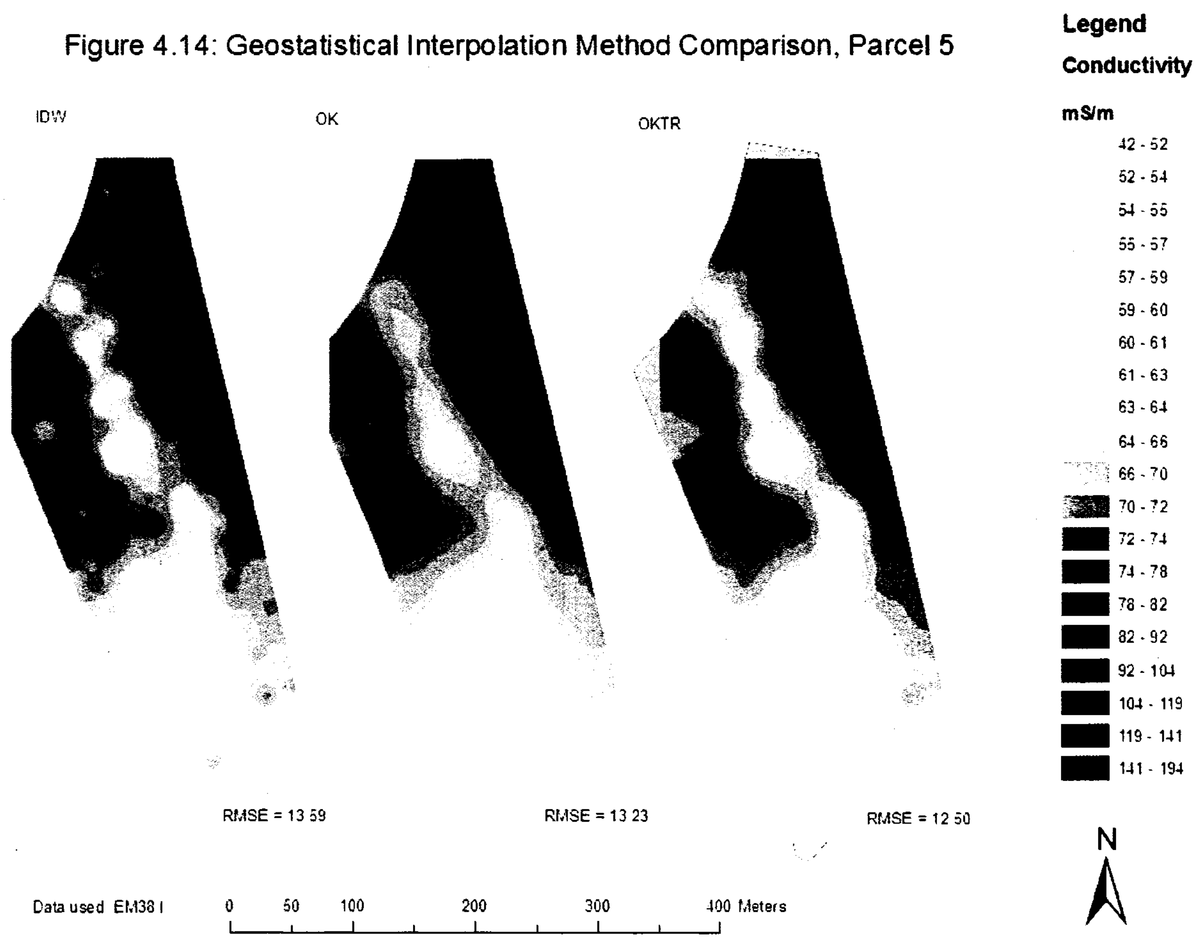


Table 4.2: RMSE's for IDW, OK and OKTR coverages

		Parcel	IDW	OK RMSE	OKTR RMSE
EM38	**Horizontal**	1_jul19	6.27	5.90	5.92
		1_july5	4.48	4.79	4.60
		5_july13	11.02	10.14	10.16
		5_june17	13.59	13.23	12.50
		23_july8	16.79	17.76	18.36
		23_june13	15.60	17.52	16.35
		32_july28	30.09	28.72	28.93
		32_aug12	25.57	25.34	25.06
		89_july17	10.00	9.74	9.69
		89_june23	8.51	8.12	7.88
		113_jul15	13.65	13.07	13.03
		113_jun27	14.32	13.53	12.89
		146_aug17	25.56	23.12	22.99
		146_july20	23.28	24.20	24.24
		Average	**15.62**	**15.37**	**15.19**

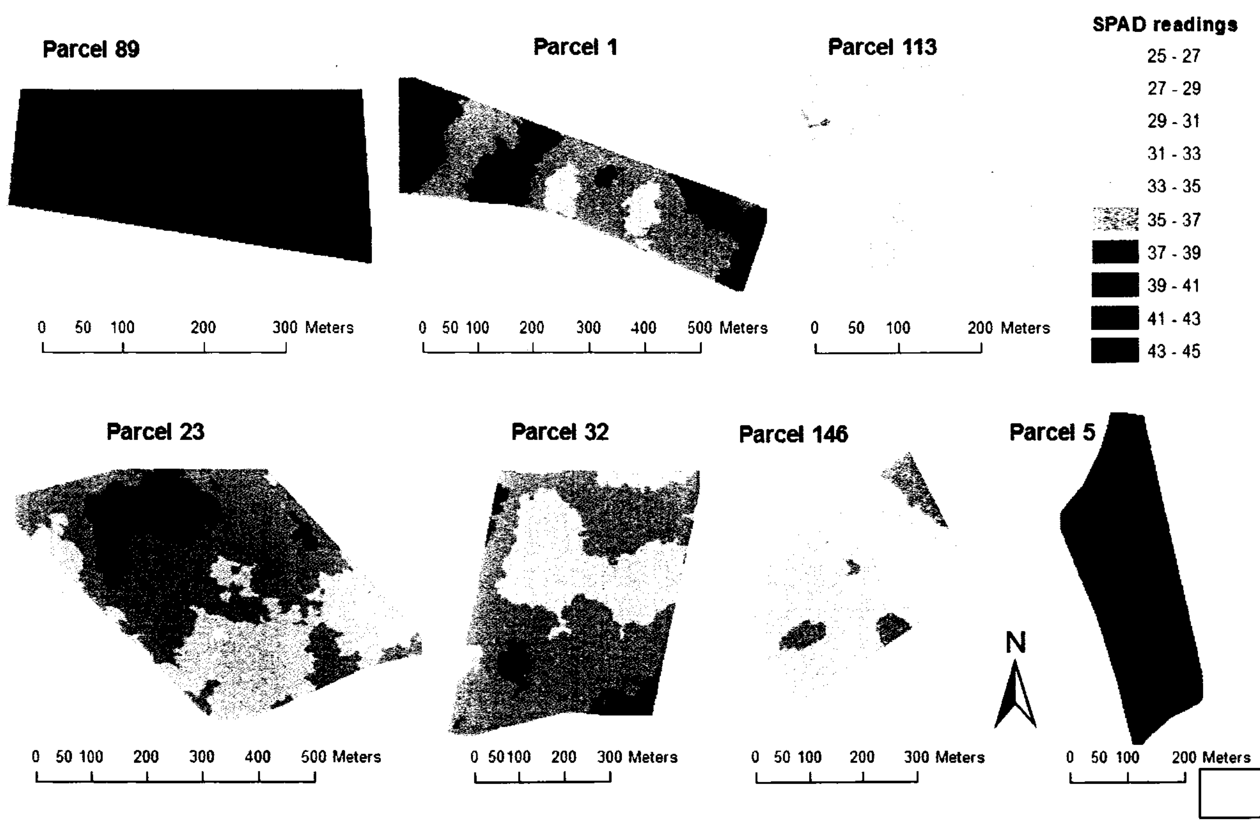
4.4 Plant chlorophyll mapping

4.4.1 Nitrogen management zones

Plant chlorophyll mapping was undertaken in order to create maps of plant health status at a given time for each parcel. From Figure 4.15 it is evident that plant health, which is directly affected by the amount of chlorophyll present in the leaf, varies considerably both within individual parcels as well as among the study parcels. This heterogeneity, and the fact that large contiguous areas often show depressed chlorophyll readings in comparison to other areas, is strong motivation to adopt site-specific management practices. Using such maps, it is possible to identify areas that are receiving adequate fertilization and those areas that are showing nitrogen stress.

In general, the SPAD threshold value for adequate fertilization is between 35 and 40 SPAD units, with values below this range indicating inadequate fertilization and values above indicating excess (Vidal, Longeri et al. 1999). In Figure 4.15, Parcels 23, 32, 113 and 146 and parts of Parcel 1 all show nitrogen deficiencies with SPAD values in the range ≤ 35 SPAD units and Parcels 5 and 89, as well as parts of Parcel 1, show adequate to excess fertilization with SPAD values up to 45. As fertilization on Mangote farm occurs as part of a scheme where nitrogen application is split between the seedling stage and at the early growth stage (after foliar analysis to determine N levels), maps such as the one shown in Figure 4.15, would be most useful just prior to the early growth stage application of fertilizer (Rice, Gilbert et al. 1993). Eventually, such maps could also be used in conjunction with variable rate technology (VRT) to increase nitrogen use efficiency and decrease yield variability by controlling fertilizer inputs based on the SPAD variation maps (Liang, Huang et al. 2004).

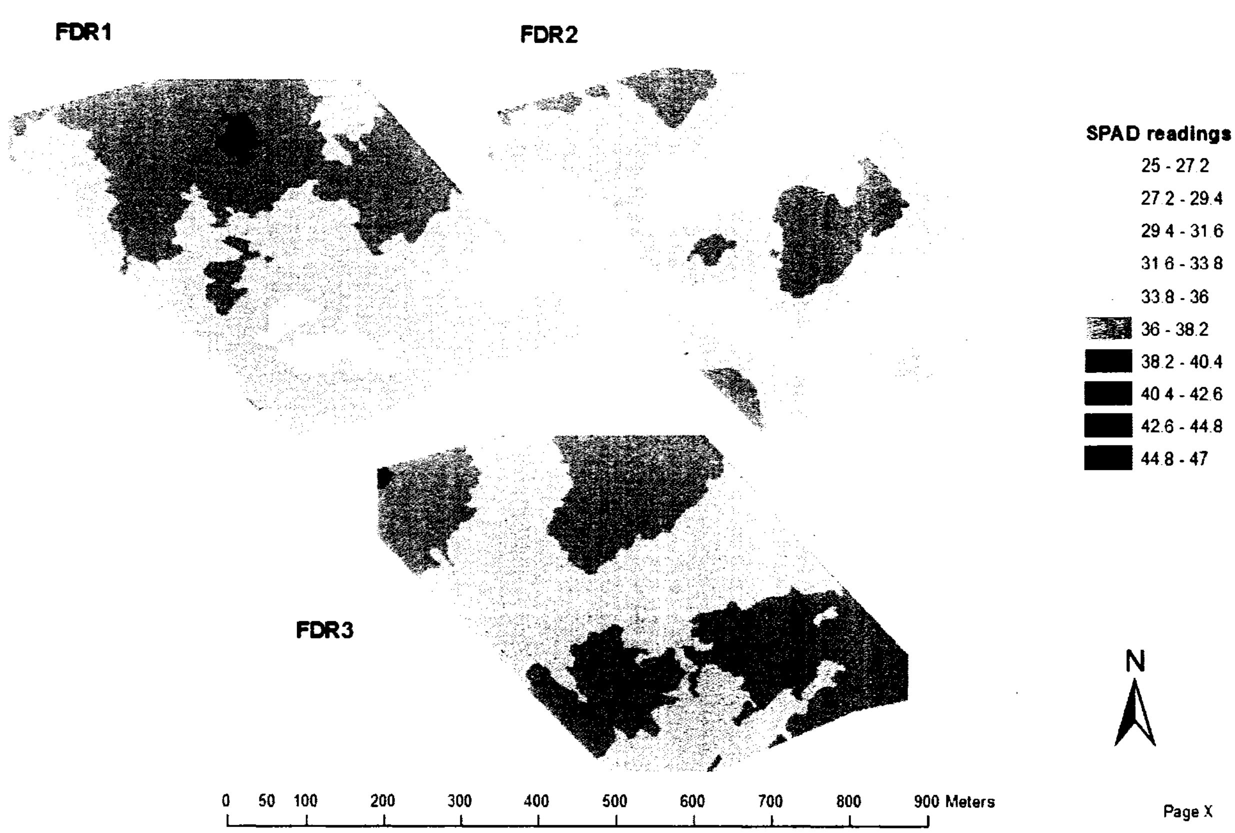
Figure 4.15: Plant chlorophyll profiles, SPAD readings for FDR1, All Parcels



4.4.2 Chlorophyll changes overtime

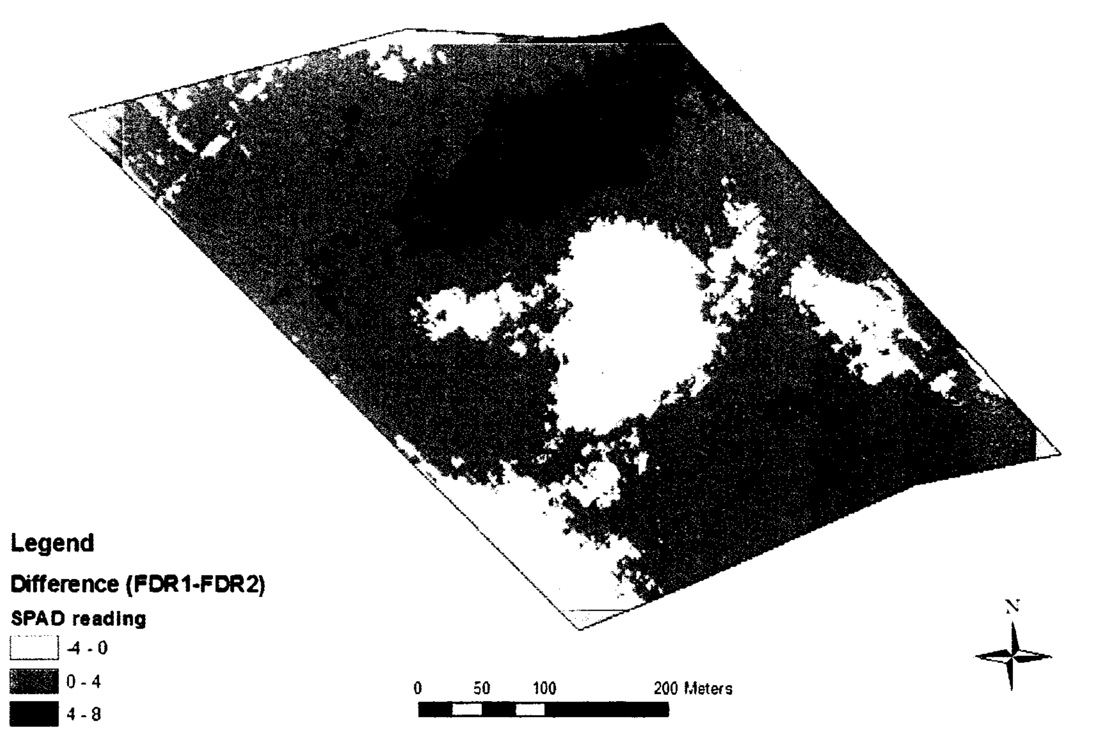
Unlike soil conductivity profiles, plant chlorophyll profiles are much more variable over time, as indicated by Figure 4.16. These changes over time of plant chlorophyll patterns in the field can be explained by a variety of factors. Plant chlorophyll is not only affected directly by nitrogen uptake (Noh, Zhang et al. 2003) but also shows variable changes as crop maturation occurs (Murdock, Jones et al. 1997). Furthermore anything that causes plant stress, such as water or nutrient deficiencies, or excess soil salinity will affect the SPAD readings (Murdock, Jones et al. 1997). Although SPAD measurements are much more variable over the field season, unlike soil conditions which are more stable, the literature suggests that a thorough characterization of plant nitrogen deficiency at an *early* growth stage is most effective to predict yield (Simões, Rocha et al. 2005).

Figure 4.16: Plant chlorophyll zones at different times, Parcel 23



As was done with soil conductivity readings over time, in Figure 4.9, it is possible to display the areas where chlorophyll changes have occurred over time using the Raster Calculator. The map shown in Figure 4.17 was derived by subtracting the plant chlorophyll profile raster created from the FDR1 collection (started Dec. 6. 2005) from the raster of the FDR 2 collection (started Jan. 25, 2006). The figure therefore shows the change in plant chlorophyll which occurred in the field between these two dates. The lightest areas of Figure 4.17 represent those in which chlorophyll levels have dropped during the time period and the darkest areas show where chlorophyll levels have risen. This information can be used to target and redirect fertilizer applications where they are most necessary.

Figure 4.17: Chlorophyll change over time, Parcel 23, Raster difference, Parcel 23

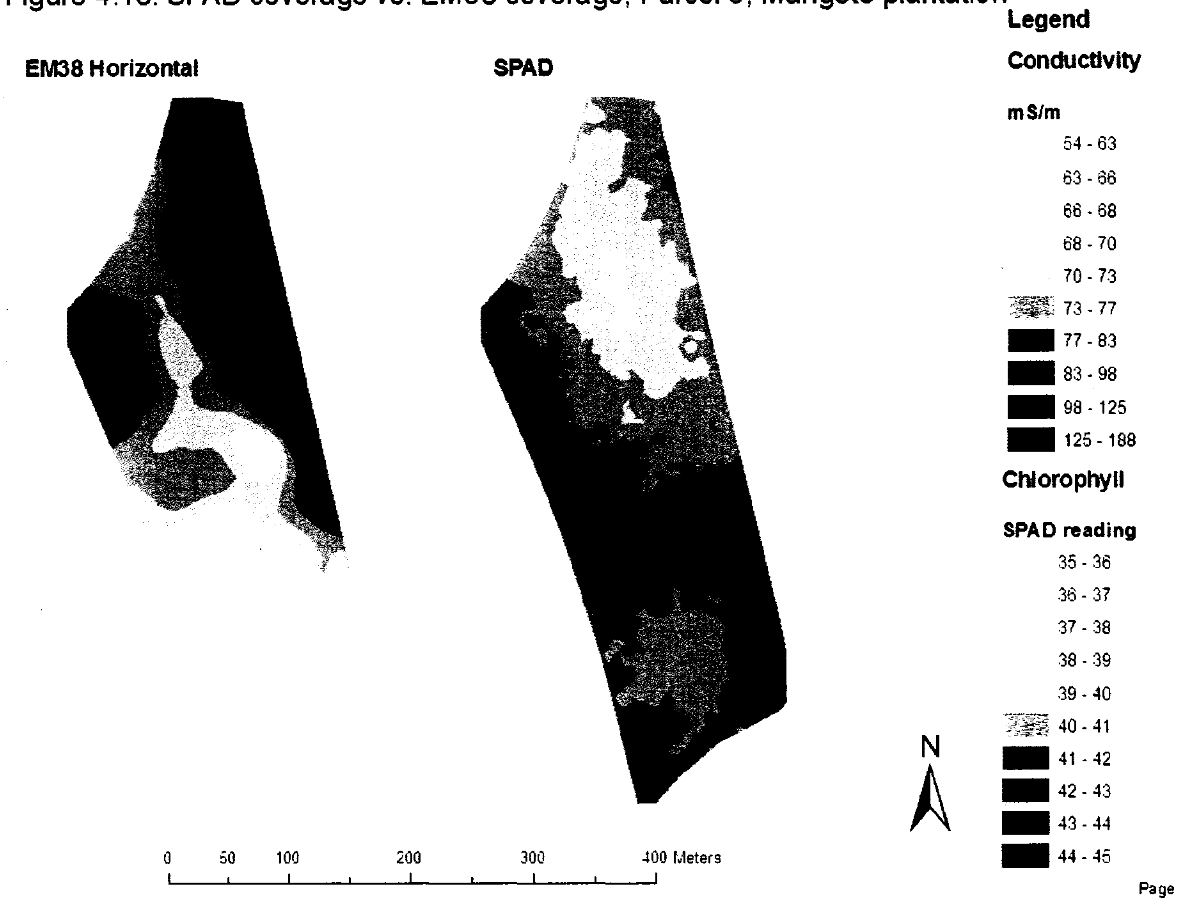


4.4.3 Correlation of plant chlorophyll with other properties

a) Soil conductivity

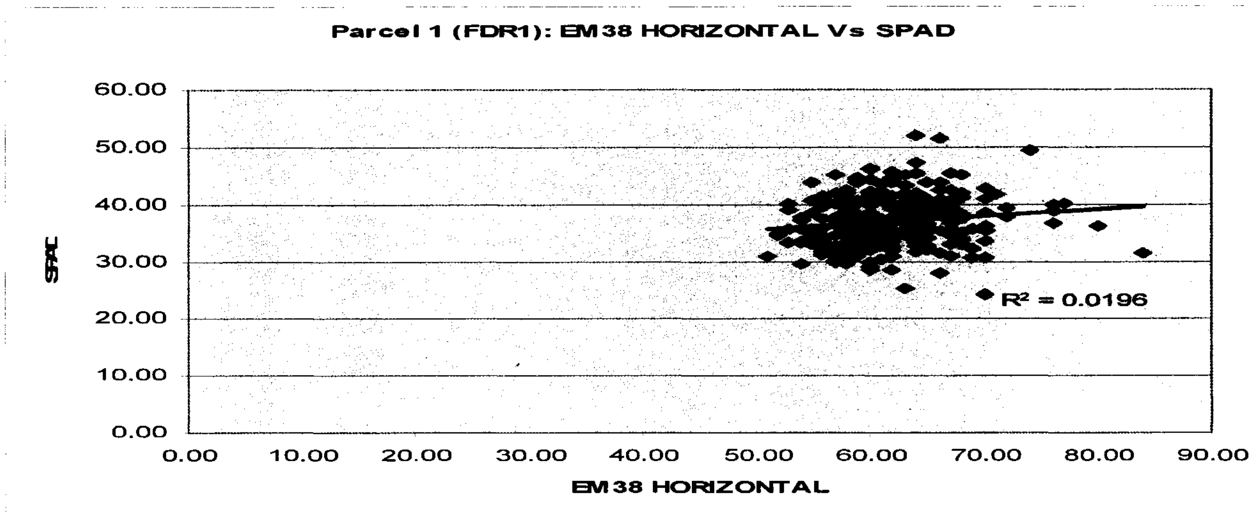
From a comparison of Figure 4.15 with Figure 4.6, it is interesting to note that parcels 23, 32, 113 and 146 which show relatively depressed SPAD readings, are also those with the highest soil salinity. Parcels 1, 5 and 89 on the other hand, which are considered parcels with the most fertile soils show SPAD readings in the high range, implying a that there is a relationship between the salinity level of the soil and plant vigor. In light of the fact that soil conductivity is directly affected by both soil salinity and soil moisture, both of which have an effect on plant health, some correlation was expected to be found between soil EM38 readings and leaf chlorophyll measurements made with the SPAD meter. Upon examination of Figure 4.18 however, it is evident that there is not a strong agreement between the spatial patterns of soil conductivity and plant chlorophyll over the field for Parcel 5. Although the extremely saline portion of the field in the northeast corner of Parcel 5 also displays depressed SPAD readings, the spatial extent of these areas do not completely overlap and the area of highest salinity does not correspond to the area of lowest plant chlorophyll. This lack of correlation implies that there are other factors (such as nutrients other than N and other biotic and abiotic factors) affecting the distribution of plant chlorophyll readings over the field, and that the variation cannot just be explained by the variation in salinity.

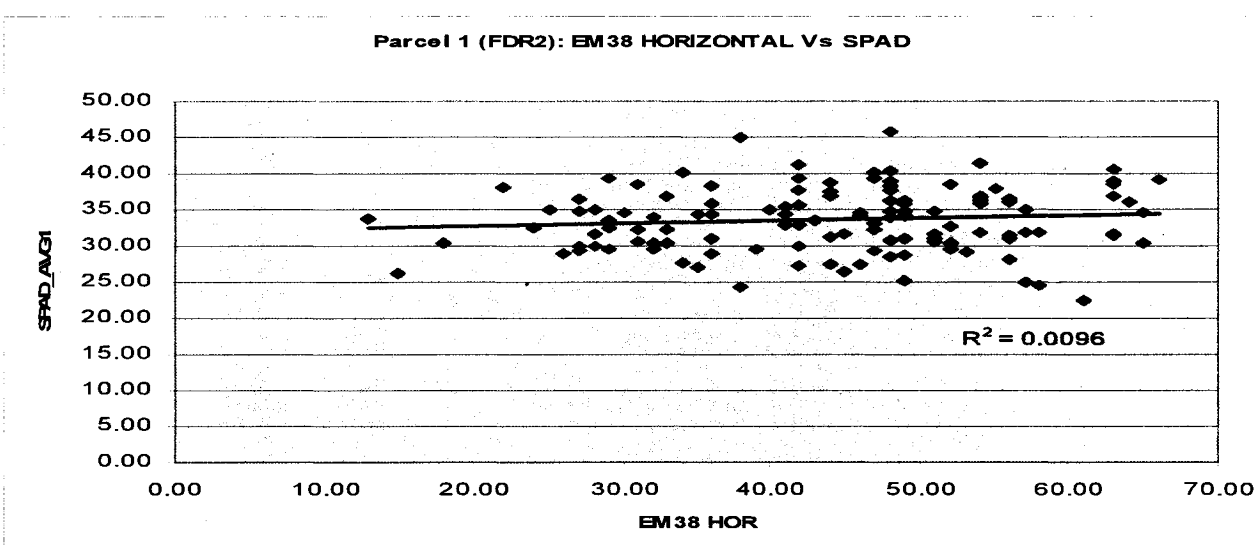
Figure 4.18: SPAD coverage vs. EM38 coverage, Parcel 5, Mangote plantation

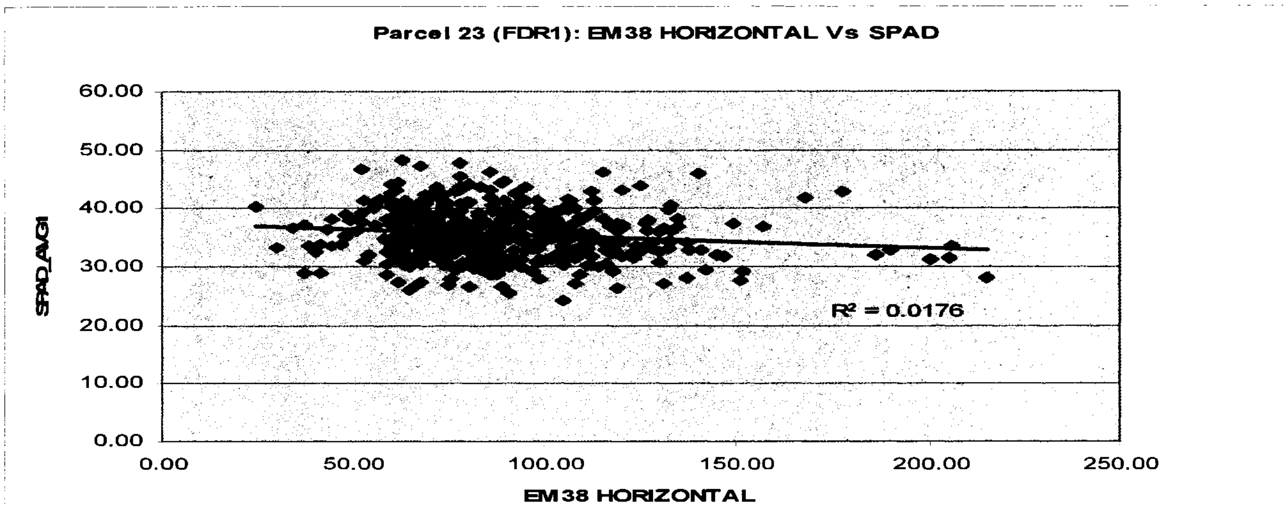


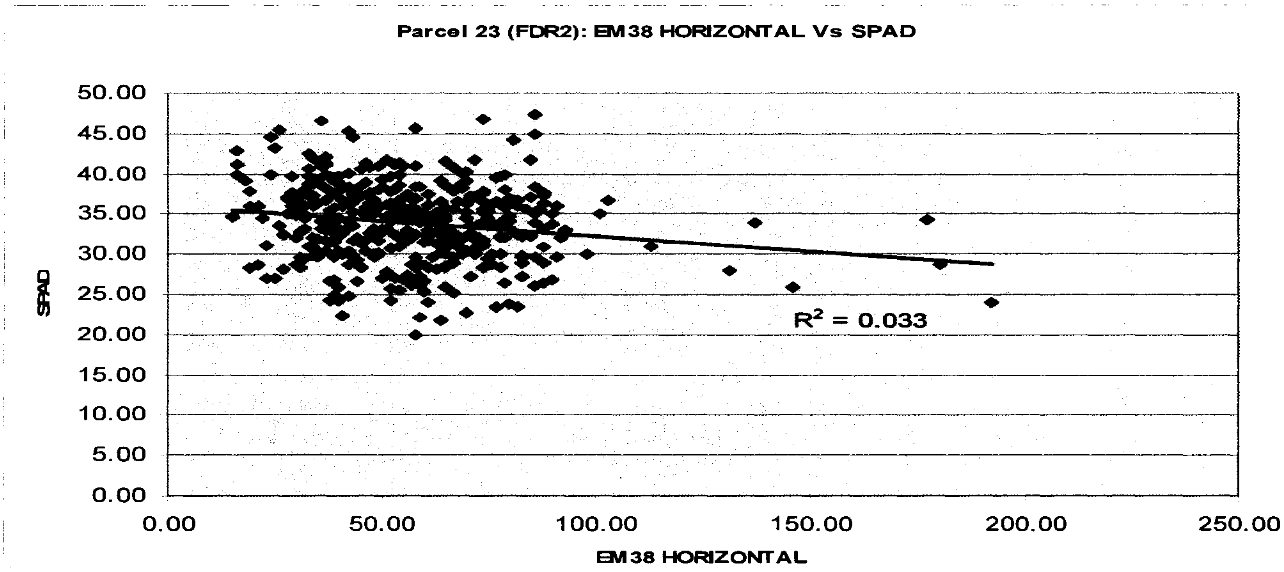
The lack of spatial correlation is confirmed by plotting the soil conductivity measurements (EM 38 horizontal) against the plant chlorophyll readings (SPAD) taken at the same point. The R^2 values derived from these plots also imply that there is little correlation (see Figure 19). It is noted that these findings do not reveal that there is *no* correlation between SPAD and EM38 readings; however the analysis implies that the interrelation between the two parameters is confounded by other variables. Most importantly, SPAD readings are most likely disproportionately sensitive to fertilizer applications over the variations in plant health caused by underlying soil conditions.

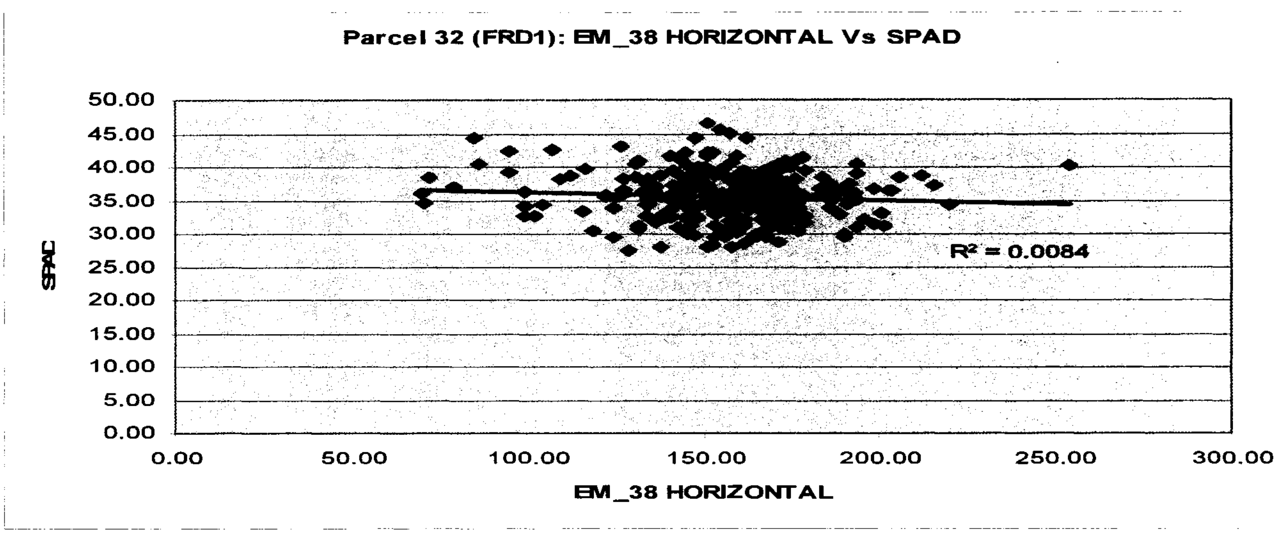
Fig. 4.19: Correlation of plant chlorophyll (SPAD) with Soil conductivity (EM38 hor)

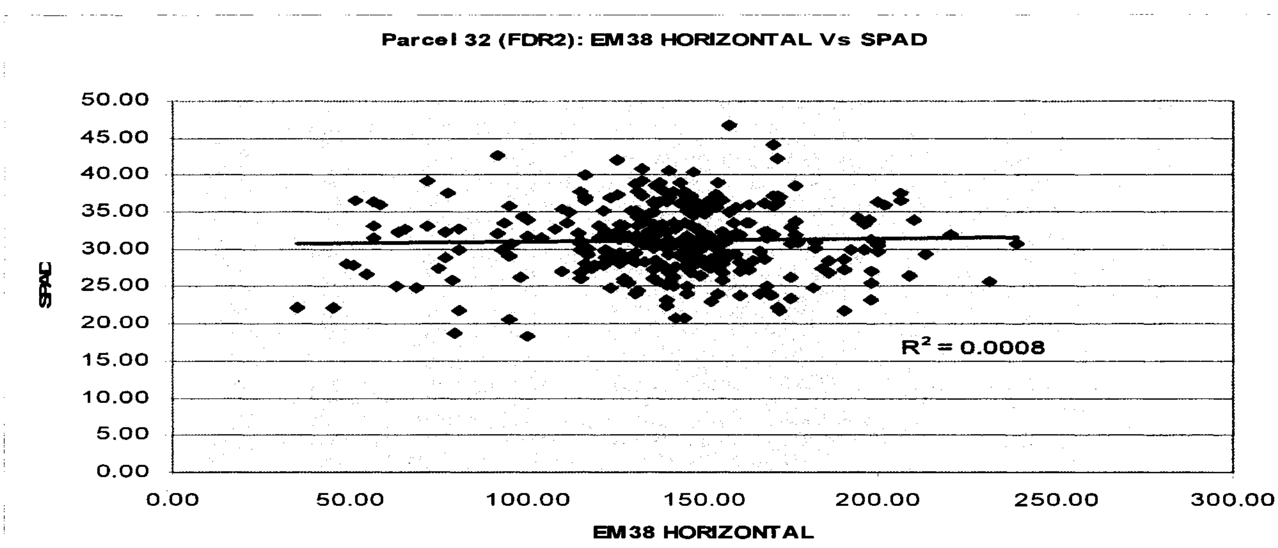





Parcel 23 (FDR1): EM38 HORIZONTAL Vs SPAD
SPAD_AVG1
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.00
50.00
100.00
150.00
200.00
250.00
EM38 HORIZONTAL
R² = 0.0176


Parcel 23 (FDR2): EM38 HORIZONTAL Vs SPAD
SPAD
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
50.00
100.00
150.00
200.00
250.00
EM38 HORIZONTAL
R² = 0.033



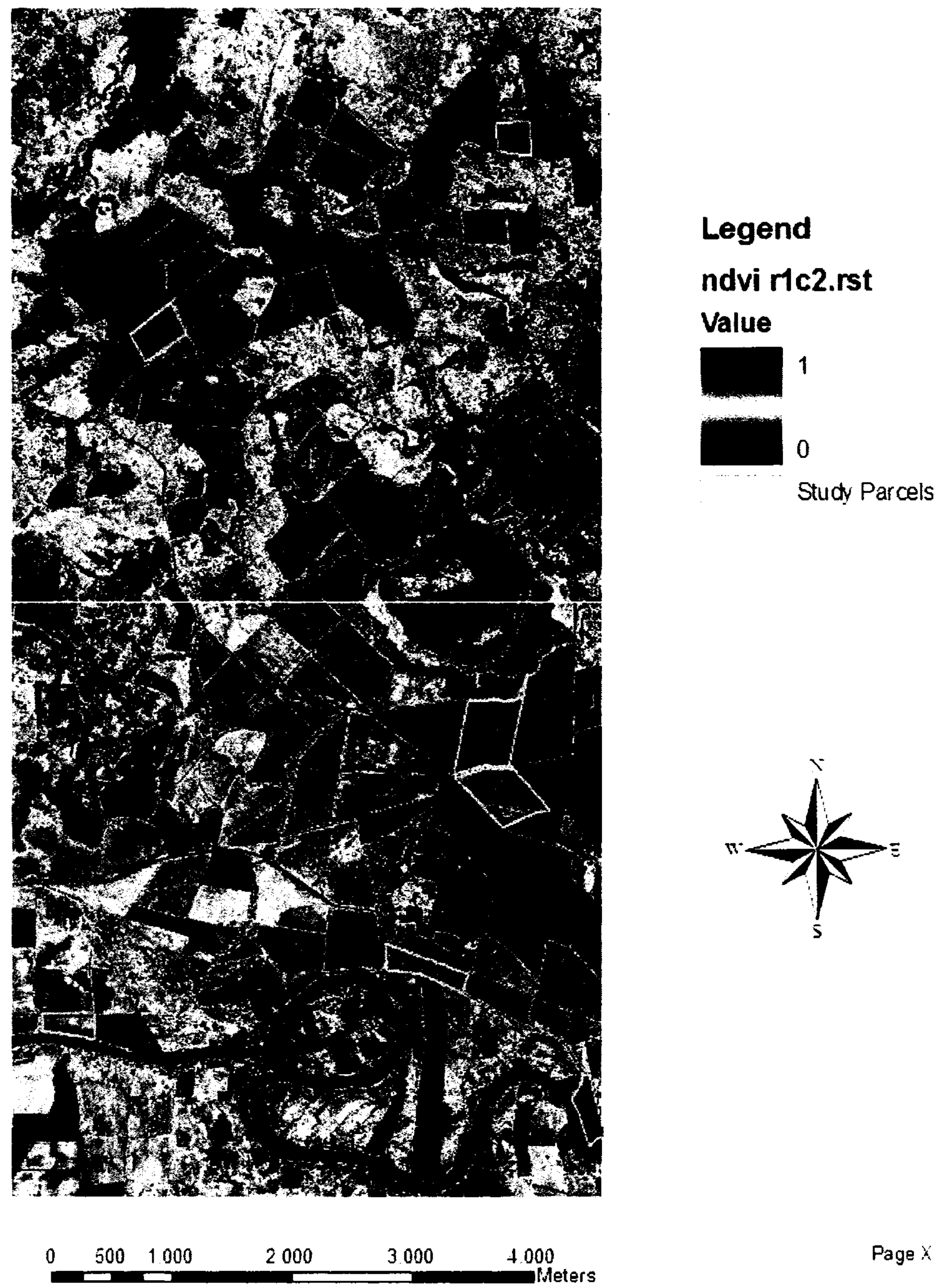


b) Plant chlorophyll mapping using NDVI

A high resolution Quickbird image was obtained of the study area near the end of the 2006 harvest season (Acquisition data: February 3rd, 2006). The image capture covered 79km^2, covering the spatial extent of Mangote farm and all of the seven study parcels where detailed sampling occurred. From Figure 4.20 which shows the NDVI coverage obtained of the Mangote plantation, one can clearly identify bare soil parcels (which appear red) in contrast to planted parcels (which appear green). The fine resolution of the image (60 cm for panchromatic and 2.44 m for multispectral) also allows identification of within parcel plant health variability. As discussed in Chapter 2, NDVI values for this scene should vary from 0 to 1, where 0 indicates the absence of vegetation while an increasing positive value indicates an increase in the plant density and vigor. These images are very useful for identifying areas of plant stress and decreased biomass within a field. From the NDVI coverage shown in the right in Figure 4.21 areas of decreased plant health are clearly visible in streaks appearing in the south area of the parcel as well as at the northern tip of the field. Another useful way to use NDVI coverages is as a direct indicator of plant nitrogen status which can potentially save the time required to collect ground-based data (Lamb 2000).

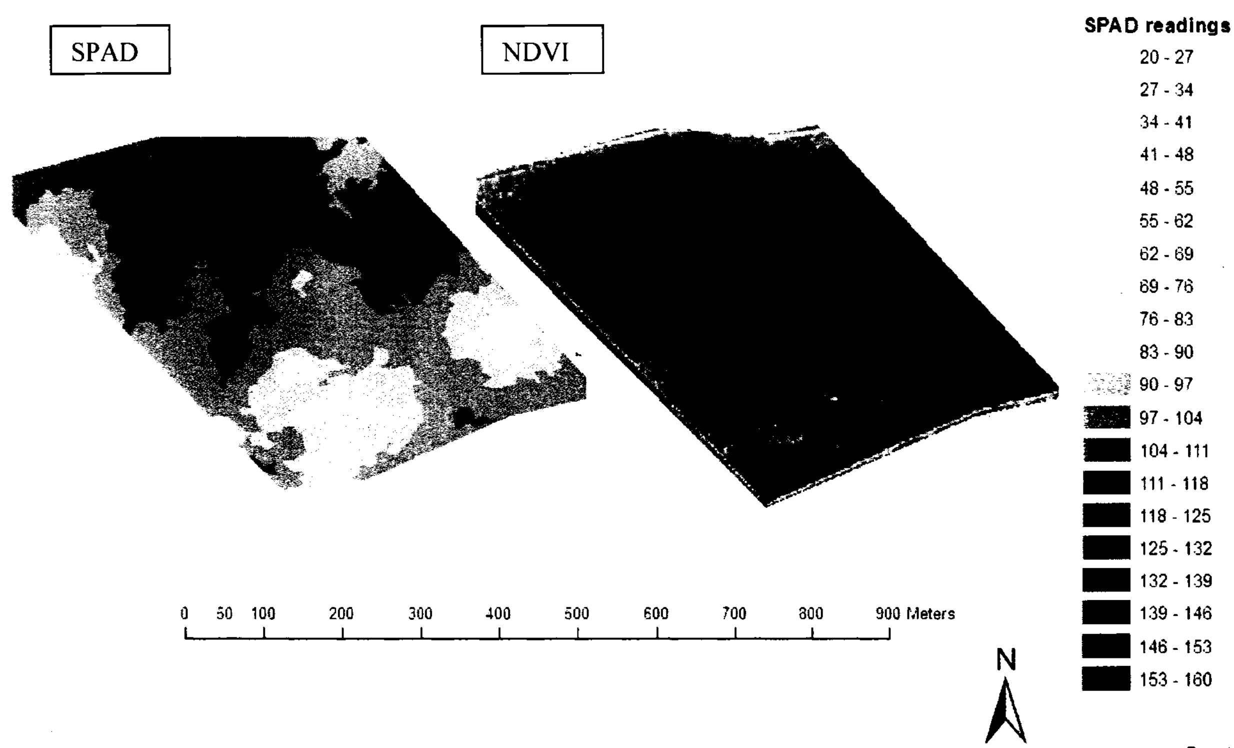
Figure 4.20: NDVI Index , Mangote Plantation

Dervived from QuickBird Satellite Imagery



Comparing the SPAD plant health coverage with the NDVI coverage of Parcel 23, both shown in Figure 4.21, there is some correspondence between areas of low chlorophyll observed in both coverages. The area of depressed SPAD values in the south region of the plant chlorophyll coverage shown on the left of Figure 4.21 are matched by the area of evident plant stress and/or decreased biomass evident in the south corner of the NDVI coverage shown on the right. However the problem with trying to find a direct correlation between the NDVI coverage and the coverage created using the plant chlorophyll readings obtained from the SPAD meter is that, whereas NDVI is sensitive to the leaf area index (LAI) and soil background reflectance, the SPAD meter does not capture these variations (Daughtry, Walthall et al. 2000).

Figure 4.21: Chlorophyll profile vs. NDVI coverage, Parcel 23



It is also recognized that it is often difficult to isolate the parameters that contribute to stress measured by the chlorophyll meter due to the complexity of interrelated factors (Ahmad, Reid et al. 1999). This reveals that, although several studies

(Jackson 1986; Pinter and Moran 1994; Wiegand, Anderson et al. 1996; Blackburn 1999, Lamb 2000) have shown correlations between nitrogen deficiencies detected in the field with those obtained from satellite imagery derived NDVI, the chosen method of characterizing plant chlorophyll conditions over the field is not appropriate. That is, taking point SPAD readings over the entire field, rather than intensively on smaller plots, is not conducive to finding a correlation between SPAD and NDVI.

One limitation of the SPAD data is that a large number of random observations must be averaged to reduce variability and make statistical comparisons meaningful and hence there is a point sampling limitation in obtaining SPAD readings (Adamsen and Pinter, 1999).

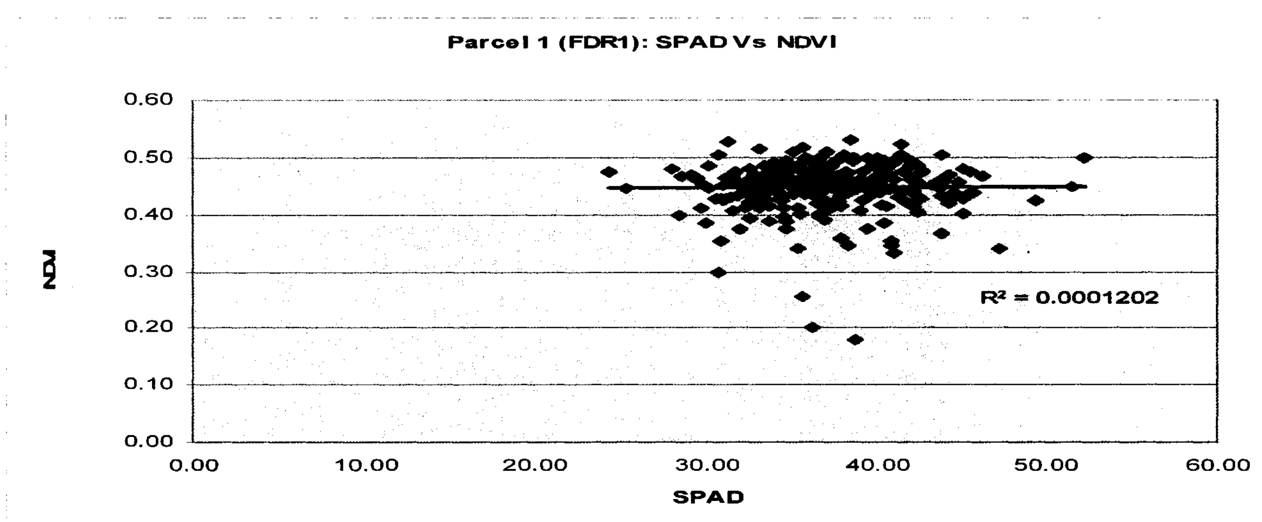
Another principle challenge encountered in trying to correlate SPAD readings with NDVI values is the small variation in the SPAD variations. SPAD readings typically range from 25 to 50 with the majority of readings falling in the 30 to 45 range. In order to detect such a subtle variations in chlorophyll concentrations for the purposes of scientific studies artificial nitrogen deficiencies are often created by applying many times the normal amount of nitrogen to test plots (Feng, Hu et al. 2005). This results in pronounced and detectable differences in chlorophyll concentrations which can be correlated to NDVI.

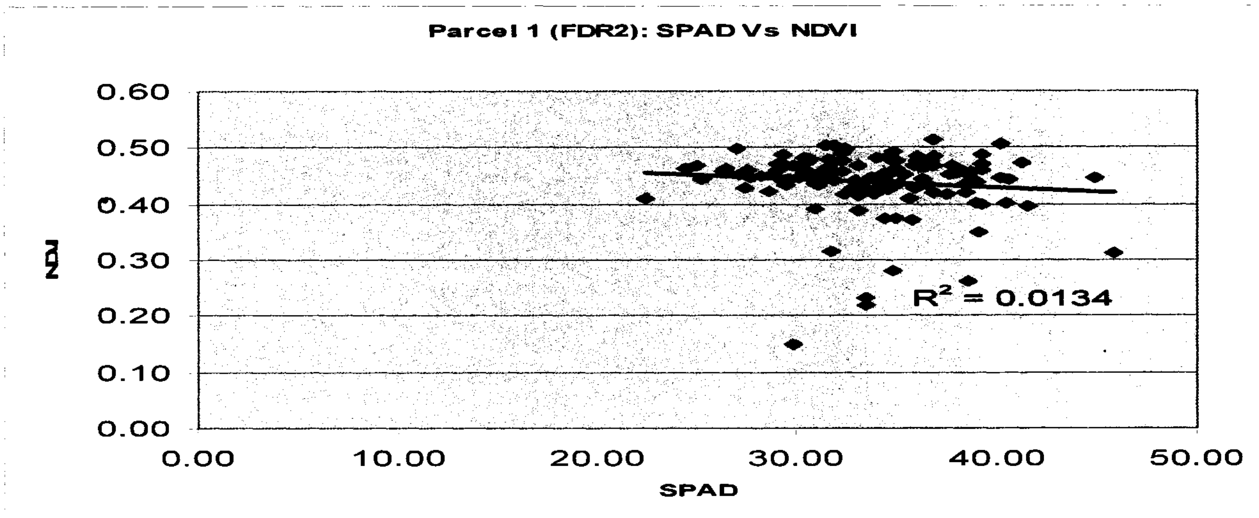
Furthermore the problem is compounded by the fact that SPAD readings are sensitive to leaf water status, time of measurement (morning vs. afternoon) as well changes in irradiance; One study showed that SPAD values varied by up to 4 units over the course of a day in the same well watered maize plants and that small changes in leaf water status and irradiance caused changes of 2-3 units. This becomes an issue because SPAD readings must be taken over a certain time period (the length of which depends on the size of the field) whereas NDVI readings are taken in 'one-shot'. This is very significant considering the narrow range of SPAD readings and one can see from Figure 4.17 that the greatest difference in SPAD readings from one field run to the next is within 8 units.

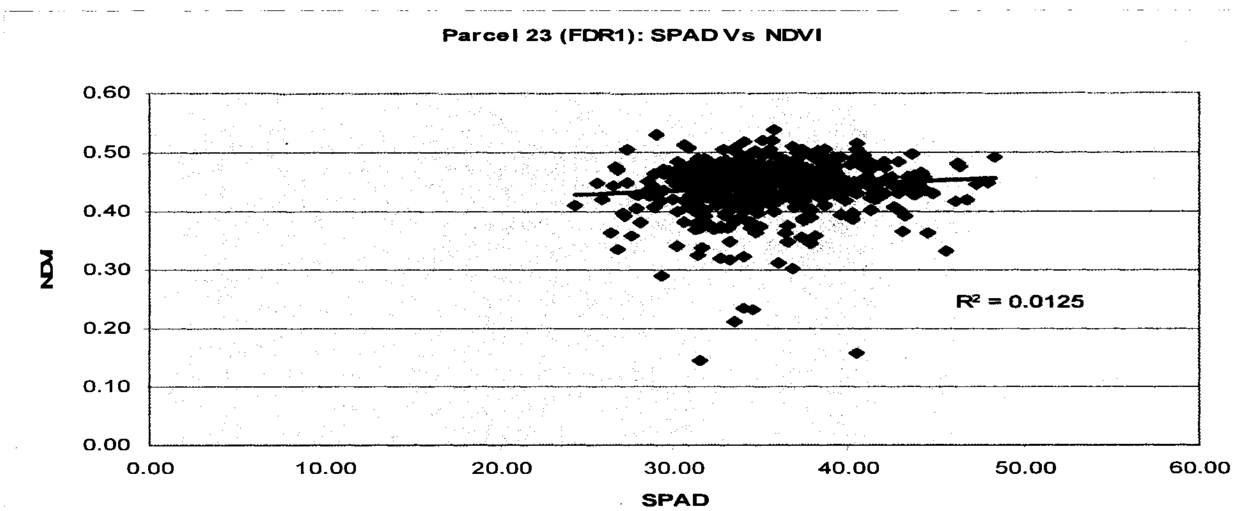
The use of point sampling analogous to using a very small treatment plot also limits the use of using Quickbird imagery in this study, as corroborated by another similar study (Wu, Wang et al. 2007). When correlations have been attempted between

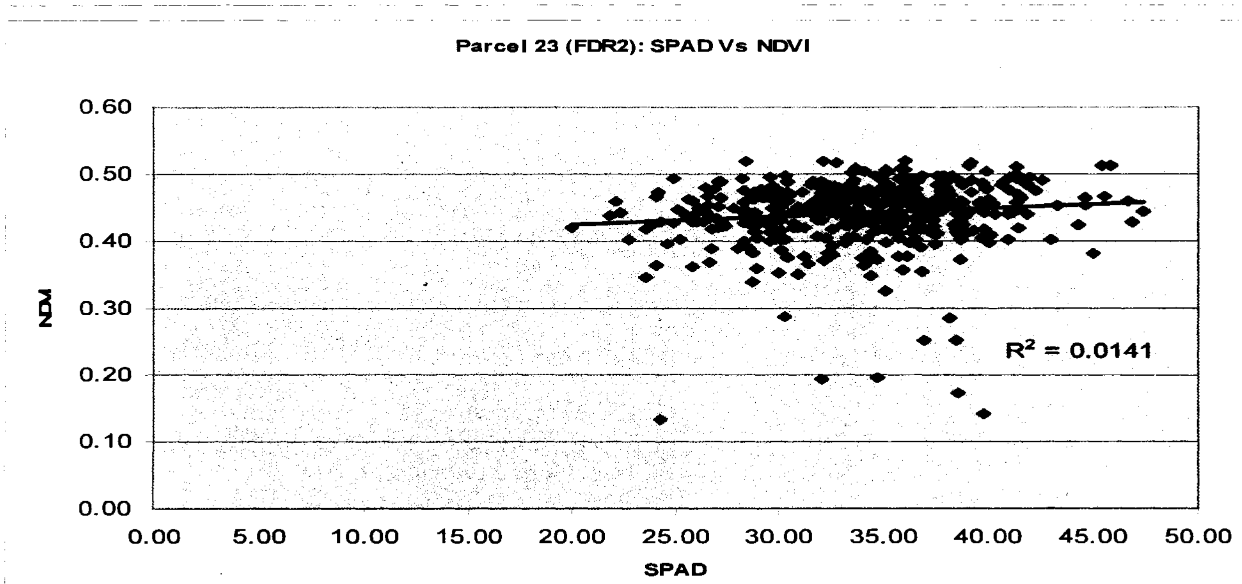
SPAD readings and aerial imagery for scientific purposes, treatment plots are created where usually at least 30 readings are taken per plot and at least 3 readings are taken per leaf in order to overcome SPAD variations, which implies over 90 readings are taken per plot (Le Bail, Jeuffroy et al. 2005). These findings are further confirmed by Australian researchers, that note that the link between remotely sensed data (such as NDVI) and crop biophysical parameters (such as leaf chlorophyll content) seem only to work in the context of research projects involving single or localized collection within fields (Lamb 2000) It is concluded that work remains to be done in correlating the information found in these images with ground-truth data such as plant chlorophyll readings from a SPAD meter, collected at the field scale for practical applications. Regardless, high resolution satellite imagery used to produce NDVI coverages, remains a very useful tool to visually identify nutrient deficient problem areas in the field.

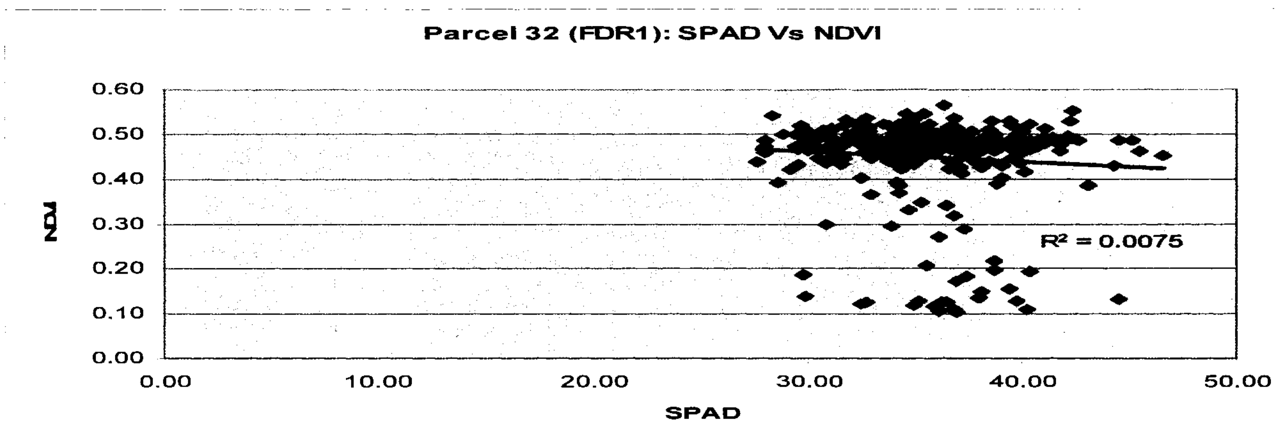
Fig 4.22: Correlation of plant chlorophyll (SPAD) with Spectral response (NDVI)



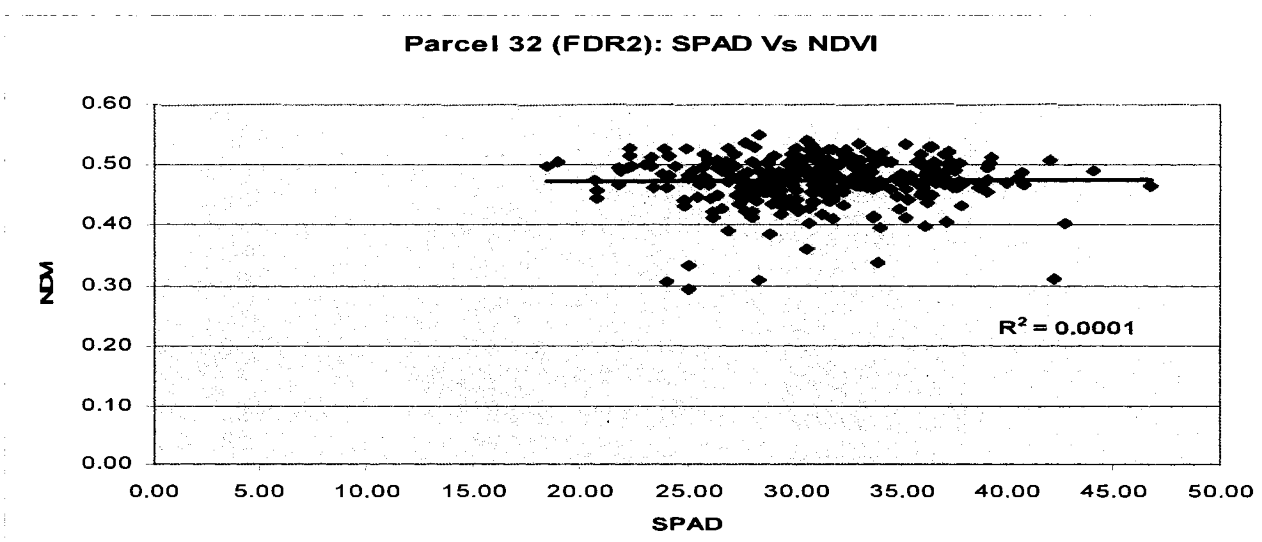

Parcel 1 (FDR2): SPAD Vs NDVI
0.60
0.50
0.40
0.30
0.20
0.10
0.00
NDVI
R² = 0.0134
0.00
10.00
20.00
30.00
40.00
50.00
SPAD


Parcel 23 (FDR1): SPAD Vs NDVI
0.60
0.50
0.40
0.30
0.20
0.10
0.00
NDVI
R² = 0.0125
0.00
10.00
20.00
30.00
40.00
50.00
60.00
SPAD


Parcel 23 (FDR2): SPAD Vs NDVI
0.60
0.50
0.40
0.30
0.20
0.10
0.00
NDVI
R² = 0.0141
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
SPAD



Parcel 32 (FDR1): SPAD Vs NDVI
0.60
0.50
0.40
0.30
0.20
0.10
0.00
NDVI
R² = 0.0075
0.00
10.00
20.00
30.00
40.00
50.00
SPAD



Parcel 32 (FDR2): SPAD Vs NDVI
0.60
0.50
0.40
0.30
0.20
0.10
0.00
NDVI
R² = 0.0001
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
SPAD

4.5 Precision Agriculture: implementation challenges and considerations for the future

Although much PA development and implementation has taken place in a 'high-tech' context in developed countries, the principles of PA are equally applicable to developing countries in which access to resources may be limited. Although investment in equipment such as the ground based monitoring tools used in this project, or high resolution satellite imagery may not be possible for many developing country producers, knowledge of environmental heterogeneity can certainly be used to adjust management with simpler means, without recourse to high-tech PA options, (Booltink, van Alphen et al. 2001) Furthermore, many developing countries, and at the least large scale producers within those countries *do* have access to the technologies required to make PA work. Far from being a luxury, the use of spatial information to reduce uncertainty is essential to accelerate change, promote economic development and reduce environmental impacts in the developing world (Cook, O'Brien et al. 2003).

The key to successful implementation of site-specific management in the global south is promoting access to resources and training (Kalluri, Gilruth et al. 2003). Furthermore, a Geographic Information System created for crop management is only as powerful as its users and in order for the system to be of use, it must be accessible to all farm managers and to those individuals directly involved with the management of inputs, so that local knowledge in spatial analysis and use of the software continues to evolve (Ramasubramanian 1999). For this reason, frequent meetings were held with all farm managers and administrators at the plantation on a regular basis during the creation of the initial database. The ultimate success of the project will depend on continued communication between as GIS users at the central office, farm managers and those workers directly applying inputs in the field.

Ultimately economic incentive will be the driving force for larger scale implementation and as discussed in Chapter 2, the incorporation of environmental costs into economic analysis will play an important role. Although the Panamanian government does not yet have legislation in place to control allowable pollutant concentrations in agricultural effluents, charging farmers for irrigation water is one step towards controlling excessive water use for irrigation purposes. Continued large scale efforts to put precision agriculture principles into practice have the potential to influence other countries in the region to adopt similar initiatives.

The International Center for Tropical Agriculture has also identified the potential value of spatial information in developing agriculture and assessed the reality of providing spatial information in developing countries (Cook, O'Brien et al. 2003). They conclude that although systems which rely on expensive sampling or monitoring may not always be appropriate, especially for smaller land-owners and subsistence farmers, management schemes which take into account local knowledge of environmental variance can be used to create larger management zones which can be administered accordingly. According to Maohua (2001), development should be an evolutionary process and it should be possible to demonstrate PA ideas in larger farms through agricultural technical extension systems with contact services to farmers even when local expertise are not directly available (Maohua 2001). Furthermore, donor funded programs have great potential to increase provision of spatial information to regional and national governments. In fact, some specific development initiatives aim to provide the basic infrastructure for more democratic knowledge sharing, such as the recent World Bank project to establish a platform GIS in Latin America (World Bank 2002).

Stafford (2000) identifies three important drivers that will provide the motivation for widespread uptake of precision agriculture; environmental legislation, traceability and public concern over farming practices. The fourth driver may be public aversion to genetic modification of crops whereby PA provides an alternative means to reduce and optimize the use agrochemicals (Stafford 2000). All of these studies demonstrate that the principle challenge of future worldwide PA adoption is therefore effective global information sharing, capacity building of PA related technologies and recognition and economic reward for PA environmental benefits.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The goal of this project was to establish a Geographic Information System for the management of crop information at the Azucarera Nacional sugarcane plantation in the Republic of Panama. In order to accomplish this, the first step was to create a base map of Mangote plantation with up-to-date boundaries of each parcel. Secondly, seven individual parcels on the farm were chosen and detailed field sampling was carried out on these parcels. This discrete data was interpolated using Geostatistical methods in order to create continuous coverages of two properties: soil conductivity and plant chlorophyll. The soil conductivity maps can be used as a tool to create salinity management zones. Issues concerning the change of salinity over time and over depth were explored. Two interpolation methods, IDW and OK, were then compared. Plant chlorophyll maps were constructed and their usefulness was discussed; the possible correlation between plant chlorophyll measurements and soil conductivity as well as NDVI was also explored. Finally, some of the challenges encountered during PA implementation were discussed and the several considerations related to future PA implementation were explored.

5.2 Conclusions

1. Creating digital maps of land holding is a promising tool for sugarcane crop management in Panama, particularly for creating a central system for resource management in general and for crop data management (storage and retrieval) in particular.
2. Thematic maps are a useful analysis tool in GIS to improve crop management, specifically for identifying contributions to low yield and for modeling management scenarios.
3. Parcels 1, 5 and 89 can be considered non-saline to slightly saline. Parcels 23, 113, 146 contain zones of slight, moderate and very high salinity; these parcels provide an example of the merit of creating management zones. Parcel 32 can be considered extremely saline.

4. There is sufficient soil salinity variation within some parcels studied to justify creation of soil salinity management zones.

5. Salinity management zones were relatively stable over the study period.

6. In general, the conductivity at a depth is higher than at the surface (EM 38 vertical readings are higher than EM 38 horizontal readings) for the study parcels. This implies that adequate leaching is, at this time, occurring and that salts are not accumulating at the surface, although longer periods of time must be studied in order to substantiate this.

7. The root mean square errors obtained using IDW as opposed to OK do not vary greatly (RMSE of 15.62 for IDW and 15.19 for OKTR) and hence it is recommended to use the simpler and more 'user-friendly' option of IDW for the purposes of creating raster coverages for PA application at the study site.

8. Plant chlorophyll maps reveal nitrogen deficiencies in five out of seven parcels (Parcels 23, 23, 113, and 146, as well as in parts of Parcel 1).

9. Plant chlorophyll readings show significant within parcel variability as well as variability over the study period.

10. Little to no spatial correlation was found between conductivity readings and plant chlorophyll readings although in general parcels with extreme salinity showed depressed chlorophyll values.

11. NDVI coverages derived from high resolution satellite imagery were deemed useful for the visual identification of plant stress. The chosen point sampling scheme for creating field-scale plant chlorophyll coverage using SPAD meter readings was shown to have little to no correlation with the NDVI coverages. As explained in section 4.4.3, this is likely due to the sensitivity of SPAD readings to a variety of factors as well as point sampling limitations.

12. Although PA implementation faces particular barriers in the developing country context, in the author's opinion increased environmental awareness and decreased costs will act as a facilitator for more widespread adoption.

5.3 Suggestions for Further Research

A vast amount of data was collected over the two years of field data collection. Due to time constraints, much of the data was not used for analysis purposes related to the current dissertation, however all of the data is available to the GIS user for future analysis and in order to build historical records. This data includes soil texture, pH, soil organic content, and soil micronutrients as well as soil conductivity and plant chlorophyll data that were interpolated but not presented directly for discussion. Furthermore, a thorough examination of the use of spectral indices using the high resolution Quickbird image should be undertaken and alternative sampling schemes explored. Sampling for other parcels should be sub-divided into zones in order to cut down on sampling time. Future investments at the plantation should include a yield monitor and a combine with GPS in order to collect 'on-the-go' soil conductivity readings. Climatic data should also be included on a regular basis in the system. Farmers in the area can also pool there resources in the future with other large land owners in order to purchase aerial imagery of the area. Training and collaborations should also continue between Universidad Tecnológica de Panama and the company.

ArcGIS is continually evolving as a tool for spatial analysis. ArcInfo 9.3 will offer the possibility of carrying out much more sophisticated regressions and comparisons between surfaces. Also, from within the ArcView Spatial Analyst extension it is possible to use the Avenue programming language, as well as ModelBuilder to explore various land use scenarios, based on the relationships between yield and other relevant mapped parameters, before actually implementing such scenarios on the field.

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A1 EM-38 1

Parcel	Decimo	Point	x	y	Vertical	Horizontal
1	1	1	545367	900507	76	71
1	1	2	545359	900504	69	71
1	1	3	545360	900500	77	71
1	2	1	545351	900483	78	75
1	2	2	545354	900474	71	74
1	2	3	545354	900467	60	64
1	3	1	545353	900395	61	61
1	3	2	545359	900404	71	69
1	3	3	545359	900418	66	64
1	4	1	545366	900426	67	66
1	4	2	545370	900438	68	64
1	4	3	545373	900445	65	63
1	5	1	545375	900450	62	61
1	5	2	545380	900456	63	65
1	5	3	545388	900469	67	66
1	6	1	545388	900482	69	69
1	6	2	545389	900491	73	65
1	6	3	545389	900502	68	66
1	7	1	545411	900480	73	66
1	7	2	545423	900477	73	65
1	7	3	545444	900474	71	66
1	8	1	545432	900443	68	65
1	8	2	545416	900443	69	68
1	8	3	545398	900460	76	68
1	9	1	545386	900421	65	64
1	9	2	545394	900415	71	70
1	9	3	545411	900408	64	61
1	10	1	545413	900391	64	61
1	10	2	545397	900393	68	61
1	10	3	545381	900400	63	62
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1	11	2	545365	900363	63	60
1	11	3	545384	900368	60	62
1	12	1	545383	900343	61	58
1	12	2	545373	900346	61	57
1	12	3	545365	900343	58	56
1	13	1	545365	900328	57	59
1	13	2	545376	900320	52	50
1	13	3	545374	900317	57	47
1	14	1	545386	900311	54	52
1	14	2	545392	900306	64	60
1	14	3	545398	900304	67	61
1	15	1	545424	900322	59	57
1	15	2	545415	900320	65	62
1	15	3	545396	900325	62	58
1	16	1	545398	900347	64	63

1	16	2	545413	900347	67	63
1	16	3	545427	900341	70	61
1	17	1	545443	900371	63	57
1	17	2	545435	900384	69	60
1	17	3	545423	900391	68	62
1	18	1	545432	900409	65	64
1	18	2	545438	900413	66	63
1	18	3	545453	900414	59	53
1	19	1	545463	900429	71	65
1	19	2	545450	900439	77	65
1	19	3	545438	900453	76	63
1	20	1	545448	900467	82	75
1	20	2	545465	900465	76	71
1	20	3	545467	900453	72	58
1	21	1	545477	900455	70	66
1	21	2	545492	900462	77	70
1	21	3	545511	900449	64	59
1	22	1	545510	900423	59	58
1	22	2	545482	900424	67	61
1	22	3	545476	900433	72	68
1	23	1	545465	900412	62	63
1	23	2	545472	900401	65	64
1	23	3	545485	900395	64	61
1	24	1	545477	900374	66	60
1	24	2	545462	900372	71	68
1	24	3	545450	900380	68	59
1	25	1	545438	900350	70	67
1	25	2	545459	900346	70	65
1	25	3	545465	900331	64	69
1	26	1	545459	900310	71	73
1	26	2	545441	900314	64	66
1	26	3	545431	900322	67	58
1	27	1	545470	900314	72	69
1	27	2	545478	900310	72	73
1	27	3	545501	900300	66	67
1	28	1	545514	900330	67	61
1	28	2	545501	900336	72	63
1	28	3	545487	900341	63	59
1	29	1	545488	900357	65	63
1	29	2	545502	900358	67	65
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1	30	2	545511	900381	70	62
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1	31	2	545531	900404	71	66
1	31	3	545535	900395	69	65
1	32	1	545551	900436	72	65

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1	32	3	545517	900442	67	55
1	33	1	545554	900429	68	70
1	33	2	545575	900412	72	71
1	33	3	545593	900410	76	64
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1	36	1	545557	900335	68	68
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1	37	3	545536	900299	62	67
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1	41	3	545596	900401	61	58
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1	46	3	545599	900323	67	64
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1	47	2	545601	900692	72	65
1	47	3	545610	900685	63	53
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1	57	2	545672	900269	69	61
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1	99	2	545010	900227	59	62
1	99	3	545016	900243	70	67
1	100	1	545019	900249	82	73
1	100	2	545019	900259	81	68
1	100	3	545021	900271	79	72

Parcel	Decimo	Point	x	y	Vertical	Horizontal
5	1	1	547034	899404	261	194
5	1	2	547037	899395	228	180
5	1	3	547037	899388	209	152
5	2	1	547040	899384	202	139

5	2	2	547045	899374	224	183
5	2	3	547051	899347	188	141
5	3	1	547051	899338	167	129
5	3	2	547053	899321	171	133
5	3	3	547060	899301	200	146
5	4	1	547064	899291	180	130
5	4	2	547063	899277	161	121
5	4	3	547067	899249	210	153
5	5	1	547073	899244	220	166
5	5	2	547076	899227	208	163
5	5	3	547084	899206	178	141
5	6	1	547085	899201	160	119
5	6	2	547090	899189	130	104
5	6	3	547098	899163	128	100
5	7	1	547098	899153	134	106
5	7	2	547100	899132	136	120
5	7	3	547106	899115	111	80
5	8	1	547105	899109	101	90
5	8	2	547110	899091	94	80
5	8	3	547113	899073	80	61
5	9	1	547115	899062	78	71
5	9	2	547121	899041	79	72
5	9	3	547124	899020	67	69
5	10	1	547130	899008	67	64
5	10	2	547129	898989	63	63
5	10	3	547140	898977	80	71
5	11	1	547141	898968	51	54
5	11	2	547140	898945	60	59
5	11	3	547151	898923	62	62
5	12	1	547125	898899	56	57
5	12	2	547119	898924	57	58
5	12	3	547121	898942	54	53
5	13	1	547121	899951	63	64
5	13	2	547118	898970	62	73
5	13	3	547115	898996	62	60
5	14	1	547112	899002	68	71
5	14	2	547100	899020	64	64
5	14	3	547099	899035	75	65
5	15	1	547094	899045	81	68
5	15	2	547088	899061	93	76
5	15	3	547092	899084	90	73
5	16	1	547085	899096	92	74
5	16	2	547079	899112	74	64
5	16	3	547074	899128	73	66
5	17	1	547072	899166	79	70
5	17	2	547069	899151	110	92
5	17	3	547060	899171	117	89

5	18	1	547059	899184	140	101
5	18	2	547057	899204	147	116
5	18	3	547052	899222	144	107
5	19	1	547050	899227	152	112
5	19	2	547045	899244	172	122
5	19	3	547045	899273	176	138
5	20	1	547042	899279	212	158
5	20	2	547034	899296	219	170
5	20	3	547029	899310	150	119
5	21	1	547029	899618	152	113
5	21	2	547025	899640	142	106
5.	21	3	547021	899361	112	87
5	22	1	547017	899369	122	89
5	22	2	547011	899390	132	103
5	22	3	547001	899406	147	118
5	23	1	546988	899380	77	65
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5	23	3	547000	899345	97	71
5	24	1	547002	899343	119	89
5	24	2	547005	899323	123	92
5	24	3	547014	899301	125	91
5	25	1	57020	899250	135	106
5	25	2	547021	899271	138	100
5	25	3	547033	899263	124	97
5	26	1	547027	899250	131	90
5	26	2	547032	899226	164	118
5	26	3	547031	899204	99	74
5	27	1	547036	899204	98	77
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5	27	3	547042	899160	73	65
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5	28	2	547053	899136	66	59
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5	29	1	547062	899114	60	55
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5	30	2	547073	899042	72	60
5	30	3	547078	899022	58	59
5	31	1	547080	899016	59	54
5	31	2	547087	899000	61	52
5	31	3	547088	8998975	60	62
5	32	1	547091	898967	62	60
5	32	2	547094	898948	60	58
5	32	3	547100	898937	66	62
5	33	1	547101	898923	52	55
5	33	2	547107	898903	55	60

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5	34	2	547079	898891	62	60
5	34	3	547085	898901	56	58
5	35	1	547084	898906	59	60
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5	35	3	547070	898941	62	56
5	36	1	547068	898948	60	57
5	36	2	547065	898967	62	62
5	36	3	547063	898993	55	59
5	37	1	547058	898999	61	53
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5	37	3	547049	899036	59	51
5	38	1	547045	899045	65	57
5	38	2	547041	899066	67	64
5	38	3	547042	899091	66	63
5	39	1	547037	899096	93	67
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5	39	3	547025	899131	89	72
5	40	1	547024	899136	69	63
5	40	2	547020	899153	73	63
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5	41	2	547008	899199	73	65
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5	43	2	546984	899295	79	74
5	43	3	546981	899317	79	63
5	44	1	546980	899342	85	69
5	44	2	546978	899335	119	94
5	44	3	546975	899344	135	101
5	45	1	546956	899293	61	55
5	45	2	546963	899275	69	67
5	45	3	546969	899258	61	59
5	46	1	546973	899253	58	53
5	46	2	546979	899235	72	60
5	46	3	546985	899216	60	59
5	47	1	546983	899207	62	55
5	47	2	546985	899189	72	69
5	47	3	546993	899169	61	52
5	48	1	546996	899160	63	54
5	48	2	546999	899141	64	72
5	48	3	547006	899110	96	71
5	49	1	547011	899111	102	77

5	49	2	547012	899094	88	69
5	49	3	547015	899069	76	62
5	50	1	547017	899066	64	57
5	50	2	547018	899045	64	55
5	50	3	547029	899028	52	48
5	51	1	547032	899023	53	50
5	51	2	547035	898002	59	58
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5	53	1	547052	898922	61	50
5	53	2	547057	898900	65	64
5	53	3	547061	898882	61	57
5	54	1	547064	898877	59	61
5	54	2	547067	898862	58	55
5	54	3	547066	898856	49	47
5	55	1	546932	898269	92	74
5	55	2	546936	898263	102	82
5	55	3	546947	898247	103	80
5	56	1	546953	898238	117	86
5	56	2	546958	898227	113	93
5	56	3	546964	898200	100	76
5	57	1	546962	898193	103	86
5	57	2	546966	898179	84	73
5	57	3	546967	898162	98	78
5	58	1	546973	898150	91	78
5	58	2	546984	898125	98	80
5	58	3	546987	898091	97	81
5	59	1	546977	898080	89	69
5	59	2	546981	898059	83	73
5	59	3	546988	898046	71	62
5	60	1	546992	898042	79	66
5	60	2	546997	898026	66	60
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5	61	1	547003	898995	61	54
5	61	2	547009	898978	53	54
5	61	3	547010	898969	65	60
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5	62	2	547019	898942	49	44
5	62	3	547022	898919	53	53
5	63	1	547029	898912	47	42
5	63	2	547037	898889	59	53
5	63	3	547036	898868	55	53
5	64	1	547038	898863	65	61
5	64	2	547042	898857	62	57
5	65	1	546973	899097	80	75

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5	66	1	546961	899135	77	159
5	66	2	546949	899159	98	76
5	66	3	546943	899170	89	74
5	67	1	546938	899179	83	70
5	67	2	546939	899186	73	63
5	67	3	546933	899208	91	75
5	68	1	546932	899220	85	72
5	68	2	546917	899236	104	80
5	68	3	546910	899244	100	82

Parcel	Decimo	Point	x	y	Vertical	Horizontal
23	1	1	546314	901499	73	75
23	1	2	546324	901500	71	78
23	1	3	546333	901502	74	88
23	2	1	546352	901509	81	84
23	2	2	546360	901521	105	98
23	2	3	546367	901526	103	102
23	3	1	546389	901531	111	131
23	3	2	546397	901539	122	126
23	3	3	546409	901541	126	138
23	4	1	546424	901548	173	131
23	4	2	546435	901556	170	178
23	4	3	546446	901561	169	149
23	5	1	546463	901566	178	174
23	5	2	546472	901569	179	153
23	5	3	546488	901578	169	135
23	6	1	546498	901587	156	140
23	6	2	546521	901586	167	149
23	6	3	546530	901587	164	140
23	7	1	546546	901593	198	166
23	7	2	546554	901598	186	191
23	7	3	546566	901604	169	152
23	8	1	546576	901609	178	160
23	8	2	546588	901616	174	171
23	8	3	546601	901622	152	159
23	9	1	546614	901632	169	149
23	9	2	546627	901641	171	143
23	9	3	546642	901644	162	157
23	10	1	546649	901650	168	152
23	10	2	546657	901649	175	155
23	10	3	546665	901655	165	144
23	11	1	546649	901672	171	147
23	11	2	546641	901668	185	156
23	11	3	546632	901663	160	149
23	12	1	546618	901658	165	162

23	12	2	546605	901653	175	139
23	12	3	546591	901647	149	142
23	13	1	546584	901642	171	156
23	13	2	546575	901637	163	156
23	13	3	546557	901629	175	149
23	14	1	546542	901627	171	147
23	14	2	546533	901621	162	147
23	14	3	546520	901614	160	132
23	15	1	546505	901611	172	150
23	15	2	546492	901607	147	125
23	15	3	546479	901599	170	154
23	16	1	546469	901593	147	123
23	16	2	546454	901589	176	138
23	16	3	546433	901579	138	115
23	17	1	546427	901575	156	132
23	17	2	546413	901567	172	149
23	17	3	546398	901562	168	173
23	18	1	546393	901556	150	177
23	18	2	546377	901549	122	139
23	18	3	546361	901544	115	115
23	19	1	546355	901540	86	80
23	19	2	546344	901531	82	84
23	19	3	546323	901527	181	177
23	20	1	546313	901522	74	84
23	20	2	546297	901516	63	77
23	20	3	546285	901511	54	57
23	21	1	546267	901533	59	68
23	21	2	546287	901542	114	120
23	21	3	546297	901546	92	84
23	22	1	546305	901550	87	79
23	22	2	546317	901562	145	163
23	22	3	546328	901570	142	170
23	23	1	546341	901575	141	126
23	23	2	546355	901580	160	136
23	23	3	546363	901587	127	106
23	24	1	546377	901580	142	111
23	24	2	546386	901594	141	117
23	24	3	546405	901602	165	142
23	25	1	546414	901605	159	133
23	25	2	546427	901610	187	170
23	25	3	546442	901618	160	143
23	26	1	546454	901622	161	145
23	26	2	546469	901626	141	130
23	26	3	546482	901635	132	115
23	27	1	546490	901639	133	117
23	27	2	546501	901646	138	119
23	27	3	546518	901654	140	127

23	28	1	546527	901654	142	132
23	28	2	546542	901659	146	132
23	28	3	546560	901664	150	130
23	29	1	546575	901670	138	133
23	29	2	546587	901667	155	129
23	29	3	546594	901687	141	127
23	30	1	546606	901689	146	113
23	30	2	546615	901696	138	123
23	30	3	546619	901701	126	123
23	31	1	546604	901713	137	116
23	31	2	546593	901710	147	123
23	31	3	546586	901707	132	110
23	32	1	546578	901703	142	130
23	32	2	546572	901699	143	127
23	32	3	546551	901690	151	125
23	33	1	546539	901690	142	130
23	33	2	546524	901682	147	137
23	33	3	546514	901674	137	139
23	34	1	546463	901549	154	137
23	34	2	546448	901641	138	138
23	34	3	546433	901639	144	148
23	35	1	546503	901669	146	133
23	35	2	546490	901661	154	143
23	35	3	546474	901656	144	145
23	36	1	546426	901634	138	121
23	36	2	546414	901628	163	138
23	36	3	546396	901624	161	145
23	37	1	546385	901619	157	137
23	37	2	546375	901612	142	125
23	37	3	546354	901608	143	111
23	38	1	546348	901601	131	105
23	38	2	546334	901597	150	121
23	38	3	546320	901592	122	104
23	39	1	546311	901582	118	97
23	39	2	546297	901583	141	127
23	39	3	546279	901576	153	138
23	40	1	546272	901569	170	160
23	40	2	546256	901558	177	158
23	40	3	546250	901554	143	125
23	41	1	546223	901579	131	114
23	41	2	546239	901590	117	105
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23	42	1	546259	901596	93	88
23	42	2	546272	901600	101	97
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23	43	1	546300	901610	108	94
23	43	2	546306	901615	126	109

23	43	3	546324	901626	146	113
23	44	1	546332	901632	173	139
23	44	2	546349	901639	162	140
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23	45	2	546389	901652	125	122
23	45	3	546405	901656	130	111
23	46	1	546414	901661	122	118
23	46	2	546429	901663	137	135
23	46	3	546449	901668	135	112
23	47	1	546454	901677	124	104
23	47	2	546460	901688	119	108
23	47	3	546481	901692	117	114
23	48	1	546487	901701	101	98
23	48	2	546499	901707	102	102
23	48	3	546520	901711	114	111
23	49	1	546520	901718	106	88
23	49	2	546539	901725	108	111
23	49	3	546555	901730	106	98
23	50	1	546561	901735	108	97
23	50	2	546572	901733	121	110
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23	54	2	546447	901710	105	95
23	54	3	546429	901705	92	81
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23	55	2	546407	901696	87	89
23	55	3	546387	901690	73	75
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23	57	1	546349	901661	111	95
23	57	2	546335	901658	110	93
23	57	3	546315	901651	143	123
23	58	1	546308	901650	142	135
23	58	2	546393	901643	136	124
23	58	3	546274	901637	121	99
23	59	1	546268	901635	110	97

23	59	2	546256	901627	111	96
23	59	3	546239	901610	130	109
23	60	1	546263	901609	127	113
23	60	2	546218	901607	91	91
23	60	3	546203	901603	85	95
23	61	1	546183	901619	91	86
23	61	2	546201	901623	124	111
23	61	3	546318	901624	116	100
23	62	1	546216	901637	155	131
23	62	2	546230	901640	104	96
23	62	3	546247	901650	126	108
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23	67	1	546408	901718	74	73
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23	68	1	546445	901739	88	82
23	68	2	546459	901746	89	85
23	68	3	546475	901754	90	87
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23	69	2	546499	901777	104	100
23	69	3	546514	901779	100	93
23	70	1	546520	901775	100	103
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23	72	3	546470	901782	82	83
23	73	1	546457	901775	88	80
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23	74	3	546327	901745	76	71

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23	75	2	546366	901734	73	91
23	75	3	546349	901726	65	85
23	76	1	546340	901723	74	78
23	76	2	546320	901714	87	92
23	76	3	546310	901710	85	90
23	77	1	546302	901708	73	82
23	77	2	546290	901702	76	75
23	77	3	546273	901693	85	86
23	78	1	546265	901686	96	99
23	78	2	546250	901680	117	114
23	78	3	546235	901675	93	93
23	79	1	546227	901681	92	87
23	79	2	546210	901666	111	105
23	79	3	546195	901691	100	93
23	80	1	546190	901657	130	118
23	80	2	546170	901650	162	138
23	80	3	546157	901644	164	142
23	81	1	546139	901662	161	130
23	81	2	546153	901669	116	110
23	81	3	546167	901675	105	95
23	82	1	546178	901680	103	94
23	82	2	546191	901685	89	92
23	82	3	546208	901691	38	50
23	83	1	546213	901694	46	55
23	83	2	546230	901702	44	53
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23	84	1	546255	901713	60	64
23	84	2	546267	901721	54	64
23	84	3	546279	901728	60	64
23	85	1	546284	901732	60	64
23	85	2	546301	901737	69	72
23	85	3	546320	901745	70	73
23	86	1	546327	901752	73	72
23	86	2	546348	901757	76	74
23	86	3	546356	901771	73	73
23	87	1	546374	901777	73	72
23	87	2	546380	901775	80	82
23	87	3	546393	901781	76	74
23	88	1	546401	901784	75	75
23	88	2	546417	901789	86	84
23	88	3	546435	901779	85	79
23	89	1	546444	901801	89	80
23	89	2	546457	901806	77	76
23	89	3	546471	901816	82	78
23	90	1	546477	901820	78	75
23	90	2	546495	901825	95	91

23	90	3	546499	901827	101	89
23	91	1	546481	901844	108	102
23	91	2	546486	901842	105	97
23	91	3	546472	901840	77	85
23	92	1	546453	901837	83	76
23	92	2	546440	901830	77	79
23	92	3	546424	901822	73	72
23	93	1	546416	901816	83	79
23	93	2	546298	901810	83	86
23	93	3	546386	901801	72	68
23	94	1	546372	901881	88	92
23	94	2	546361	901794	77	76
23	94	3	546347	901788	70	79
23	95	1	546335	901784	71	77
23	95	2	546323	901776	65	72
23	95	3	546310	901778	56	58
23	96	1	546304	901773	64	62
23	96	2	546288	901758	68	69
23	96	3	546271	901752	63	57
23	97	1	546273	901747	58	60
23	97	2	546250	901741	71	77
23	97	3	546233	901737	63	70
23	98	1	546227	901733	36	48
23	98	2	546209	901722	36	45
23	98	3	546193	901720	47	54
23	99	1	546187	901713	53	57
23	99	2	546175	901707	58	75
23	99	3	546159	901701	85	78
23	100	1	546149	901696	95	57
23	100	2	546136	901688	112	95
23	100	3	546121	901683	127	107
23	101	1	546100	901706	75	75
23	101	2	546115	901716	74	70
23	101	3	546126	901722	53	70
23	102	1	546135	901728	80	82
23	102	2	546151	901734	100	92
23	102	3	546165	901739	105	94
23	103	1	546174	901744	103	183
23	103	2	546186	901749	113	101
23	103	3	546202	901758	108	97
23	104	1	546210	901773	115	103
23	104	2	546223	901775	101	94
23	104	3	546238	901775	117	107
23	105	1	546244	901780	130	112
23	105	2	546259	901784	125	108
23	105	3	546278	901794	93	82
23	106	1	546285	901796	101	87

23	106	2	546296	901800	121	109
23	106	3	546315	901810	111	107
23	107	1	546319	901813	127	111
23	107	2	546336	901821	121	124
23	107	3	546350	901828	124	115
23	108	1	546374	901830	118	109
23	108	2	546376	901834	135	120
23	108	3	546392	901840	119	104
23	109	1	546398	901845	125	104
23	109	2	546413	901850	111	101
23	109	3	546429	901860	97	83
23	110	1	546438	901861	90	73
23	110	2	546447	901879	90	79
23	110	3	546456	901881	90	89
23	111	1	546437	901892	112	104
23	111	2	546428	901886	125	127
23	111	3	546422	901884	105	88
23	112	1	546414	901880	107	96
23	112	2	546400	901872	120	100
23	112	3	546381	901875	100	86
23	113	1	546375	901881	108	82
23	113	2	546354	901885	108	100
23	113	3	546344	901848	91	108
23	114	1	546333	901844	123	110
23	114	2	546324	901842	124	104
23	114	3	546304	901834	128	103
23	115	1	546298	901829	125	110
23	115	2	546288	901822	116	99
23	115	3	546272	901810	108	96
23	116	1	546266	901808	132	106
23	116	2	546250	901803	139	115
23	116	3	546232	901795	130	107
23	117	1	546222	901794	140	117
23	117	2	546207	901785	140	117
23	117	3	546192	901780	130	113
23	118	1	546184	901776	137	103
23	118	2	546178	901779	127	107
23	118	3	546151	901770	101	87
23	119	1	546152	901756	92	87
23	119	2	546137	901755	94	96
23	119	3	546119	901743	87	72
23	120	1	546112	901739	90	69
23	120	2	546102	901737	70	77
23	120	3	546089	901727	73	80
23	121	1	546058	901750	112	95
23	121	2	546075	901758	117	108
23	121	3	546086	901764	105	97

23	122	1	546089	901767	110	94
23	122	2	546107	901771	139	120
23	122	3	546126	901780	129	101
23	123	1	546131	901784	131	105
23	123	2	546143	901793	137	121
23	123	3	546158	901798	146	113
23	124	1	546162	901803	137	107
23	124	2	546178	901806	171	144
23	124	3	546203	901817	138	110
23	125	1	546205	901822	137	105
23	125	2	546219	901827	174	138
23	125	3	546237	901834	152	115
23	126	1	546244	901839	167	130
23	126	2	546253	901844	155	121
23	126	3	546268	901856	136	107
23	127	1	546279	901861	141	107
23	127	2	546293	901862	168	143
23	127	3	546313	901869	138	106
23	128	1	546319	901873	134	106
23	128	2	546331	901880	110	102
23	128	3	546346	901892	95	86
23	129	1	546357	901890	98	100
23	129	2	546373	901896	174	135
23	129	3	546384	901908	147	120
23	130	1	546394	901907	160	123
23	130	2	546399	901904	160	125
23	130	3	546414	901913	216	151
23	130	4	546410	901919	329	247
23	130	5	546409	901918	326	246
23	130	6	546410	901913	231	182
23	131	1	546392	901936	347	312
23	131	2	546389	901938	381	300
23	131	3	546389	901937	418	333
23	131	4	546376	901937	428	327
23	131	5	546376	901927	346	253
23	132	1	546371	901923	349	256
23	132	2	546356	901920	280	197
23	132	3	546341	901910	119	92
23	133	1	546332	901904	119	102
23	133	2	546319	901897	104	97
23	133	3	546301	901889	110	93
23	134	1	546299	901887	118	102
23	134	2	546285	901881	116	96
23	134	3	546362	901873	112	90
23	135	1	546260	901869	109	90
23	135	2	546249	901865	127	107
23	135	3	546228	901854	149	118

23	136	1	546219	901822	145	116
23	136	2	546210	901849	161	117
23	136	3	546186	901840	146	113
23	137	1	546183	901839	151	120
23	137	2	546164	901831	163	138
23	137	3	546149	901826	148	112
23	138	1	546143	901822	140	110
23	138	2	546130	901819	123	102
23	138	3	546109	901810	163	123
23	139	1	546107	901805	148	113
23	139	2	546095	901798	133	106
23	139	3	546076	901790	153	126
23	140	1	546070	901784	157	119
23	140	2	546053	901775	143	115
23	140	3	546043	901766	119	100
23	141	1	546022	901791	100	81
23	141	2	546034	901805	152	123
23	141	3	546042	901809	117	105
23	142	1	546049	901811	134	108
23	142	2	546061	901815	164	139
23	142	3	546078	901826	166	119
23	143	1	546083	901829	163	123
23	143	2	546105	901834	155	1120
23	143	3	546122	901840	135	114
23	144	1	546127	901842	121	97
23	144	2	546138	901848	127	173
23	144	3	546161	901855	162	122
23	145	1	546165	901859	169	123
23	145	2	546181	901868	159	124
23	145	3	546194	901874	145	114
23	146	1	546199	901878	140	117
23	146	2	546216	901880	171	136
23	146	3	546234	901890	151	109
23	147	1	546234	901895	115	93
23	147	2	546258	901903	68	73
23	147	3	546268	901912	118	95
23	148	1	546276	901917	154	117
23	148	2	546292	901925	268	203
23	148	3	546299	901931	275	207
23	149	1	546258	901928	116	97
23	149	2	546239	901924	115	96
23	149	3	546225	901917	105	83
23	150	1	546216	901912	119	94
23	150	2	546202	901909	136	106
23	150	3	546185	901898	140	116
23	151	1	546179	901893	144	111
23	151	2	546164	901887	174	143

23	151	3	546148	901879	146	117
23	152	1	546141	901877	132	104
23	152	2	546125	901873	145	114
23	152	3	546107	901865	146	113
23	153	1	546100	901865	174	124
23	153	2	546084	901856	180	132
23	153	3	546070	901849	132	107
23	154	1	546064	901847	144	109
23	154	2	546052	901841	117	95
23	154	3	546032	901829	117	93
23	155	1	546028	901824	134	100
23	155	2	546016	901821	130	104
23	155	3	546000	901818	94	75
23	156	1	545975	901833	82	70
23	156	2	545985	901842		80
23	156	3	546000	901852		89
23	157	1	546006	901856	106	88
23	157	2	546015	901860	108	89
23	157	3	546036	901867	96	80
23	158	1	546043	901871	90	78
23	158	2	546062	901875	146	110
23	158	3	546079	901886	123	100
23	159	1	546081	901890	118	97
23	159	2	546103	901898	92	76
23	159	3	546115	901903	76	68
23	160	1	546120	901907	81	78
23	160	2	546130	901911	106	90
23	160	3	546148	901921	107	87
23	161	1	546155	901930	86	74
23	161	2	546164	901931	83	72
23	161	3	546192	901936	99	87
23	162	1	546138	901929	120	85
23	162	2	546126	901925	110	94
23	162	3	546114	901923	125	99
23	163	1	546103	901917	106	86
23	163	2	546082	901911	101	85
23	163	3	546069	901905	89	72
23	164	1	546063	901903	91	82
23	164	2	546044	901896	95	85
23	164	3	546028	901892	84	78
23	165	1	546084	901829	93	80
23	165	2	546009	901883	81	76
23	165	3	545995	901875	161	128
23	166	1	545985	901870	167	122
23	166	2	545972	901863	200	149
23	166	3	545950	901856	183	127
23	130	1	546374	901934	385	290

23	130	2	546383	901939	405	344

Parcel	Decimo	Point	x	y	Vertical	Horizontal
32	1	1	545910	901932	189	129
32	1	2	545928	901935	226	169
32	1	3	545945	901937	239	180
32	2	1	545962	901996	234	160
32	2	2	545951	901998	258	171
32	2	3	545928	902000	246	170
32	3	1	545941	902056	241	160
32	3	2	545960	902050	241	160
32	3	3	545975	902047	250	171
32	4	1	545998	902094	264	170
32	4	2	545980	902103	272	183
32	4	3	545971	902108	177	182
32	5	1	545959	902160	296	200
32	5	2	545970	902158	288	187
32	5	3	545981	902151	249	172
32	6	1	545982	902226	284	185
32	6	2	545986	902209	267	180
32	6	3	545977	902213	250	169
32	7	1	545974	902266	299	214
32	7	2	545989	902268	266	180
32	7	3	546012	902265	255	182
32	8	1	546022	902325	274	183
32	8	2	546013	902329	250	160
32	8	3	545992	902328	237	179
32	9	1	545998	902368	273	196
32	9	2	546016	902379	245	163
32	9	3	546027	902372	150	106
32	10	1	546042	902438	254	168
32	10	2	546032	902439	208	144
32	10	3	546015	902436	96	72
32	11	1	546017	902493	236	169
32	11	2	546034	902489	225	155
32	11	3	546052	902485	241	162
32	12	1	546064	902481	287	191
32	12	2	546077	902478	299	201
32	12	3	546092	902475	213	144
32	13	1	546088	902484	256	175
32	13	2	546075	902421	299	203
32	13	3	546065	902419	244	170
32	14	1	546038	902361	106	77
32	14	2	546053	902362	172	123
32	14	3	546072	902361	247	173
32	15	1	546059	902367	280	188
32	15	2	546051	902309	294	191

32	15	3	546045	902315	230	163
32	16	1	546021	902256	260	188
32	16	2	546038	902250	286	196
32	16	3	546049	902251	285	191
32	17	1	546038	902206	297	199
32	17	2	546021	902207	282	193
32	17	3	546055	902210	270	182
32	18	1	545990	902163	250	174
32	18	2	546006	902149	243	166
32	18	3	546029	902143	277	188
32	19	1	546021	902106	248	176
32	19	2	546014	902104	277	179
32	19	3	545988	902103	242	174
32	20	1	545966	902042	247	163
32	20	2	545994	902038	247	169
32	20	3	546016	902038	231	266
32	21	1	545993	901984	249	169
32	21	2	545986	901983	230	156
32	21	3	545975	901987	208	132
32	22	1	545960	901941	189	143
32	22	2	545974	901942	200	140
32	22	3	545986	901948	195	132
32	23	1	545999	901953	174	143
32	23	2	546009	901952	182	155
32	23	3	546035	901957	209	147
32	24	1	546049	902022	252	172
32	24	2	546033	902031	222	148
32	24	3	546021	902035	208	150
32	25	1	546031	902091	210	157
32	25	2	546056	902085	262	185
32	25	3	546069	902083	272	183
32	26	1	546071	902139	248	170
32	26	2	546059	902143	239	159
32	26	3	546044	902147	213	150
32	27	1	546050	902208	299	180
32	27	2	546065	902203	268	169
32	27	3	546075	902201	272	190
32	28	1	546095	902252	272	191
32	28	2	546076	902254	279	174
32	28	3	546062	902258	62	258
32	29	1	546079	902309	291	200
32	29	2	546095	902307	300	202
32	29	3	546108	902302	216	195
32	30	1	546106	902353	278	190
32	30	2	546096	902360	262	182
32	30	3	546083	902364	248	166
32	31	1	546095	902413	282	191

32	31	2	546111	902419	298	195
32	31	3	546128	902419	284	202
32	32	1	546141	902488	225	147
32	32	2	546113	902495	136	92
32	32	3	546095	902281	218	141
32	33	1	546196	902459	271	193
32	33	2	546195	902471	115	90
32	33	3	546177	902468	175	122
32	34	1	546128	902413	225	153
32	34	2	546138	902419	88	64
32	34	3	546158	902415	239	151
32	35	1	546162	902365	247	168
32	35	2	546136	902361	146	114
32	35	3	546120	902358	242	153
32	36	1	546092	902297	248	163
32	36	2	546118	902303	158	116
32	36	3	546132	902302	145	110
32	37	1	546126	902247	248	166
32	37	2	546105	902244	255	167
32	37	3	546087	902245	270	189
32	38	1	546086	902181	141	162
32	38	2	546106	902188	295	204
32	38	3	546123	902190	250	163
32	39	1	546108	902134	251	169
32	39	2	546093	902137	260	290
32	39	3	546080	902140	251	166
32	40	1	546061	902086	261	180
32	40	2	546080	902085	268	188
32	40	3	546091	902082	251	170
32	41	1	546086	902015	229	159
32	41	2	546081	902022	225	162
32	41	3	546064	902027	249	175
32	42	1	546039	901963	227	152
32	42	2	546050	901964	209	143
32	42	3	546082	901970	230	144
32	43	1	546121	902031	274	31
32	43	2	546128	902034	294	34
32	43	3	546130	902040	294	205
32	44	1	546131	902027	236	166
32	44	2	546109	902030	221	156
32	44	3	546094	902036	200	146
32	45	1	546116	902081	229	149
32	45	2	546123	902084	246	171
32	45	3	546140	902085	243	170
32	46	1	546155	902132	267	179
32	46	2	546137	902035	151	174
32	46	3	546117	902025	272	187

32	47	1	546132	902189	238	158
32	47	2	546146	902184	242	177
32	47	3	546160	902177	245	171
32	48	1	546140	902246	258	170
32	48	2	546156	902242	255	173
32	48	3	546166	902243	243	168
32	49	1	546184	902293	282	199
32	49	2	546170	902295	254	175
32	49	3	546145	902309	215	145
32	50	1	546166	902355	278	176
32	50	2	546180	902352	281	196
32	50	3	546197	902350	296	203
32	51	1	546204	902408	279	197
32	51	2	546181	902408	240	174
32	51	3	546168	902411	249	159
32	52	1	546195	902469	182	135
32	52	2	546205	902465	176	132
32	52	3	546214	902465	179	140
32	53	1	546239	902536	279	184
32	53	2	546226	902501	308	198
32	53	3	546222	902460	317	195
32	54	1	546221	902455	301	198
32	54	2	546217	902426	229	172
32	54	3	546212	902403	260	164
32	55	1	546211	902402	264	170
32	55	2	546204	902282	282	175
32	55	3	546199	902347	280	173
32	56	1	546197	902338	294	175
32	56	2	546195	902324	270	179
32	56	3	546187	902291	280	169
32	57	1	546185	902290	254	161
32	57	2	546182	902265	173	122
32	57	3	546178	902237	228	151
32	58	1	546175	902229	225	138
32	58	2	546166	902208	182	136
32	58	3	546164	902181	258	164
32	59	1	546163	902172	279	167
32	59	2	546158	902153	245	165
32	59	3	546153	902129	250	164
32	60	1	546151	902125	257	169
32	60	2	546148	902107	244	155
32	60	3	546143	902073	237	164
32	61	1	546141	902065	245	154
32	61	2	546127	902026	242	158
32	61	3	546124	901982	195	136
32	62	1	546171	901990	168	126
32	62	2	546166	902023	202	134

32	62	3	546172	902056	210	144
32	63	1	546173	902062	212	152
32	63	2	546179	902084	223	153
32	63	3	546187	902113	207	152
32	64	1	546187	902119	204	143
32	64	2	546191	902145	220	155
32	64	3	546198	902173	201	134
32	65	1	546196	902179	185	140
32	65	2	546199	902198	97	72
32	65	3	546208	902231	210	147
32	66	1	546214	902234	198	135
32	66	2	546213	902261	219	148
32	66	3	546217	902282	230	163
32	67	1	546220	902287	230	161
32	67	2	546226	902311	218	147
32	67	3	546229	902340	234	159
32	68	1	546230	902348	232	155
32	68	2	546240	902382	235	158
32	68	3	546243	902402	236	166
32	69	1	546242	902404	246	168
32	69	2	546241	902424	238	156
32	69	3	546252	902458	259	164
32	70	1	546251	902460	283	174
32	70	2	546269	902481	272	179
32	70	3	546277	902519	296	205
32	71	1	546313	902521	230	162
32	71	2	546310	902492	235	151
32	71	3	546300	902454	250	163
32	72	1	546299	902450	240	161
32	72	2	546297	902428	232	157
32	72	3	546291	902391	247	164
32	73	1	546290	902380	220	238
32	73	2	546287	902360	238	148
32	73	3	546279	902336	230	156
32	74	1	546278	902331	215	141
32	74	2	546276	902318	220	145
32	74	3	546263	902285	199	127
32	75	1	546261	902280	208	135
32	75	2	546258	902261	203	135
32	75	3	546251	902232	203	138
32	76	1	546247	902229	174	115
32	76	2	546234	902200	105	79
32	76	3	546231	902181	224	152
32	77	1	546230	902175	210	139
32	77	2	546227	902150	210	145
32	77	3	546225	902118	207	142
32	78	1	546227	902111	190	128

32	78	2	546226	902087	205	128
32	78	3	546221	902055	205	138
32	79	1	546219	902047	196	124
32	79	2	546212	902032	184	125
32	79	3	546206	901999	148	110
32	80	1	546239	902001	167	127
32	80	2	546247	902029	210	142
32	80	3	546252	902055	220	147
32	81	1	546255	902060	225	60
32	81	2	546258	902079	220	145
32	81	3	546266	902114	230	154
32	82	1	546267	902119	214	164
32	82	2	546269	902143	196	130
32	82	3	546273	902173	130	96
32	83	1	546272	902178	114	85
32	83	2	546277	902204	73	55
32	83	3	546286	902223	215	153
32	84	1	546284	902222	220	152
32	84	2	546293	902245	202	137
32	84	3	546303	902282	210	155
32	85	1	546303	902290	205	153
32	85	2	546304	902309	240	167
32	85	3	546308	902337	220	153
32	86	1	546307	902340	218	156
32	86	2	546311	902352	201	129
32	86	3	546323	902389	205	139
32	87	1	546323	902398	207	141
32	87	2	546329	902417	220	161
32	87	3	546332	902445	250	147
32	88	1	546334	902448	245	152
32	88	2	546341	902469	255	162
32	88	3	546349	902499	220	170
32	89	1	546384	902491	265	177
32	89	2	546380	902460	242	181
32	89	3	546377	902438	208	141
32	90	1	546375	902429	230	155
32	90	2	546373	902413	260	170
32	90	3	546369	902389	230	165
32	91	1	546368	902377	240	157
32	91	2	546361	902355	248	159
32	91	3	546358	902333	245	158
32	92	1	546357	902327	230	155
32	92	2	546349	902295	230	148
32	92	3	546346	902275	242	170
32	93	1	546348	902270	215	149
32	93	2	546336	902248	215	148
32	93	3	546329	902230	219	151

32	94	1	546328	902221	220	156
32	94	2	546324	902198	215	154
32	94	3	546316	902170	220	148
32	95	1	546314	902163	243	169
32	95	2	546307	902130	210	148
32	95	3	546311	902112	120	85
32	96	1	546312	902110	103	80
32	96	2	546304	902084	83	70
32	96	3	546293	902046	105	75
32	97	1	546292	902038	145	38
32	97	2	546287	902014	160	14
32	97	3	546282	901991	205	135
32	98	1	546319	901984	118	96
32	98	2	546322	902008	168	11
32	98	3	546328	902032	208	32
32	99	1	546329	902037	230	156
32	99	2	546333	902056	237	164
32	99	3	546341	902094	235	162
32	100	1	546343	902098	236	160
32	100	2	546347	902117	242	171
32	100	3	546350	902140	251	181
32	101	1	546352	902149	235	157
32	101	2	546360	902178	235	154
32	101	3	546367	902204	249	174
32	102	1	546366	902211	250	177
32	102	2	546372	902242	229	157
32	102	3	546378	902272	237	161
32	103	1	546377	902283	241	172
32	103	2	546381	902302	238	165
32	103	3	546389	902323	235	160
32	104	1	546390	902327	237	157
32	104	2	546397	902352	230	161
32	104	3	546402	902380	235	181
32	105	1	546405	902385	230	171
32	105	2	546409	902412	235	165
32	105	3	546415	902439	250	171
32	106	1	546417	902447	245	161
32	106	2	546429	902495	235	171
32	106	3	546434	902522	242	169

Parcel	Decimo	Point	x	y	Vertical	Horizontal
89	1	1.1	542484	899785	78	73
89	1	1.2	542513	899788	65	41
89	1	1.3	542583	899769	68	66
89	1	1.4	542579	899813	68	67
89	1	1.5	542532	899814	64	60
89	1	1.6	542486	899812	77	70

89	1	1.7	542479	899861	63	64
89	1	1.8	542517	899862	61	65
89	1	1.9	542586	899860	63	61
89	2	2.1	542584	899867	62	67
89	2	2.2	542516	899863	61	67
89	2	2.3	542479	899866	62	65
89	2	2.4	542491	899913	72	75
89	2	2.5	542529	899914	63	68
89	2	2.6	542581	899912	67	70
89	3	3.1	542588	899911	63	77
89	3	3.2	542680	899910	70	77
89	3	3.3	542680	899870	68	62
89	3	3.4	542592	899866	73	67
89	3	3.5	542592	899893	61	65
89	3	3.6	542682	899890	64	60
89	4	4.1	542595	899851	67	65
89	4	4.2	542686	899686	64	61
89	4	4.3	542689	899689	66	67
89	4	4.4	542598	899598	64	65
89	4	4.5	542594	899829	64	58
89	4	4.6	542689	899822	67	60
89	5	5.1	542600	899784	67	66
89	5	5.2	542690	899763	62	68
89	5	5.3	542688	899783	66	71
89	6	6.1	542706	899770	72	67
89	6	6.2	542793	899765	65	70
89	6	6.3	542796	899742	66	58
89	6	6.4	542702	899779	69	71
89	6	6.5	542755	899787	66	70
89	6	6.6	542753	899747	73	67
89	7	7.1	542703	899794	64	65
89	7	7.2	542787	899987	66	59
89	7	7.3	542790	899799	65	61
89	7	7.4	542696	899845	68	64
89	7	7.5	542699	899820	63	65
89	7	7.6	542792	899829	66	63
89	8	8.1	542696	899872	67	62
89	8	8.2	542779	899916	84	76
89	8	8.3	542777	899875	69	67
89	8	8.4	542695	899914	72	76
89	8	8.5	542694	899886	67	69
89	8	8.6	542783	899900	83	70
89	9	9.1	542801	899918	99	88
89	9	9.2	542887	899919	129	105
89	9	9.3	542890	899874	69	66
89	9	9.4	542807	899872	66	71
89	9	9.5	542803	899897	77	67

89	9	9.6	542890	899901	77	69
89	10	10.1	542807	899850	75	66
89	10	10.2	542889	899854	70	71
89	10	10.3	542895	899804	63	65
89	10	10.4	542808	899803	71	88
89	10	10.5	542809	899827	67	60
89	10	10.6	542897	899826	64	62
89	11	11.1	542811	899786	72	68
89	11	11.2	542897	899778	68	70
89	11	11.3	542902	899723	66	72
89	11	11.4	542810	899744	64	73
89	11	11.5	542819	899768	65	57
89	11	11.6	542900	899749	64	67

Parcel	Decimo	Point	x	y	Vertical	Horizontal
113	1	1	546311	907075	77	52
113	1	2	546317	907077	95	63
113	2	1	546316	907097	113	82
113	2	2	546301	907101	83	65
113	3	1	546288	907126	92	65
113	3	2	546294	907125	87	59
113	3	3	546308	907127	82	69
113	4	1	546311	907155	125	105
113	4	2	546293	907072	92	72
113	4	3	546275	907062	82	62
113	5	1	546280	907190	141	116
113	5	2	546292	907191	145	101
113	5	3	546318	907193	145	107
113	6	1	546308	907219	148	118
113	6	2	546290	907217	145	104
113	6	3	546271	907216	136	117
113	7	1	546272	907248	165	120
113	7	2	546295	907249	153	122
113	7	3	546303	907249	138	131
113	8	1	546298	907281	162	139
113	8	2	546277	907279	175	155
113	8	3	546263	907273	173	125
113	9	1	546303	907278	172	138
113	9	2	546318	907282	165	135
113	9	3	546240	907288	166	109
113	10	1	546340	907258	148	124
113	10	2	546330	907257	162	128
113	10	3	546309	907260	146	115
113	11	1	546310	907219	140	115
113	11	2	546329	907220	140	112
113	11	3	546346	907221	146	107
113	12	1	546347	907196	132	99

113	12	2	546330	907198	129	92
113	12	3	546312	907195	139	103
113	13	1	546315	907165	127	86
113	13	2	546333	907167	110	91
113	13	3	546351	907169	115	76
113	14	1	546354	907137	92	70
113	14	2	546339	907136	113	88
113	14	3	546317	907134	94	75
113	15	1	546321	907103	116	84
113	15	2	546332	907102	64	40
113	15	3	546352	907104	31	17
113	15	4	546355	907102	34	22
113	16	1	546359	907072	112	75
113	16	2	546348	907074	109	78
113	16	3	546326	907047	107	74
113	17	1	546364	907059	81	62
113	17	2	546373	907056	78	56
113	17	3	546396	907056	92	65
113	18	1	546394	907077	94	71
113	18	2	546380	907083	89	59
113	18	3	546360	907076	95	66
113	19	1	546361	907107	38	34
113	19	2	546379	907108	51	43
113	19	3	546396	907111	95	67
113	20	1	546393	907138	106	85
113	20	2	546375	907140	102	86
113	20	3	546355	907143	93	67
113	21	1	546353	907105	124	105
113	21	2	546368	907164	100	94
113	21	3	546385	907161	98	75
113	22	1	546387	907201	137	130
113	22	2	546376	907203	124	108
113	22	3	546350	907198	129	105
113	23	1	546346	907230	145	119
113	23	2	546362	907233	153	116
113	23	3	546388	907232	143	117
113	24	1	546383	907263	160	144
113	24	2	546359	907260	158	123
113	24	3	546348	907259	160	119
113	25	1	546342	907288	157	122
113	25	2	546360	907293	171	119
113	25	3	546374	907295	169	131
113	26	1	546384	907293	157	127
113	26	2	546392	907294	167	140
113	26	3	546419	907295	155	134
113	27	1	546419	907266	163	127
113	27	2	546406	907263	163	141

113	27	3	546381	907260	158	137
113	28	1	546386	907232	163	121
113	28	2	546403	907232	154	138
113	28	3	546427	907227	142	106
113	29	1	546427	907207	152	117
113	29	2	546410	907201	141	112
113	29	3	546390	907199	139	109
113	30	1	546391	907170	112	94
113	30	2	546408	907169	127	102
113	30	3	546427	907165	130	108
113	31	1	546431	907147		95
113	31	2	546415	907146	111	87
113	31	3	546394	907147	115	90
113	32	1	546400	907108	103	82
113	32	2	546418	907107	109	81
113	32	3	546434	907108	111	83
113	33	1	546435	907094	91	75
113	33	2	546422	907092	96	76
113	33	3	546405	907086	90	61
113	34	1	546405	907060	101	70
113	34	2	546420	907061	89	71
113	34	3	546446	907054	90	77
113	35	1	546470	907054	33	23
113	35	2	546456	907059	51	40
113	35	3	546441	907060	88	59
113	36	1	546437	907085	78	61
113	36	2	546452	907092	83	59
113	36	3	546466	907094	87	59
113	37	1	546468	907126	88	88
113	37	2	546453	907132	116	90
113	37	3	546439	907129	112	82
113	38	1	546436	907149	117	77
113	38	2	546450	907147	119	91
113	38	3	546470	907146	135	97
113	39	1	546467	907175	127	90
113	39	2	546448	907175	126	98
113	39	3	546433	907175	129	107
113	40	1	546430	907198	143	100
113	40	2	546449	907202	135	112
113	40	3	546462	907207	123	94
113	41	1	546462	907231	139	100
113	41	2	546444	907233	135	119
113	41	3	546427	907232	132	102
113	42	1	546424	907263	144	106
113	42	2	546441	907265	123	120
113	42	3	546460	907266	119	97
113	43	1	546454	907301	138	96

113	43	2	546431	907297	141	102
113	43	3	546418	907293	160	119
113	44	1	546460	907298	124	100
113	44	2	546471	907301	110	83
113	44	3	546485	907304	104	84
113	45	1	546494	907275	109	74
113	45	2	546475	907269	132	117
113	45	3	546463	907263	125	94
113	46	1	546462	907239	126	111
113	46	2	546483	907240	115	95
113	46	3	546505	907242	103	90
113	47	1	546504	907212	96	70
113	47	2	546485	907208	108	95
113	47	3	546472	907207	111	97
113	48	1	546470	907182	126	104
113	48	2	546487	907181	101	102
113	48	3	546504	907178	100	81
113	49	1	546505	907158	100	81
113	49	2	546494	907151	118	89
113	49	3	546475	907149	121	88
113	50	1	546475	907119	100	67
113	50	2	546494	907116	101	75
113	50	3	546512	907121	96	79
113	51	1	546516	907096	87	59
113	51	2	546495	907096	82	64
113	51	3	546467	907091	77	61
113	52	1	546479	907058	44	56
113	52	2	546502	907052	58	39
113	52	3	546519	907056	41	41
113	53	1	546525	907058	35	34
113	53	2	546544	907059	48	35
113	53	3	546559	907061	56	44
113	54	1	546551	907096	99	81
113	54	2	546540	907095	101	78
113	54	3	546525	907096	110	69
113	55	1	546518	907117	93	82
113	55	2	546531	907120	119	99
113	55	3	546541	907124	104	87
113	56	1	546540	907161	121	105
113	56	2	546524	907154	110	116
113	56	3	546509	907149	106	89
113	57	1	546507	907179	125	98
113	57	2	546528	907185	101	94
113	57	3	546540	907189	110	94
113	58	1	546540	907212	101	92
113	58	2	546527	907211	107	97
113	58	3	546506	907209	104	84

113	59	1	546500	907241	115	85
113	59	2	546522	907244	85	66
113	59	3	546536	907249	92	83
113	60	1	546536	907235	91	71
113	60	2	546520	907276	53	35
113	60	3	546501	907280	103	74
113	61	1	546497	907306	96	71
113	61	2	546516	907305	75	62
113	61	3	546532	907308	125	94

Parcel	Decimo	Point	x	y	Vertical	Horizontal
146	1	1	543348	905354	110	93
146	1	2	543364	905361	123	101
146	1	3	543366	905371	104	88
146	2	1	543368	905360	103	87
146	2	2	543387	905375	157	118
146	2	3	543398	905381	155	117
146	2	4	543409	905388	170	128
146	3	1	543411	905393	159	119
146	3	2	543418	905397	154	116
146	3	3	543427	905409	158	117
146	3	4	543444	905417	281	221
146	3	5	543443	905423	211	169
146	3	6	543473	905435	252	254
146	3	7	543458	905427	317	266
146	3	8	543462	905422	302	254
146	3	9	543456	905433	133	271
146	4	1	543476	905472	238	229
146	4	2	543492	905429	255	210
146	4	3	543506	905455	206	165
146	4	4	543520	905467	232	202
146	4	5	543539	905477	225	170
146	5	1	543542	905483	232	190
146	5	2	543554	905491	261	211
146	5	3	543569	905502	245	170
146	5	4	543583	905512	198	153
146	5	5	543597	905529	196	125
146	6	1	543606	905528	168	122
146	6	2	543618	905537	229	182
146	6	3	543633	905547	127	185
146	6	4	543649	905556	206	115
146	6	5	543660	905564	167	125
146	6	6	543670	905571	135	101
146	6	7	543674	905578	162	121
146	7	1	543643	905646	137	112
146	7	2	543636	905630	205	149
146	7	3	543633	905614	204	163

146	7	4	543630	905598	223	173
146	7	5	543626	905582	264	235
146	7	6	543624	905559	260	145
146	7	7	543615	905545	229	186
146	8	1	543604	905522	202	150
146	8	2	543609	905563	232	190
146	8	3	543612	905586	235	192
146	8	4	543618	905600	204	165
146	8	5	543621	905633	194	141
146	8	6	543636	905663	215	151
146	9	1	543615	905704	182	135
146	9	2	543614	905679	220	157
146	9	3	543608	905662	181	133
146	9	4	543597	905619	217	157
146	9	5	543589	905598	210	157
146	9	6	543581	905566	184	144
146	10	1	543572	905568	193	152
146	10	2	543573	905536	178	140
146	10	3	543570	905514	217	175
146	10	4	543572	905508	251	208
146	10	5	543562	905522	185	136
146	10	6	543565	905541	168	131
146	10	7	543571	905564	200	147
146	11	1	543572	905578	107	140
146	11	2	543575	905599	208	158
146	11	3	543584	905620	210	161
146	11	4	543600	905657	195	153
146	11	5	543603	905686	209	153
146	11	6	543605	905713	170	122
146	12	1	543585	905758	141	102
146	12	2	543581	905743	161	121
146	12	3	543571	905708	203	135
146	12	4	543572	905672	224	165
146	12	5	543566	905645	202	155
146	12	6	543571	905618	160	113
146	13	1	543550	905610	191	138
146	13	2	543541	905578	192	153
146	13	3	543534	905548	244	187
146	13	4	543537	905513	246	198
146	13	5	543531	905494	211	160
146	14	1	543499	905537	244	195
146	14	2	543496	905520	224	172
146	14	3	543486	905501	210	161
146	14	4	543485	905478	222	180
146	14	5	543475	905452		
146	15	1	543490	905555	245	202
146	15	2	543509	905582	206	146

146	15	3	543517	905618	216	166
146	15	4	543528	905622	218	170
146	16	1	543527	905671	184	133
146	16	2	543537	905719	182	128
146	16	3	543541	905741	183	122
146	16	4	543562	905804	86	66
146	17	1	543557	905811	101	85
146	17	2	543554	905762	139	104
146	17	3	543535	905725	165	110
146	17	4	543514	905688	184	133
146	18	1	543521	905688	202	151
146	18	2	543511	905644	200	145
146	18	3	543498	905602	191	138
146	18	4	543494	905570	163	128
146	19	1	543495	905556	219	175
146	19	2	543488	905523	194	155
146	19	3	543483	905487	171	161
146	19	4	543473	905475	160	150
146	20	1	543424	905391	127	99
146	20	2	543443	905428	233	111
146	20	3	543434	905442	254	215
146	20	4	543446	905493	152	155
146	21	1	543448	905504	46	48
146	21	2	543453	905523	166	160
146	21	3	543460	905487	206	173
146	21	4	543468	905475	191	150
146	22	1	543472	905614	200	147
146	22	2	543475	905633	186	139
146	22	3	543478	905667	166	114
146	22	4	543489	905699	175	119
146	23	1	543495	905713	175	133
146	23	2	543487	905584	163	116
146	23	3	543481	905647	218	147
146	23	4	543473	905621	185	143
146	24	1	543470	905602	167	124
146	24	2	543457	905657	216	170
146	24	3	543447	905530	203	170
146	24	4	543445	905501	51	55
146	25	1	543443	905477	182	163
146	25	2	543433	905445	255	210
146	25	3	543428	905415	206	159
146	25	4	543424	905380	168	122
146	26	1	543366	905362	92	85
146	26	2	543376	905376	89	82
146	26	3	543380	905416	93	92
146	26	4	543386	905442	73	68
146	27	1	543490	905498	100	93

146	27	2	543397	905478	189	139
146	27	3	543401	905496	111	90
146	27	4	543410	905540	44	69
146	28	1	543415	905548	118	98
146	28	2	543414	905570	225	178
146	28	3	543421	905588	203	144
146	28	4	543429	905628	186	135
146	29	1	543440	905643	219	169
146	29	2	543454	905651	201	156
146	29	3	543462	905718	142	112
146	29	4	543464	905771	143	113
146	30	1	543453	905732	161	120
146	30	2	543447	905709	186	145
146	30	3	543438	905670	198	143
146	30	4	543434	905655	234	175
146	31	1	543432	905432	193	153
146	31	2	543428	905428	126	165
146	31	3	543423	905423	222	164
146	31	4	543413	905413	93	87
146	32	1	543409	905537	41	45
146	32	2	543403	905503	44	45
146	32	3	543397	905466	167	122
146	32	4	543389	905436	91	78
146	33	1	543388	905426	75	74
146	33	2	543381	905394	105	95
146	33	3	543373	905367	94	93
146	33	4	543370	905353	99	88
146	34	1	543374	905405	101	95
146	34	2	543379	905412	98	85
146	34	3	543390	905430	96	96
146	34	4	543403	905438	111	101
146	35	1	543333	905379	66	63
146	35	2	543339	905397	64	64
146	35	3	543363	905469	89	73
146	35	4	543364	905482	71	66
146	36	1	543332	905383	53	54
146	36	2	543340	905405	59	57
146	36	3	543368	905481	80	72
146	36	4	543375	905485	83	91
146	37	1	543358	905489	65	62
146	37	2	543356	905491	78	70
146	37	3	543360	905493	76	71
146	37	4	543361	905502	116	94
146	38	1	543369	905502	137	110
146	38	2	543368	905530	170	136
146	38	3	543379	905534	240	182
146	38	4	543381	905581	204	136

146	39	1	543382	905587	176	135
146	39	2	543379	905601	213	153
146	39	3	543383	905633	190	144
146	39	4	543384	905639	214	163
146	40	1	543393	905656	182	139
146	40	2	543396	905664	219	168
146	40	3	543387	905675	203	151
146	40	4	543406	905698	208	160
146	41	1	543390	905686	194	151
146	41	2	543383	905679	194	157
146	41	3	543362	905666	221	161
146	41	4	543352	905658	245	193
146	42	1	543353	905643	226	167
146	42	2	543352	905636	249	188
146	42	3	543342	905621	215	168
146	42	4	543341	905614	190	139
146	43	1	543339	905597	166	123
146	43	2	543338	905589	232	165
146	43	3	543331	905566	213	154
146	43	4	543326	905521	143	113
146	44	1	543327	905534	162	118
146	44	2	543326	905532	186	124
146	44	3	543321	905516	94	88
146	44	4	543320	905498	84	73
146	45	1	543312	905470	52	50
146	45	2	543309	905458	48	45
146	45	3	543308	905441	68	58
146	45	4	543309	905437	95	81
146	46	1	543292	905466	77	67
146	46	2	543291	905475	60	56
146	46	3	543293	905491	76	68
146	46	4	543290	905502	87	73
146	47	1	543288	905588	105	84
146	47	2	543287	905550	110	85
146	47	3	543302	905578	157	108
146	47	4	543304	905589	194	146
146	48	1	543294	905614	171	120
146	48	2	543299	905620	145	114
146	48	3	543309	905625	217	174
146	48	4	543315	905631	250	205
146	49	1	543262	905602	161	129
146	49	2	543263	905593	224	166
146	49	3	543253	905588	164	115
146	49	4	543231	905567	100	82