DISSERTATION

SPATIAL DISTRIBUTION OF AVAILABLE NITROGEN UNDER CENTER PIVOT SPRINKLERS

Submitted by

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In partial fulfillment of the requirements

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY STANLEY C. BEST ENTITLED "SPATIAL DISTRIBUTION OF AVAILABLE NITROGEN UNDER CENTER PIVOT SPRINKLERS" BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

SPATIAL DISTRIBUTION OF AVAILABLE NITROGEN UNDER CENTER PIVOT SPRINKLERS

The water and nitrogen application from center pivot irrigation systems, in most situations, is assumed to be uniform; however, significant changes in the water and N distribution can occur with both location and time. This study was conducted to determine whether water and N spatial distribution, along with physical and chemical conditions of soil can be used to determine spatial application patterns of nutrients that will minimize leaching and maintain an economic yield under two farmer-operated fields irrigated by center pivot.

Pivot position, irrigation mainline pressures and flows, and depth of fertilizer in the supply tank were recorded throughout the irrigation seasons (1998 and 1999) so that spatial distribution of water and N application could be estimated by using USDA's Center Pivot Evaluation and Design (CPED). Opus simulation model was used to simulate spatial distribution of leaching for both fields, using CPED output as input data in conjunction with plant, soil and weather data required by the model.

Although farmers historically assumed that each component of fertilizer is uniformly distributed at some average value, the results of my research show considerable variability in N potentially available to the crop. Fertigation was the largest single source of N applied across each field. For field 6 the fertigated amount varied from 70 to 180 kg-N/ha in 1998 and from 150 to 225 kg-N/ha in 1999, and for field 39 varied from 73 to 210 kg-N/ha. Estimated seasonal potentially available N showed a high overapplication of N in certain areas and a low overapplication under other areas of the field, which explains the variability of leaching obtained in the simulations, ranging for more significant areas from 20 to 40 kg-N/ha on field 6 and from 3 to 20 kg-N/ha on field 39 in 1999.

A cluster analysis was done with the input and output variables in order to identify areas that can be managed similarly in both fields.

The variability of N applied by fertigation suggests that uniformity of irrigation is important to optimize N fertilizer application and to reduce potential leaching. In addition, improved irrigation uniformity will help to make the management decisions easier.

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DEDICATION

To my lovely wife, who has been with me in the good and bad days of my life. She has been a support and an inspiration of effort and love. To my parents who helped me to be all that I am. To my parents in-law for their support and love.

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CHAPTER 1

INTRODUCTION

1.1. Background

Groundwater is an important natural resource. In the United States, nearly one half of the total population and 95 % of the rural population are using this resource as drinking water (United States; Environmental Protection Agency, 1984).

One big problem that is becoming a serious environmental and human concern is the increasing NO_3-N concentrations in ground water sources. Nitrogen is present in soils in several forms. Bacteria convert these forms into NO_3. Nitrate is soluble in water and not tightly held by soil particles. Therefore, it travels through the soil with percolating water and contaminates groundwater supplies.

The Environmental Protection Agency (EPA) has set a maximum contaminant level (MCL) of 10 parts-per-million (ppm) for NO_3-N in public water supplies. This level provides a margin of safety regarding a significant risk for human health.

Nitrate is a relatively non-toxic substance that occurs naturally as part of the N cycle. However, NO_3 can be converted readily by bacteria into NO_2. This occurs in the environment, in foods, in the human mouth and gastrointestinal tract. Once N is converted into NO_2, it can have harmful health effects. For example, high nitrites in drinking water can cause methemoglobinemia, resulting from the reaction of nitrites with hemoglobin in red blood cells, affecting the ability of the blood to carry sufficient oxygen to individual cells of the body. A number of cases of infant methemoglobinemia have been reported in Nebraska. A survey of physicians reported in the Nebraska Medical Journal in 1981 indicated that at least eight cases of infant methemoglobinemia were treated in Nebraska between 1973 and 1978 (Grant, 1981). More recently, two South Dakota infants with the blue baby syndrome were identified by the State Department of Health. In one case, the farm's well water was found to have 150 ppm NO_3-N concentration while the level was 54 ppm in the other. Although these levels of NO_3-N are extremely high, a case of methemoglobinemia was reported in Colorado involved an infant ingesting municipal system water containing 13.3 ppm NO_3-N (Fan et al., 1987). No cases have been identified with water testing below the MCL of 10 ppm NO_3-N.

On the other hand, in order to achive some yield production, a minimum amount of NO_3 must be absorbed by plant roots during the growth cycle. The rate of uptake appears to be regulated by the plant to a great extent, and cannot be described adequately by assuming that it is taken up passively along with the water extracted for transpiration (Follett, 1991). From a management standpoint, NO_3 leaching losses are minimized by maximizing the residence time of the chemical in the crop root zone. This must be balanced against the water holding capacity and evapotranspiration in order to avoid plant water stress and a possible yield reduction. Unfortunately, soils are not uniform and there is a spatial variability of soils that makes water and N fertilizer management difficult. Soil spatial heterogeneity in fields has been reported in many studies (Baker, 1978; Burden and Selim, 1989; Agbu and Olson, 1990). This dichotomy has made N fertilizer and water management for minimum leaching and maximum yield a subtle and active research area.

Recent studies for reducing N contamination of groundwater are using site-specific crop management (SSCM) or what has become known as precision farming (PF) (Omary et al., 1997). In precision farming, a field is divided into several management zones and each zone is treated differently.

Precision farming involves doing the right thing, in the right way, at the right place and time. It is not just a bunch of pretty maps for visceral viewing, but mapped data and a set of new procedures linking these data to appropriate management actions.

1.2. Problem Statement

The water application from center pivot irrigation systems, in most situations, is assumed to be uniform; however, significant changes in the water distribution can occur with both location and time.

Variable topography changes the pressure distribution in the sprinkler pipe from that which occurs over level terrain. Both the discharge and wetted diameter of an individual sprinkler head are dependent on the operating pressure. Therefore, variations in the pressure distribution affect the wetted area under a sprinkler head as well as the depth applied. When the elevation increases, the pipeline pressure is reduced at individual heads, resulting in lower discharge from those heads. This problem is magnified by turning the end gun on and off. This problem can be solved to a certain degree using pressure regulators.

When one is not using pressure regulators, and topography varies significantly, water application depth from a center pivot irrigation system may not be uniformly distributed across a field. If fertigation is involved with a center pivot system, or if the water supply contains significant nutrients, the nutrient inputs to the field will not be uniformly distributed either (Evans et al., 1995; and Duke et al., 2000). In addition, variability of the N concentration will occur, due to the variability of the chemical injection rate caused by the changes of the pressure in the mainline. Moreover, N content of soils varies throughout a field and may require different application rates of N (Omary et al., 1997).

Variability in the irrigation and N application, as well as variability in the available soil water holding capacity, create the potential for variability in deep percolation and leaching throughout the field (Bruckler et al., 1997). This variability may be expressed in the yield and in N leaching.

In order to reduce the risk of underirrigating or underfertilizing, farmers, put an extra amount of both, producing excess deep percolation and leaching to the groundwater.

In order to apply the precision farming principle to leaching reduction, yet maintain an optimal yield, resource managers need cost-effective tools to identify areas that are potentially vulnerable to leaching so that management plans can be implemented to reduce the potential pollution problems (Sunday, 1996).

Simulation models are among the most efficient and cost-effective tools for analyzing water resource problems, and are widely used for natural resource management. Some of the limitations of models, however, include the inability to determine and manage large amounts of model input data required, and to account for spatial variability and heterogeneity that are often present in environmental systems (Wu et. al., 1996).

Recent advances in GIS, a technology designed to store, analyze, manipulate, retrieve, and display spatial and attribute data, provide the tools for generating and organizing spatially variable model input data.

1.3 Objectives

My hypothesis is that knowledge of water and nutrient spatial distribution, along with physical and chemical conditions of soil can be used to determine spatial application patterns of nutrients that will minimize leaching and maintain an economic yield.

The specific objectives of this research are:

1. Determine the spatial and temporal variability of N application across farmer operated fields using measured N concentration data and a proven computer simulation to estimate water and N spatial application.
2. Estimate the spatial and temporal variability of NO_3 leaching through use of these spatial N application data and a deterministic computer simulation model.
3. Find the spatial pattern of N application, leaching and crop yield to help target areas that can be similarly managed.
4. Develop recommendations for management of the spatial application of water and N under a center pivot system.

1.4. Approach

The USDA Center Pivot Evaluation and Design (CPED) program, first developed by Heermann and Hein (1968) and further expanded by

Kincaid and Heermann (1970), Beccard and Heermann (1981), Heermann and Stahl (1986), and Heermann (1990) was used to simulate the water depth and N applied through the center pivot.

The simulated application depths of water and N applied were then overlaid onto a polar grid to associate a depth of water and quantity of N with each polar grid cell in order to produce maps of the seasonal water and N application. The simulated application depths and N applied were also used to estimate the average irrigation application depth and N within a 250 foot (76.2 m) rectangular grid system for use in a deep percolation and leaching simulation with the Opus computer model (Smith, 1992).

Maps of the seasonal water and N application, leaching, deep percolation, soil characteristics, and yield were used in order to define areas of the field that require similar management.

CHAPTER 2

LITERATURE REVIEW

Growing concern for environmental quality and the preservation of vital natural resources has significantly increased, as has concern about the potential impact of agricultural chemicals on water quality and human health. Agriculture is increasingly being criticized for contributing to the deterioration of the nation's water quality. The presence of agricultural chemicals in ground water has been reported in a number of states (Hallberg, 1987).

In response to these concerns, the United States Congress passed a number of legislative bills to protect water quality. One of those actions was the Clean Water Act (CWA) establishing the objective to "restore and maintain the biological, chemical, and physical integrity of the nation's waters". More specifically, it requires individual states to assess the extent to which nonpoint sources cause water quality problems, and calls upon the states to develop programs and means for addressing these problems. Sections 208 and 319 of CWA require state agencies to develop and implement agricultural best management practices (BMPs) for controlling nonpoint source pollution of surface and ground water (Sunday, 1996).

To meet this requirement, growers need to identify areas that are potentially nonpoint sources of pollution so that management plans can be implemented to reduce the pollution problems while maintaining an economic crop yield (Eatock and Inggs, 1994). One technique that has been gaining importance to help manage those areas, is the concept of precision farming (Buchleiter et al., 1997).

2.1. Precision Farming Approach

It has long been accepted by agricultural producers that homogenous treatment of a field gives suboptimal crop production because of the variability of many factors within the field (Lachapelle et al., 1994).

Spatial variability of yield limiting factors such as N, water, soil texture, and organic matter, within a field has been recognized for a long time (Franzen et al., 1996; Vanden Huevel, 1997; Hosseini et al., 1994; Cooke et al., 1993; and Jim Yeh et. al., 1986). To achieve optimal crop production potential, these variabilities must be understood and treated appropriately. In order to achieve those objectives through precision farming, growers attempted to determine an appropriate sampling and interpretation methods to make better management decisions (Heermann and Spofford, 1998). The major hurdle to archiving this has been to determine the density at which a piece of information is gathered. If data are too sparse, errors in interpolation may draw researchers to incorrect conclusions (Chen and Kocher, 1994). Geographic positioning systems (GPS) provide accurate positioning capabilities, and through integration with other sensors, allow much of the necessary data to be collected during normal farming operations, important from a cost-effectiveness point of view (Lachapelle et al., 1994; and Eatock and Inggs, 1994).

Recent advances in geographic information systems (GIS), a technology designed to store, analyze, manipulate, retrieve, and display spatial and attribute data, provide the tools for generating and organizing spatially variable field data (Sunday, 1996; Wu et al., 1996).

2.2. Spatial water application under center pivot irrigation systems

Soil water variability is a major cause of yield variability, especially in areas not irrigated (Heermann et. al., 2000). Different types of soil have different water holding capacities and hydraulic conductivities; therefore they require different water application depths and rates to reach field capacity and to minimize runoff and deep percolation (Jim Yeh et al., 1986; Cooke et al., 1993; and Omary et al., 1997). The control of water is an important variable in irrigated crop production (Bruckler et. al., 1997).

Variability in the system design, soil properties, topography, plant density and growth stage, and precipitation patterns result in a lack of uniformity of water infiltration, storage, and subsequent plant water use across the field (Duke et al., 1997; Lord et al., 1997).

Water application depth from a center pivot irrigation system is not uniformly distributed across a field (Duke et al., 1991). Nonuniformity under the center pivot can be a result of problems in system design, such as end-gun operation or improper nozzle size installed, or the sprinkler spacing (Jordan, 1998). In addition, the uniformity can be affected by particles within irrigation water that can wear nozzles and increase their sizes. The discharge and wetted diameter of a sprinkler are pressure dependent (Heermann, 1968).

Another source of nonuniformity under center pivots is changes in topography across the field (James, 1982; Duke et al., 1997). Variations in field topography can change the system pressure distribution along the lateral pipeline, which in turn can change the water application depth at different lateral positions, even with flow control nozzles or pressure regulators at each head (Evans et al., 1995).

Most sprinkler package designs are based upon no elevation change (level field) between the pivot point and the end tower. If the field is not level, the flow of water out of each sprinkler will be less than design where the elevation is higher or greater than design where the elevation is lower than the pivot point. Due to the pressure differentials caused by elevation differences, if the pivot operates downhill, more water will be applied near the end gun than near the pivot point. Conversely, if the system operates uphill, more water will be applied near the pivot point than near the end gun. If a system operates over rolling terrain, more water will be applied to the low lying areas than to the top of hills. In either case, the result is uneven water application.

In such cases, using catch-can tests (ASAE standards, 1992) to determine the spatial distribution of water application depth and application uniformity is not practical. In addition, catch-can testing is very time-consuming and data can only be collected along a limited number of radial lines. The results are also subject to errors caused by evaporation and in wind caused divergence around the container.

An alternative method is to use computer simulation models to generate water application depth data (Evans et al., 1995). A computer program, known as USDA Center Pivot Evaluation and Design (CPED), based on the model originally developed by Heermann and Hein (1968) modified by Beccard and Heermann (1981), and finally adjusted by Heermann and Stahl (1986), can be used to obtain a spatial water application depth along the sprinkler pipeline (Jordan, 1998) with any elevation profile.

2.3. Spatial N application under center pivot irrigation systems

Chemigation through irrigation systems has been used for more than three decades as an effective technique to apply some chemicals. About 85% of chemigation performed in the United States was under sprinkler irrigation systems, with center pivot systems being the most popular (Thomson and Threadgill, 1988). Center pivot systems provide a convenient method for application of chemicals ranging from N fertilizer to a wide range of pesticides (Cochran et. al., 1986, Duke et. al., 1997). Nitrogen fertilizer can be injected via a chemical injector pump into the water flowing in the center pivot irrigation system (Thomson and Threadgill, 1988; Haman et al., 1993). There are several type of injectors used for N injection into a center pivot irrigation system. These injectors can be classified into four major groups: centrifugal pumps, positive displacement pumps, pressure differential methods, and methods based on the venturi principle (Burt et al., 1995). In addition, some injectors use a combination of these methods (Burt et al., 1995).

Most fertilizer injection pumps are manually adjusted to apply the desired amount of chemical to the field (Thomson and Threadgill, 1988). Each time a center pivot's speed is changed, a corresponding pump flow rate must be recalculated and the pump recalibrated so that a given amount of N can be applied per unit area. The amount of N injected into the water is affected by water pressure in the center pivot, even when positive displacement pumps are used. As a result of the variation in the N injected, differential N concentration in the water will occur through out the field (Duke et al., 2000). In addition, the time it takes for the N to reach the end of the system affects the distribution of the N concentration in the pipe (DeTar, 1983; Clothier and Sauer, 1984). Due to the variability of N concentration, the uniformity of N distribution across the field will be no better than the distribution of the water. As the distribution of N is non-uniform, variability of N applied over the field will occur (Duke et al., 2000).

The non-uniformity of the water and N application and soil texture variability across a field have implications regarding deep percolation and leaching variability (Morton, 1998). Both the N and the water distribution are important in evaluating crop growth and N leaching problems (Evans et. al., 1995).

2.4. Leaching and crop yield relationship

Nitrogen fertilizer has received attention for a long time as a source of ground water pollution because of the mobility of the NO_3 ion through the soil and because of the large amount of N fertilizer used (Smika et al., 1977). To avoid the risk of reduction of yield, farmers may over-irrigate and over-fertilize their crops in order to achieve a higher production. Under this management, the risk of contaminating the surface water and subsurface groundwater increases.

Numerous studies on groundwater contamination by N fertilizer have been documented (Duke et al., 1978; Timmons, 1984; Ritter and Manger, 1985; Bergstrom and Johansson, 1991; Follett, 1991; and Sexton et al., 1996). Much work has been done to establish better management practices for water and NO_3 use in agriculture (Bruckler et al., 1992). In addition, managing water and N fertilizers is challenging because those inputs, in conjunction with soil properties, affect the biological cycles in the soil, which vary widely in space and time (Russo and Bresler, 1981; Vieira et al., 1981; and Grundmann et al., 1988). Therefore, adequate sampling strategies need to be implemented in order to identify chemical process variability in the soil. Incorporation of variability in chemical and physical soil properties into hydrologic modeling methodology is necessary to provide accurate representations of the uncertainty induced by simulating soil variability and the hydrologic response (Wu et al., 1996).

Field experiments are very helpful in understanding the movement and fate of N through soil, but these experiments are time consuming and expensive. Also, computer simulation models provide an efficient way to simulate the effect of various combinations of hydrologic, chemical and management factors on the behavior of N in the environment (Borah and Pasantra, 1998). Computer simulation studies can be used because they are inexpensive, time efficient, and an environmentally safe technique to evaluate the effect of various agricultural management practices on the subsurface movement of NO_3 (Singh and Kanwar, 1995). However, it has been recognized that the spatio-temporal variability in such factors as topography, soil chemical and physical properties, climate, and land management influence the response of natural systems and limit the applicability of such computer simulation models (Sunday, 1996).

2.5. Geographic Information Systems (GIS) and computer simulation models

The creation of Geographic Information Systems (GIS) has allowed the investigator to store, manipulate, analyze, and report large amounts of data and display the results as maps (Marble, 1990; and Shaffer, 1995). Simulation modeling and GIS have a natural affinity as the domains dealing with both technologies are spatially distributed (Moore et al., 1993).

One of the major merits of GIS is that it offers the potential to increase the extent of the definition of spatial subunits for simulation modeling such that it has been successful in solving for time variation but not spatial disaggregation (Maidment, 1993). The main idea of coupling GIS with computer simulation models is to organize the output from GIS and use that as input to the computer simulation models. The output of the computer simulation model is subsequently submitted to the GIS for display (Sunday, 1996). A comprehensive review of interfacing land surface-subsurface processes with GIS is provided by Moore et al. (1993) and Maidment (1993).

In summary, much research has been done to identify practices that will reduce leaching and pollution of the ground water. From this research, I hope to develop management tools to achieve the goal of reducing pollution.

Timing fertilizer applications to be applied at frequent intervals to coincide with the crop demand is a practical method of reducing nutrient loss due to leaching where fertilizer injection can be used in conjunction with sprinkler irrigation systems (Rhoads and Stanley, 1981). Another possible management tool is the use of irrigation scheduling, in order to apply appropriate depths of water and avoid excess deep percolation and leaching (Duke et al., 1991).

As has been covered in this review, there are many tools that can be used to reduce groundwater contamination by N. In order to make efficient use of these tools, I need to take into consideration the spatial and temporal variability of the environmental processes that impact this nonpoint source pollution.

CHAPTER 3

MATERIALS AND METHODS

3.1. Study Site

This project was conducted as a part of a multidisciplinary project on precision farming made up of scientists from USDA-ARS and Colorado State University. This study was focused on two field (fields 6 and 39) approximately 10 km apart, both with center pivot irrigation systems. Both are located north of Wiggins, Colorado in Morgan County. Field 6 is 70 ha and field 39 is 52 ha in size. The center pivot on field 6 is 448.5 m long with nine towers and the center pivot on field 39 is 385.4 m long with seven towers. The period included in this study were the 1998 and 1999 crop seasons. The crop studied in both years was corn.

The soils on both fields are primarily sand. The Morgan county soil survey (Jordan, 1998) shows Valentine and Valentine Dwyer sands (sandy, mixed, nonacid, mesic, typic ustipsamments) and Bijou loamy sand (coarse loamy, mixed, mesic, Mollic Haplargids) on both fields. Field 39 also contains Truckton loamy sand (coarse loamy, mixed, mesic, udic argiustolls).

3.2. Spatial irrigation water depth maps

A center pivot moves in a circle on the field, therefore is more readily described in a polar coordinate system than a Cartesian coordinate system. As recommended by Jordan (1998), I used a polar coordinate system that was built in AutoCAD, with concentric spacing of 7.6 m and radial increments of 5 degrees. This polar grid was used as a reference to divide the area into cells small enough to characterize a specific area of the field while reflecting the operating characteristics of the system (outer nozzles move faster and cover a larger area than the inner nozzles).

To estimate the irrigation water distribution depth under the polar grid, I used the CPED program, which was tested by Jordan (1998). In general, he found good agreement between the model prediction and data from the field. I also tested the program, using field collections and came to the same conclusion that Jordan (1998) found in his research. One limitation identified was that CPED can simulate the water depth distribution through the entire length of the pipeline only in one angular position each time. Due to the topographic variability of the fields, and the lack of pressure regulators on both center pivots, I ran the CPED program every 5 degrees in order to estimate the total water distribution depths across both fields.

3.2.1. CPED requirements and running

The CPED model requires physical characteristics of the center pivot and the operating parameters in order to run a simulation. I can define this information as follows:

a.- Pump Information

b.- Sprinkler Information

c.- Tower Information

d.- Span Information

e.- System Information

f.- Simulation Parameter input

a.- Pump Information

The program uses the actual pump curve in conjunction with calculated sprinkler pressure head and head losses to determine the pump operating pressure and discharge. I conducted several pump tests at different flows and pressures, in order to estimate the actual pump curve, because the Fairbanks Morse pumps installed at both fields were too old (deteriorated performance) to use the manufacturer's pump curve. Discharge was measured using a Controllotron 1010DP transit time ultrasonic flow meter. A transit time flow meter measures the effect of a liquid's flow velocity on bi-directional ultrasonic signals. An upstream transducer sends a signal to a downstream transducer that in turn sends a signal back. The effect of the liquid's flow velocity on the acoustical signal is to assist the signal in the upstream to downstream direction and hinder the signal in the downstream to upstream direction. The difference in travel time between the transducers in each direction is used to determine the flow velocity, which is used to calculate a flow rate based on user entered pipe dimensions. Controllotron specifications indicate a velocity measurement error of ± 2% of mean. Pivot pressure was measured at the first outlet beyond the collector ring using a Druck DPI 601 digital pressure indicator which has a resolution of ± 0.07 kPa. The pivot pressure and the discharge were measured at several different angles in order to capture their variability across the field, due to changes in topography, end gun operation, and water table position.

Our assumption was, for both center pivots, that the pump had one stage and was sitting on the ground only a few centimeters from the riser pipe at the point that I measured the flow. This assumption was made in order to be more accurate in the net pump curve calculation.

The head vs discharge graph for the pump on the system was used to develop a regression equation that describes the pump discharge at both center pivots. The pump curve can be described by a polynomial equation as :

$$Q = \beta_0 + \beta_1 H + \beta_2 H^2 \qquad \textbf{3.2.1.1}$$

Where Q = discharge (l/s),

H = head per stage (m), and

β_0 , β_1 , β_2 = regression coefficients.

The coefficients of equation 3.2.1.1 were determined by a least squares fit to measured data using SAS program (SAS. Rel. 8.0, 2000). The pump bowls and pump coefficients are given in Table 1.

Table 1. Pump bowls and coefficients entered into CPED.

Pivot	Bowl size [cm]	Model	Impeller diameter [cm]	No of stages	β_0	β_1	β_2
6	30.5	12MC	18.95	1	-10.77	1.98	-0.059
39	30.5	12MC	18.95	1	-3.03	0.85	-0.025

b.- Sprinkler Information

Discharge and wetted radius of sprinkler heads are simulated by CPED using polynomials describing the discharge coefficient and the sprinkler pattern radius in the form of :

$$C_D = \beta_0 + \beta_1 d^2 + \beta_2 H \qquad \textbf{3.2.1.2}$$

and

$$R = \beta_3 + \beta_4 (d_r^2 H) + \beta_5 (d_r^2 H)^2 \qquad \textbf{3.2.1.3}$$

Where

C_D = discharge coefficient,

d = equivalent nozzle radius (m) where $d = \frac{1}{2}(d_r^2 + d_s^2)^{0.5}$,

d_r = range nozzle diameter (m)

d_s = spreader nozzle diameter (m),

H = sprinkler pressure head (m), and

R = pattern radius, (m)

$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ = regression coefficients.

The coefficients for the polynomials are determined from a least squares fit to the manufacturer's performance data using equations 3.2.1.2 and 3.2.1.3 for each sprinkler model and those are entered into the CPED program.

The sprinkler package on pivot 6 consists of 103 Nelson R30 heads with D4 plates mounted on drops 2 m above the ground, and a Nelson R100 end gun. There are pressure regulators installed in the first seven sprinklers of the system (7 m for the first four and 10.5 m for the rest). The end gun is turned on only between 0-35, 50-100, 115-165, 175-315, and 330-360 degrees relative to true north.

The sprinkler package on pivot 39 consists of 142 Rainbird 8X spray heads with medium groove concave deflectors mounted above the pipeline, one Rainbird 85 spray head and a Nelson SR100 end gun. There are no pressure regulators on the system. Pivot 39 has a booster pump installed at the end gun. The end gun is turned on only between 25-75, 100-165, 225-255, and 330-340 degrees. In addition, when the SR100 end gun is on, the Rainbird 85 spray head is off and vice versa. The regression coefficients for these sprinklers are shown in Table 2.

Table 2. CPED sprinkler coefficients for simulated systems.

Sprinkler	β_0	β_1	β_2	β_3	β_4	β_5
Nelson R30	1.035	-264.2	4.06E-4	30	0	0
Rainbird 8X	0.9226	-916.6	3.0E-05	21.21	312.5	-1628
Rainbird 85	0.9603	-118.7	9.86E-5	54.74	175	-155.4
Nelson SR100	0.9799	-0.449	-2.40E-05	86.09	104.3	-27.32

Because the pattern radius is not significantly affected by pressure in the Nelson R30 (regression was not statistically significant at 0.05), the coefficients β_4, and β_5 were set to zero.

c.- Tower Information

Variable topography changes the pressure distribution in the sprinkler pipe from that which occurs over level terrain. The CPED model takes into consideration the change in the hydraulics of the center pivot when the topographic elevation changes along the length of the pipeline. I used a detailed topographic survey conducted on each field (Jordan, 1998) to determine tower elevation for the model. The surveys were conducted using a total station. The boundaries of the cultivated areas were also mapped using differential GPS. Tower elevation data were determined using the survey data and the analysis tools of ArcView 3.1 and ArcView Spatial Analyst 1.0. The elevation surfaces used are shown in Figures 1 and 2.

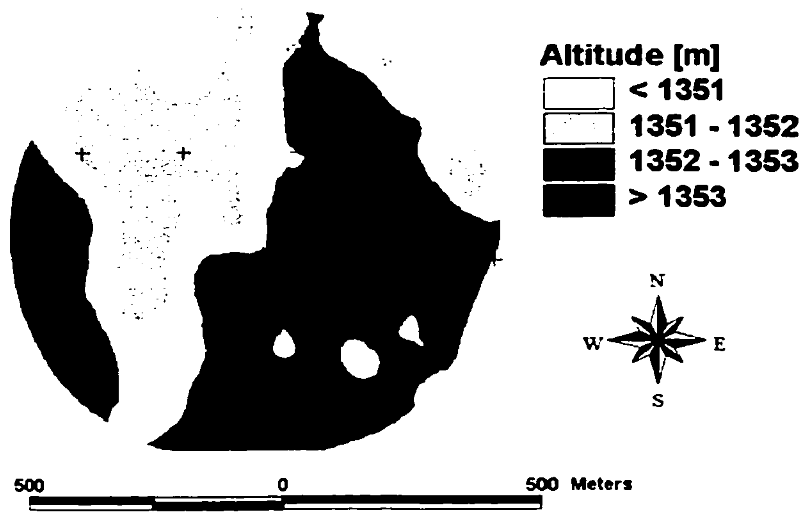


Figure 1. Elevation surface of center pivot 6.

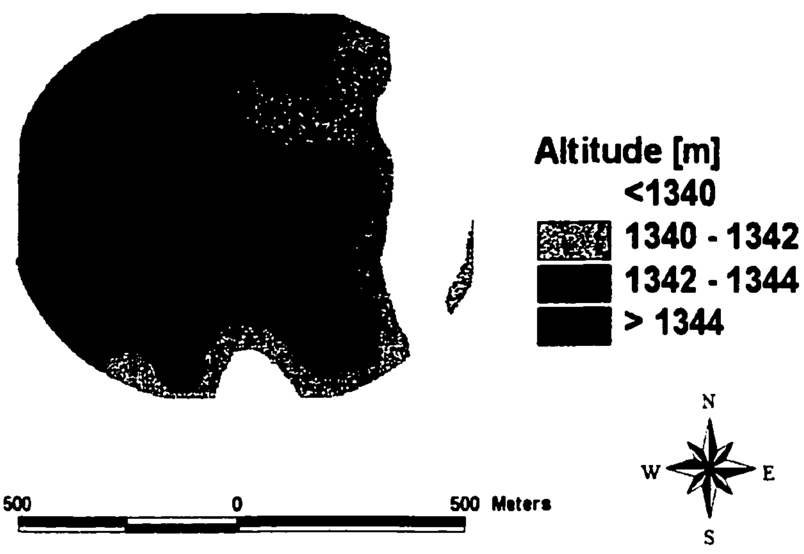


Figure 2. Elevation surface of center pivot 39.

As we can see from Figures 1 and 2, center pivot 39 has considerably more topographic relief than center pivot 6, which affected the water distribution depth on it more, as we will see in chapter 4. In order to represent the water distribution depth over the area, I entered the topographic elevation of each tower every 5 degrees (72 different positions) into CPED.

d.- Span Information

This input data also represent the length and internal diameter of each section of the pipe that was installed on each field. In addition, to be more accurate in the calculation made for CPED, I the calculated Darcy-Weisbach resistance coefficient (*f*) from the Darcy-Weisbach equation:

$$h_f = f \frac{L}{d} \frac{V^2}{2g} \qquad \textbf{3.2.1.4}$$

Where:

h_f = Friction head loss (m),

f = Darcy-Weisbach resistance coefficient,

L = Pipe length (m),

d = Pipe internal diameter (m),

V = Mean water velocity in the pipeline (ms^{-1}), and

g = Gravitational acceleration (ms^{-2}).

I calculated the first approximation of the Darcy-Weisbach resistance coefficient from data obtained in the field, as shown in Table 3 and adjusted it by trial and error using CPED until calculated line pressures equaled measured pressures. The coefficient was found to be equal to 0.02.

Table 3. Field data from center pivot 39.

Tower	Distance from pivot	Ground elevation	Pressure Head	Pivot Pressure	Angle
	m	m	m	m	Deg
1	48.43	1343.04	30.23	34.45	20
2	102.75	1342.62	29.53	34.45	20
3	157.07	1341.52	28.83	34.45	20
4	211.36	1341.28	28.12	34.45	20
5	265.68	1342.25	27.42	34.45	20
6	320.00	1342.46	26.01	34.45	20
7	374.29	1342.43	24.61	34.45	20

e.- System Information

I entered information about the pressure control and booster pump installed in each center pivot, which is important in modeling the water output. In center pivot 6, the first 7 sprinklers have pressure regulators with 7 m (10 PSI) at the first 4 sprinklers and 10.5 m (15 PSI) at the next 3 sprinklers. Center pivot 6 does not have a booster pump. In Center pivot 39 does not have pressure regulators, but has a booster pump to increase the pressure of the end gun.

f.- Simulation Parameter Input

To run CPED, the characteristics of the simulation desired need to be defined, such as hours per revolution, start distance, stop distance, and distance increment at which depth calculation is desired. To obtain the hours per revolution of each irrigation, a datalogger was installed in the panel of the each center pivot. This datalogger registers: day of the year (1 to 365), time (hhmm), position (degree), pressure of the system (PSI), stop/run (0=stopped, 1=running), forward/reverse (0=forward, 1=reverse), and motor timer setting (percent duty), each 15 minutes.

I recorded the actual irrigation schedule used by the farmer for each center pivot (irrigation management) through both seasons, in order to define the hours per revolution for each one (Appendix 1). These records revealed that irrigation management by each farmer was variable. They sometime stopped the machine and changed the speed of the center pivot or stopped and did not finish the irrigation due to a rain. Those problems were taken into consideration in running the seasonal CPED simulation.

The start position refers to the radius at the beginning of the simulation and could be the center pivot position or something close to it; I started all the simulations at a radius of zero. The stop position refers to the ending radius of the simulation, and could be the edge of the field or something near it. I used the point at which the depth applied was less than or equal to 0.02 mm for the simulations, with 520 m and 430 m for center pivot 6 and 39 respectively. The distance increment recommended by Jordan (1998) of 3 m (173 and 143 points for center pivot 6 and 39 respectively) that is enough small to catch the variability of the water distribution depth under the center pivot pipeline was used.

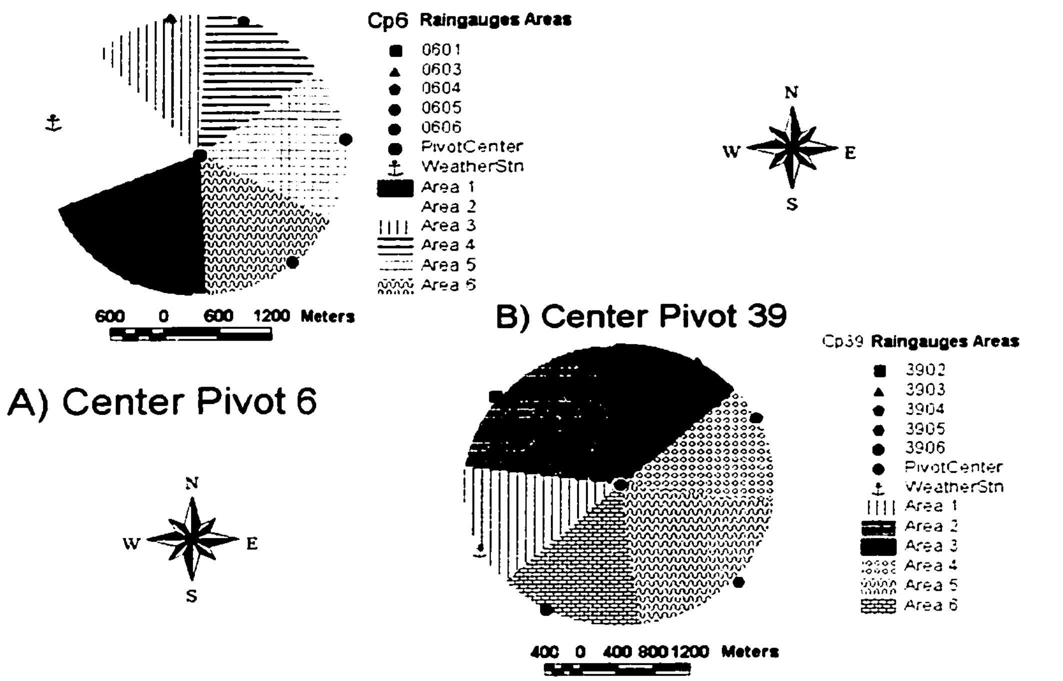
With all parameters already determined and incorporated in CPED, I built the system file (example in Appendix 1) for each 5 degrees of the polar grid and ran CPED for each one. The seasonal amounts were calculated by accumulating the simulated depths for all irrigations. The revolution speed for each irrigation was set, in each center pivot, using the actual schedule used by the farmer.

To create an irrigation application map, this information was imported into a GIS environment. This was done using the coordinates generated by the procedure developed by Jordan (1998). A table was made with the coordinates of each simulated application depth, its radius and angle and its water depth for each recorded irrigation event. The irrigation depths were summed to achieve a seasonal irrigation depth at each point. This table was then imported to ArcView, mapped and overlain with the polar grid through a spatial join, which assigns data from points to areas. The average data from the points are joined into the area containing them.

3.3. Spatial water depth maps

To obtain the total water applied under the center pivot, I included the rain that was received on the area. To be more accurate in my calculation, I used a preinstalled set of raingauges in each field. In each field there are 6 raingauges and 1 at the weather station, distributed around the area in order to capture the rain variability within each field (Figure 3).

As shown in Figure 3, the circle was divided like a pie graph, with the half distance between each raingauge and the next as a point of division. In those areas, the average of daily rain between peripheral the raingauge on the center of each center pivot was used. Finally, I calculated the total amount of rain in each area and added it to the irrigation depth of each point in order to obtain the total applied water maps.



06xx and 39xx = Raingauge No XX

Figure 3. Raingauges and weather station locations with their respective area subdivision.

3.4. Spatial map of N applied through fertigation

Because some areas of each center pivot were occupied by other research projects, not all of each center pivot was fertigated. The area without fertigation on center pivot 39 was between 40 and 70 degrees, while in center pivot 6, fertigation was not applied between 20 – 40 and 215 – 300 degrees. Thus, I did the spatial analysis for N only in the areas with fertigation.

To build the maps of spatial N applied through fertigation, I accounted for the variability of N injection rate due to line pressure changes and the variability of N applied due to the variability of water applied. All other possible factors were assumed to be not significant.

The solution injected was UAN 32, that has 32 % N in the solution in the forms of urea (16.4 %), ammonia (7.8 %), and NO_3 (7.8 %). The injection pumps were hydraulic and electric for center pivots 6 and 39, respectively.

A Campbell Scientific Inc. 21X Micrologger was installed and connected to a float in the top of a stilling well connected with each fertilizer tank to register the level of the fertilizer in the tank each 15 min while the injection was taking place (Figure 4 and photograph in Appendix 2).

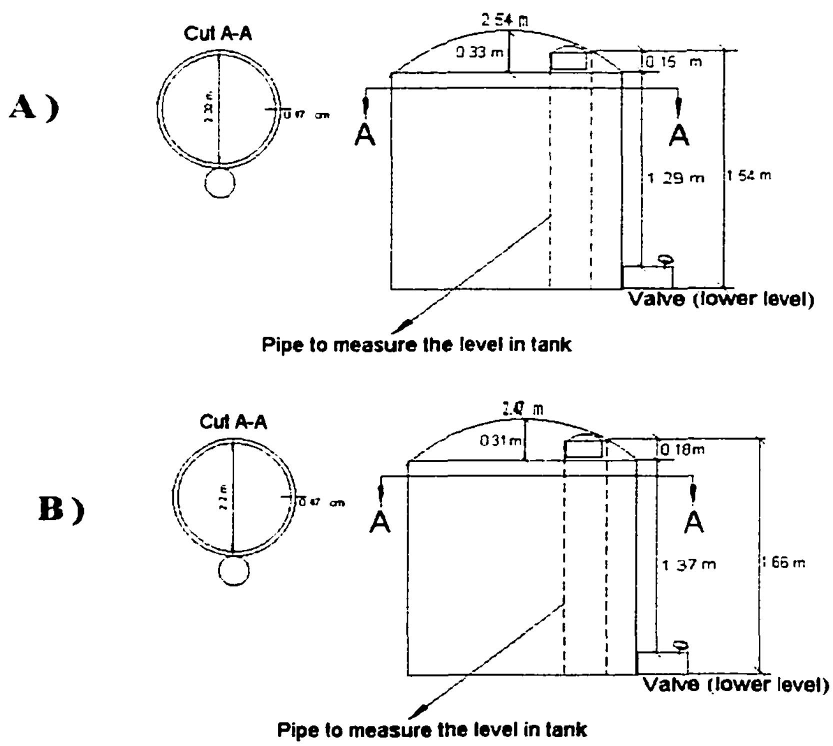


Figure 4. Diagram of 21X Micrologger set up on center pivot 6 (A) and 39 (B).

To calculate the variability of the N injection into the water the following procedure was used. I used the dimensions of each tank (Figure 4) and the differences of level from the 21X Micrologger to calculate the volume of UAN 32 that was injected each 15 minutes. At the same time, I used the location and line pressure data from the pivot panel datalogger and the irrigation pump curve (Equation 3.2.1.1 and Table 1) to calculate the volume of water pumped during the same 15 minute period and its location. Finally, both volumes were used to calculate the concentration of N (ppm) in the pipe at each 5° increment around the field. An example of this calculation is given in Appendix 2 (Table 20).

In the last calculation, the concentration of N was assumed to be uniform and instantly mixed along the sprinkler pipe. First, I calculated the travel time (T) from the equation given by DeTar (1983) as follow:

$$T = \sum_{i=1}^{n} t' * (0.577 + LN (n)) \qquad \textbf{3.4.1}$$

Where: t' = $A*L/Q$,

A = Area of pipe [L^2],

L = Distance between two outlet [L],

Q = Flow per outlet [L^3/T], and

n = Number of outlets in the pipeline.

The average travel time was 13 and 8 minutes for center pivots 6 and 39, respectively. As the sample period was 15 minutes and those times were smaller than 15 minutes, I assumed that any change in concentration would propagate to the end of the sprinkler line during one sample period.

The variability of the N applied due to the variability of water applied was taken into consideration with the use of the CPED simulation model. The water depth along the pipeline was simulated for each 5°, and the average value of depth was assigned to each polar grid cell.

Using the capabilities of MapCalculator of ArcView 3.1, I calculated of the amount of N applied through fertigation with the follow equation.

$$C_{app} = K * C_{nw} * D_w \qquad \textbf{3.4.2}$$

Where : C_{app} = Amount of N applied [kg-N/ha],

K = Constant of unit transformation = 0.254,

C_{nw} = Concentration of N in the water [ppm], and

D_w = Water depth [mm].

These calculations were performed for each fertigation at 5° interval for both center pivots. All fertigations were added together to determine the seasonal N applied through fertigation.

At the location of each computed irrigation depth, an estimate of N applied for each fertigation was made and summed to obtain the seasonal amount. Finally, I used the capabilities of ArcView to map the N applied and overlay it with the polar grid through a spatial join. These calculations were made for the 99 season for both center pivots but only per center pivot 6 in the 98 season, because I did not have the injection rates for center pivot 39 in the 98 season.

To verify the calculation result, I selected points in each center pivot (only for season 1999) in order to take field samples for analysis of N concentration and to compare with the calculated values at the same location (Appendix 2).

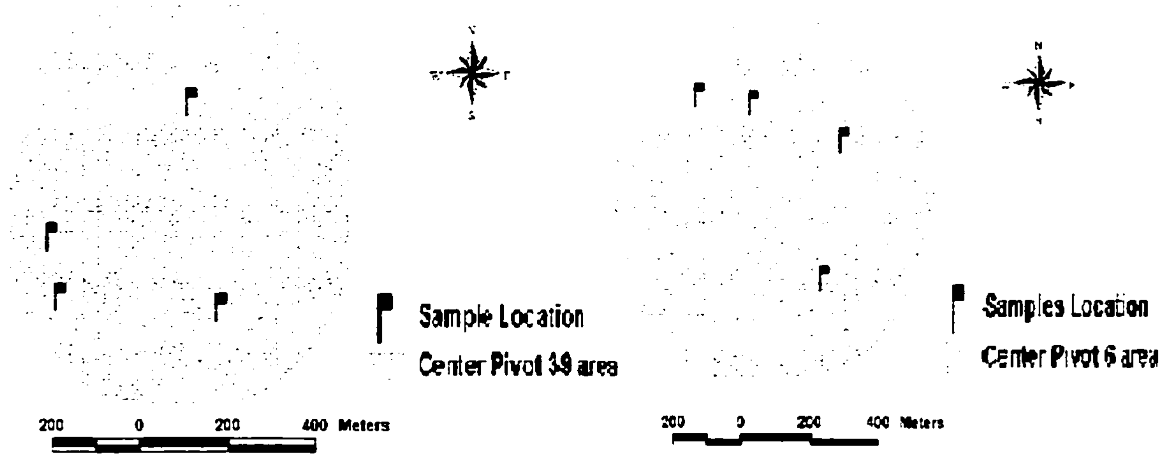


Figure 5. Water sample location on center pivot 6 (A) and 39 (B).

The root mean square error (RMSE) and the adjusted coefficient of determination (r^2) as recommended by Loague and Green (1991) were used to verify the correlation between the simulated data and the data obtain from laboratory (field samples). Those values were calculated with SAS System for Windows, Release 8.0 and they are in Chapter 4.

3.5. Spatial leaching maps

The data were transformed from the polar grid into a cartesian grid, because my project is part of a bigger multidisciplinary project and most of the data collected and analysis has been obtained under a 76.2 x 76.2 m grid (referred to as the " coarse grid"). Because some areas in each center pivot were not fertigated, I only used those areas with fertigation for this study (Appendix 3). ArcView 3.1 and Spatial analysis 1.0 were used to join the polar grid with the coarse grid and to find an average value for each coarse grid of water and each source of N from the maps explained above.

To estimate N transport through the soil (N leaching) under our coarse grid in each field, I used a simulation model of nonpoint source pollutant transport called Opus (Smith, 1992). The remaining analyses were simulations, since no instruments were installed in the field to take deep percolation samples. Opus is a computer model for the transport of water and dissolved chemicals in soil and surface water. The model is a simulation tool for studying the potential pollution from various agricultural management practices. It simulates water movement that results from irrigation and rainfall inputs, as affected by soil, crop, topography, water use, and many types of management actions. Opus includes models for the growth of plants; development of cover; water use; uptake of nutrients; cycling of soil N; transport of nutrients; interaction of surface water and soil water; runoff; erosion; and leaching.

To obtain the leaching map for each season, I determined the required model inputs for each coarse grid (117 and 103 grids for center pivots 6 and 39, respectively) and ran Opus for each one. For the previously explained reasons, simulations were conducted on each center pivot for season 99, but only on center pivot 6 for season 98.

3.5.1. Opus input requirements

Opus requires three input files in order to make a simulation. Those files required, as described by Ferreira and Smith (1992), are :

a.- Actual (*.ACT data file extension) : Includes daily maximum and minimum temperatures (Celsius), and daily incoming solar radiation (Langleys) values. These data were obtained from the weather station located at each center pivot (see appendix 3).

b.- Meteorology (*.PPT data file extension): Includes rainfall dates and depths.

As Opus does not accept an irrigation event as input (can only be simulated as precipitation), I created a file combining rain and irrigation depth for each date. Thus, each irrigation was entered as a rain event in the input file (see Appendix 4 for example).

c.- Parameter (*.PAR data file extension): This is the most extensive and important input file. The parameter file contains the data necessary to define the problem for simulation.

I used the Opus graphical input interface (beta version, 1999), built by Hamid J. Farahani, USDA-ARS-Water Management Research Unit, Fort Collins, CO. The data input for the PAR files of Opus are identified in this interface by general types in ten sections as listed in Table 4 (Ferreira and Smith,1992). An example is shown in Appendix 4.

Table 4. OPUS input data organization

Record Section ID	Data type	Input file
I	ID and run controls	Parameter file
II	General state/initial conditions	Parameter file
III	Soil horizons	Parameter file
IV	Crops	Parameter file
V, VI, VII & VIII	Management	Parameter file
IX	Topology	Parameter file
X	Erosion/sediment	Parameter file

i. **ID and run controls** : In this part, general information such as unit parameters, simulation identification information, time period of simulation, output file options, and others were provided.

ii. **General state/initial conditions** : In this part, I introduced field information (area and location), water table location, soil surface conditions, water content at start of simulation, SCS curve number (i.e. Soil Conservation Service curve number method for modeling runoff hydrographs) and other parameters such as the potential evapotranspiration (reflects the combined effects of wind and humidity on ET) and annual mean concentration of N in natural rainwater. For the last two variables, I was forced to make some assumptions.

First, I used the potential evapotranspiration to adjust the seasonal evapotranspiration of the field, in each center pivot, to the value calculated by the USDA irrigation scheduling program[1]. This was required because Opus does not calculate the evapotranspiration very accurately.

Second, I assumed the N concentration in the rain was zero. The irrigation water was added into the model as rain, including the irrigation water N concentration, in order to accurately calculate the total N applied. To estimate the annual mean concentration of N in the irrigation water, groundwater samples in both seasons and center pivots were collected and sent to the laboratory (Appendix 5). Because the samples were not very variable throughout the season (in either center pivot), an average seasonal value was used to estimate the annual mean concentration of N in the groundwater for input to Opus. This value also took into consideration of dilution from rainwater.

iii **Soil horizons :** Soil physical and initial chemical characteristics were used, as were depth to soil layers, porosity, sand fraction, silt fraction, clay fraction, saturated hydraulic conductivity, field capacity, wilting point, bubbling pressure, pore size distribution index, and soil water content at saturation (Appendix 6). Data from Morton (1998) for each field were used. He collected soil samples in each field in order to describe the soil hydraulic conductivity variability (Figure 6).

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1 Duke, H.R. 1999. Unpublished irrigation management calculations using USDA irrigation scheduling program. USDA-ARS, Fort Collins, CO.

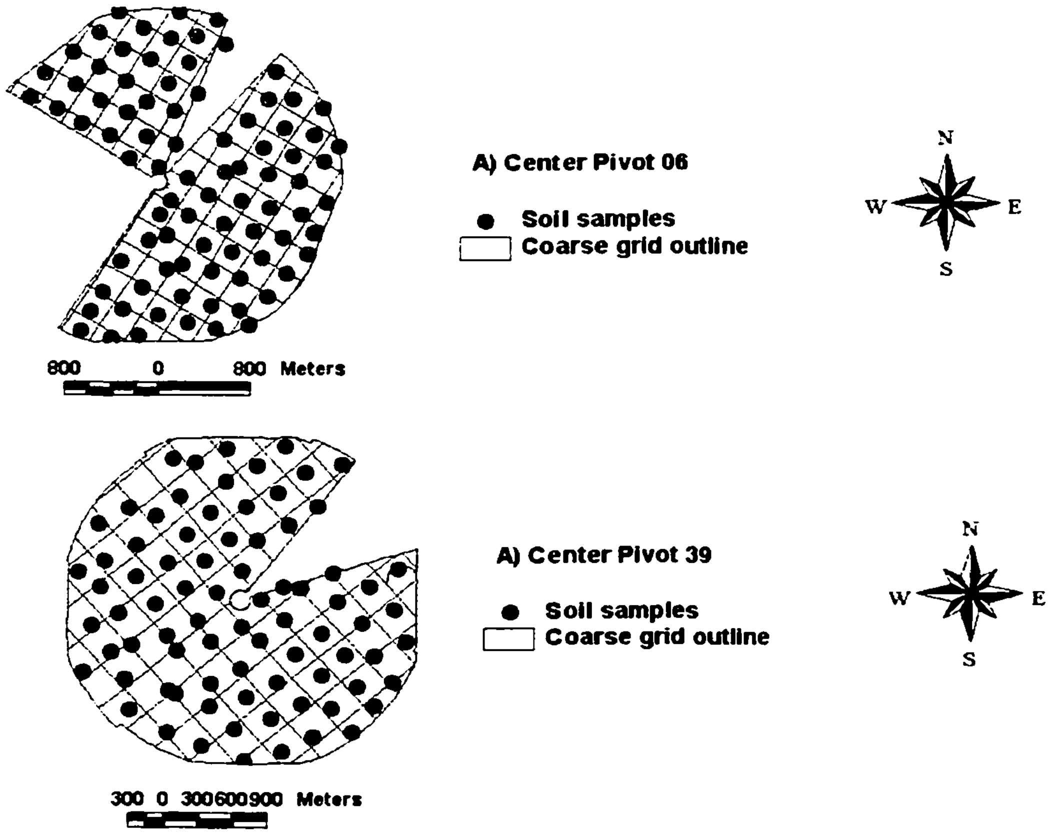

Figure 6. Point samples in each field (only in fertigated areas).

For the chemical characteristics, such as initial organic carbon content (organic matter divided by 1.73), and initial organic N content, data provided by other members of the research team were used. It was necessary to make an assumption of the initial N content for the surface layer in the 1999 season in the center pivot 6, due to lack of data (the farmer applied fertilizer immediately before our soil samples were collected). I used the assumption of Ehrhardt and Bundy (1995), in which they used a regression analysis between of the N content in the first and second layer of the previous year to estimate the N content in the first layer in the follow year. In the same way, I used the data from 1998 (Figure 7) to adjust the 1999 first layer N content (Appendix 6).

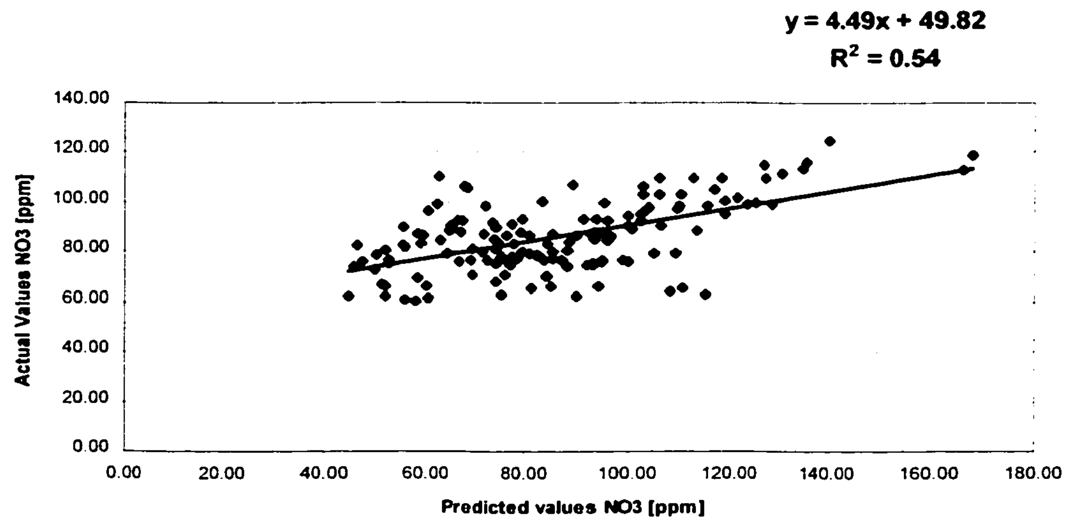

Figure 7. Observed and predicted N content for first layer, 1998, center pivot 6.

iv. Crops: The corn parameters were taken from Morton (1998) such as, potential yield of dry matter and grain, maximum leaf area index for crop, potential maximum root depth for plant, degree-days measured from planting of crop, its maturity, potential total plant height, relative amount of ground surface covered by projected area of crop when mature, minimum temperature for growth of plant, temperature at which plant grows at its maximum rate, above ground lignin content of plant, below ground lignin content of plant, and other parameters (Appendix 4).

Management: This part is subdivided into four different parts, which are:

v. **Tillage types and equipment parameters:** Obtained from other members of the research team.

vi. **Pesticide type and parameters** : This part was not used in my research.

vii. **Manure types and parameters** : This part was not used in my research.

viii. **Tillage and Fertilizer:** Tillage date and types were obtained from other team members.

The fertilizer data for each grid were obtained from the coarse grid maps built in section 3.4 of this dissertation. From the applied N maps, the ammonia, NO_3, and urea components of the UAN solution applied in each coarse grid (Appendix 7) were calculated.

In Opus, the fertilizer can be introduced only as ammonia or NO_3. Since UAN 32% was used in my research, I assumed that the ammonia and NO_3 part of the UAN solution was applied at the same time as the fertigation application, and that the urea was transformed to NO_3 later. Due to the limitations of Opus in the number of fertilizer events (only 10 possible events), I assumed (in order to fit the number of actual fertilizer applications that I had) that the urea transformation to NO_3 was at the same time as the next fertigation event, between 7 and 10 days later. This assumption was made for each fertigation event. Because I applied the irrigation like a rain event, I had to consider those fertilizer events as a surface application.

The preplant and starter fertilizer dates and amount for each center pivot were obtained from other members of the research team (Table 5). Those values were assumed to be uniform and were introduced to Opus as well as the previous fertigation events.

Table 5. Surface fertilizer application, center pivot 6 season 98 - 99, and center pivot 39, season 99.

Date	Center Pivot 6 N-N03 Rate (average) [kg/ha]	Center Pivot 39 N-N03 Rate (average) [kg/ha]	Type	Note
04/16/98	112		Starter	
04/29/98	28		Preplant	
03/18/99	33.6		Preplant	South east half
03/29/99	212.8		Starter	North west half
04/26/99		56	Preplant	
05/07/99		28	Starter	
05/09/99	28		Starter	

ix. **Topography** : The field elevations were obtained from the Jordan (1998) research.

x. **Erosion/sediment** : I used the Opus default erosion and sediment parameters because no surface transport of water was observed on these two fields.

3.5.2. Running Opus simulations

The PAR, PPT, and ACT input files were introduced into the input screen of Opus. Finally, from the available Opus options, the following output files were created :

a. **Main file (*.OUT output file extension):** Includes daily and cumulative evapotranspiration, deep percolation, and N leaching.
b. **Subsurface (*.SUB output file extension)**: Includes the daily moisture content of each soil layer.
c. **Nitrogen cycling report (*.CRP output file extension)** : Includes the daily N balance in the soil.

Data could then be extracted from Opus output files for further analysis. In my research, I only used the main output file (*.out), from which I obtained the cumulative and monthly deep percolation and N leaching maps. The subsurface (*.sub) and N cycling report (*.CRP) output files extension were not used in this research but will be used for further studies in this multidisciplinary project.

3.6. Nitrogen Mass balance

In order to assess whether Opus is meaningful in its calculations of leaching losses, a mass balance was developed for both fields in the period of study to compare Opus computed losses with the mass balance calculations.

The mass balance was calculated for each cell of the coarse grid. Nitrogen leaching and microbiological retention were considered as losses in this mass balance. On the other hand, starter and preplant, fertigated, mineralized, difference in storage (initial minus final N concentration), and irrigation water (ground water N concentration), N were considered as inputs to the system. The equation used to calculate the mass balance is :

$$N_l = N_a - N_u \qquad \textbf{3.6.1}$$

Where :

N_l = N potentially leached [kg-N/ha]

N_a = N potentially available [kg-N/ha]

N_u = N uptake [kg-N/ha]

The N potentially available (N_a) to the plant in each cell was calculated with the following equation :

$$N_a = N_{gw} + N_{si} + N_f + N_m + N_{ds} - N_{mf} \quad \textbf{3.6.2}$$

Where :

N_{gw} = Nitrogen in irrigation water [kg-N/ha],

N_{si} = Nitrogen surface incorporate (starter and preplant) [kg-N/ha],

N_f = Nitrogen applied by fertigation [kg-N/ha],

N_m = Nitrogen mineralized [kg-N/ha] where N_m = OM * 22.5,

OM = Percentage of organic matter (%),

N_{ds} = Nitrogen available in soil obtained by difference between initial and final N concentration [kg-N/ha], and

N_{mf} = Nitrogen used by microbes in the soil (30%[2] of total N fertilizer input) [kg-N/ha].

The amount of N available in the soil due to mineralization of the organic matter was obtained in the same way as Opus calculated this value.

The N uptake was calculated from yield obtained in each cell with the following equation :

$$N_u = Y * I + Y * E \quad \textbf{3.6.3}$$

Where :

Y = Grain yield [kg/ha],

I = % of N in the grain = 1.06[3] %, and

E = % of N in the stalks = 36 % of I (Follett, 1991).

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2 Dr. W. Parton (2001) personal communication.
3. Dr. W. Bausch (2001) personal communication.

3.7. Using output data

The output data and some input data for Opus, such as water and N applied, texture, initial N content, topography, and others were used to obtain relationships between these respective variables and yield through regression analysis and spatial analysis, using ArcView 3.1 spatial analysis 1.0 tools. Results of those analyses can be found in the Results and Discussion chapter and in Appendix 8.

3.8. Target defined areas

A general question facing researchers in many areas of inquiry is how to organize observed data into meaningful structures, that is, to develop taxonomies. For example, biologists have to organize different species of animals before a meaningful description of the differences between animals is possible. According to the modern system employed in biology, man belongs to the primates, the mammals, the amniotes, the vertebrates, and the animals. Note how in this classification, the higher the level of aggregation the less similar are the members in the respective class. Man has more in common with all other primates (e.g., apes) than it does with the more "distant" members of the mammals (e.g., dogs), etc.

In my research I had similar questions as described above. This question was addressed through the use of cluster analysis statistical procedures. The cluster procedure used was the centroid method from

SAS System for Windows Release 8.0. This was used to cluster the different variables such as water and N applied, soil texture, initial N content, and topography in order to select areas for similar management. Results of those analyses can be also found in chapter 5 and in Appendix 8.

The purpose of cluster analysis is to place objects into groups or clusters suggested by the data, which are not defined a priori, such that objects in a given cluster tend to be similar to each other in some sense, and objects in different clusters tend to be dissimilar. There are many methods of cluster analysis. However, in all cases the intent of cluster analysis is to identify and group cases with similar patterns in the set of attributes used to describe each case. In the agglomerative methods, such as the centroid method, each individual case in a data set begins as a cluster. The two most similar clusters are identified and joined. The clustering process continues to identify and join the next most similar data into clusters until there is only one cluster. In the centroid method, when the cluster is made up of two or more data points, the cluster is characterized by a vector of attribute averages for that cluster, and this vector of attributes is used for computing the similarity to other clusters. The criteria used for identifying similarity between clusters in the SAS centroid method (SAS. Rel. 8.0, 2000) is the euclidean distance between the set (= vector) of attributes for each cluster. The smaller the euclidean distance, the more similar the clusters. At each cluster level, the euclidean distances between all cluster pairs are computed, and the two most similar clusters (smallest euclidean distance) are merged to form a new cluster.

CHAPTER 4

RESULTS AND DISCUSSION – SPATIAL WATER AND NITROGEN APPLICATION

In Chapters 4 and 5, results of this study will be presented and discussed. The assessment of the spatial distribution of water and potentially available N will be presented in Chapter 4 and the results of the deep percolation and leaching simulation made with Opus will be presented in Chapter 5. In addition, statistical analyses described in Chapter 3 will be presented and discussed in conjunction with all results presented here.

4.1. Verification of CPED simulation results

The CPED simulation model was tested by Jordan (1998) to determine irrigation distribution uniformity prediction, using several can tests following ASAE Standard S436, to verify the behavior of the simulation (Table 6).

Table 6. Can test vs. simulated uniformity coefficients.

	Can Test						Simulation		
	1a	1b	2a	2b	3a	3b	1	2	3
	NU						NU		
Cu – Pivot 6	0.72	0.78	0.79	0.84	0.85	0.86	0.80	0.92	0.95
Cu – Pivot 39	0.79	0.84	0.86	0.82	0.83	0.83	0.84	0.88	0.87

Cu : Heermann and Hein (1968) uniformity coefficient; NU : No unit.

The simulation and can test uniformity coefficients showed acceptable agreement in his research. He concluded that the simulation results for tests 2 and 3 show the largest differences, possibly due to wind conditions or high evaporation during the measurements.

I conducted one can test in center pivot 39, in order to test the CPED simulation. Results of this test are in Table 7 and Figure 8. Good agreement occurred between the simulation and the can test. The difference between coefficients could be attributed to windy conditions during the test. As a result of the comparisons done by Jordan and me it was concluded that CPED adequately describes the "no wind" water distribution under the sprinklers used in this study.

Table 7. Can test vs. simulated uniformity coefficients for center pivot 39.

Can Test	Can	Simulation
	— NU —	
Cu – Pivot 39	0.82	0.89

Cu : Heermann and Hein (1968) uniformity coefficient ; NU : No unit.

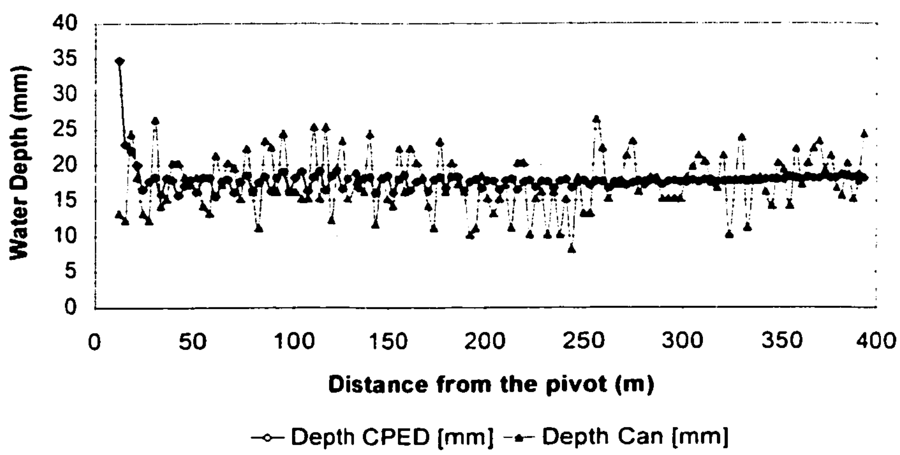


Figure 8. Can test and CPED simulation depth on center pivot 39.

4.2. Irrigation application maps

The 1998 seasonal irrigation application for center pivot 6 is shown in Figure 9, and the 1999 seasonal irrigation application for center pivots 6 and 39 are shown in Figures 10 and 11, respectively. Because of the lack of fertilizer injection data for the 1998 season, only the 1999 data for center pivot 39 were analyzed.

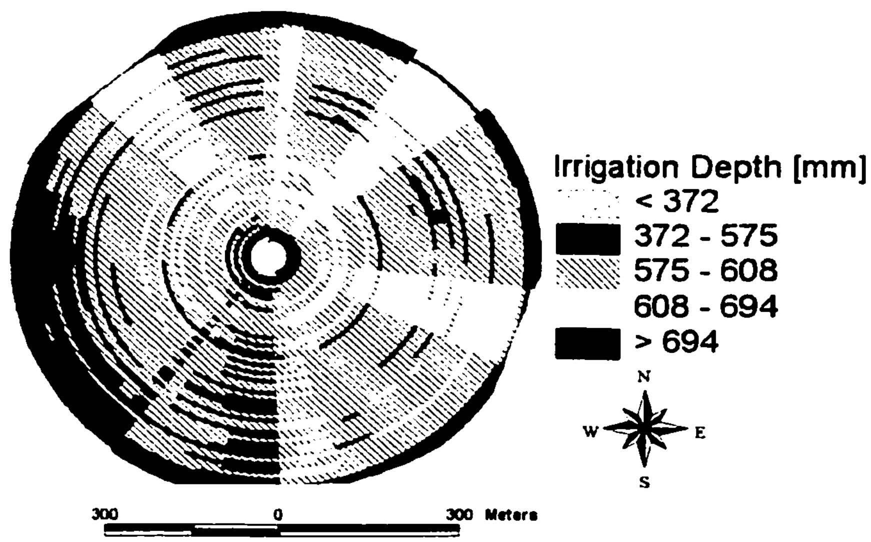


Figure 9. Seasonal irrigation distribution for center pivot 6 - 1998.

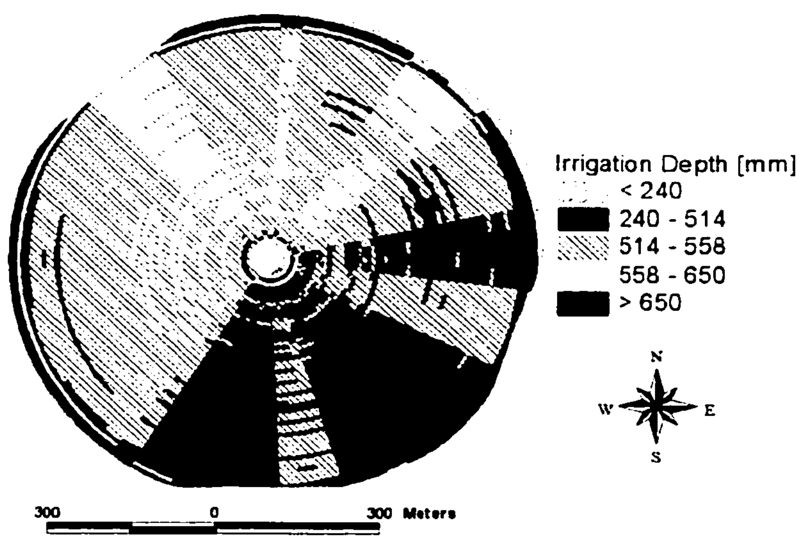


Figure 10. Seasonal irrigation distribution for center pivot 6 - 1999.

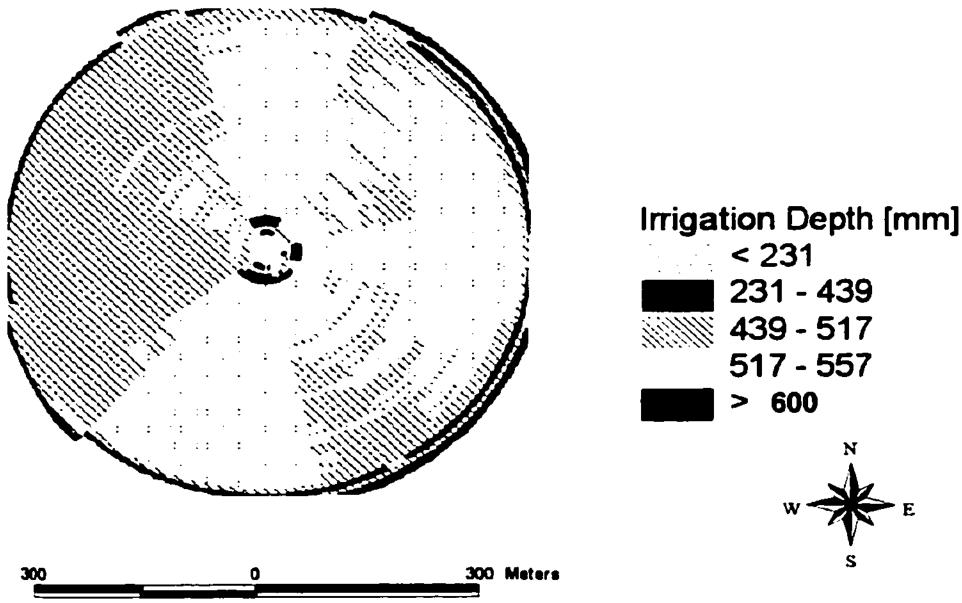


Figure 11. Seasonal irrigation distribution for center pivot 39 - 1999.

The figures showing seasonal irrigation distribution, based on the coarse grid, can be found in Appendix 9. Mean weighted (by area) seasonal depth for center pivot 6, computed from the polar grid, were 582 mm and 518 mm for 1998 and 1999, respectively, and for center pivot 39 was 521 mm for 1999. The uniformity coefficient values computed from the polar grid for the entire field were 0.94 and 0.89 for center pivots 6 and 39, respectively.

As we can see from Figures 9, 10 and 11, the topography (Figures 1 and 2) on center pivot 6 plays a lower role in the water distribution than in center pivot 39 because center pivot 39 has an 8 meter topographic difference and center pivot 6 has only 3 meters. The higher topographic elevations (Figures 1 and 2) result in lower water application, as we can see in the northeast and southwest areas of center pivot 6 and northwest area in center pivot 39. The lower topographic levels result in higher water application, as we can see in the northwest area of center pivot 6 and southeast and northeast areas in center pivot 39.

Lower water application in the southeast area of field 6 in 1999 (Figure 10) was due to changes in the center pivot speed by the farmer and stopping irrigation because of a rain event. The effect of the topography is increased by turning on and off the end gun in each center pivot. When the end gun is turned on, the pressure in the system decreases and with less pressure in the system, the sprinklers discharge less water. On the other hand, when the end gun is off, the pressure in the system increases and the sprinklers discharge more water. The changes in the sprinkler flows due to the end gun operation occur because the pump equilibrium operation point (intersection between pump curve and the system curve) is forced to a point of higher discharge and lower pressure when the end gun is on and lower discharge and higher pressure when the end gun is off. These phenomena can be easily seen in center pivot 6 (Figures 9 and 10), when the end gun is off (between 35-50, 100-115, 165-175, and 315-330 degrees) as shown by arcs of higher application and by lower application in the positions when the end gun is on. The same behavior was evident for center pivot 39 when the end gun is turned off (between 0-25, 75-110, 165-225, 255-330, and 340-360 degrees) and on. The rings of lower and higher application at the outer edge of each center pivot (Figures 9 and 10) are due to improper nozzle sizes and improper setting of the operation angles of the large end guns.

Both center pivots applied similar mean depths in 1998 and 1999. Even when big differences in topography and end gun management exist between center pivots (in center pivot 6 the end gun is on over almost all the field) small differences in total mean uniformity through the area were found (0.94 and 0.89 for center pivot 6 and 39, respectively). However, there are larger local differences in uniformity, such as in areas with the end gun off/on and higher and lower topography that may affect the uniformity and final grain yield. Nevertheless, both farmers applied more water than the crops required in both years, which reduced yield response to water and increased the potential leaching, as I will discuss later in Chapter 5.

4.3. Rain distribution

The average seasonal rain by area for center pivot 6 and 39 for 1999 can be seen in Figure 12 (both seasons data can be found in Appendix 9). As we can see from Figure 12, some differences exist in the rain distribution across both fields, with 18.8 and 19.0 mm of difference between areas in center pivots 6 and 39, respectively, for 1999. For 1998, the range was 24.8 and 12.5 mm for center pivots 6 and 39, respectively. If irrigation were managed carefully, the spatial distribution of rain might affect water stress, percolation, and crop yield.

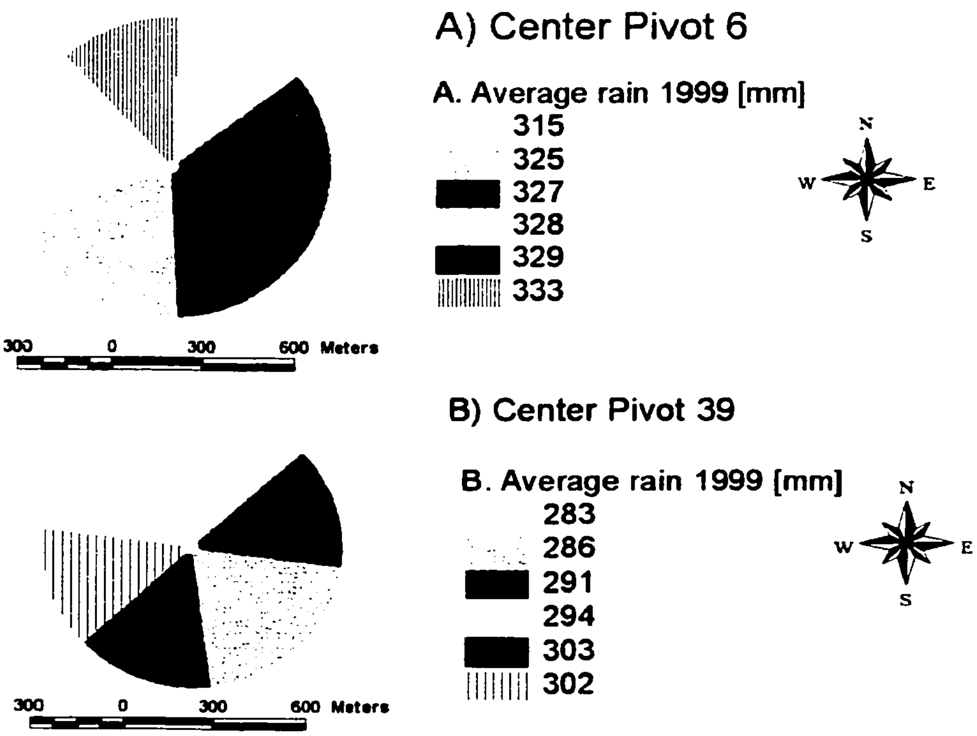


Figure 12. Distribution and average rain in center pivot 6 (A) and 39 (B) for 1999.

4.4 Spatial water application

The variation in the rainfall distribution introduces a variable input into the total water distribution that we cannot control to improve the distribution of the water applied. This means that we have some variability in the total water applied because of weather conditions, which could be another important source of the nonuniformity of irrigation in addition to the design of the system (nozzle selection, pump, topography differences, etc) and management by the farmer (stop/start the system, changes in speed, etc). In Figures 13, 14 and 15 we can see the total water applied through center pivot 6 for 1998 and 1999, and center pivot 39 for 1999. The coarse grid was used to show the total water distribution figures for both center pivots, because leaching analyses were estimated for each of these grids.

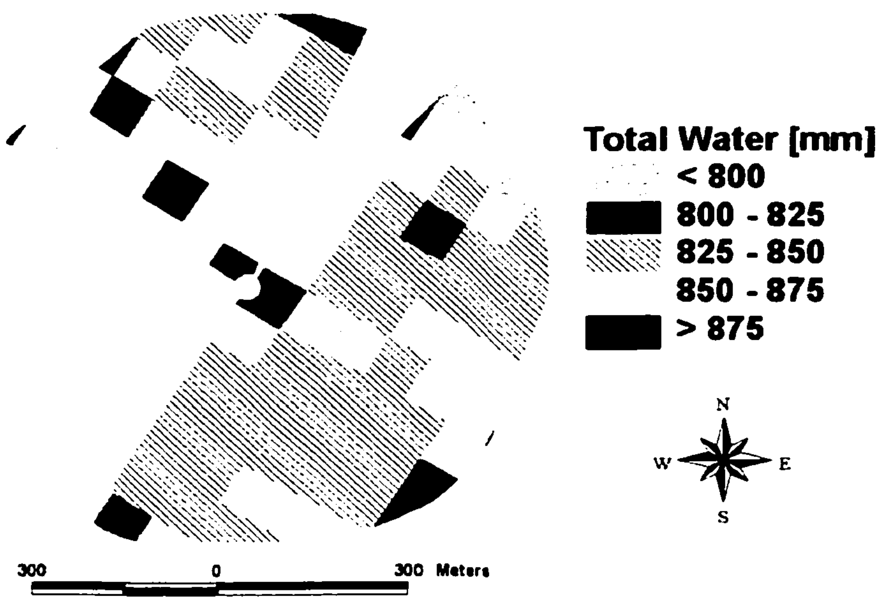


Figure 13. Total water applied (irrigation + rain), center pivot 6, 1998.

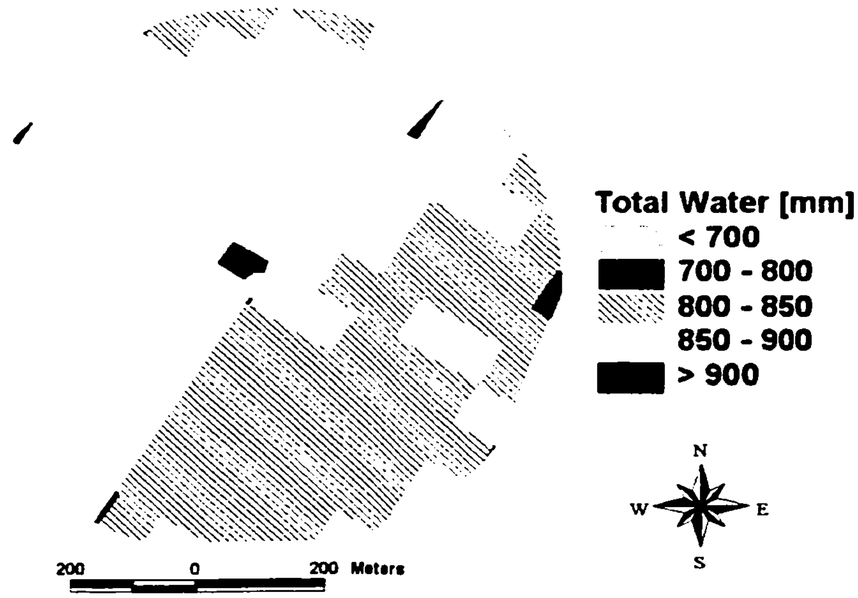


Figure 14. Total water applied (irrigation + rain), center pivot 6, 1999.

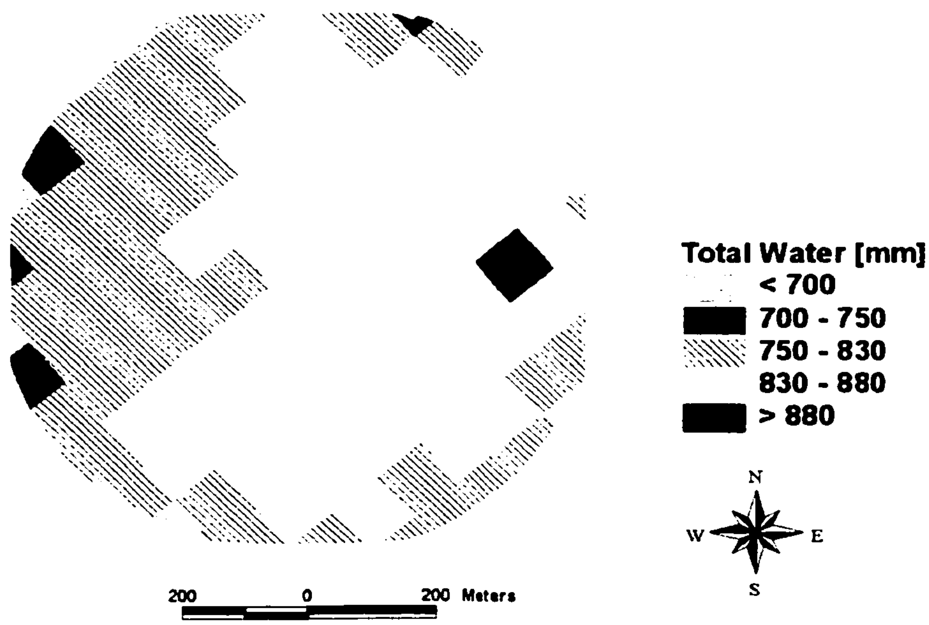


Figure 15. Total water applied (irrigation + rain), center pivot 39, 1999.

If we compare Figures 9,10 and 11 with 13,14 and 15, we can see that there are some differences in the total water distribution applied in both center pivots as compared to the irrigation application. The additional variability of the rain within areas where the irrigation variability is not great shows the relative effect of the end gun turning off and on and of topography. Higher water application in the northwest (lower topography) and the areas where the end gun is off in center pivot 6 is apparent for both years; higher water application in the west half (lower topography) and end gun off areas is also apparent in center pivot 39 .

The most important factor in the spatial water applied was due to changes of the pressure due to changes in topography and off/on of the end gun. This variability may be improved by installing pressure regulators and renozzling the system or by changing the pivot speed across the problem areas. We not only need to attain uniform irrigation water application across the field but also to take into consideration other factors such as soil textures, fertigation, leaching, and others that I will explain in detail in Chapter 5.

4.5. Spatial N application

4.5.1. Nitrogen injection

As discussed in chapter 3, these fields had two different types of pump to inject N (UAN solution) into the water pipe; a hydraulic pump on pivot 6 and an electric injection system for center pivot 39 (see photo of each system in Appendix 2).

To evaluate each system, I measured the depth of UAN solution in the supply tank each 15 minutes at each center pivot. The average injection rate per irrigation was then calculated and is shown in Tables 8 and 9. I used the lower value of injection rate to normalize (divide all the injections by the lower one) the rest of the injections. A sample calculation of the N injection rate per angle in each center pivot can be found in Appendix 7.

Table 8. Average fertilizer injection rate, 1999 center pivot 6.

	Fertilizer Injection rate	
Mean Fertigation Applied*	Mean injection rate	Normalized Injection rate†
kg/ha	L/15 min	
34 (4) δ	9.56	9.56
42 (8)	13.22	8.65
45 (11)	14.20	9.67
34 (13)	9.65	9.65
34 (15)	9.65	9.65

*** Mean obtained from of the polar grid (Figure 23).**
† Fertigation normalized by the lower rate of application.
δ Irrigation number during the season (Appendix 1; Table 17)

Table 9. Average fertilizer injection rate, 1999 center pivot 39.

	Fertilizer Injection rate	
Mean Fertigation Applied*	Mean injection rate	Normalized Injection rate†
Kg/ha	L/15 min	
12 (3) δ	2.29	2.29
12 (4)	2.29	2.29
31 (5)	6.16	2.03
30 (9)	6.42	2.16
30 (10)	6.42	2.16
28 (12)	5.83	2.15

*** Mean obtained from of the polar grid (Figure 24).**

† Normalized fertigation by the lower rate of application.

δ Irrigation number during the season (Appendix 1; Table 18)

As we can see from Tables 8 and 9, when I adjusted (normalized) the injection rates to account for differences in application, there was a relatively constant injection rate between applications in both center pivots. However, the differences were significant ($p<0.01$). In center pivot 39, the first two fertigations were at a lower adjusted injection rate because the electric pump was set at only 80 % capacity, then reset to 100% for the rest of the fertigations (5 until 12). There was 12% variability in adjusted (normalized) injection rate on center pivot 6 (Table 8) and 11% on center pivot 39 (Table 9), indicating that the average fertigation was not repeatable from one event to the next. Center pivot 6 had a more variable injection rate than 39 because it had a hydraulic injection pump that is more affected by changes in the sprinkler line pressure across the area (by topography) and during the season (by changes in groundwater level).

Changes of pressure across the area (X axis of Figure 16 and 17 indicate angle position) and during the season can be appreciated from Figures 16 and 17 for center pivots 6 and 39, respectively. The first and final fertigations applied in each field (8 and 15, and 5 and 12 for field 6 and 39, respectively) were used to analyze the variation with time of the injection rates. From Figure 16, changes of pressure in the system with position (angle) can be seen easily. Those changes were due to changes in topography. At high elevations (between angles 100 and 300) the pump produce a higher pressure at the pivot and lower flows. If we compare irrigation 8 with 15 from Figure 16, we find that the pressure in the system goes down from the earlier irrigation (8) to the later one (15). That phenomenon probably occurred because of the groundwater level decline during the season (close to 4 m in each field). Even with changes in pipe pressure, the difference in water flow rates during the season was small (around 100 L/min). However, that was enough to produce significant differences ($p<0.01$). Center pivot 39 followed the same behavior (Figure 17). Lower pressures and higher flows were observed in the lower elevations (between angles 50 and 250) and higher pressures and lower flows in the higher elevations (between angles 250 and 50).

Even when we have large differences in topography (8 m) which result in more variability in pressure and flow (Figure 17), the change in flow was not large between irrigation number 5 and 12 (around 50 L/min), but large enough to produce statistical differences ($p<0.001$).

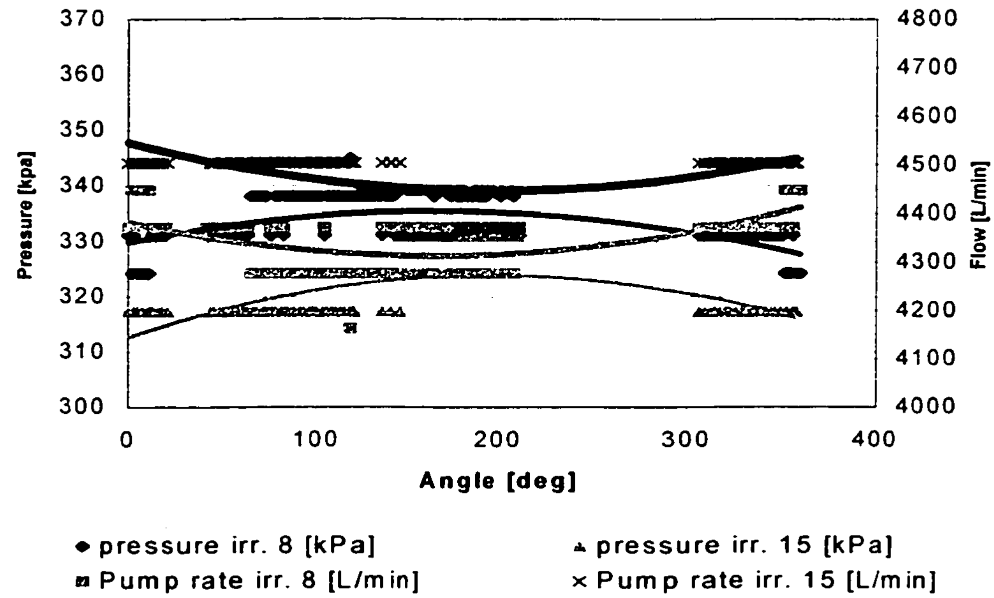


Figure 16. Variation of pressure with angle and time (irrigation number 8 and 15) for center pivot 6 in 1999.

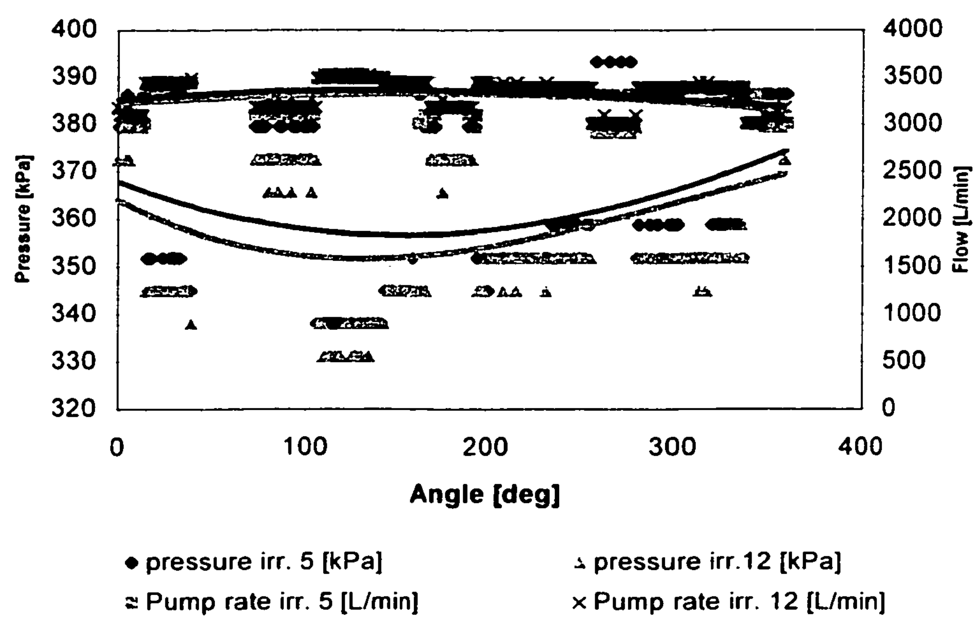


Figure 17. Variation of pressure with angle and time (irrigation 5 and 12) for center pivot 39 in 1999.

To analyze how those changes of pressure and flow affected the fertilizer injection rate, I plotted the variation of the fertilizer injection rate with field position and irrigation for both center pivots 6 and 39 for 1999. In Figures 16 and 17, the first and the final fertigation were used to show differences in N injections. In addition, because the amount of N applied in each fertigation was different (fertigation amounts were not constant), the proportion of difference between the early (Figure 18 and 19) and later average N applied was used to adjust the first.

From Figures 18 and 19, we can see that areas with low topography in each center pivot had higher injection rates and in areas with high topography we found lower injection rates. The effect of the topography on the injection rate was explained by less (low topography) or greater (high topography) backpressure on the fertilizer injection pump. As the mainline pressure decreased, the fertilizer injection rate increased. At the same time, the water flow increased, compensating for the increase in fertilizer injection rate. The resulting dilution of the injected fertilizer was almost enough to compensate for increased injection rate, but significant differences were found ($p<0.01$).

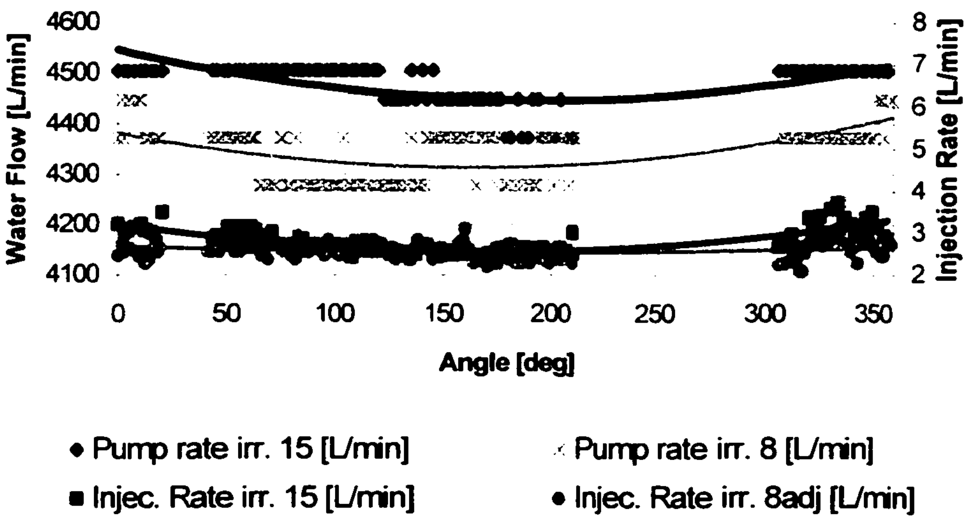


Figure 18. Variation of fertilizer injection rate (normalized) with angle and time (irrigation 8 and 15) for center pivot 6 in 1999.

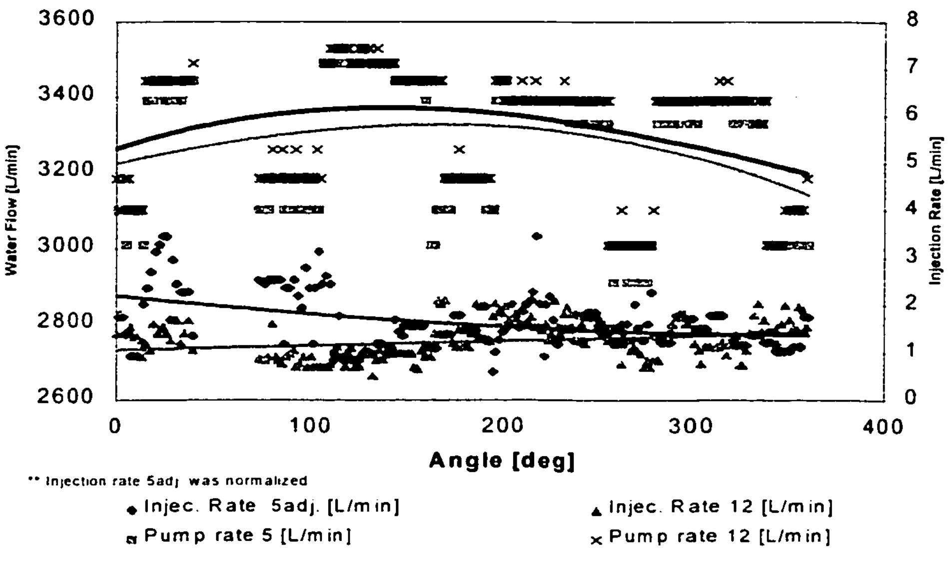


Figure 19. Variation of fertilizer injection rate (normalized) per angle and time (irrigation 5 and 12) for center pivot 39 in 1999.

In Figures 18 and 19, the first and the final fertigations were used to show N concentration differences in Figures 20 and 21. As the amount of N applied in each fertigation was different (fertigation amounts were not constant), the proportion of difference between the early (Figure 20) and later average N applied was used to adjust the first. Figures 20 and 21 show, for 1999, the concentration of N (ppm of NO_3-N) by angle for both early and late irrigations in center pivots 6 and 39, respectively. In both center pivots, the N concentration in the irrigation water is nearly constant under a big percentage of the fields (Figure 20 and 21), with variability only in the low elevations of both fields. The differences found in each field were big enough to make significant differences ($p<0.01$) in the N concentrations. The change of the N concentration in the low elevations was explained by the increments of the N injection rate being larger than the increment in flows, producing an increment in the water N concentrations in those areas.

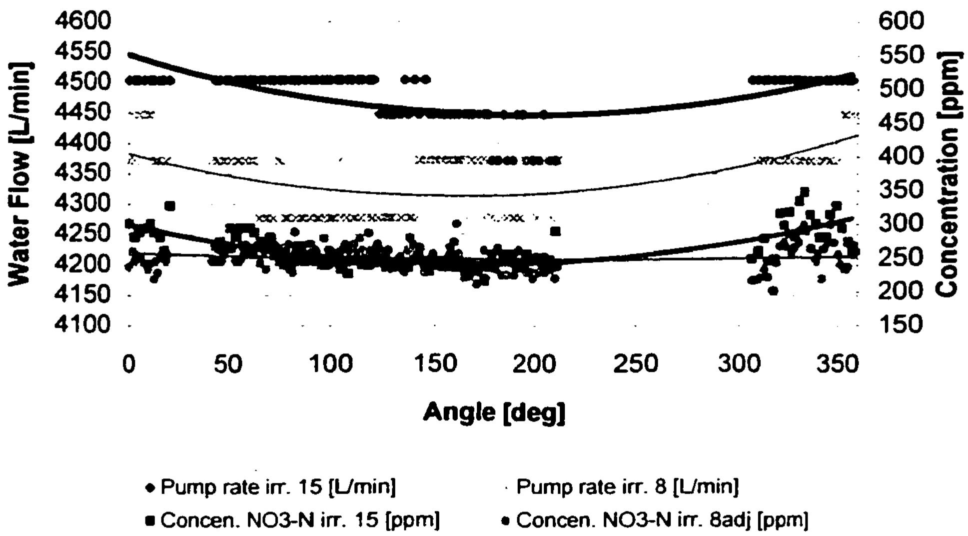


Figure 20. Variation of N concentration (ppm of NO_3-N) in the irrigation water as a function of angle and time for irrigations 8 (normalized) and 15, center pivot 6 in 1999.

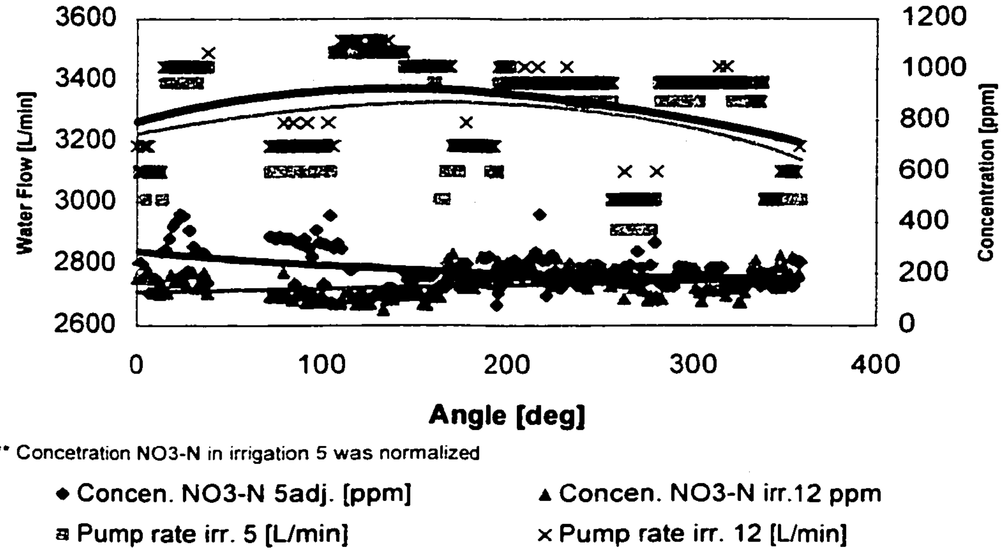


Figure 21. Variation of N concentration (ppm of NO_3-N) in the irrigation water as a function of angle and time for irrigations 5 (normalized) and 12, center pivot 39 in 1999.

4.5.2. Spatial N applied

To calculate the N applied in each fertigation event for both center pivots, equation 3.4.2 (page 34) was used. This allows nitrogen concentration to vary as shown in Figures 20 and 21 and uses the irrigation depths simulated by CPED (Figures 9-11) to obtain the seasonal N application in each center pivot. All the fertigation layers were added to obtain the total for the season.

The seasonal spatial N application by fertigation (kg-N/ha), for both center pivots, is shown in Figures 22 to 24.

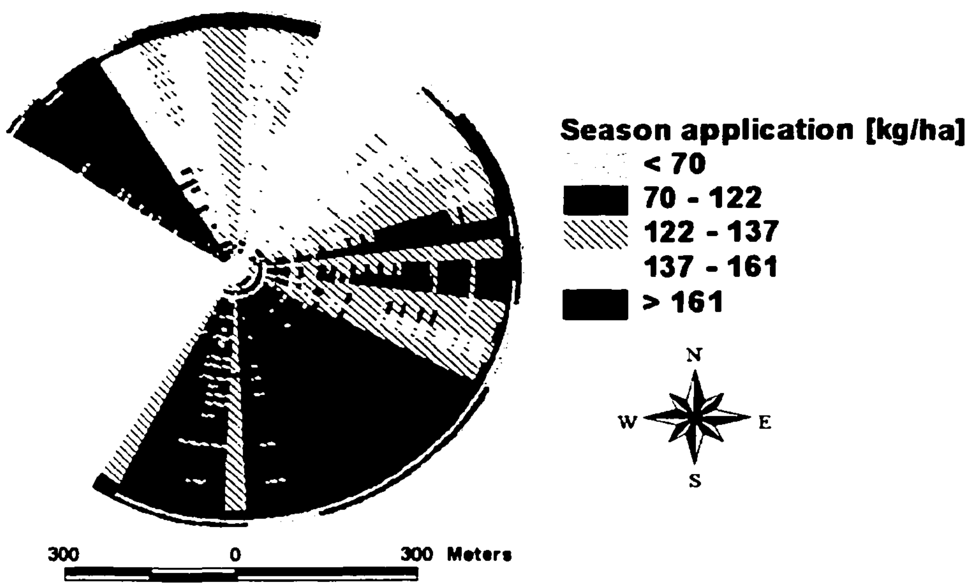


Figure 22. Spatial N application (kg-N/ha) for center pivot 6 in 1998.

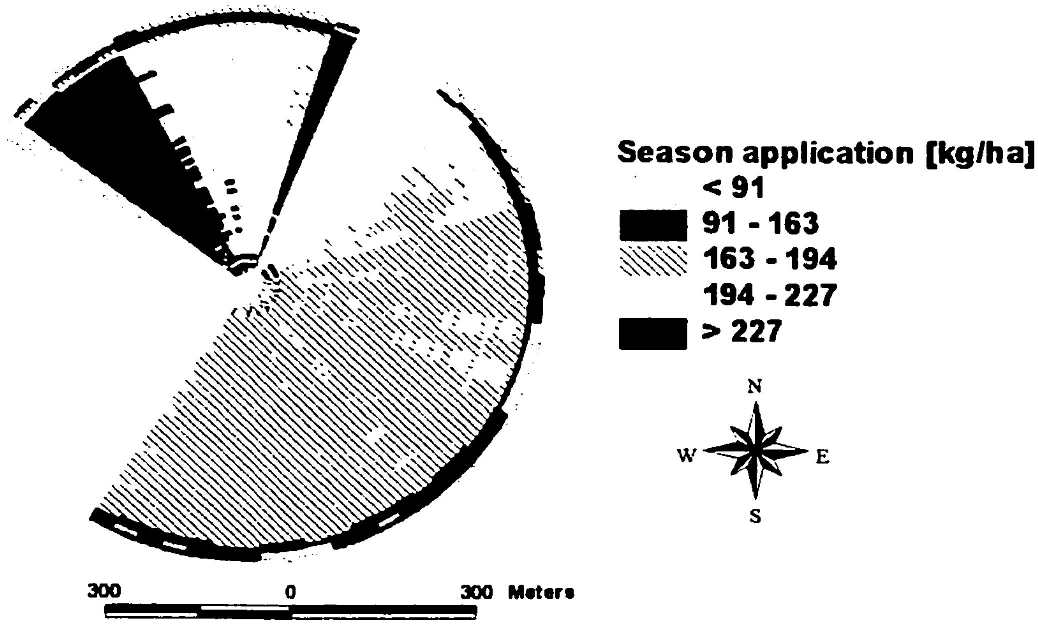


Figure 23. Spatial N application (kg-N/ha) for center pivot 6 in 1999.

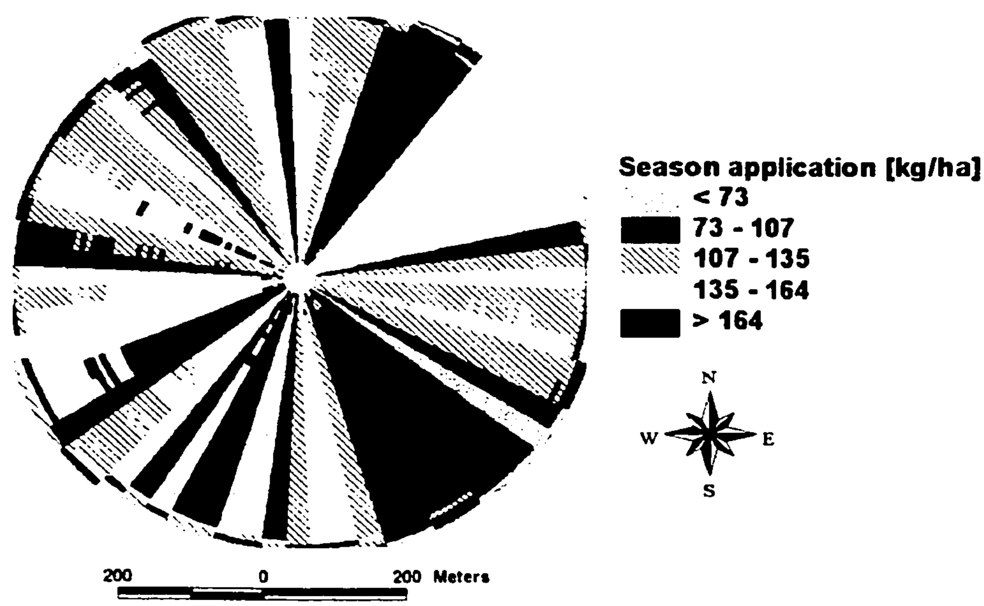


Figure 24. Spatial N application (kg-N/ha) for center pivot 39 in 1999.

The segments without data in center pivot 6 and 39 were areas where fertigation was not applied. Those areas were part of another research study under this multidisciplinary project. The areas with low nitrogen application at the beginning and end of each area without fertigation were caused by errors in the starting and ending injection position (angle) of the system during the season.

For Figures 22 and 23, we can see that the high N application was under the northwest area where we have low topography (Figure 1) and high water application (Figures 9 and 10). In addition, in those areas we can see the effect of turning the end gun off, increasing the amount of N applied because of greater water application. In areas where the end gun is on (from 130 to 230 degrees in center pivot 6) and the elevations are high, there is high mainline pressure and reduction in water flow (Figure 16). The injection system in those areas was giving a reduced rate (Figure 18) but not enough to make big changes in the N concentration in the water (Figure 20). Because the N concentration in the irrigation water is almost constant and less water is applied, in those areas less N is applied (Figures 22 and 23).

Center pivot 39 (Figures 11 and 24) showed the same behavior as center pivot 6, but the differences caused by topography were more marked due to the higher topography differences (8 m in center pivot 39 and 3 m in center pivot 6). This had a similar effect as that discussed for center pivot 6 (see Figure 24). In the areas of higher topography of center pivot 39 (west half), we calculated less uniform N application than in the higher topography areas of center pivot 6, principally because water application uniformity was less.

4.5.3. Verification of N concentration calculations

To verify the calculations of N concentration, I collected samples from the field (figure 5) and sent them to the laboratory, in order to obtain the N concentration in those samples (see data in appendix 5).

I calculated N concentration at the same locations and times as the samples were collected. As discussed in chapter 3, I evaluated this comparison by both the root mean square error (RMSE) and the adjusted coefficient of determination (r^2), values of which can be seen in Figures 25 and 26 for center pivots 6 and 39, respectively.

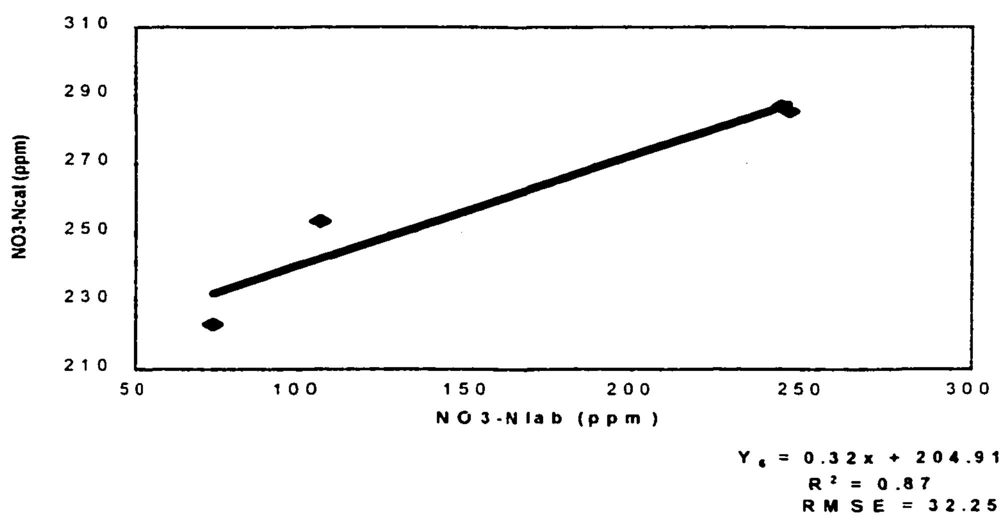


Figure 25. Statistical fit of N concentration measured in irrigation water and calculated from injection rate for center pivot 6 in 1999.

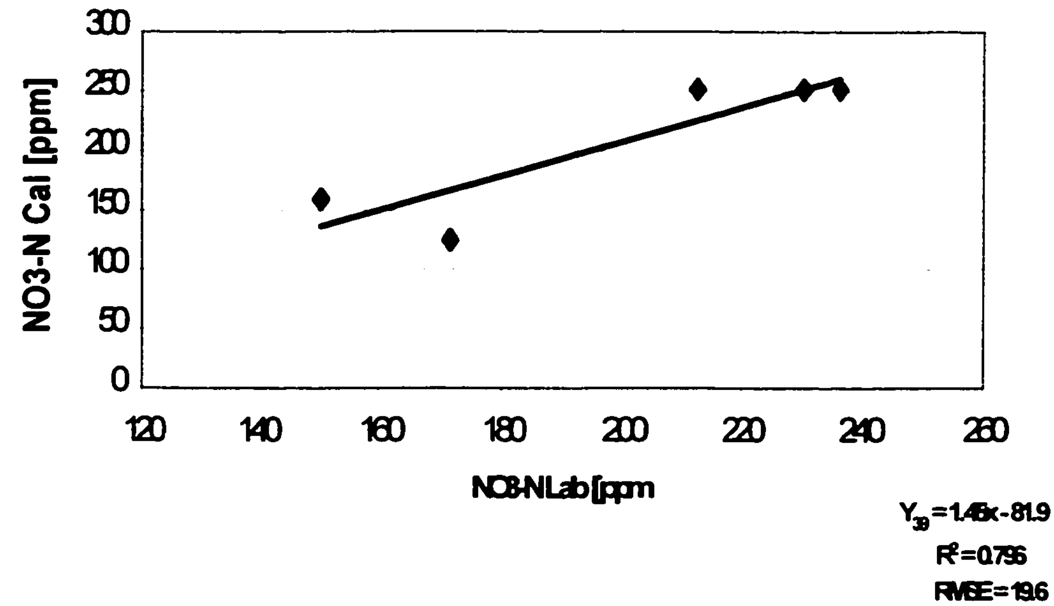


Figure 26. Statistical fit of N concentration measured in irrigation water and calculated from injection rate for center pivot 39 in 1999.

From Figures 25 and 26 we can see that the comparison between N concentration in the irrigation water calculated and measured in field samples was very close in almost all the samples. Low N concentration can be overestimated from CPED calculations, but those low concentration (lower than 160 ppm) were not frequent in the field. From statistical analyses done with data computed with CPED and laboratory analysis, I concluded that CPED calculation concentrations agreed reasonably with the actual concentrations. The calculated concentrations were used as an estimate of the actual N concentrations for the leaching analysis that is discussed in Chapter 5 of this dissertation.

4.5.4. Uniformity of nitrogen application

The calculation of the N uniformity coefficient was made using the area weighted average data from each polygon of the polar grid for 1999 (we did not have data for center pivot 39 in 1998). The N and water uniformity coefficients for both center pivots for 1999 are shown in Table 10. The N and water uniformity coefficients for center pivot 6 for 1998 are the same as those for 1999, because neither the injection pump characteristics nor the water distribution obtained from CPED simulation changes.

Table 10. Nitrogen and water uniformity coefficient for center pivot 6 for 1998 and 1999; and for center pivot 39 for 1999.

	Nitrogen UC*	Water UC*
Center Pivot 6	0.86	0.95
Center Pivot 39	0.79	0.89

UC = uniformity coefficient (no unit), calculated by procedure of Heermann and Hein (1968).

The uniformity of the N was lower than the uniformity of the water (Table 10). As discussed earlier, fertigated N application was affected by more factors than was water depth, thus its application is more variable. No similar studies were found in the literature in order to compare with my results. Because the water uniformity on center pivot 39 is 89%, we might assume that it is acceptable, but the lower N uniformity (79%) may accentuate yield differences attributable to N stress or result in leaching losses. In order to solve this first problem, the farmer is applying extra fertilizer in order to have enough N for plants in all areas, resulting in potential leaching and groundwater contamination. This point is very important, and demonstrates that we must have a high uniformity of water application in order to get acceptable N uniformity, which can reduce leaching problems. This point is even more important when we consider soil characteristics and residual N, points that I will discuss in Chapter 5.

4.5.5. Nitrogen distribution from ground water

Since the N concentration in groundwater was very constant through the season, the annual average concentration of N in the groundwater (Appendix 5) was used to calculate the N contribution from this source. This N is distributed across the field following the same distribution as the irrigation depths. This results in another source of nouniformity of the N applied. Due to limitations of the Opus model, the N applied with the ground water was assumed distributed with the rain and follows the rainfall distributions. For the mass balance approach, I calculated the N applied with the ground water from the water depths and average N concentration, which gives a more realistic distribution than the Opus approach. Because the average N application by irrigation water was less than 2 kg/ha in each irrigation, it appears that the assumptions required by Opus have no significant effect on the N spatial distribution.

4.5.6. Relationship between water, N, and yield.

Poor correlation coefficients were found between variables water depths, N fertigated, total N applied, and yield (Table 11).

Table 11. Correlation coefficients (r^2) between water depths, N fertigated, total N applied and yield for center pivot 6 for 1998-99 and center pivot 39 for 1999.

	Season	Water & yield	N fertigated & yield	Total N & yield
			r^2	
CP 6	1998	0.003	0.07	0.08
	1999	0.113	0.11	0.16
CP 39	1999	0.005	0.34	0.42

These low values resulted because of the over application of water and fertilizer beyond what the plants normally require. Thus, neither water nor N limited yield and yield variability was not expected to correlate with either. The higher correlation coefficients found in center pivot 39 are attributed to the poorer water and N distribution that may have resulted in some stress during the season, but these are not highly correlated and are not considered significant.

4.5.7. Summary

The regular thought of farmers that over applying water and N will result in better yields is a result of their field experience. However, this over application compensates for the nonuniformity of water and N application. In this chapter we learned that to improve the N and water application from a normal farmer management to a more technical approach which meets plant requirements, we need to take into consideration the factors that can improve the uniformity of the water and N, such as system design (use of pressure regulators if it is necessary), end gun operation, topography, type of the injector, scheduling of irrigations, and N timing.

CHAPTER 5

RESULTS AND DISCUSSION – SPATIAL DEEP PERCOLATION AND NITROGEN LEACHING

Prediction of N leaching under field conditions and development of management practices to minimize leaching is helpful to both the farmer (saves money) and environmental agencies (regulations). I reported in Chapter 4 that irrigation nonuniformity affects the N application through fertigation and that N uniformity was lower than irrigation uniformity. Both of these nonuniformity factors (also from N in irrigation water) have their effect on N leaching (Molle et al., 2000). However, attaining high irrigation and N uniformity is not enough to assure a reduction in leaching. In addition, the timing and amount of both water and N applications must be considered as well as the soil variability and crop response to these inputs (Millen et al., 2000; and Duke et al., 2000).

In this chapter, results of the Opus simulation will be presented, and the spatial variability of soil, water, and N (Chapter 4) will be considered to assess their importance to leaching processes under center pivots. In addition, using the simulation results from CPED and Opus, I will present a methodology that can help identify problematic areas under a center pivot irrigated field which may warrant spatially variable N application that would reduce the N leaching potential.

5.1. Running Opus simulation

As discussed in chapter 3, to run Opus required simplifying assumptions and adjustments to input data. The biggest assumption was the adjustment of the potential evapotranspiration parameter of the evapotranspiration equation (Ritchie (1972) equation) used to calculate evapotranspiration in Opus. For the local conditions, we used a more accurate evapotranspiration equation form the USDA irrigation scheduling program[4] (based on the 1982 Kimberly-Penman equation). I adjusted the evapotranspiration calculated with Opus to obtain nearly the same values obtained with the USDA program. After adjusting the evapotranspiration calculation, I ran the Opus simulation in each grid (117 and 106 cells of the coarse grid for center pivots 6 and 39, respectively) and the results are given in Table 12.

[4] Duke, H.R. 1999. Unpublished irrigation management calculations using USDA irrigation scheduling program. USDA-ARS, Fort Collins, CO.

Table 12. Average total water applied, evapotranspiration, and water excess in each center pivot for the study period.

	Season	Total water applied	Et*	Water excess
	Year		mm	
Center Pivot 6	1998	849	736	113
Center Pivot 6	1999	827	616	211
Center Pivot 39	1999	813	645	168

* Et = Evapotranspiration computed by Opus, Ritchie (1972).

5.2. Opus results

The accumulative evapotranspiration, deep percolation, and N leaching were obtained from the output files of Opus simulation for center pivot 6 for 1999 and 1998 and for center pivot 39 for 1999 for each grid cell. These data were used to generate the final spatial distributions of evapotranspiration, deep percolation, and N leaching under each center pivot.

5.2.1. Deep percolation maps

The seasonal deep percolation for each center pivot is shown in Figures 27 to 29. The highest deep percolation in center pivot 6 for 1998 and 1999 was found in areas next to the strip without fertigation (left and right) in the northeast direction.

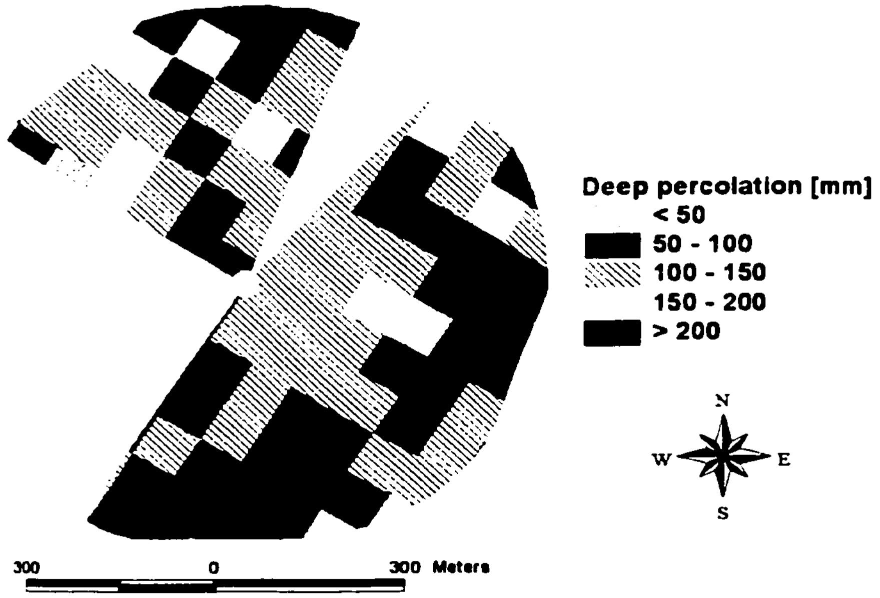


Figure 27. Accumulative deep percolation for 1998, center pivot 6.

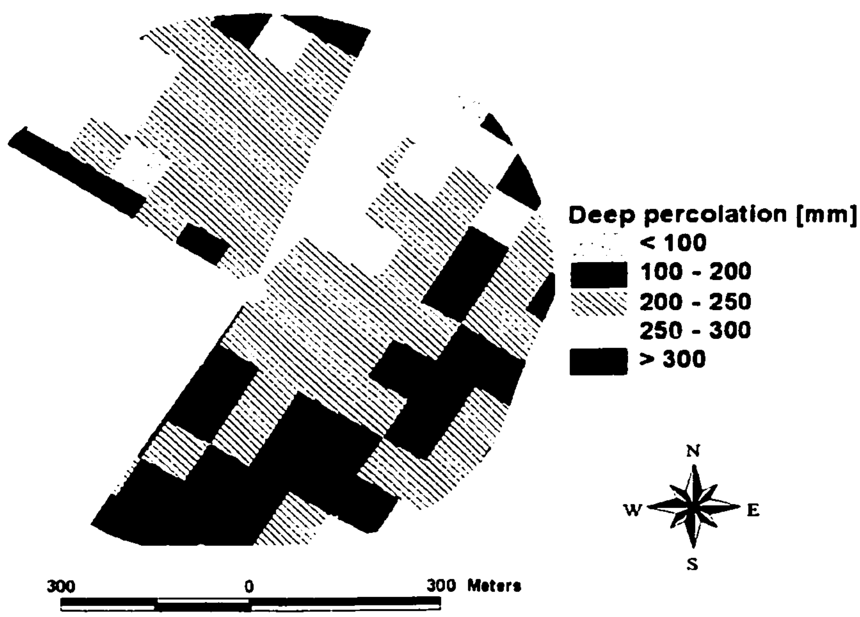


Figure 28. Accumulative deep percolation for 1999, center pivot 6.

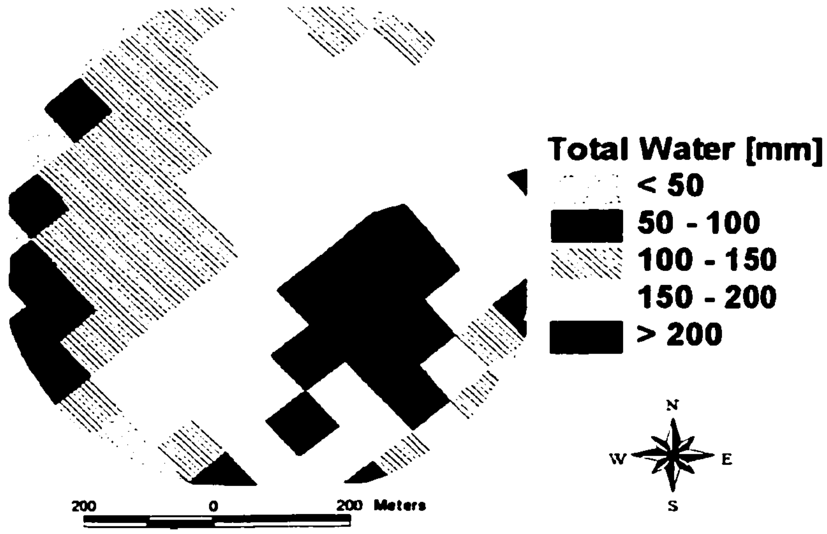


Figure 29. Accumulative deep percolation for season, center pivot 39.

Even in 1998, when center pivot 6 had lower average excess water applied than in 1999 (Table 12, and figures 32 to 34) higher deep percolation was found in areas next to the strip without fertigation (left and right) in the northwest direction. This high leaching in those areas can be easily explained when we see the soil characteristics (Figure 30) which are more sandy in that region of the field (especially on northwest area). In addition, those areas had higher total water application (Figures 13 and 14).

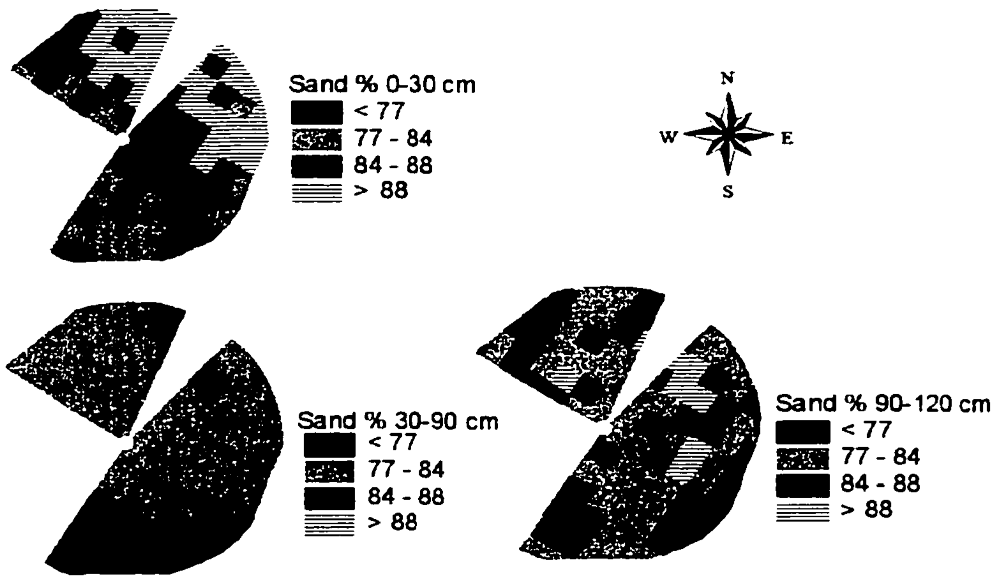


Figure 30. Sand percentage by layer for center pivot 6.

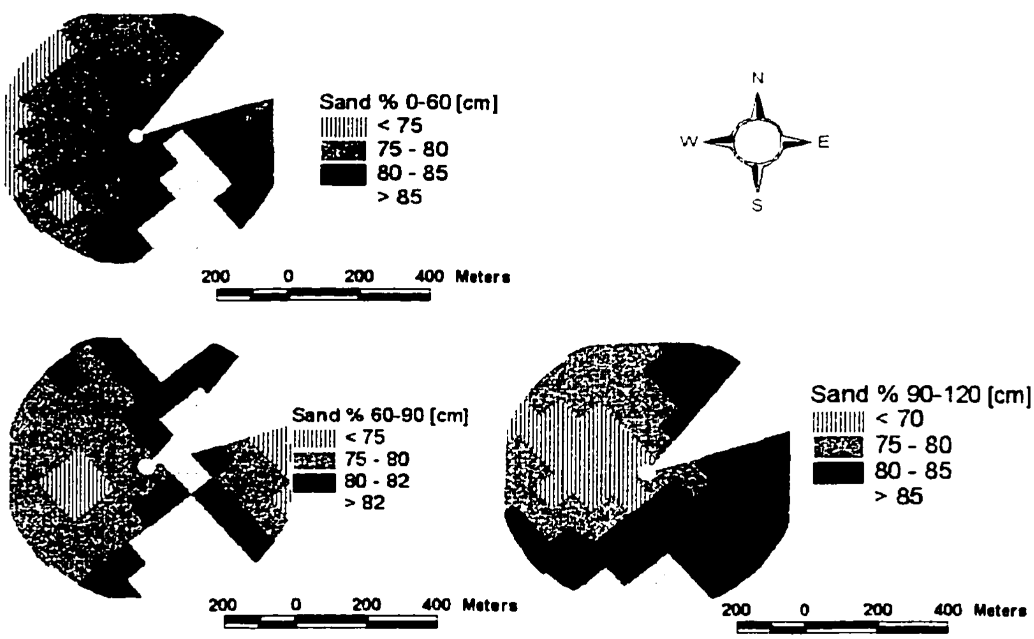


Figure 31. Sand percentage by layer for center pivot 39.

Because of heavy water application occurring in areas where the soils have higher hydraulic conductivity, water moves quickly through the root zone. This caused a short term reduction in the evapotranspiration (Figure 94 and 95, Appendix 9) due to lack of water availability. This situation increased the excess of water applied (total water applied minus evapotranspiration) as we can see from Figures 32 and 33, that finally leaves the root zone as deep percolation.

Similar situations were found in center pivot 39, where the higher deep percolation occurred in the sandy areas of the field in the southeast (Figure 29 and 31).

In both center pivots, areas with sandy soils were areas with high water application. At the same time, reduced evapotranspiration and greater excess of water applied produced greater amounts of deep percolation in those areas. The sandy soil conditions and the greater application of water (due to poor uniformity of the system) under those areas increases the potential leaching as described in the next section.

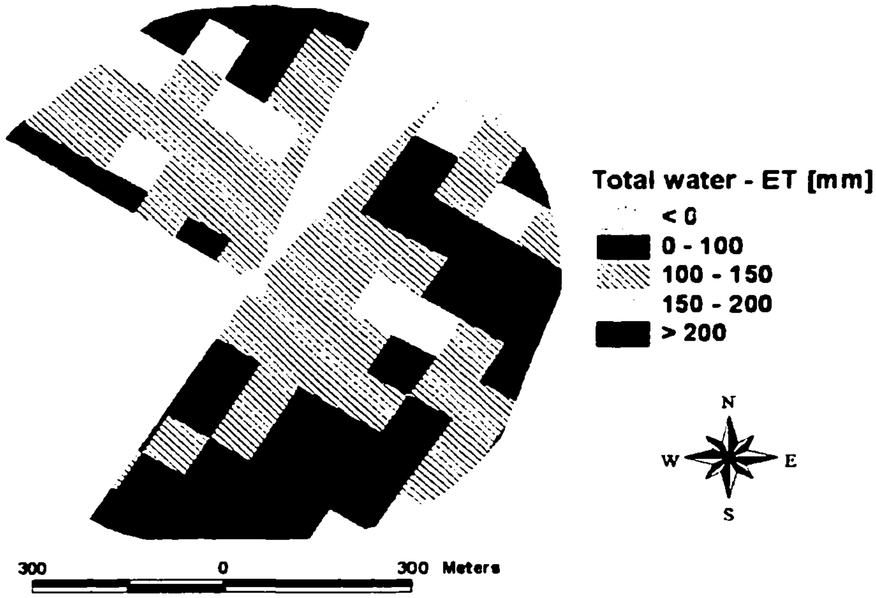


Figure 32 Excess water application under center pivot 6, 1998.

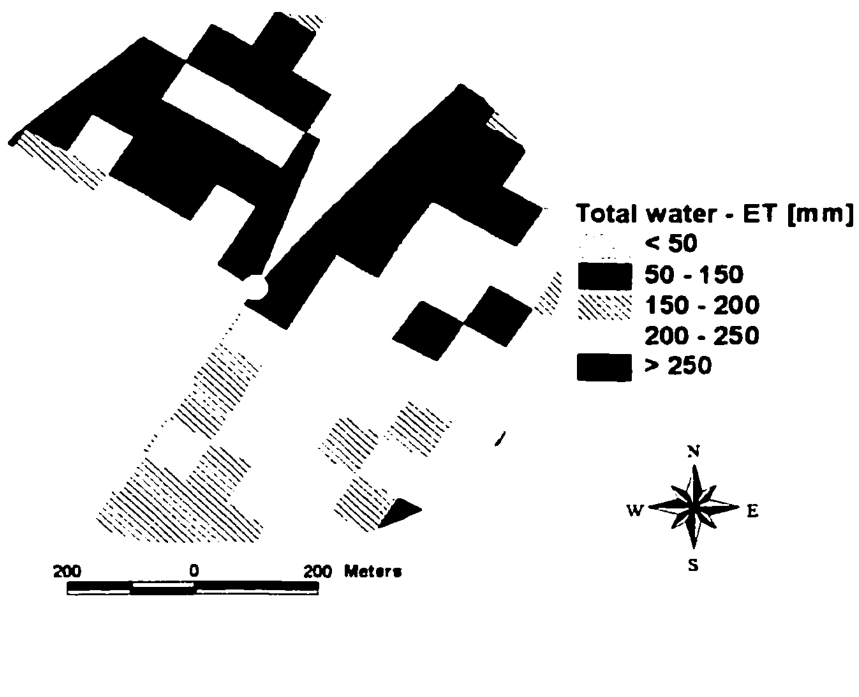


Figure 33 Excess water application under center pivot 6, 1999.

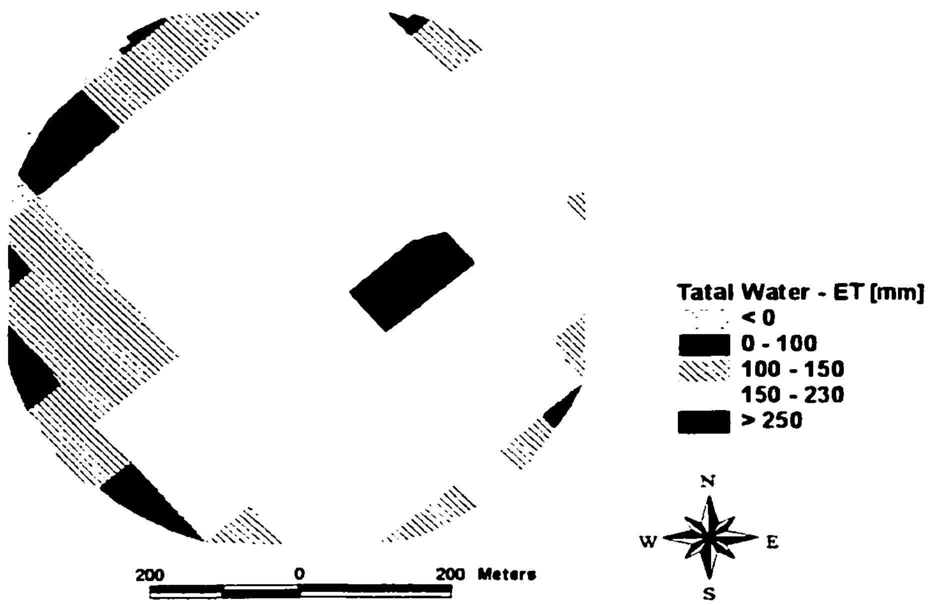


Figure 34 Excess water application under center pivot 39, 1999.

5.2.2. Nitrate Leaching

The seasonal NO_3 leaching computed for each center pivot is shown in Figures 35 and 36. In Field 6 in 1999, I removed from subsequent analyses the northwest area because the farmer mistakenly applied extra N starter fertilizer (179 kg-N/ha more than the east half). Figure 36 shows the differences in leaching in the area with extra starter fertilizer and the rest of the fertigated area.

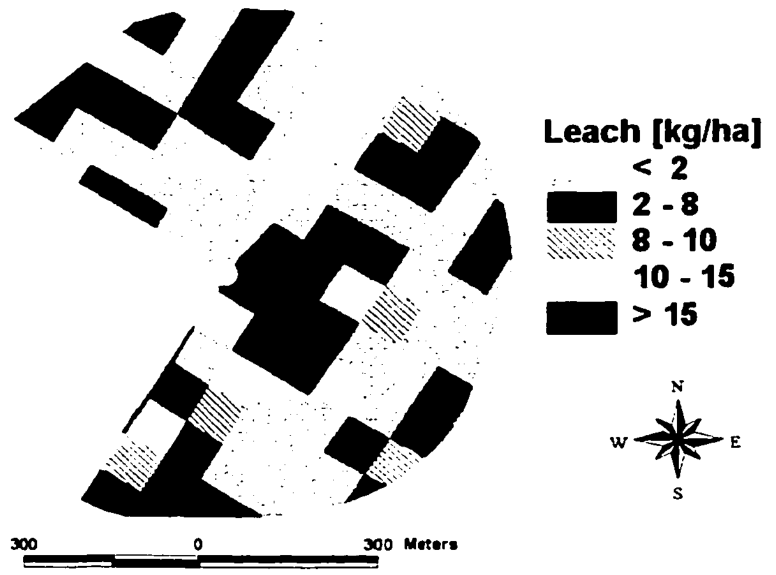


Figure 35. Nitrogen (kg/ha of NO_3-N) leaching under center pivot 6, 1998.

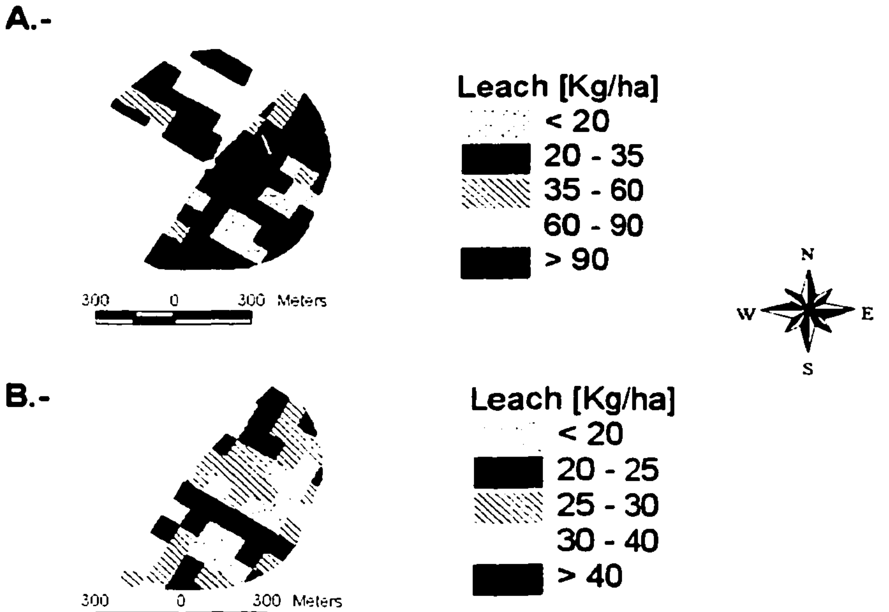


Figure 36. Nitrogen (kg/ha of NO_3-N) leaching under center pivot 6 for fertigated area (A) and without area with extra starter fertilizer (B), for 1999.

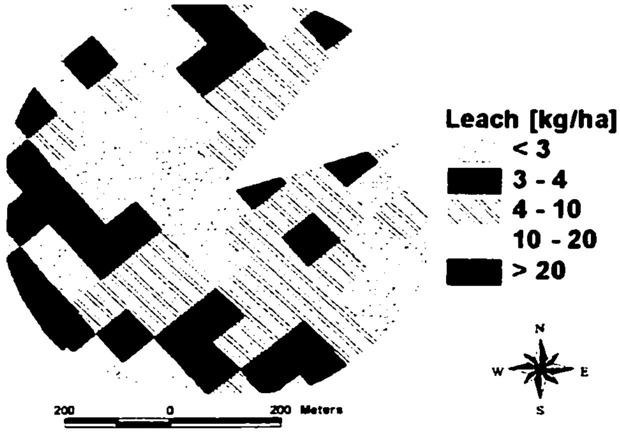


Figure 37. Nitrogen (kg/ha of NO_3-N) leaching under center pivot 39, 1999.

Little literature was found relative to leaching estimated by Opus simulation but those found agreed with my results. Santos et. al. (1997), worked with Opus to simulate leaching under a level basin irrigation system planted with corn on an alluvial soil located in the Sorraia River Irrigation Project in Southern Portugal in 1993. They collected soil samples at five depths during the season to validate the Opus simulation. They found satisfactory comparisons between Opus and observed data (5 ppm NO_3-N deviation between simulated and observed data). Smith (1995) found similar results under a dryland wheat/sugarbeet plot near Neuenkirchen, Germany. Those results, even though they found good agreement, cannot be compared with my results because they were conducted under totally different management (irrigation, fertilization, soil, and weather) and environmental conditions that make invalid any comparison with my research. However, their results do give confidence in the model.

The average amount of leaching computed by Opus in each center pivot can be see in table 13.

Table 13. Average seasonal leaching (kg-N/ha) for center pivots 6 (1998-99) and 39 (1999).

Field	J	F	M	A	M	J	J	A	S	O	N	D	Total Leaching
							$\frac{kg\ N}{ha}$						
CP6 1998	—	—	—	0.1	1.9	2.3	3.5	0.0	0.0	0.0	0.0	0.0	7.7
CP6 1999	0.2	0.1	0.1	4.1	9.1	5.5	5.3	0.5	0.2	0.2	0.1	0.1	25.2
CP39 1999	0.0	0.0	0.1	0.2	1.2	0.9	1.6	0.5	0.1	0.2	0.1	0.1	5.1

5.2.2.1. Residual N effect

The higher leaching amounts under center pivot 6 (Figures 35 and 36 B), were not only in the areas with high deep percolation (Figures 27 and 28) but also areas of high N applied by fertigation (Figures 22 and 23).

For both years under center pivot 6, areas with high initial soil N concentration (southwest direction) were found in the soil with higher clay content. From the results of the Opus simulation, those areas were found to result in high leaching with respect to the rest of the clay areas, even when these areas just received a medium N fertigation (Figures 22 and 23). The higher residual N from the previous growing season (Figures 38 and 39) made those areas start to leach with the early rain of the season (before the farmer applied any fertigation). The early leaching found under those areas from the Opus simulation occurred in both the 1998 and 1999 seasons. I explain this extra leaching in those areas because of higher clay content retaining more N which is readily leached by early rains of the season. In addition, we found by Opus simulation that when the farmer applies more water and N through fertigation, as occurred in 1999 in center pivot 6, leaching continued after the growing season.

In center pivot 39, because the residual N content from the previous season was lower and more homogenous across the field (Figure 40) a different situation was found from the Opus simulation results than in center pivot 6. The clay areas (the southwest area) of center pivot 39 have a higher percentage of sand than those of center pivot 6 (Figure 31) that result in almost no residual N, thus no early season leaching in field 39. In the northeast area, near the segment without fertigation, some areas with higher initial N content (Figure 40) but not high in clay (Figure 37), were found with early leaching from the results of Opus simulation. This high nitrogen content found under this area could be a mistake in the laboratory analyses or in the sampling because the texture of those areas are sandy and it is difficult to keep N from one season to another. Another explanation is that there may have been an extra N fertilization under this area, but no data to suggest this were found. However, those are only a small percentage of the entire field and do not affect the final conclusion from the Opus simulation (as an average of the field) of almost no initial N leaching (Table 13) .

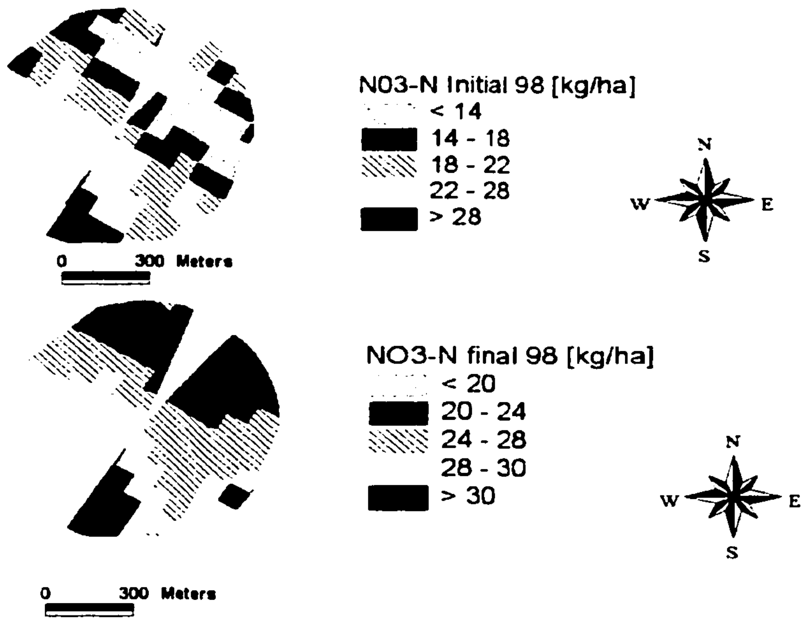


Figure 38. Initial and final 0-30 cm nitrogen concentration (NO_3-N in kg/ha), center pivot 6, 1998.

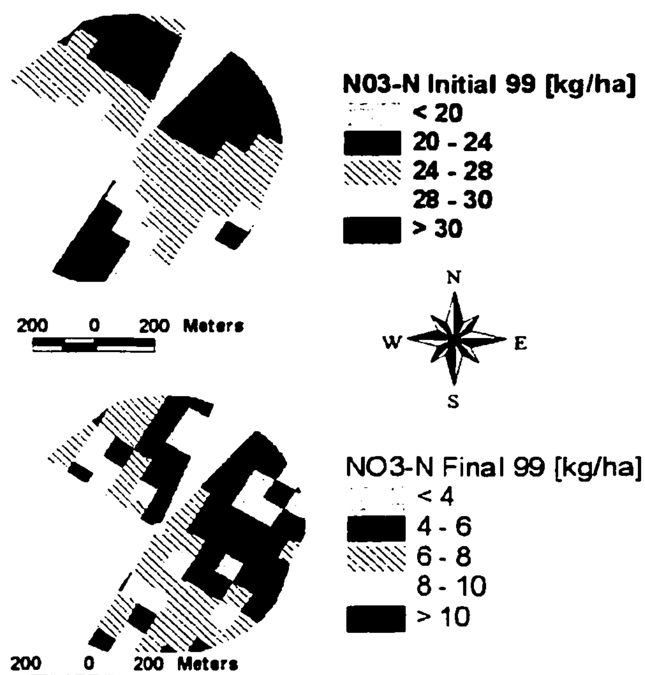


Figure 39. Initial and final 0-30 cm nitrogen concentration (NO_3-N in kg/ha), center pivot 6, 1999.

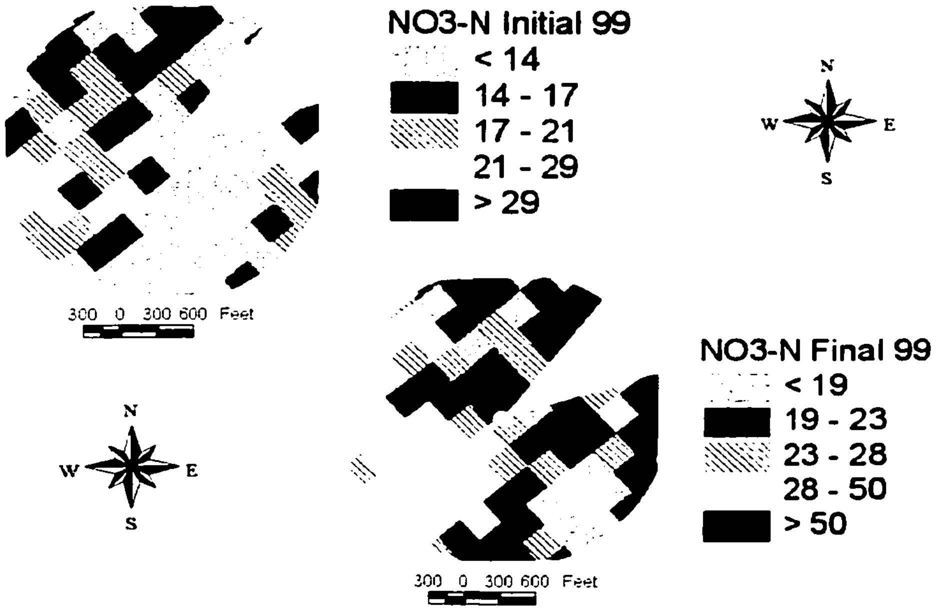


Figure 40. Initial and final 0-30 cm nitrogen concentration (NO_3-N in kg/ha), center pivot 39, 1999.

5.2.2.2. Irrigation scheduling effect

An important factor influencing leaching in center pivot 6 was the amount of irrigation water applied. In 1999, under center pivot 6, the farmer applied 170 kg/ha of N through fertigation, and in 1998 he applied 125 kg/ha. Table 12 shows that the excess water applied in center pivot 6 for 1999 was higher than for 1998 (211 and 113 mm, respectively). However, 32 irrigations were applied in 1998 and only 25 in 1999. Because of fewer irrigations in 1999 with greater irrigation depths (poor irrigation scheduling) being applied, in conjunction with the higher amount of N applied as fertigation, N leaching was higher in 1999 by Opus simulation (Table 13).

5.3. Nitrogen mass balance

N mass balances for both field were developed to assess whether Opus is meaningful in its calculations of N leaching losses. The comparison of mass balance results and Opus output are shown in Table 14.

Table 14. Nitrogen Mass Balance and Opus results

	Season	Area	Opus Total Leaching	Mass Balance Total Leaching
	year	[ha]	[kg N/ha]	[kg N/ha]
CP* 6	1998	47	7.7	117.8
	1999	36†	25.2	81.8
CP 39	1999	46	5.2	9.1

* CP = Center Pivot
† only the area without high starter fertilizer.

There are big differences between Opus and mass balance results for center pivot 6 but that is not the case in center pivot 39. I can attribute those differences to unusual conditions that existed under this center pivot (hail storm in 1998 and herbicide damage in 1999) that could reduce the plant N uptake and, even more important, the final yield that affect our N mass balance (Equation 3.6.3). Opus cannot simulate those conditions, which explains the differences found in center pivot 6. On the other hand, in center pivot 39, where the conditions were normal during 1999, small differences (if we compare with the total applied of more than 200 kgN/ha) were found between N mass balance and OPUS. Those results suggest that Opus tends to underestimate the real leaching existing in the area, but further research is needed in order to corroborate this assumption.

5.4. Economic and environmental effect

The cost of N lost to leaching as estimated by Opus and by the N mass balance approach, assuming $ 0.87 per kilogram[5] of N is shown in the following Table.

Table 15. Cost of fertilizer lost by leaching for each center pivot as estimated by Opus and mass balance approach.

	Season	Area	OPUS Leach	OPUS Total Loss	Mass Balance Leach	Mass Balance Total Loss
	year	[ha]	[kg/ha]	[$]	[kg/ha]	[$]
CP* 6	1998	47	7.7	142	117.8	2160
	1999	36†	25.2	355	81.8	1150
CP 39	1999	46	5.2	95	9.1	167

* CP = Center Pivot
† only the area without high starter fertilizer.

As seen in Table 15, for center pivot 6 in 1998-99, large differences exist between mass balance and Opus, which effects the economics of

[5] K. Fleming (2001) personal communication.

leaching. Even though the leaching calculated by Opus appears underestimated, when the farmer applies excess N and irrigation water, there is an economic and environmental effect. In addition, because of the unusual conditions, the farmer tends to apply more N in order to recover the crop, increasing the leaching problem and aggravating the economic and environmental effect. When the farmer better managed the irrigation and the N applied, as with better irrigation scheduling or splitting the fertilization into more applications, he achieved better efficiency of the N applied, as in center pivot 39, 1999.

Even when the farmer lost money, and maybe it was not a big amount, base on this research, the environmental effect is more important than the money losses, because of pollution of the sources of water and their implication for the future of the area.

5.5. Statistical relationship between variables and grain yield

A regression analysis between the variables evaluated, including total water applied, total N available, N applied through fertigation, deep percolation, and leaching and grain yield was made. Data can be found in Table 16 or Appendix 8. Yield layers are shown in Figures 41 to 43.

The objective of this regression analysis was to find the best correlated variables in order to make a multiple regression analysis between those variables and yield.

Table 16. Correlation between simulated variables and yield.

Yield v/s	Center Pivot 6 1998	Center pivot 6 1999	Center pivot 39 1999
		r^2	
Water			
Total Water	0.03	0.12	0.10
Deep Percolated	0.01	0.12	0.13
Nitrogen			
Available	0.077	0.16	0.42
Fertigated	0.072	0.11	0.34
Leaching	0.02	0.14	0.07

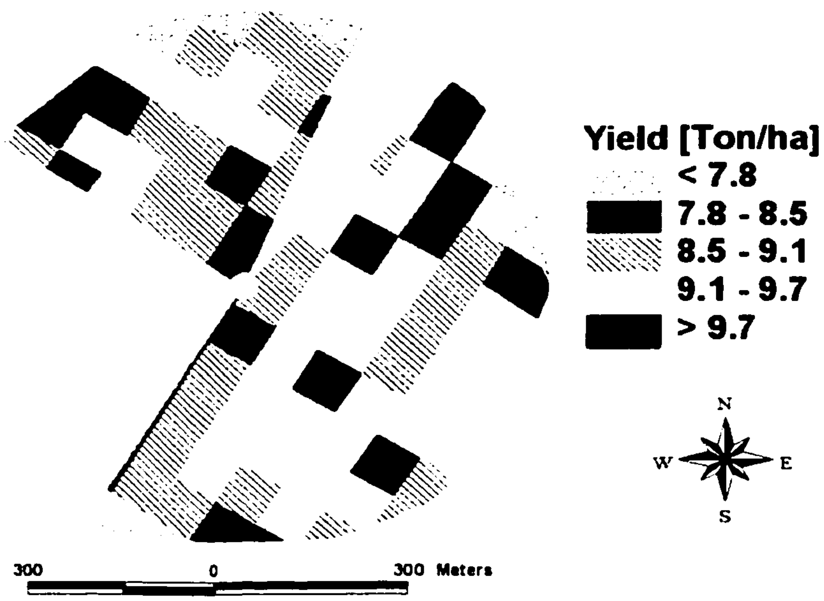


Figure 41. Yield obtained (Ton/ha) on center pivot 6, 1998.

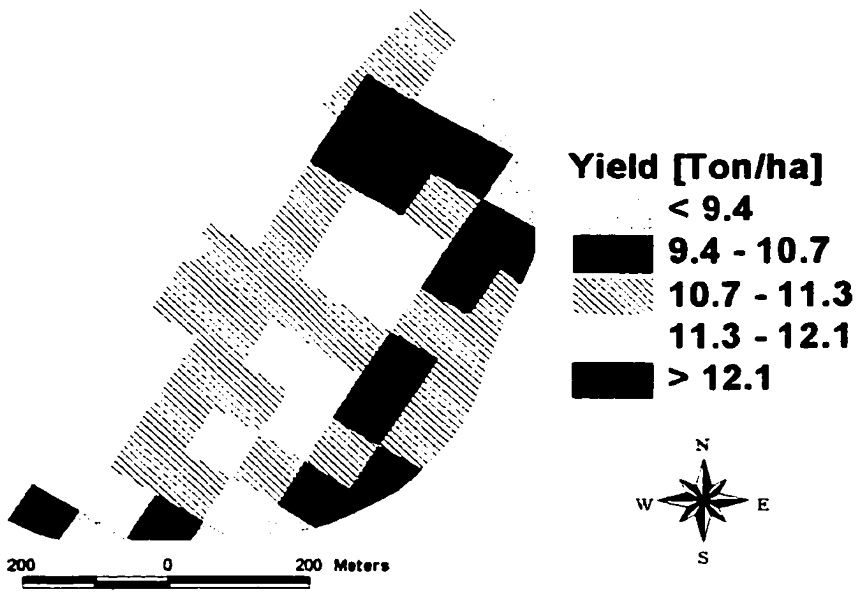


Figure 42. Yield obtained (Ton/ha) on center pivot 6, 1999.

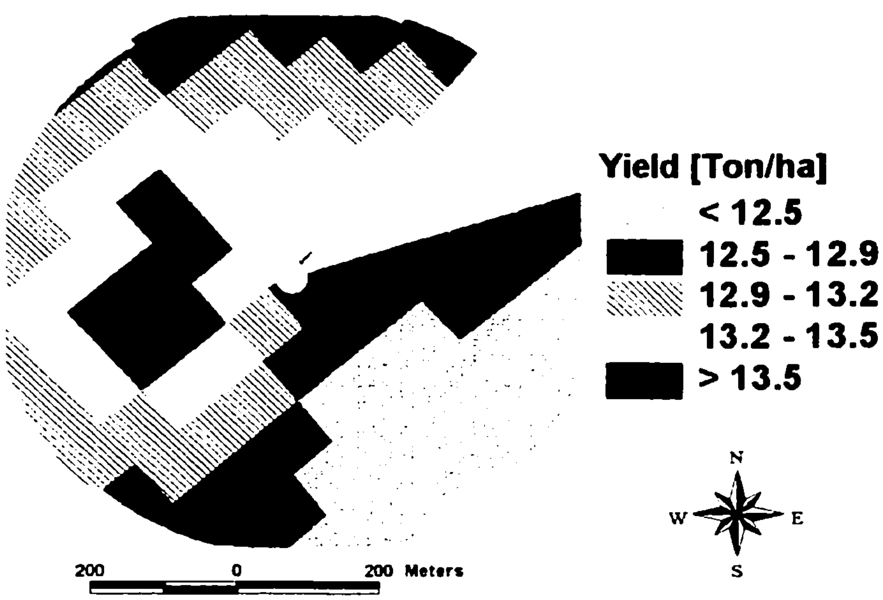


Figure 43. Yield obtained (Ton/ha) on center pivot 39, 1999.

As we can see from Table 16 or by comparing the yield layers (Figures 41 and 42) with the variables evaluated, total water applied, total N available, and N applied through fertigation, in center pivot 6 there is a low correlation between these input variables and the yield for both years. This can be explained because the farmer applied an excess of all inputs to reduce the risk of those variables reducing the yield. In addition, in both years there was an unusual event (hailstorm in 1998 and herbicide damage in 1999) that could affect the spatial variability of yield more than the effect of those input variables.

The correlation between the leaching and deep percolation with yield was also poor. The poor correlation can be attributed to the impossibility of Opus to simulate the external effects that occurred and this effect on the deep percolation and leaching results for both seasons.

In center pivot 39, when there was no such unusual event, a different situation was found. The higher variability in the input parameters, such as N and water (as was discussed in Chapter 4), could have a greater influence on the spatial yield. The farmer applied a large amount of water under this center pivot 39, thus I found a low correlation between yield and water applied.

The N leaching potential available found from both N mass balance and Opus simulation results shows that the farmer applied only enough N to satisfy crop requirements. Thus, I found a slightly better correlation of yield with N.

Due to the low correlation between input variables evaluated and yield, no multiregression analysis was performed and I decided to perform a statistical cluster analysis in order to try to find a pattern of input variables which might be useful to make decisions in the management of each field. This might help to target problematic areas and provide a recommendation of the division of the field into smaller management areas. Results of this analysis are discussed in the following section.

5.6. Cluster Analysis

The purpose of the cluster analysis is to place variables into groups or clusters suggested by the data, which are not defined *a priori*. For example, variables in a given cluster tend to be similar to each other in some sense, and variables in different clusters tend to be dissimilar. Cluster analysis is not as much of a statistical test as it is a "collection" of different algorithms that put variables into groups. I applied the cluster analysis technique with the objective of identifying the patterns that exist between different variables such as leaching, soil texture, topography, and fertigation applied, to produce different clusters or groups of variables under each center pivot. The clusters found were used to identify differences within each field that follow the same patterns of excess N applied related to the topography and high leaching related with texture. Those can be used to define areas for differential management within each field.

The algorithm used was the tree diagram procedure with centroid method as recommended in the SAS manual (SAS Rel. 8.0, 2000) when you expect clusters of unequal size and dispersion, as was the situation with these data. All the procedures used in SAS (SAS Rel. 8.0, 2000), can be found in Appendix 8.

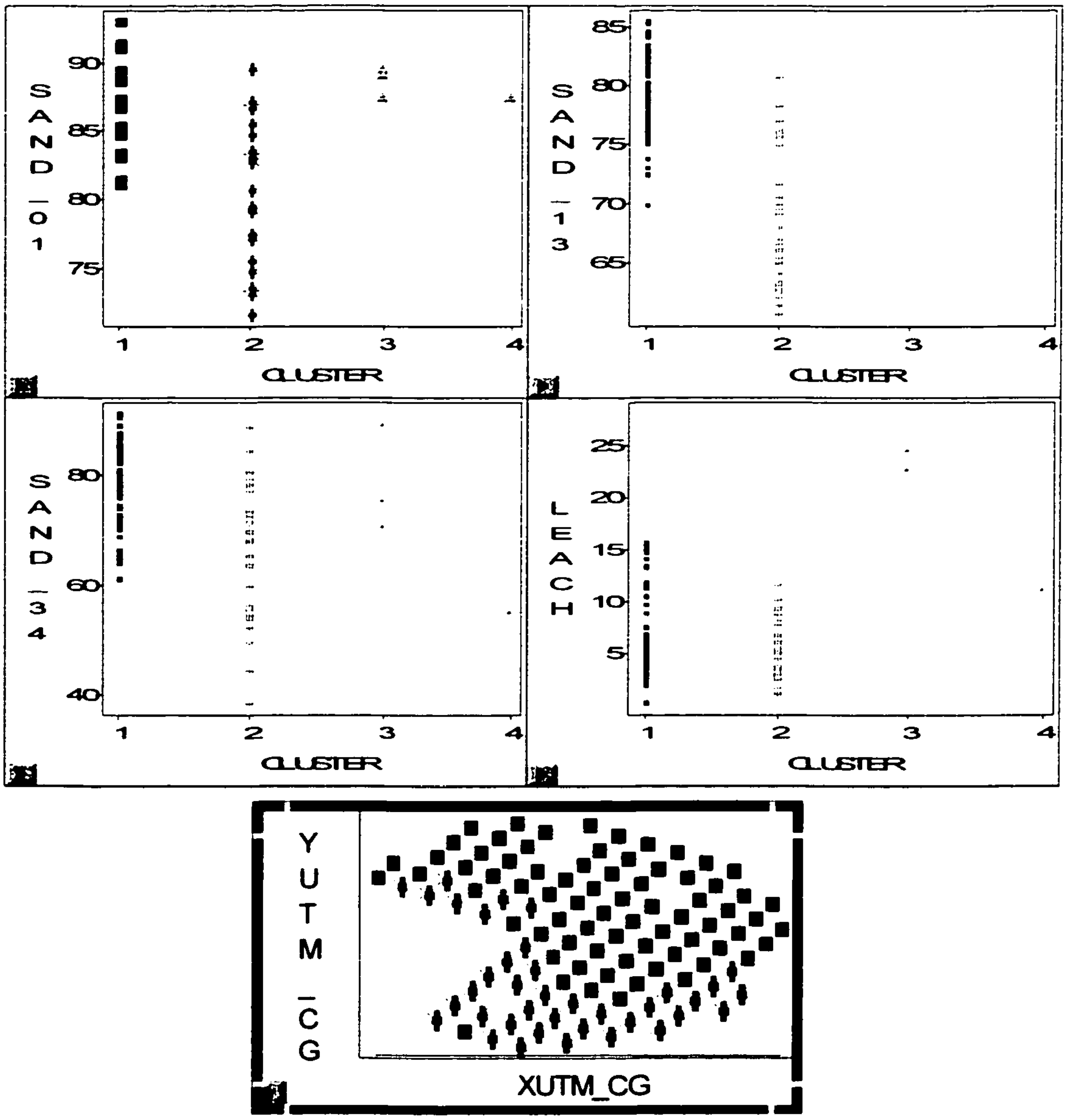
Because the relationships between input variables and yield were weak and influenced by the excess inputs applied by the farmer, I decided to run a cluster analysis in order to indicate which areas might be similarly managed. I used the sand percentage and total Opus calculated leaching to delineate areas by leaching amount and their effect due to differences in texture. At the same time, topography and the N applied by fertigation (which has a better correlation with yield than does water) was used to aggregate data by amount of fertilization applied in water and the topographic effect. Results of these analysis can be see in Figures 44 through 47 for center pivot 6 in 1998-99, and Figures 48 and 49 for center pivot 39 in 1999 and in Appendix 8.

Figures 44 to 49 are formed of two parts. The first shows graphs of the number of clusters found and the variables used in the analysis. The second shows a representation of the coarse grid central point with different symbols, as used in the first graphs, that represent the location of each cluster found in the field.

The cluster analysis (Figure 44) suggests division of the field into two different areas. Those are the areas with higher clay content (✲

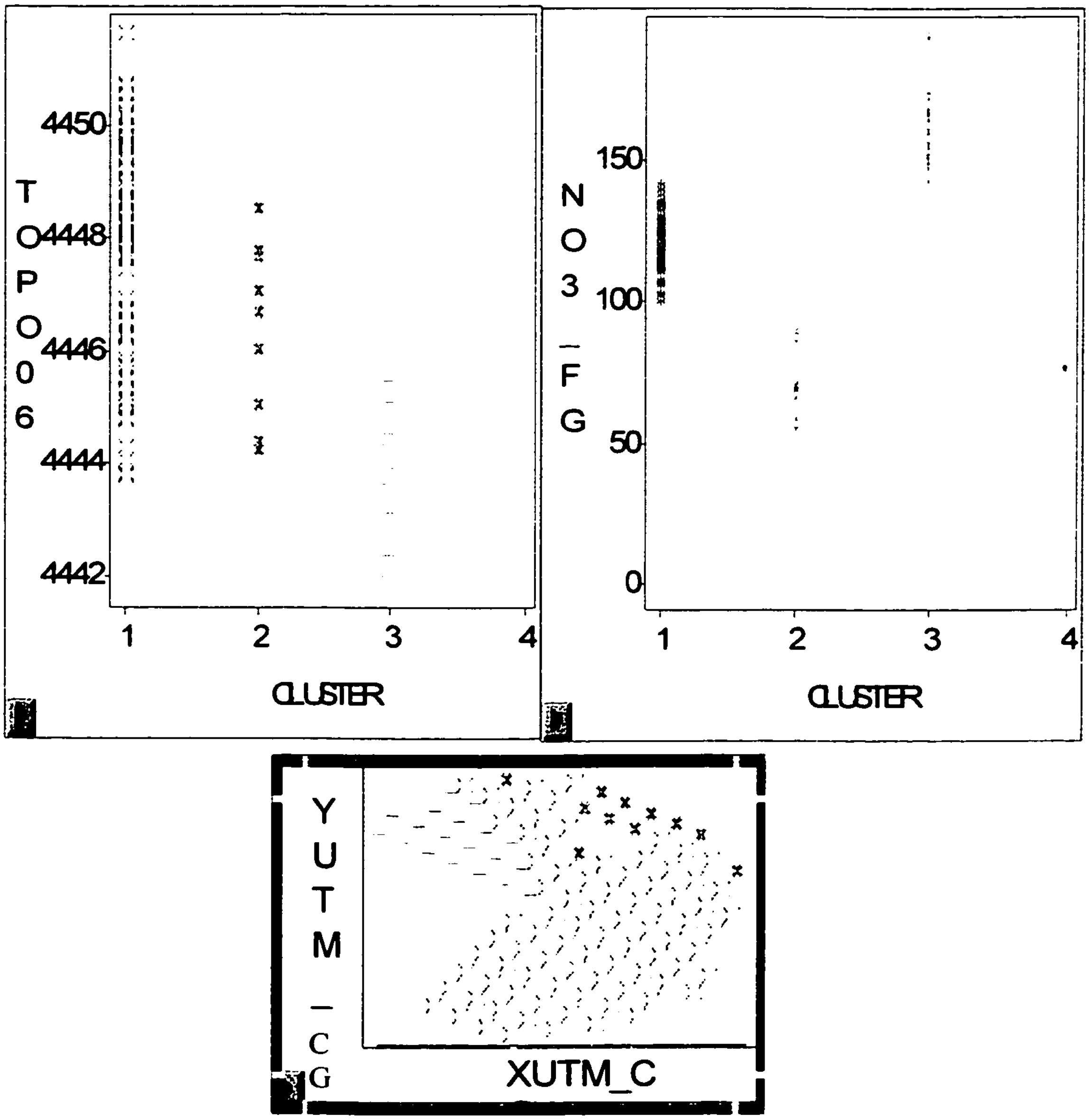
symbols in the Figure 44) and variable leaching (low to high in Figure 44) and the sandiest areas (■ symbols in Figure 44). Under the clay areas, there are spots of higher leaching where initial N content was high (▲ symbols in the south west in Figure 44) . A similar pattern was observed in the clay areas in 1999 (Figure 46, ✖ symbols in the south west), even when the farmer applied a lot more N and excess water. This indicates that we should have collected many soil samples in the field to find spots with different N content (if they exist) and to correct the fertilization in those areas in order minimize as much as possible future leaching. Under center pivot 6 for 1999, differences between the sandiest areas (Figure 46, ◆ symbols) and the less sandy areas (Figure 46, ✖ symbols) were accentuated, but similar division was found in this field in which the clay and sandy areas are in different clusters (Figure 46).

On the other hand, when I made the analysis between topography and N applied by fertigation, for 1998 (1999 data were excluded from the analysis because of high initial fertilization), cluster analysis shows that the area in the northwest, which was heavily fertigated, should be separated from the rest of the area in the management. In addition, that area is high in sand, which results in high leaching. As was discussed in Chapter 4, this was due to the low elevation of the area.



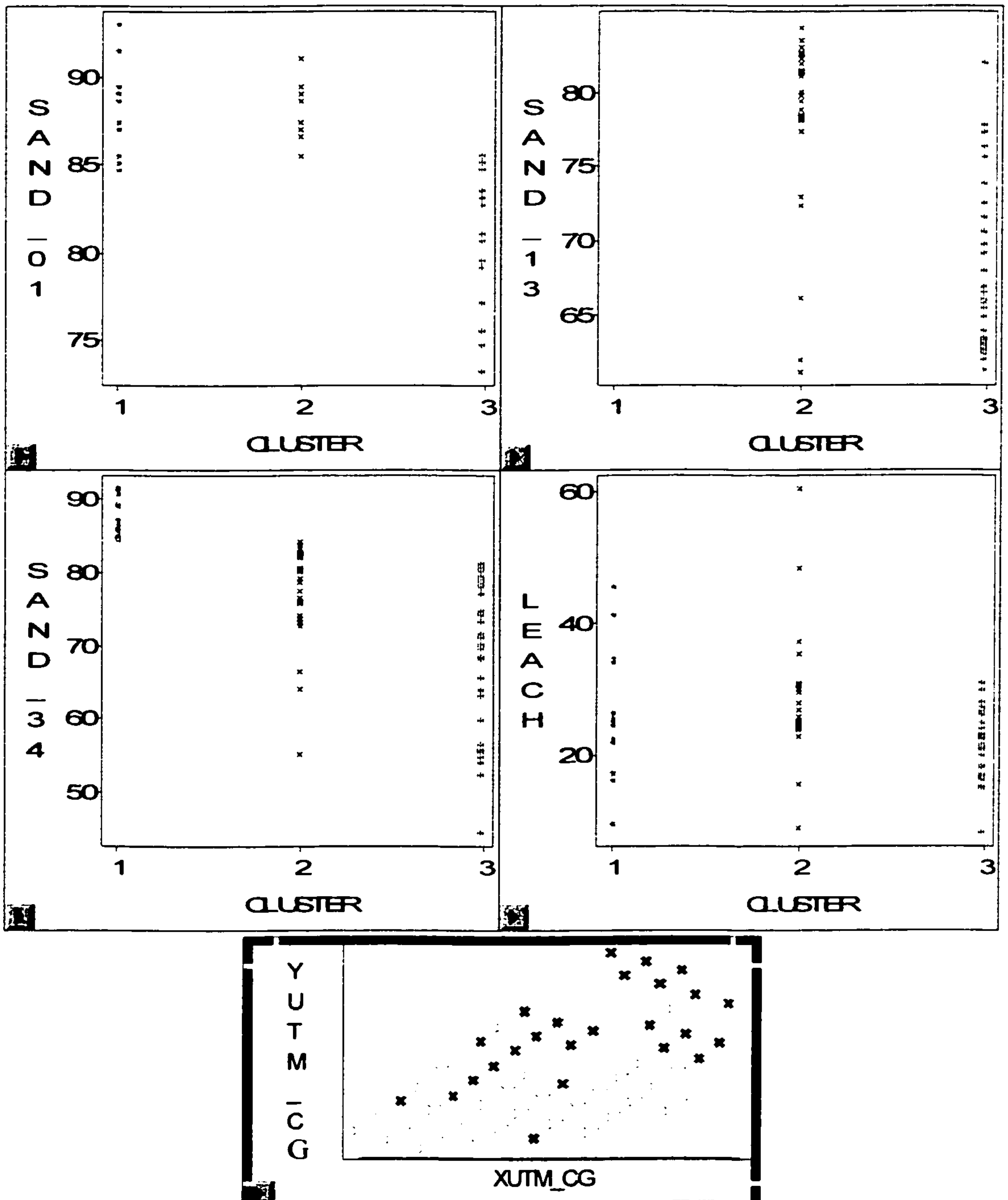
**** Figures axis : Sand 01 = Percentage of sand 0 to 30 cm.; Sand 13 = Percentage of sand 30 to 90 cm.; Sand 34 = Percentage of sand 90 to 120 cm.; LEACH = seasonal leaching [kgN/ha]; YUTM_CG = North-South coarse grid UTM coordinates.; YUTM_CG = East-West coarse grid UTM coordinates.**

Figure 44. Center pivot 6, 1998, cluster analysis with 4 clusters using sand percentages by layer and total leaching as variables.



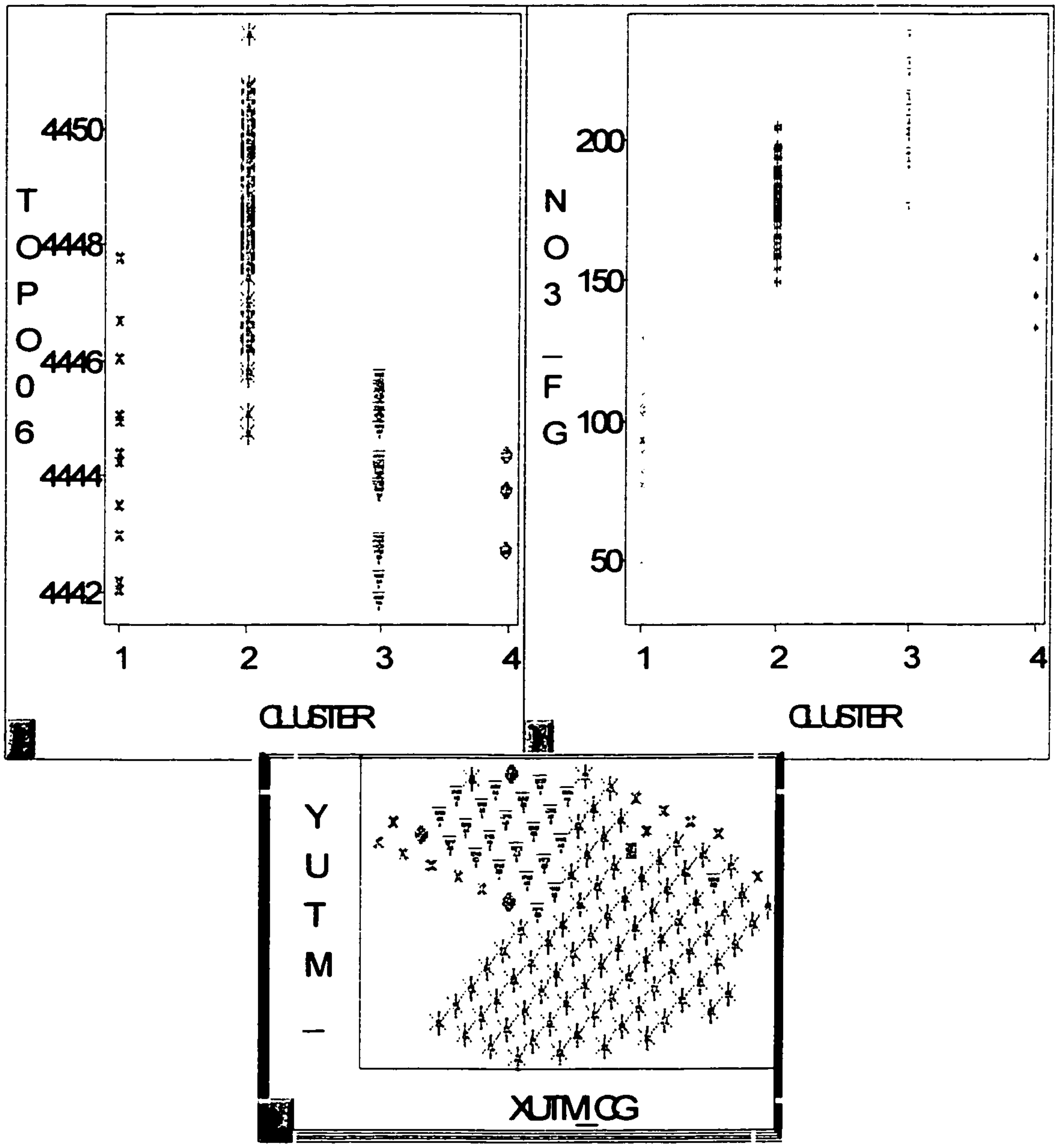
** Figures axis : TOPO06 = Topographic elevations [ft], NO_3_FG = seasonal nitrogen applied by fertigation [kgN/ha]; YUTM_CG = North-South coarse grid UTM coordinates.; YUTM_CG = East-West coarse grid UTM coordinates.

Figure 45. Center pivot 6, 1998, cluster analysis with 4 clusters using topographic elevation and N applied through fertigation as variables.



** Figures axis : Sand 01 = Percentage of sand 0 to 30 cm.; Sand 13 = Percentage of sand 30 to 90 cm.; Sand 34 = Percentage of sand 90 to 120 cm.; LEACH = seasonal leaching [kgN/ha]; YUTM_CG = North-South coarse grid UTM coordinates.; YUTM_CG = East-West coarse grid UTM coordinates.

Figure 46. Center pivot 6, 1999, cluster analysis with 4 clusters using sand percentages by layer and total leaching as variables.

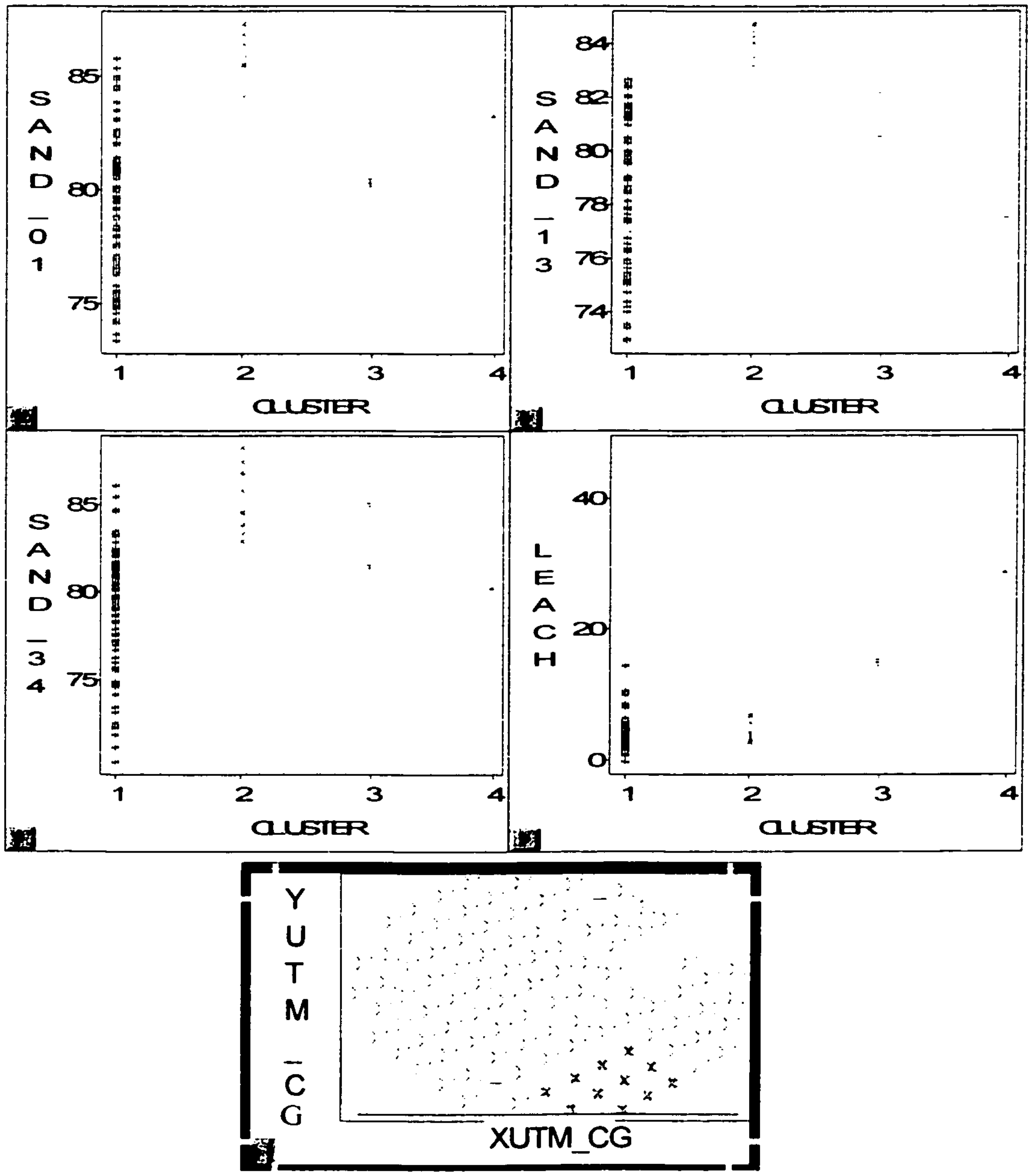


** Figures axis : TOPO06 = Topographic elevations [ft], NO_3_FG = seasonal nitrogen applied by fertigation [kgN/ha]; YUTM_CG = North-South coarse grid UTM coordinates.; YUTM_CG = East-West coarse grid UTM coordinates.

Figure 47. Center pivot 6, 1999, cluster analysis with 4 clusters using topographic elevation and N applied through fertigation as variables.

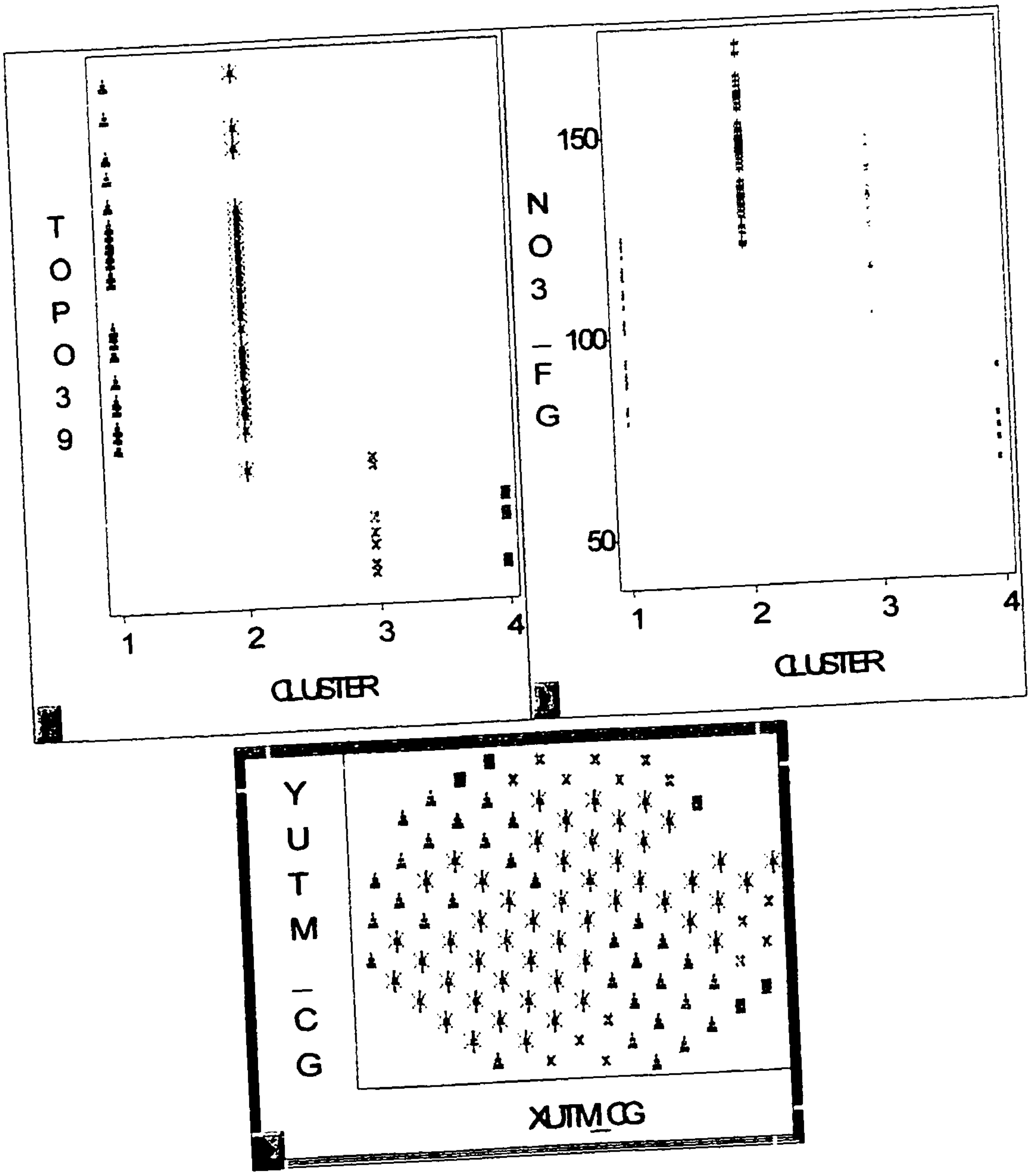
Similar patterns as found in center pivot 6 were found on center pivot 39. Figure 48 shows that the cluster analysis divides the field into the more sandy areas (✖ symbols, with leaching medium to high) and the rest of the area with higher clay content.

When I ran the cluster analysis between elevation and the N applied through fertigation, the areas were divided according to heavy, medium (sandiest area) and lower fertigated areas. For this year, Opus estimated low leaching under this center pivot, but as shown in Figure 48, the highest leaching is under the high and medium sandy areas, almost the same tendency as under center pivot 6.



<u>Figures axis :</u> Sand 01 = Percentage of sand 0 to 30 cm.; Sand 13 = Percentage of sand 30 to 90 cm.; Sand 34 = Percentage of sand 90 to 120 cm.; LEACH = seasonal leaching [kgN/ha]; YUTM_CG = North-South coarse grid UTM coordinates.; YUTM_CG = East-West coarse grid UTM coordinates.**

Figure 48. Center pivot 39, 1999, cluster analysis with 4 clusters using sand by percentages per layer and total leaching as variables.



** Figures axis : TOPO39 = Topographic elevations [ft], NO_3_FG = seasonal nitrogen applied by fertigation [kgN/ha]; YUTM_CG = North-South coarse grid UTM coordinates.; YUTM_CG = East-West coarse grid UTM coordinates.

Figure 49. Center pivot 39, 1999, cluster analysis with 4 clusters using topographic elevation and N applied through fertigation as variables.

5.7. Summary

The farmer did not follow the evapotranspiration and weather data to adjust his irrigations, which lead to over application of water. The problem is even worse when he is applying N with the irrigation water, because excess water equates to excess N application, resulting in N leaching and pollution of the groundwater resource.

Simulation models such as Opus can be used as tools to predict N leaching, which is almost impossible to measure in the field. In this chapter, I showed that Opus simulation had a satisfactory agreement with an N mass balance when no crop damage occurred. I showed a methodology to identify differences between areas, which can help in the application of variable rate technology under those fields. Finally, in this chapter we see that the leaching problem was increased due to the nonuniformity of water and N applications, thus it is important to correct those parameters to improve the management under these fields.

CHAPTER 6

Conclusions and Recommendations

6.1. Conclusions

The main contribution of this research is in defining the water and N spatial variability and their implications to agronomic and environmental management. In my research, I showed a possible methodology to follow in order to define areas requiring similar management of the spatial N application under a center pivot irrigation system.

The tendency of farmers is to apply excessive water and N in order to minimize the risk of yield reduction. In addition, using current technology, farmers do not have the ability to consider spatial variability of water and nitrogen requirements by plants in a field, thus the entire field is treated the same. This problem results in potential leaching of N (carried by the excess water) through the root zone toward the groundwater, possibly producing contamination. The N losses reduce the potential income of the farmers; in some cases to a significant extent. However, the environmental effect on the groundwater could be more important if trends in groundwater NO_3 content are to be reversed.

I found significant variability in irrigation application due to the topography and the end gun operation that affects the differential deep percolation across fields. The seasonal irrigation depth was 582 and 526 mm with 83 and 79 mm of standard deviation for 1998 and 1999, respectively, for field 6, and 541 mm with 77 mm of standard deviation in 1999 for field 39. In addition, the variability of the rain across each field increases the variability of water availability to the crops, which could be important in a rainy year. The N application was influenced by irrigation variability because N was applied in irrigation water. Moreover, the fertilizer injection rate was influenced in the same way as irrigation depth by the topography of the areas. This effect magnified the N spatial variability and the CU dropped from 94 % for water to 86 % for N for center pivot 6 and from 89 % to 79 % in center pivot 39. The variable N application, in conjunction with the soil variability, produces variability in the total N available to the crops. The results show that there was significant variability in potential N available to the crop across both fields, which ranged from 113 to 273 kg-N/ha in 1998 and from 102 to 268 kg-N/ha in 1999 for field 6, and from 114 to 240 kg-N/ha in 1999 for field 39. This proves that there is significant variability of N availability on fields which have historically been assumed to be managed uniformly by the farmer. The variability of water and N application and soil physical and chemical properties results in areas with possible high N leaching. This variability presents an opportunity to improve N management using variable rate technologies (VRT).

When no abnormal events (hail or herbicide damage) occurred, an acceptable agreement was found between simulation results from the Opus model and an N mass balance (4 kg-N/ha average difference between Opus and N mass balance). From Opus simulations, I found that the sandiest areas will produce the greatest leaching, which varied from 15 to 30 kg-N/ha and 28 to 46 kg-N/ha for center pivot 6 in 1998 and 1999, respectively and from 10 to 30 kg-N/ha for center pivot 39 in 1999. Areas with higher initial soil NO_3 were observed to produce early leaching, which increases leaching problems when an excess of N is applied on these areas.

Finally, maximizing the water and N uniformity results in an important point for improving the field management. In addition, The Opus simulation model could be used to predict effects of different management to develop an optimum management strategy to maximize economic return and minimize environmental impact.

6.2. Recommendations

In order to reduce N losses due to leaching, farmers should test yearly for residual soil NO_3 to more accurately determine fertilization applications. In addition, when it is necessary, farmers should consider redesigning their irrigation systems using new sprinklers heads with pressure regulators in order to obtain a more uniform water and N application distribution. Moreover, using a lower pressure system will reduce the required energy, thus will reduce operation cost. Removing the end gun will significantly improve the uniformity of both water and chemical application. Design improvements will make management of the irrigation and fertigation system much easier in order to applied the required amount of water and N. Improving the uniformity of N available to plants will reduce possible leaching problems. Another management improvement to reduce potential leaching is to use the sandiest areas as the point of control for irrigation water management. Finally, I suggest that specific research be initiated to determine the optimum fertigation numbers required, in order to better quantify the importance of fertigation timing in leaching reduction.

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Appendix 1

Spatial Water Application

1. Center pivot evaluation and design (CPED)

1.1. Irrigation history

In the next 3 pages, I will present the irrigation history through the season 1998 and 1999 for center pivot 6 in table 1 and 2 respectively. Table 3 shows the irrigation history for center pivot 39 for season 1999.

To develop the tables 1 until 3, I used the data from the datalogger installed in the panel of each center pivot.

Those dataloggers, registered the date, hour, position (degree) of the center pivot, pressure, center pivot direction (reverse or forward), and speed.

Table 17. Irrigation history for center pivot 6, season 1998.

Julian Day	Position	Time of Change	Speed	Notes
173	215	14:56	49%	
175	213	4:41	49%	at road, stop 49% rev
176	213	9:39	27%	start 27% rev
178	213	20:39	27%	end 27% rev
179	213	10:09	36%	start 36% rev
181	160	1:09	36%	stopped
181	166-212	11:39-13:39	100%	moved to road with no water
182	213	17:09	27%	start 27% rev
183	29	21:23	27%	stopped
184	29	7:23	41%	speed changed
184	50	9:53	41%	stopped, speed change
185	168	6:38	27%	stopped, speed change
185	168	8:23	15%	
185	213	21:08	15%	end
186	213	12:23	27%	start
186	221	13:53	19%	speed changed
189	213	22:31	19%	end 19%
190	213	14:46	19%	start 19%
194	213	2:11	19%	end 19%
194	213	11:46	53%	start 53%
195	213	18:15	19%	crossed road, start 19%
196	329	20:00	19%	stopped
198	329	12:16	19%	restart
200	213	21:46	19%	crossed road, start 19%
204	213	8:30	19%	crossed road, start 19%
205	1	17:30	19%	stopped
208	1	9:45	41%	restart at 41%
208	90	20:15	41%	stopped
209	90	0:30	41%	restart
209	213	17:15	41%	cross road, cont at 41%
210	315	4:45	41%	stopped
210	315	7:30	41%	restart
210	0	13:09	19%	speed changed to 19%
212	213	15:39	19%	cross road, cont at 19%
213	329	16:54	19%	stopped
216	329	7:39	19%	restart
218	213	2:11	19%	end 19%
219	213	7:39	34%	start 34%
221	162	0:14	34%	stopped
221	162	8:44	34%	restart
221	213	15:29	34%	end 34%
222	213	16:44	34%	start 34%

Julian Day	Position	Time of Change	Speed	Notes
224	213	15:59	34%	end 34%
225	213	17:14	28%	start 28%
228	213	3:01	28%	end 28%
229	213	9:16	28%	start 28%
231	213	1:58	28%	stop 28%
232	213	17:58	45%	start 45%
234	213	5:43	45%	end 45%
236	213	7:58	31%	start 31%
238	213	11:28	31%	end 31%
239	213	7:58	31%	start 31%
240	38	21:37	31%	stopped
241	38	4:52	31%	restarted
242	213	6:52	31%	end 31%
243	213	22:37	35%	start 35%
244	41	21:52	35%	stopped
245	41	1:22	35%	restarted
246	213	0:07	35%	end
246	213	19:22	35%	start 35%
246	231	21:37	35%	stopped
246	231	23:37	35%	restarted
247	63-79	13:29-14:29	100%	Backed up over 63-79 deg with water on
247	63	14:29	35%	speed returned to 35%
248	213	10:14	35%	end 35%
251	213	10:14	47%	start 47%
252	50	4:29	47%	stopped
252	50	7:29	47%	restarted
252	213	23:44	47%	end 47%
253	213	17:59	47%	start 47%
255	213	4:29	47%	end 47%

Table 18. Irrigation history for center pivot 6, season 1999.

Irrigation event	Start date	hour	Stop date	hour	Stop Angle (deg)	Direction	Velocity (%)	time for 1 revolution (hrs)
1	12-May	---	13-May	---	213	F	without data	36
2	4-Jun	3:00	5-Jun	14:45	213	F	45	36
3	8-Jun	3:30	8-Jun	16:00	305	F	32	52
	8-Jun	18:45	8-Jun	23:00	40	F	without water	
	8-Jun	23:30	9-Jun	3:45	305	R	without water	
	9-Jun	4:00	10-Jun	19:09	121	F	32	52
	11-Jun	8:24	11-Jun	13:24	213	F	85	19.5
4**	**21-Jun**	**9:41**	**21-Jun**	**23:26**	**340**	**F**	**40**	**41.5**
	22-Jun	**13:57**	**23-Jun**	**16:42**	**213**	**F**	**40**	**41.5**
5	25-Jun	7:41	28-Jun	8:11	213	F	22	73
6	28-Jun	18:41	29-Jun	21:11	32	F	29	54.5
	30-Jun	7:11	1-Jul	12:26	213	F	29	54.5
7	1-Jul	12:41	1-Jul	22:56	276	F	26	62
	2-Jul	7:26	4-Jul	10:17	213	F	26	62
8**	**4-Jul**	**10:37**	**6-Jul**	**23:32**	**213**	**F**	**26**	**62**
9**	**7-Jul**	**12:02**	**9-Jul**	**23:14**	**213**	**F**	**27**	**60.5**
10	10-Jul	15:44	11-Jul	18:44	25	F	27	60.5
	12-Jul	**17:44**	**14-Jul**	**13:00**	**213**	**F**	**27**	**60.5**
11**	**14-Jul**	**13:50**	**17-Jul**	**12:42**	**213**	**F**	**27**	**60.5**
12	17-Jul	12:57	19-Jul	16:12	213	F	25	65
13**	**19-Jul**	**10:57**	**20-Jul**	**21:38**	**213**	**F**	**46**	**35**
14	21-Jul	17:53	22-Jul	14:23	305	F	19	85
	22-Jul	14:38	23-Jul	8:08	36	F	23	72
	23-Jul	8:23	24-Jul	6:38	213	F	19	85
15	26-Jul	11:50	28-Jul	17:00	213	F	40	41.5
16	28-Jul	17:16	30-Jul	10:35	213	F	40	41.5
17	30-Jul	11:35	31-Jul	4:20	303	F	23	72
	31-Jul	4:35	1-Aug	0:05	31	F	19	85
	1-Aug	0:20	1-Aug	8:20	73	F	19	85
	1-Aug	8:35	1-Aug	21:20	213	F	50	33
18	4-Aug	8:35	5-Aug	7:53	56	F	38	43.5
	5-Aug	8:00	5-Aug	11:23	213	F	38	43.5
19	9-Aug	8:08	10-Aug	16:36	54	F	26	62
	10-Aug	16:51	10-Aug	18:51	73	F	45	36
	10-Aug	19:06	11-Aug	2:36	213	F	83	20
20	13-Aug	8:10	15-Aug	20:40	213	F	27	60.5
21	16-Aug	7:20	18-Aug	18:20	213	F	28	59
22	19-Aug	9:15	21-Aug	20:15	213	F	28	59
23	23-Aug	12:30	25-Aug	17:05	213	F	31	52.5
24	25-Aug	18:20	27-Aug	22:50	213	F	31	52.5
25	31-Aug	7:15	1-Sep	19:10	213	F	45	36
26	1-Sep	19:25	3-Sep	7:20	213	F	45	36
27	8-Sep	7:35	10-Sep	23:45	213	F	25	65
28	14-Sep	9:30	16-Sep	9:45	213	F	33	48.75

**** Fertigation event.**

Table 19. Irrigation history for center pivot 39, season 1999.

Irrigation event	Start date	hour	Stop date	hour	Stop Angle (deg)	Direction	Velocity (%)	time for 1 revolution (hrs)
1	19-May	7:30	19-May	9:30	230	R	100	14
2	7-Jun		9-Jun	16:11	230	R	40	35.5
3**	**12-Jun**	**8:47**	**12-Jun**	**22:32**	**230**	**R**	**100**	**14**
4**	**13-Jun**	**17:02**	**14-Jun**	**6:17**	**230**	**R**	**100**	**14**
5**	**22-Jun**	**16:43**	**24-Jun**	**17:43**	**230**	**R**	**27**	**52.5**
6	24-Jun	18:28	25-Jun	12:28	143	R	18	78
	25-Jun	14:43	26-Jun	14:43	29	R	18	78
	26-Jun	18:28	28-Jun	2:58	230	R	18	78
7	28-Jun	2:58	28-Jun	7:28	208	R	18	78
	28-Jun	7:43	29-Jun	9:54	91	R	16	82
	29-Jun	18:08	1-Jul	19:38	230	R	16	82
8	2-Jul	7:23	5-Jul	14:08	230	R	16	82
9**	**5-Jul**	**15:38**	**7-Jul**	**18:08**	**230**	**R**	**27**	**52.5**
10**	**8-Jul**	**6:08**	**10-Jul**	**8:30**	**230**	**R**	**27**	**52.5**
11	10-Jul	14:15	13-Jul	23:03	230	R	16	82
12**	**13-Jul**	**23:18**	**17-Jul**	**7:48**	**230**	**R**	**16**	**82**
13	17-Jul	8:03	19-Jul	20:29	333	R	16	82
	20-Jul	6:18	20-Jul	7:33	297	R	without water	
	20-Jul	17:27	20-Jul	18:57	259	R	without water	
	21-Jul	6:42	21-Jul	8:27	230	R	without water	
14	21-Jul	17:42	24-Jul	17:46	230	R	18	78
15**	**26-Jul**	**8:01**	**27-Jul**	**16:59**	**74**	**R**	**18**	**78**
	27-Jul	**11:14**	**29-Jul**	**7:44**	**230**	**R**	**19**	**74**
16	30-Jul	7:29	1-Aug	7:59	230	R	27	52.5
17	4-Aug	7:29	5-Aug	6:59	115	R	18	78
	9-Aug	6:59	10-Aug	19:29	290	R	18	78
	11-Aug	8:30	11-Aug	10:35	230	R	without water	
18	13-Aug	7:32	14-Aug	20:32	260	R	36	39.5
19	16-Aug	9:47	19-Aug	10:47	230	R	18	78
20	19-Aug	11:02	20-Aug	20:27	63	R	18	78
	21-Aug	7:17	22-Aug	21:47	230	R	18	78
21	23-Aug		25-Aug		230	R	21	67.5
22	31-Aug	6:30	2-Sep	9:35	230	R	27	52.5
23	2-Sep	10:45	4-Sep	14:15	230	R	27	52.5
24	8-Sep		10-Sep	7:48	230	R	27	52.5
25	17-Sep	13:33	18-Sep	23:18	230	R	40	35.5

**** Fertigation event.**

1.2. CPED input and output screens

In the follow figures (44 until 58), I will present a sample of the input and output screen of CPED, with an example of data from center pivot 6.

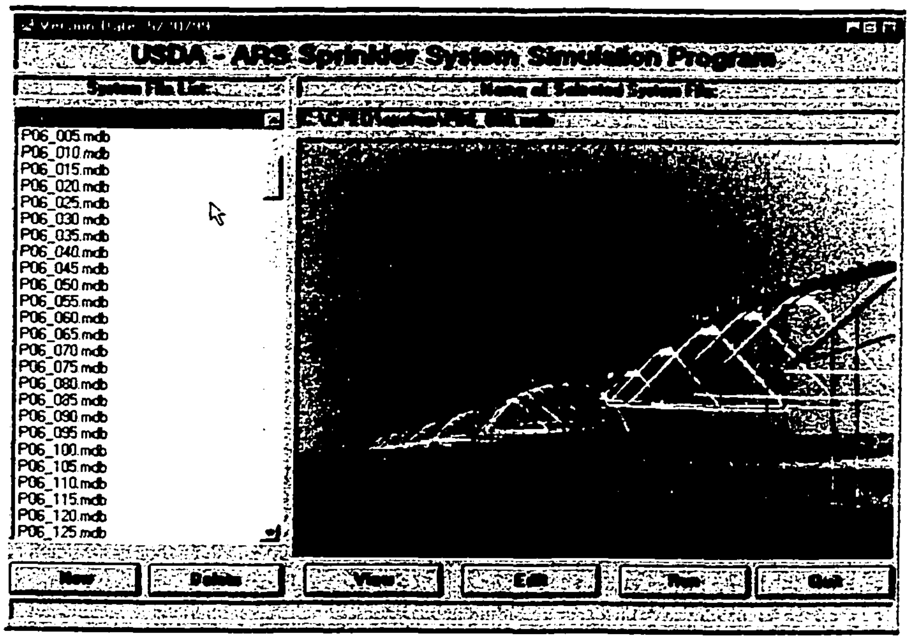


Figure 50. Main screen of CPED, use the New button to build a new system file.

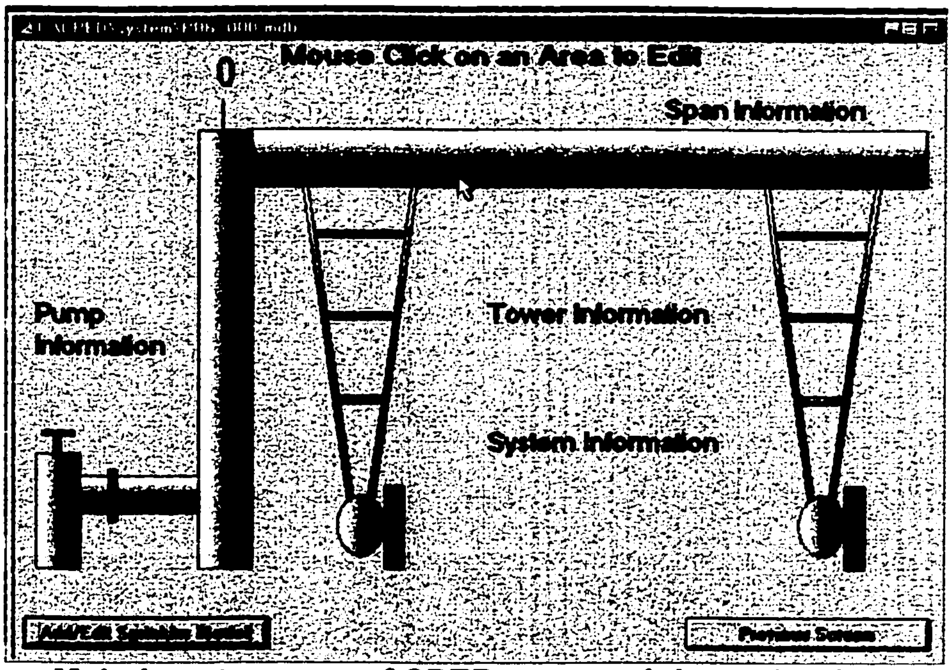


Figure 51. Main input screen of CPED, use each legend to introduce the data into the new system file.

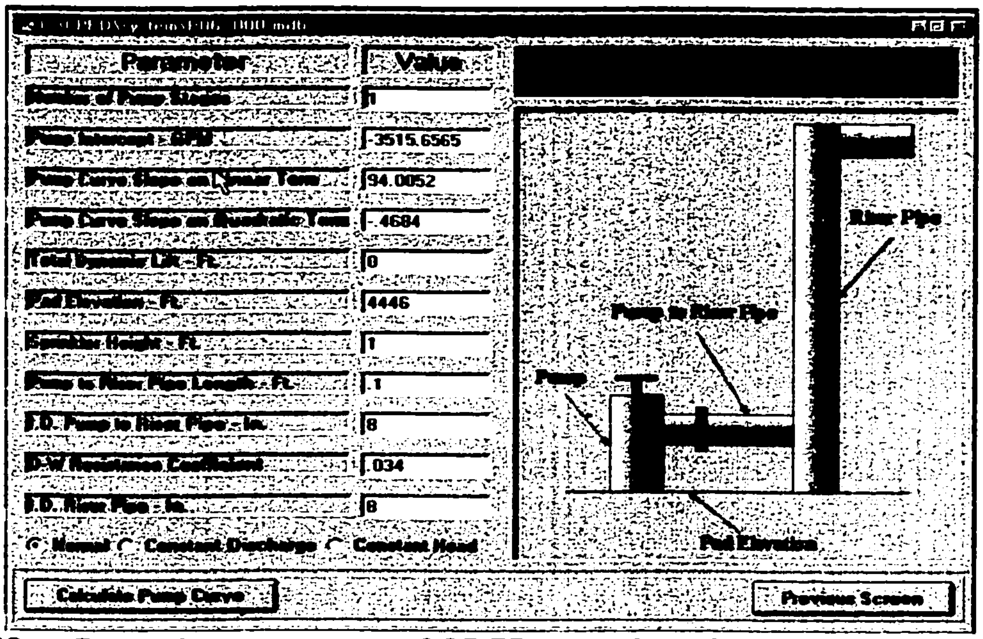


Figure 52. Pump input screen of CPED, use the white boxes to introduce the pump data into the new system file (if you have data from field you can build the pump curve from the button with the same name).

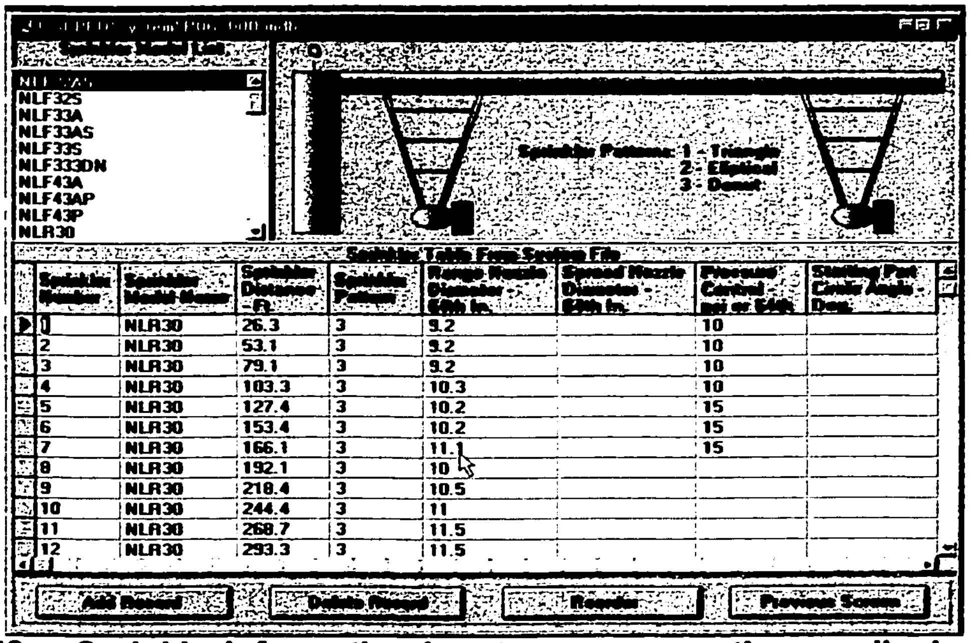


Figure 53. Sprinkle information input screen, use the scroll windows to select the sprinkler used and introduce the exta data required from the sprinkler into the white boxes.

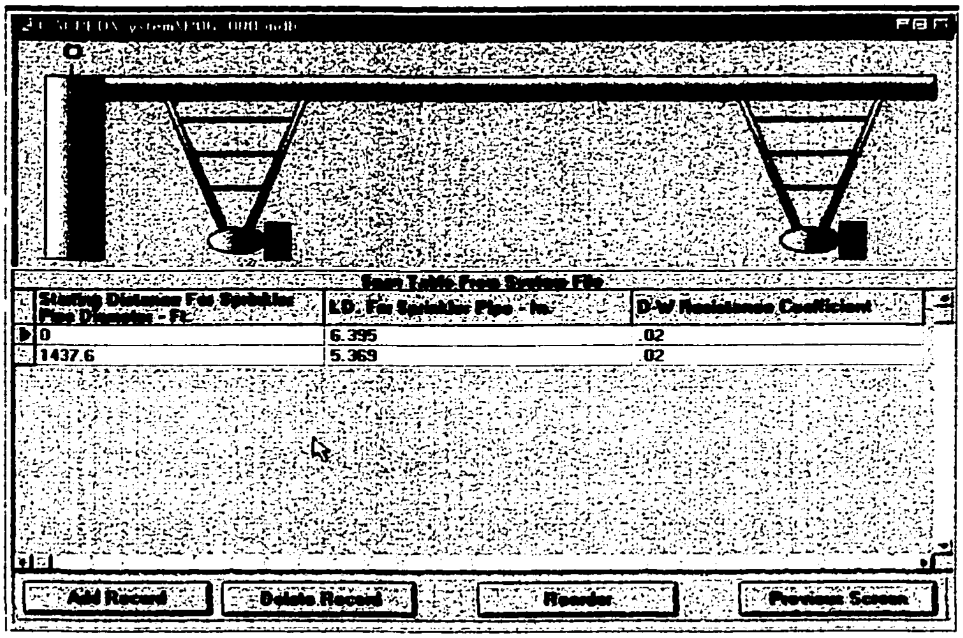


Figure 54. Data introduction of span information required (as I did, is better to calculate the D.W. resistance coefficient from field data to obtain a better simulation)

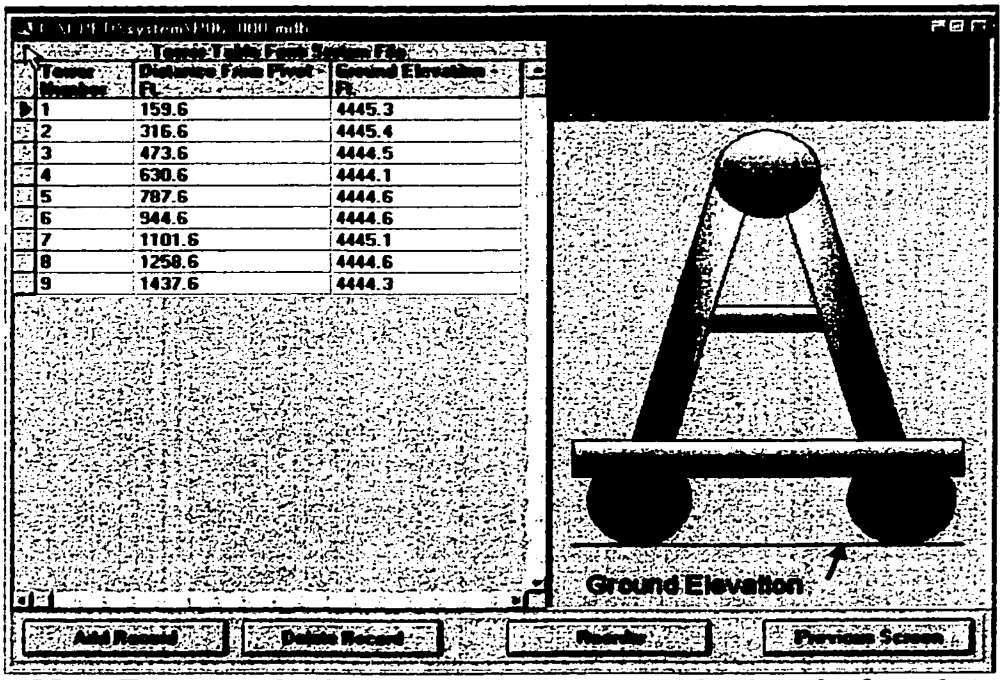


Figure 55. Topography input screen (topography level of each tower each 5 degrees).

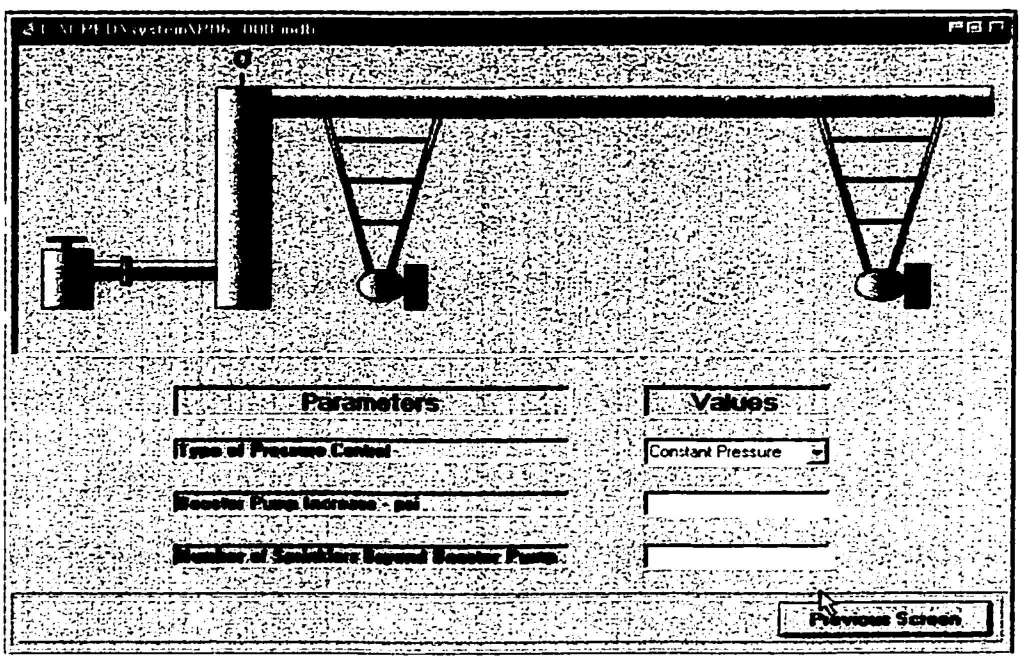


Figure 56. System information screen (introduce extra information as pressure regulator that we have in the first 7 sprinklers in center pivot 6, buster pump as in center pivot 39).

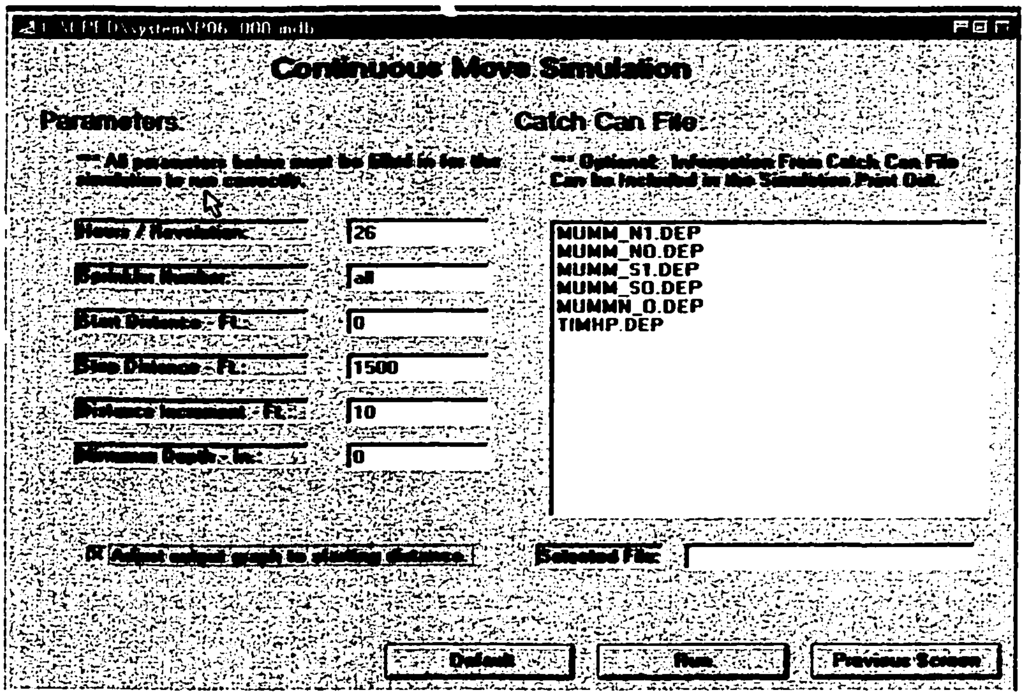


Figure 57. Run screen (introduce the data required in each white box).

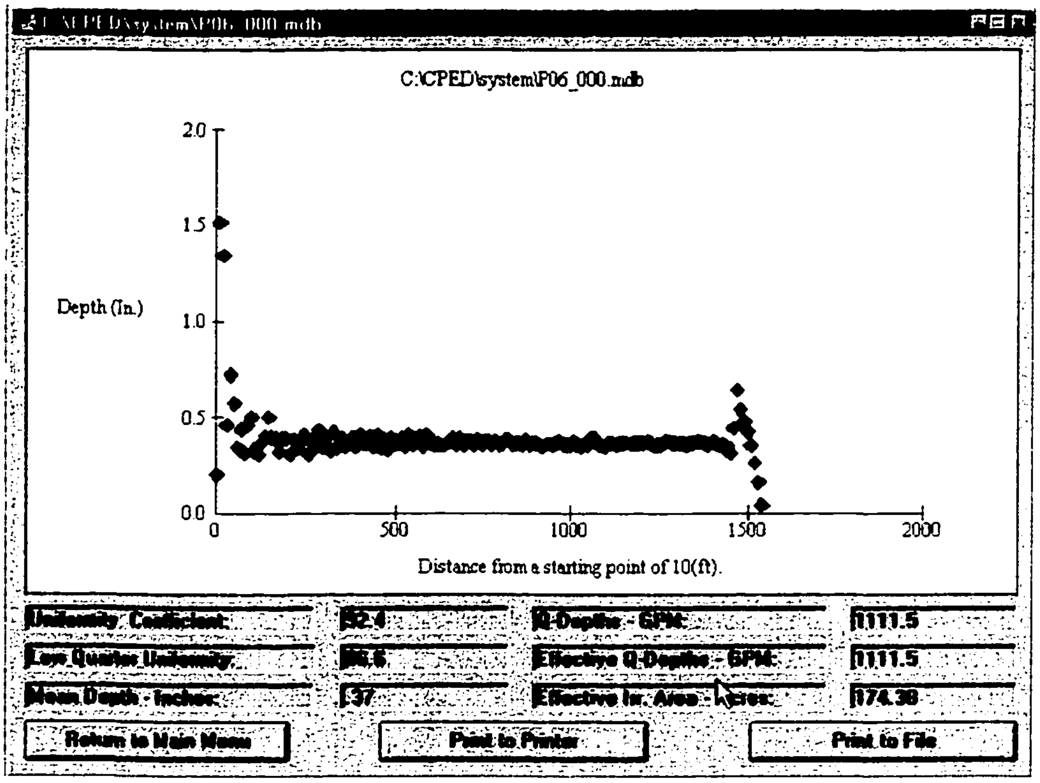


Figure 58. Output screen (sample from center pivot 6 with the input data from the figures 3 to 6).

Appendix 2

Spatial nitrogen Application

2. Nitrogen injection (UAN solution)

In figure 59 you can see a photograph of the injection system in each center pivot.

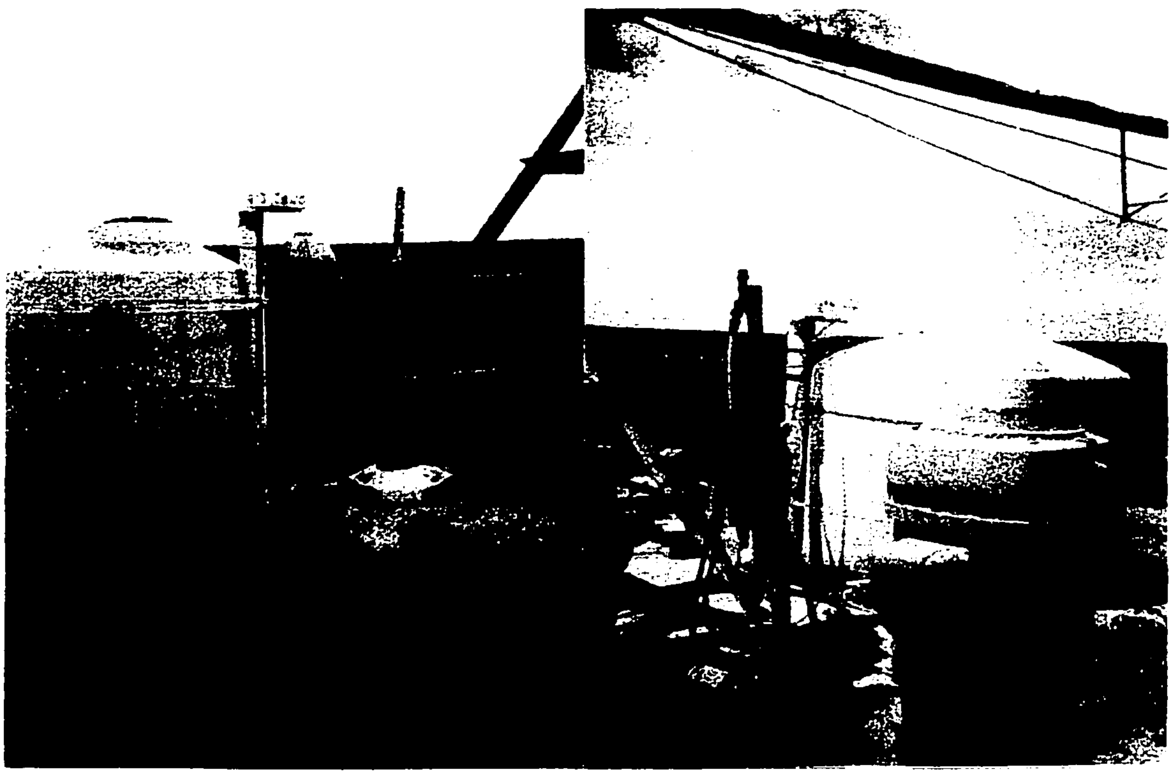


Figure 59. Hydraulic injection system utilized in center pivot 6 (right) and electric injection system utilized in center pivot 39 (left).

As you can see from figure 59, I measured the injection of the UAN solution from each tank from a datalogger located next to each tank.

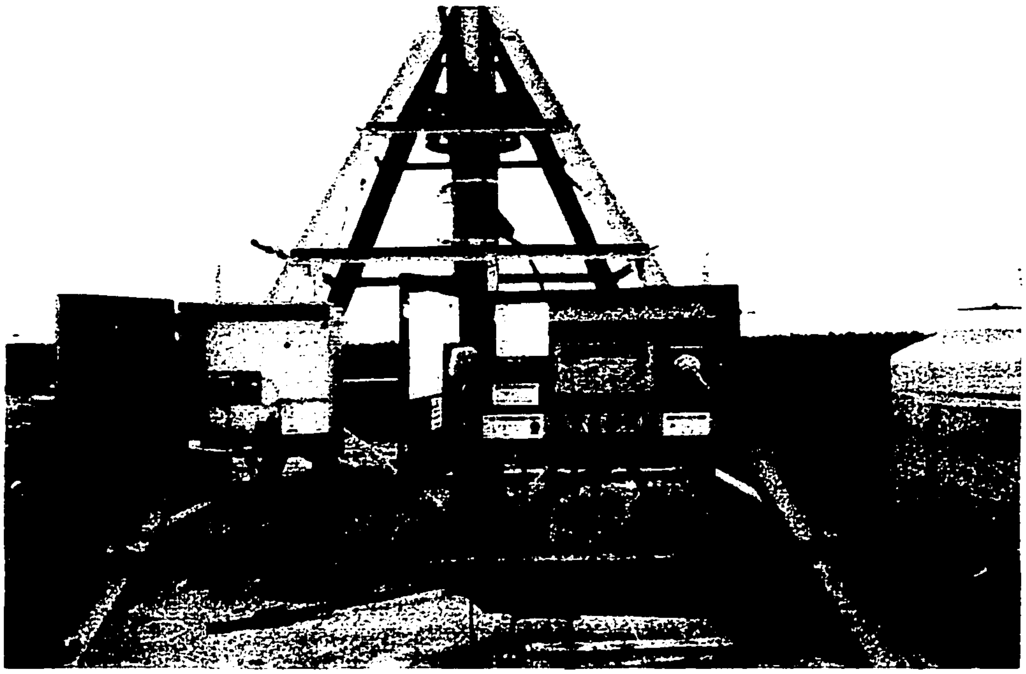


Figure 60. Panel with datalogger (inside the panel) in each center pivot location.

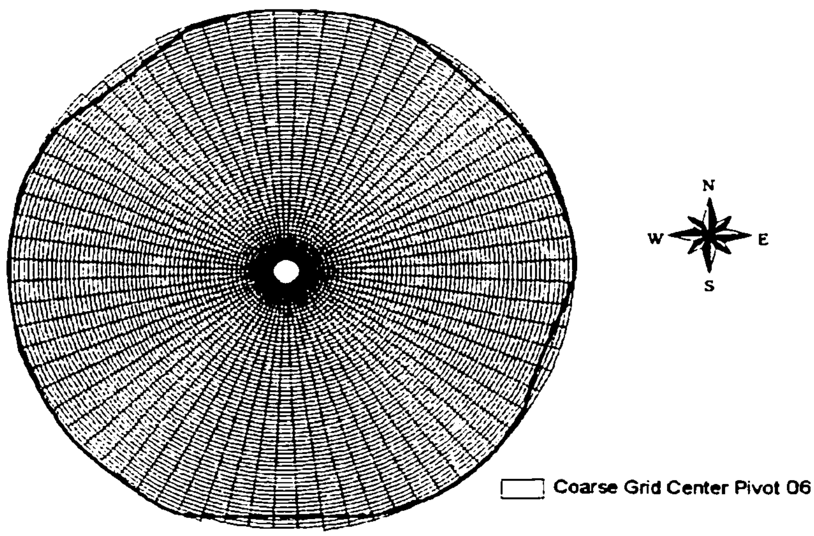
From those data in conjunction with the panel data (figure 60) and the pump equation of each center pivot, I calculated the injection rate and concentration per angle position. An example of those calculation can be see in table 20.

Table 20. Calculation example of nitrogen injection and water concentration.

CP	day	hour [hrs]	angle [deg]	pressure [psi]	pressure [ft]	depth tank [cm]	Dif. Level [cm]	Dif. Level [m]	Vol [m3]	Inyec. Rate lt/min	Inyec. Rate gpm	N lb/min	N mg/min	Pump rate gpm	Pump rate lt/min	Concen. NO3-N ppm
6	184	1806	96	47	108.41	72.95	1.20	0.0120	0.051	3.382	0.890	3.144	1425836.1	1170.45	4447.70	320.6
6	184	1821	97	47	108.41	74.15	1.20	0.0120	0.051	3.382	0.890	3.144	1425836.1	1170.45	4447.70	320.6
6	184	1836	99	47	108.41	75.35	1.20	0.0120	0.051	3.382	0.890	3.144	1425836.1	1170.45	4447.70	320.6
6	184	1851	100	47	108.41	76.60	1.25	0.0125	0.053	3.523	0.927	3.275	1485245.9	1170.45	4447.70	333.9
6	184	1906	102	47	108.41	77.95	1.35	0.0135	0.057	3.805	1.001	3.537	1604065.6	1170.45	4447.70	360.7
6	184	1921	104	48	110.72	79.00	1.05	0.0105	0.044	2.959	0.779	2.751	1247606.6	1150.53	4372.00	285.4
6	184	1936	105	47	108.41	80.30	1.30	0.0130	0.055	3.664	0.964	3.406	1544655.8	1170.45	4447.70	347.3
6	184	1951	107	48	110.72	81.55	1.25	0.0125	0.053	3.523	0.927	3.275	1485245.9	1150.53	4372.00	339.7
6	184	2006	109	48	110.72	82.80	1.25	0.0125	0.053	3.523	0.927	3.275	1485245.9	1150.53	4372.00	339.7
6	184	2021	110	47	108.41	84.10	1.30	0.0130	0.055	3.664	0.964	3.406	1544655.8	1170.45	4447.70	347.3
6	184	2036	111	48	110.72	85.35	1.25	0.0125	0.053	3.523	0.927	3.275	1485245.9	1150.53	4372.00	339.7
6	184	2051	114	48	110.72	86.50	1.15	0.0115	0.049	3.241	0.853	3.013	1366426.2	1150.53	4372.00	312.5
6	184	2106	115	47	108.41	87.80	1.30	0.0130	0.055	3.664	0.964	3.406	1544655.8	1170.45	4447.70	347.3
6	184	2121	117	48	110.72	89.00	1.20	0.0120	0.051	3.382	0.890	3.144	1425836.1	1150.53	4372.00	326.1
6	184	2136	119	48	110.72	90.25	1.25	0.0125	0.053	3.523	0.927	3.275	1485245.9	1150.53	4372.00	339.7
6	184	2151	120	47	108.41	91.55	1.30	0.0130	0.055	3.664	0.964	3.406	1544655.8	1170.45	4447.70	347.3
6	184	2206	122	48	110.72	92.85	1.30	0.0130	0.055	3.664	0.964	3.406	1544655.8	1150.53	4372.00	353.3
6	184	2221	124	48	110.72	94.10	1.25	0.0125	0.053	3.523	0.927	3.275	1485245.9	1150.53	4372.00	339.7
6	184	2236	125	48	110.72	95.30	1.20	0.0120	0.051	3.382	0.890	3.144	1425836.1	1150.53	4372.00	326.1
6	184	2251	127	48	110.72	96.60	1.30	0.0130	0.055	3.664	0.964	3.406	1544655.8	1150.53	4372.00	353.3
6	184	2306	129	48	110.72	97.80	1.20	0.0120	0.051	3.382	0.890	3.144	1425836.1	1150.53	4372.00	326.1
6	184	2321	130	48	110.72	99.10	1.30	0.0130	0.055	3.664	0.964	3.406	1544655.8	1150.53	4372.00	353.3
6	184	2336	131	48	110.72	100.40	1.30	0.0130	0.055	3.664	0.964	3.406	1544655.8	1150.53	4372.00	353.3
6	184	2351	134	48	110.72	101.70	1.30	0.0130	0.055	3.664	0.964	3.406	1544655.8	1150.53	4372.00	353.3
6	185	6	135	48	110.72	103.05	1.35	0.0135	0.057	3.805	1.001	3.537	1604065.6	1150.53	4372.00	366.9
6	185	21	137	48	110.72	104.30	1.25	0.0125	0.053	3.523	0.927	3.275	1485245.9	1150.53	4372.00	339.7
6	185	36	138	48	110.72	105.60	1.30	0.0130	0.055	3.664	0.964	3.406	1544655.8	1150.53	4372.00	353.3
6	185	51	140	48	110.72	106.75	1.15	0.0115	0.049	3.241	0.853	3.013	1366426.2	1150.53	4372.00	312.5
6	185	106	142	48	110.72	108.00	1.25	0.0125	0.053	3.523	0.927	3.275	1485245.9	1150.53	4372.00	339.7
6	185	121	143	48	110.72	109.35	1.35	0.0135	0.057	3.805	1.001	3.537	1604065.6	1150.53	4372.00	366.9

Appendix 3

3.1. Polar and Coarse Grid base



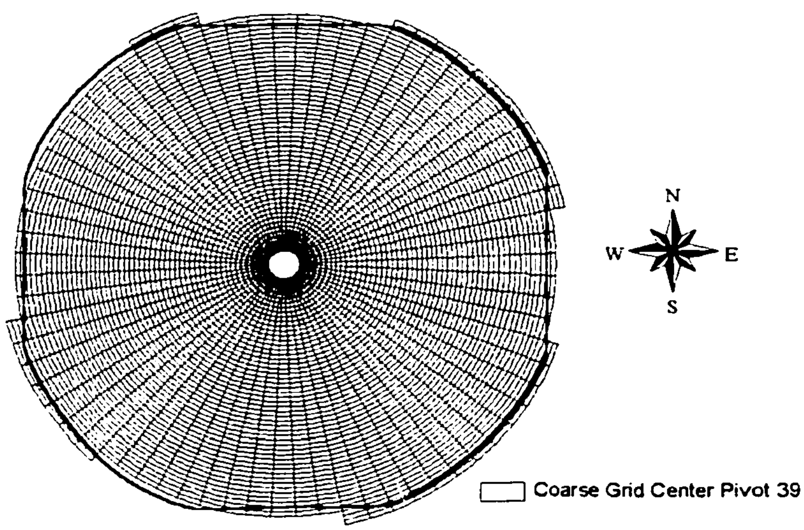


Figure 61. Polargrid base area for center pivot 39.

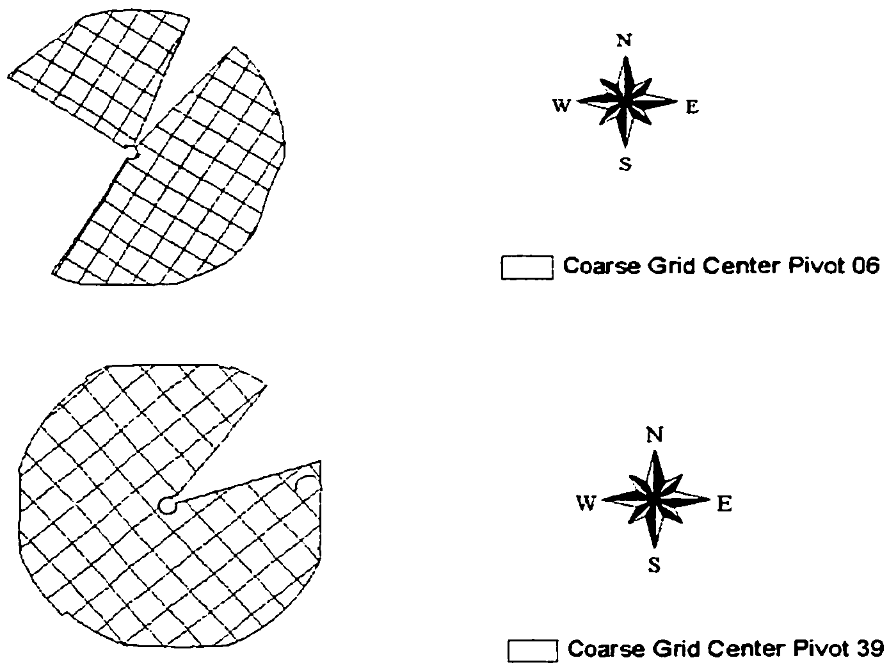


Figure 62. Coarse grid base area for each center pivot.

3.2. Weather data

The OPUS model uses the Ritchie (1972) equation (adjusted Penman equation) to calculate the potential evapotranspiration. This equation is a modification of the Penman equation (Smith, 1992).

In order to calculate the potential evapotranspiration, the Ritchie (1972) equation needs only the minimum, maximum, and solar radiation data. I obtained those data for each center pivot from the weather station located in each area (figure 3). As an example, in the next pages, I going to present the center pivot 6 season 1998 data under required OPUS format.

Wiggins Actual Weather Data: Field 6, Jan-Dec 1998

1	0	0	0	0	1	1	1
98001					13.4	-5.3	238
98002					12.9	-5.3	165
98003					1.2	-5.9	60
98004					7.3	-6.9	173
98005					8.6	-9.6	203
98006					3.8	-12.8	221
98007					5.3	-16.3	238
98008					8.4	-13.4	250
...							
...							
...							
98356					-15.7	-35.1	249
98357					-8.1	-30.6	242
98358					-10.9	-30.2	169
98359					3.6	-21.9	198
98360					7.2	-13.2	179
98361					5.8	-11.3	194
98362					9.3	-8.7	165
98363					5.7	-4.6	185
98364					14.1	-5.1	194
98365					6.4	-5.4	136

Appendix 4

4.0. OPUS input files

OPUS has an exhaustive requirement of input data. The majority of the input data used in the simulation of my thesis were found from Morton (1998) thesis. However, many of the required data for the simulation were beyond the scope of this study and the default values were used as outlined in the OPUS user manual, volume II (Ferreira and Smith, 1992).

I present, in the following appendix, an example of one grid (C9) from the coarse grid (figure 63 from appendix 3) for center pivot 6 on season 99, of the PPT (precipitation and rain input file) and PAR (parameter input file) files. I created both files (PAR and PPT) for each grid in the coarse grid in order to run the OPUS simulation in each one.

Most of the data used to created each file for each center pivot are the same only the part highlighted in bold in each file was changed in each different coarse grid and center pivot.

4.1. *.PPT input files

```
***************************************************
***************************************************
**                                               **
**   M E T E O R O L O G I C A L    D A T A     **
**PCAPS#1: sum of daily irrigation and Rain      **
***************************************************
***************************************************
TITLE : Enter one line of identifying information
Rainfall data, Wiggings, CO
H01
TXMD   ATX  CVTX ACVTX  TXMW
19.4  14.4  0.31 -.211  17.2
H02
TN  AMTN  CVTN ACVTN
6.1  12.8  0.50 -.479
H03
RMD    AR    RMW  SEED
470.0 230.0 335.0   0.0
H04
PRW2  PRW2  PRW2  PRW2  PRW2  PRW2  PRW2  PRW2  PRW2  PRW2  PRW2  PRW2
0.423 0.384 0.503 0.483 0.540 0.443 0.435 0.373 0.419 0.408 0.427 0.394
H05
PRW1  PRW1  PRW1  PRW1  PRW1  PRW1  PRW1  PRW1  PRW1  PRW1  PRW1  PRW1
0.130 0.177 0.201 0.202 0.208 0.246 0.237 0.228 0.149 0.113 0.122 0.126
H06
--------------------------------------------
The monthly ALFG and BETG values may be
blank if daily rainfall is not being
generated (IFRBY on record A03 is not 2)
--------------------------------------------
ALFG  ALFG  ALFG  ALFG  ALFG  ALFG  ALFG  ALFG  ALFG  ALFG  ALFG  ALFG
H07
BETG  BETG  BETG  BETG  BETG  BETG  BETG  BETG  BETG  BETG  BETG  BETG
H08
RI    RI    RI    RI    RI    RI    RI    RI    RI    RI    RI    RI
1.80  3.60  3.30  4.80  8.40 10.40 17.50 31.50 11.70  4.10  3.60  3.00
H09
--------------------------------
The monthly temp values may be
blank if IFT on record A04 is 0
--------------------------------
TAMX  TAMX  TAMX  TAMX  TAMX  TAMX  TAMX  TAMX  TAMX  TAMX  TAMX  TAMX
5.6   7.0   9.9  15.8  21.4  27.8  31.3  30.4  26.1  19.2  10.9   7.3
H10
TAMN  TAMN  TAMN  TAMN  TAMN  TAMN  TAMN  TAMN  TAMN  TAMN  TAMN  TAMN
-9.6  -7.6  -5.1   0.2   5.4  10.6  14.1  13.4   8.3   2.3  -4.7  -7.8
H11
-------------------------------------
The monthly radiation  values may be
blank if IFT on record A04 is <2
-------------------------------------
RA    RA    RA    RA    RA    RA    RA    RA    RA    RA    RA    RA
203.0 270.0 403.0 462.0 462.0 527.0 522.0 441.0 414.0 312.0 224.0 184.0
H12
```

```
-------------------------------------------------------
Pan coefficient can be blank unless radiation values
contain evap pan data (IPAN on record A03 is 1)
-------------------------------------------------------
TP05   TP6 COEFF
2.38  4.88   0.8
H13
*******************************************************
*******************************************************
**                                                   **
**              R A I N F A L L   D A T A            **
**                                                   **
*******************************************************
*******************************************************
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00          1
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00          2
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00          3
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00          4
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00          5
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00          6
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00          7
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00          8
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00          9
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00         10
99      0.00 7.50 9.00 0.00 0.00 1.00 26.005.50 6.00 22.00        11
99      8.00 4.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00         12
99      0.00 2.34 0.00 2.50 13.0014.000.00 0.50 0.00 1.00         13
99      0.00 0.00 0.00 0.00 1.50 0.00 1.50 0.50 0.00 0.00         14
99      0.50 4.00 0.50 0.00 2.34 0.00 0.00 0.00 0.00 11.38        15
99      3.50 0.00 1.00 0.00 0.50 0.00 1.00 0.00 0.00 0.00         16
99      2.00 2.70 0.00 0.00 0.00 4.75 0.00 0.00 3.55 0.00         17
99      2.00 4.03 0.00 0.00 4.03 0.00 0.00 3.94 4.50 0.00         18
99      3.94 3.00 0.00 0.00 3.94 0.00 0.00 4.23 0.00 27.28        19
99      0.50 5.53 1.00 0.00 6.50 0.00 2.70 0.00 4.70 0.00         20
99      2.65 15.000.50 0.00 0.00 7.33 11.502.50 0.00 0.00         21
99      1.30 14.501.00 0.00 3.93 0.00 0.00 3.84 0.00 0.00         22
99      3.84 0.00 2.50 0.50 3.42 0.00 4.92 0.00 2.00 11.50        23
99      0.00 0.00 3.84 2.34 14.509.00 0.00 0.00 0.00 0.00         24
99      4.23 0.00 0.00 0.00 0.00 0.00 3.24 0.00 0.00 0.00         25
99      0.00 3.00 2.50 0.00 0.00 0.00 0.00 0.00 6.60 7.87         26
99      24.640.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00         27
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00         28
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00         29
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00         30
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00         31
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00         32
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00         33
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00         34
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00         35
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00         36
99      0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00         37
```

4.2. *.PAR input files

```
*                     O P U S  Parameter  File  Template                     *
*                    ====================================                    *
*    Enter data on lines ending with record ID in col. 78-80 (e.g. A01)      *
*                                                                            *
*    See Opus User Manual for detailed description of input data.            *
*                                                                            *
*    Variable name is printed above its location: enter data right-justified to*
*    the variable name.                                                      *
*                                                                            *
*    The record ID must be in columns 78-80 of all data input records;  be sure*
*    this is accomplished when entering data on template.                    *
*                                                                            *
*    Data type (A-I) in column 78 corresponds to User Manual data type and   *
*    chapter; e.g. guidance for the management record set will be found in the *
*    User Manual on pages noted 'Management' above the page number.          *
*                                                                            *
******************************************************************************
******************************************************************************
**                                                                          **
**             R U N   I D  and  C O N T R O L   F L A G S                  **
**                                                                          **
******************************************************************************
******************************************************************************
*                                                                            *
*  TITLE : Enter 3 lines of descriptive info to identify this simulation     *
Wiggins 99 - simulating nitrate leaching C09                              A01
Field 6:  simulating the sites for in-situ                                A01
This is the data set for the in-situ for coarse grid sample               A01
*    ---------------------------------------------------
*       Enter run begin and end dates and run option flags
*    ---------------------------------------------------
*  IBDATE      IEDATE
*MO DA  IBYR   MO DA  IEYR  IFWRDA INTSP  ICON   THRESH IRYR
 01 01 1999    12 31 1999  1      1      1      10.    1                  A02
*INUN  IOU    IHOP   IPAN   IFOUT  IFRAN  IFRNCN IFREAL NROUT
1      1      1      0      2      0      0      1      1                 A03
*IFSED IFNUT  IFPEST IFIRR  IFPOND IFDRAN IVARK  IFT    IFGEN  IFHYS
1      1      0      0      0      0      0      0      0      0          A04

******************************************************************************
******************************************************************************
**                                                                          **
**   G E N E R A L   W A T E R S H E D  &  I N I T I A L   S T A T E      **
**                                                                          **
******************************************************************************
******************************************************************************

*DA    DWTB   GLAT   CN2    PHRN   CONRN  DASL   ALBS   FWIND
0.0014 28     40.334 80.    5.6    4.48   10     0.35   0.009             B01
*SRESD STDRY  THST   ROWSP  DPFR   RGSURF ZSF    DTILL
100.0  100.0  0.123  0      0      10.0   0      20.                       B02
*  -------------------------------------
*   There must be NC values of ICR on B03
*  -------------------------------------
*NC    ICR    ICR    ICR    ICR
0                                                                         B03
```

```
*****************************************************************************
*****************************************************************************
**                                                                         **
**                    S O I L   H O R I Z O N   D A T A                    **
**                                                                         **
*****************************************************************************
*****************************************************************************

*NSL   ILAY
3      20                                                               C01
*  ------------------------------------------
*   There must be NSL sets of C02-C03 prompts
*   and records, one for each horizon
*  ------------------------------------------

*GZH    POR    PSAND  PARA   PCLAY  RC     B15    PBUB   ALAM   THS
203.2   0.416  0.856  1      0.124  144.2730.07   25.0   0.44   0.40       C02
*ORGC   SRSDU  WNO3   WPLAB  SPH    PKD    FEROD  OMN    CURV   TOTP
0.5981 1.0    25.30  22.0    5.9    -1     1      -1     5      -1         C03
*GZH    POR    PSAND  PARA   PCLAY  RC     B15    PBUB   ALAM   THS
914.4   0.436  0.8171 1      0.148  75.262 0.081  35.0   0.33   0.42       C02
*ORGC   SRSDU  WNO3   WPLAB  SPH    PKD    FEROD  OMN    CURV   TOTP
0.01    0.5    3.25   15.0    6.0   -1     1      -1     5      -1         C03
*GZH    POR    PSAND  PARA   PCLAY  RC     B15    PBUB   ALAM   THS
1219.2 0.364  0.6594 1      0.1940 12.08  0.132  60.0   0.21   0.35       C02
*ORGC   SRSDU  WNO3   WPLAB  SPH    PKD    FEROD  OMN    CURV   TOTP
0.01    0.4    3.97   10.0   6.0    -1     1      -1     5      -1         C03

*****************************************************************************
*****************************************************************************
**                                                                         **
**                          C R O P   D A T A                              **
**                                                                         **
*****************************************************************************
*****************************************************************************

*NCROP
1                                                                       D01
*  -------------------------------------
*   There must be NCROP sets of D02-C04
*   prompts and data records
*  -------------------------------------

*IDCR   IPER   PLAI   DDEM   DDMX   PDRYM  POTY   RDP    PLIG   RLIG
Corn    0      4.5    60     1300   28021  11926  850.0  0.15   0.10       D02
*POTHT  PPCV   TGBM   TGOP   CONVF  DEACT  COVI   DMINIT PST    HPC
2.5     0.95   8.3    30.0   73.0   0.03   0.0    0.0    0.5    2000       D03
*CONY   CFXN   PNO    PNF    DKC    PNRAT
0.019   0      0.04   0.012  3.0    0.28                                   D04

*****************************************************************************
*****************************************************************************
**                                                                         **
**                       M A N A G E M E N T                               **
**                                                                         **
*****************************************************************************
*****************************************************************************

*THEMTH
1.0                                                                     E01
*NTL
7                                                                       E02
*  ------------------------------------------
*   There must be NTL E03 prompts and records
*   (one blank set if NTL=0)
*  ------------------------------------------
```

```
*IDTIL IDPL   NTYTL  RFT    PLOWD  EFTL   DFRW   WFRW
Disk   1      4      20.    20.    0.6    0.0    0.33                        E03
*IDTIL IDPL   NTYTL  RFT    PLOWD  EFTL   DFRW   WFRW
Ripped 1      4      20.    20.    0.5    0.0    0.33                        E03
*IDTIL IDPL   NTYTL  RFT    PLOWD  EFTL   DFRW   WFRW
MulTred1      4      10.    20.    0.3    0.0    0.33                        E03
*IDTIL IDPL   NTYTL  RFT    PLOWD  EFTL   DFRW   WFRW
Plant  1      1      10.    10.    0.15   0.0    0.0                         E03
*IDTIL IDPL   NTYTL  RFT    PLOWD  EFTL   DFRW   WFRW
Cultival      2      10.0   20.0   0.3    0.0    0.33                        E03
*IDTIL IDPL   NTYTL  RFT    PLOWD  EFTL   DFRW   WFRW
Cultival      2      10.0   20.0   0.3    0.0    0.33                        E03
*IDTIL IDPL   NTYTL  RFT    PLOWD  EFTL   DFRW   WFRW
Harvest1      3      10.0   1.0    0.15   0.0    0.0                         E03
*NPST
0                                                                          E04
*  -----------------------------------------------------
*   There must be NPST sets of E05-E07 prompts and records
*   (one blank set if NPST=0)
*  -----------------------------------------------------
*IDPST DKFL   DKSOIL DKOC   PPWLF  PINSLT PSOLUB FWASH  BEXTR  RELP
                                                                           E05
*DKTHE DKTEMP ARRHC  ZDGR   PUPTK
                                                                           E06
*PLCON PLDEP  PLCON  PLDEP  PLCON  PLDEP  PLCON  PLDEP  PLCON  PLDEP
                                                                           E07
*NMAN
0                                                                          E08
* -----------------------------------------------------------------------
*  There must be NMAN sets of E09 prompts and records (one blank set if NMAN=0)
* -----------------------------------------------------------------------
*N     ATN    ANH    APHOS  AOM
                                                                           E09
*NYROT
1                                                                          E10
*   ++++++++++++++++++++++++++++++++++++++++++++++++
*          R O T A T I O N   S C H E D U L E
*           There must be NYROT sets of
*           E11-E17 prompts and records
*   ++++++++++++++++++++++++++++++++++++++++++++++++
*NTY           YEAR
7              1999                                                        E11
* -----------------------------------------------------------------------
*  There must be NTY sets of E12 prompts and records (one blank set if NTY=0)
* -----------------------------------------------------------------------
*MO DA KTILL
04 05  1                                                                   E12
*MO DA KTILL
04 15  2                                                                   E12
*MO DA KTILL
04 20  3                                                                   E12
*MO DA KTILL
05 09  4                                                                   E12
*MO DA KTILL
06 23  5                                                                   E12
*MO DA KTILL
06 29  5                                                                   E12
*MO DA KTILL
10 29  7                                                                   E12
*NFR
8                                                                          E13
* -----------------------------------------------------------------------
*  There must be NFR sets of E14 prompts and records (one blank set if NFR=0)
* -----------------------------------------------------------------------
*MO DA KAPPL  FERN   FERP   FERA   MATYP  RATE   DEPIN
03 18  0      33.6   22.4   0      0                                           E14
*MO DA KAPPL  FERN   FERP   FERA   MATYP  RATE   DEPIN
```

```
05 09  0       28.0    33.6    0       0                                             E14
*MO DA KAPPL   FERN    FERP    FERA    MATYP   RATE    DEPIN
06 21  0       4.43    0       4.43    0                                             E14
*MO DA KAPPL   FERN    FERP    FERA    MATYP   RATE    DEPIN
07 04  0       21.85   0       12.81   0                                             E14
*MO DA KAPPL   FERN    FERP    FERA    MATYP   RATE    DEPIN
07 14  0       26.92   0       0.0     0                                             E14
*MO DA KAPPL   FERN    FERP    FERA    MATYP   RATE    DEPIN
07 19  0       4.03    0       4.03    0                                             E14
*MO DA KAPPL   FERN    FERP    FERA    MATYP   RATE    DEPIN
07 28  0       12.58   0       4.1     0                                             E14
*MO DA KAPPL   FERN    FERP    FERA    MATYP   RATE    DEPIN
08 05  0       8.62    0       0       0                                             E14
*NPS
0                                                                                    E15
* ----------------------------------------------------------------------------
* There must be NPS sets of E16 prompts and records (one blank set if NPST=0)
* ----------------------------------------------------------------------------
*MO DA KPEST   IAPLIC QPEST   FRACA   FRACP   DEPST
                                                                                     E16
*  ------------------------------------------------------
*   E17 can be blank if no irrigation (IFIRR on A04 is 0)
*  ------------------------------------------------------
*IRRDY MO DA   NIRD    AMIRR   TIRR    THIRR   QIRR
                                                                                     E17
*  -------------------------------------------------------------------------
*   If IFDRAN on C04 is 1, enter draintile data; otherwise zeros or blank:
*  -------------------------------------------------------------------------
*DRSP  DDIMP   RCLM
                                                                                     E18
****************************************************************************
****************************************************************************
**                                                                        **
**                      F I E L D     T O P O L O G Y                     **
**                                                                        **
****************************************************************************
****************************************************************************

*  ----------------------------------------
*   The following F01-F10 set describes the
*   natural, unfurrowed topology (case KL1)
*  ----------------------------------------
*IFFIX ITOCH  MULP    XLP     SLA     PAR     PMN
0      0      0       86.0    0.03    0.0014  0.005                                  F01
*NPT
                                                                                     F02
*  -------------------------------------------------
*   There must be NPT pairs of XSP Sp values
*   If NPT > 5, add a duplicate F03 prompt and record
*  -------------------------------------------------
*XSP   SP     XSP     SP      XSP     SP      XSP     SP      XSP     SP
                                                                                     F03
*XLFS  XLFE   RMNF    SLRF    PRFF
                                                                                     F04
*NPK
                                                                                     F05
*  -------------------------------------------------
*   There must be NPK pairs of XKS USK values
*   If NPK > 5, add a duplicate F06 prompt and record
*  -------------------------------------------------
*XKS   USK    XKS     USK     XKS     USK     XKS     USK     XKS     USK
                                                                                     F06
*IFFIX NUN    NEPH    XLC     SLA     ZCA     ARUP    WINIT   DINIT   PMN
0      1      0       262.0   0.005   20.0            1       1       1              F07
*NPT
1                                                                                    F08
*  ----------------------------------------
```

```
*   There must be NPT pairs of XSP SP values
*   If NPT > 5, add a duplicate F09 prompt and record
*  -------------------------------------------------
*XSP   SP     XSP    SP     XSP    SP     XSP    SP     XSP    SP
1.0    0.03                                                          F09
*XLFS  XLFE   RMNF   TAUCF  WIDFX
                                                                     F10
*---------------------------------------------------------------------------
* The following F01-F10 set describes the furrowed case; blanks or dummy values
*  are sufficient if there is no furrowed case (case KL2)
*---------------------------------------------------------------------------
*IFFIX ITOCH  MULP   XLP    SLA    PAR    PMN
0      0      2      262.0  0.005  3.11   0.03                           F01
*NPT
1                                                                    F02
*  ----------------------------------------
*   There must be NPT pairs of XSP Sp values
*   If NPT > 5, add a duplicate F03 prompt and record
*  ------------------------------------------------
*XSP   SP     XSP    SP     XSP    SP     XSP    SP     XSP    SP
1.0    0.005                                                         F03
*XLFS  XLFE   RMNF   SLRF   PRFF
                                                                     F04
*NPK
                                                                     F05
*  ----------------------------------------
*   There must be NPK pairs of XKS USK values
*   If NPK > 5, add a duplicate F06 prompt and record
*  ------------------------------------------------
*XKS   USK    XKS    USK    XKS    USK    XKS    USK    XKS    USK
                                                                     F06
*IFFIX NUN    NEPH   XLC    SLA    ZCA    ARUP   WINIT  DINIT  PMN
1      1      1      258.0  0.030  15.0          1      1      1     F07
*NPT
1                                                                    F08
*  ----------------------------------------
*   There must be NPT pairs of XSP SP values
*   If NPT > 5, add a duplicate F09 prompt and record
*  ------------------------------------------------
*XSP   SP     XSP    SP     XSP    SP     XSP    SP     XSP    SP
1.0    0.03                                                          F09
*XLFS  XLFE   RMNF   TAUCF  WIDFX
86.0   258.0  0.24   9.5    0.1                                      F10
*  ---------------------------------------------------------------
*   If IFPOND on A04 is 1, enter pond data; otherwise zeros or blank:
*  ---------------------------------------------------------------
*IFOUTLAV     BV     CV     CQ     EQ     ZQ     RLOSS
1      15.0   2000.0 2.0    2.41   2.05   0.0    0.1                    F11
****************************************************************************
****************************************************************************
**                                                                        **
**                  E R O S I O N/ S E D I M E N T                        **
**                                                                        **
****************************************************************************
****************************************************************************
*NPSE
0                                                                    G01
*  ------------------------------------------
*   There must be NPSE G02 prompts and records
*  ------------------------------------------
*DPS   RHOP   PROSL  FRASN  FRASL  FRACL  FRORG
                                                                     G02
*SSCLY SSSLT  SSSND  SSORG
20     4      0.05   500                                             G03
*ASLK  PRF    EKT1   EKT2   EKT3
0.32   0.9    0.75   0.135  -1                                       G04
```

4.3. Rain data

Data with the average rain by area on center pivot 6 for season 1998-99 and center pivot 39 for season 1999, can be see on tables 21 through 23.

Table 21. Rain (by Julian day) for center pivot 6 for 1998.

R1-RC Day	Rain mm	R2-RC Day	Rain mm	R3-RC Day	Rain mm	R4-RC Day	Rain mm	R5-RC Day	Rain mm	R6-RC Day	Rain mm
92	4.83	92	4.83	92	4.83	92	4.83	92	4.83	92	4.83
93	0.51	93	0.51	93	0.51	93	0.51	93	0.51	93	0.51
96	3.81	96	3.81	96	3.81	96	3.81	96	3.81	96	3.81
97	0.76	97	0.76	97	0.76	97	0.76	97	0.76	97	0.76
102	0.25	102	0.25	102	0.25	102	0.25	102	0.25	102	0.25
103	5.33	103	5.33	103	5.33	103	5.33	103	5.33	103	5.33
104	2.03	104	2.03	104	2.03	104	2.03	104	2.03	104	2.03
105	1.78	105	1.78	105	1.78	105	1.78	105	1.78	105	1.78
108	0.25	108	0.25	108	0.25	108	0.25	108	0.25	108	0.25
115	0.51	115	0.51	115	0.51	115	0.51	115	0.51	115	0.51
124	3.30	124	3.30	124	3.30	124	3.30	124	3.30	124	3.30
125	0.76	125	0.76	125	0.76	125	0.76	125	0.76	125	0.76
126	1.02	126	1.02	126	1.02	126	1.02	126	1.02	126	1.02
127	1.52	127	1.52	127	1.52	127	1.52	127	1.52	127	1.52
128	1.02	128	1.02	128	1.02	128	1.02	128	1.02	128	1.02
131	0.25	131	0.25	131	0.25	131	0.25	131	0.25	131	0.25
142	18.03	142	18.03	142	18.03	142	18.03	142	18.03	142	18.03
144	4.32	144	4.32	144	4.32	144	4.32	144	4.32	144	4.32
146	0.51	146	0.51	146	0.51	146	0.51	146	0.51	146	0.51
155	0.51	155	0.51	155	0.51	155	0.51	155	0.51	155	0.51
156	1.52	156	1.52	156	1.52	156	1.52	156	1.52	156	1.52
159	1.02	159	1.02	159	1.02	159	1.02	159	1.02	159	1.02
160	0.25	160	0.25	160	0.25	160	0.25	160	0.25	160	0.25
168	0.76	168	0.76	168	0.76	168	0.76	168	0.76	168	0.76
171	0.76	171	0.76	171	0.76	171	0.76	171	0.76	171	0.76
173	4.57	173	4.57	173	4.57	173	4.57	173	4.57	173	4.57
174	14.22	174	14.22	174	14.22	174	14.22	174	14.22	174	14.22
175	5.84	175	5.84	175	5.84	175	5.84	175	5.84	175	5.84
182	1.50	182	1.39	182	2.00	182	2.00	182	1.50	182	1.50
189	0.50	185	0.13	189	0.50	189	0.50	189	0.50	189	0.50
191	1.00	191	1.39	191	1.50	191	1.00	191	1.00	191	1.00
196	34.50	192	0.13	196	37.00	192	0.50	195	0.50	196	36.00
198	0.50	196	35.77	198	1.50	196	40.00	196	34.50	198	0.50
203	1.50	197	0.13	203	1.50	203	3.00	198	0.50	203	2.50
205	33.50	203	4.29	205	36.00	204	0.50	203	3.30	204	0.50
206	9.50	204	0.13	206	9.50	205	35.00	205	18.00	205	18.50
210	9.50	205	35.79	210	11.50	206	6.00	206	5.00	206	5.50

R1-RC Day	Rain mm	R2-RC Day	Rain mm	R3-RC Day	Rain mm	R4-RC Day	Rain mm	R5-RC Day	Rain mm	R6-RC Day	Rain mm
211	1.00	206	9.32	211	0.50	207	0.50	210	10.50	210	14.50
213	23.00	210	11.97	213	22.50	210	8.50	211	1.00	211	0.50
214	2.00	211	0.88	214	2.00	211	0.50	213	24.00	212	0.50
215	0.50	213	21.91	215	1.00	212	0.50	214	2.00	213	24.00
219	1.00	214	2.14	219	1.00	213	14.00	215	1.00	214	2.00
221	4.00	215	0.50	221	4.00	214	2.50	219	1.00	215	1.00
223	3.00	219	0.50	223	2.50	215	0.50	221	3.50	219	1.00
226	1.00	220	0.13	226	0.50	219	1.50	223	2.50	221	3.50
228	1.00	221	4.03	228	0.50	221	3.50	226	0.50	223	3.00
230	8.50	223	3.02	230	1.00	223	2.50	228	0.50	226	0.50
231	1.00	226	0.25	231	0.50	226	0.50	230	4.00	228	1.00
239	0.50	228	0.75	255	0.13	230	7.00	231	2.50	230	8.00
263	4.00	230	7.94	256	0.13	231	1.00	239	0.50	231	1.00
264	4.00	231	0.63	263	4.41	239	0.50	255	0.13	239	0.50
266	0.64	255	0.13	264	3.65	260	0.50	256	0.13	260	0.50
267	0.13	256	0.13	266	0.64	263	2.50	263	4.41	263	2.50
272	0.50	263	4.41	267	0.13	264	3.65	264	3.65	264	3.65
274	1.78	264	3.65	272	0.50	266	0.64	266	0.64	266	0.64
275	30.99	266	0.64	274	1.78	267	0.13	267	0.13	267	0.13
276	6.10	267	0.13	275	30.99	272	0.50	272	0.50	274	1.78
289	5.84	272	0.50	276	6.10	274	1.78	274	1.78	275	30.99
	272.9	274	1.78	289	5.84	275	30.99	275	30.99	276	6.10
		275	30.99		**271.80**	276	6.10	276	6.10	289	5.84
		276	6.10			289	5.84	289	5.84		**260.14**
		289	5.84				**265.14**		**253.10**		
			277.91								

Table 22. Rain (by Julian day) for center pivot 6 for 1999.

P-1 DATE	MM	P-2 DATE	MM	P-3 DATE	MM	P-4 DATE	MM	P-5 DATE	MM	P-6 DATE	MM
112	10.50	112	11.25	112	8.00	112	13.50	112	7.50	112	16.00
113	17.00	113	12.75	113	11.50	113	15.00	113	9.00	113	13.00
117	14.89	117	12.39	117	23.00	117	22.50	116	1.00	117	19.00
118	5.42	118	5.42	118	5.00	118	5.50	117	26.00	118	3.00
119	5.79	119	5.79	119	6.50	119	6.50	118	5.50	119	6.00
120	21.04	120	21.04	120	22.00	120	22.00	119	6.00	120	21.00
121	9.20	121	9.20	121	10.00	121	8.50	120	22.00	121	8.00
122	6.17	122	6.17	122	7.00	122	4.00	121	8.00	122	4.00
134	1.89	123	1.89	134	2.00	134	1.50	122	4.00	134	2.50
135	11.00	135	10.43	135	12.50	135	17.00	134	2.50	135	14.00
136	14.37	136	14.37	136	14.00	136	14.00	135	13.00	136	13.00
140	1.01	140	1.01	140	1.00	140	1.00	136	14.00	140	1.00
146	1.25	145	1.25	146	1.50	146	1.00	138	0.50	141	0.50
147	1.64	147	1.64	147	1.00	148	1.00	140	1.00	145	0.50
152	3.65	151	0.51	152	3.50	152	4.00	145	1.50	146	1.00
153	1.90	152	3.40	153	1.00	153	1.50	147	1.50	147	1.00
160	12.98	153	0.75	160	12.00	160	12.00	148	0.50	148	0.50
161	3.15	160	12.98	161	3.50	161	3.00	151	0.50	151	0.50
163	1.39	161	3.15	163	1.00	163	1.00	152	4.00	152	4.00
165	0.75	163	1.39	165	1.00	165	1.00	153	0.50	153	1.00
167	0.63	165	0.75	167	1.00	167	1.00	160	8.00	160	12.00
171	1.51	167	0.63	171	1.50	171	2.00	161	3.50	161	3.50
181	2.14	171	1.51	181	2.00	181	2.00	163	1.00	163	1.00
189	5.93	181	2.14	189	5.50	189	5.00	165	0.50	165	0.50
192	4.04	189	5.93	192	3.00	192	3.00	167	1.00	167	1.00
200	22.16	192	4.04	200	23.50	200	23.00	171	2.00	171	1.50
203	1.51	200	22.16	203	1.00	201	1.00	181	2.00	181	2.00
205	6.55	201	1.00	205	8.00	203	1.00	189	4.50	183	0.50
209	1.76	205	6.55	209	2.50	205	7.00	192	3.00	189	4.50
212	13.48	209	1.76	212	15.50	209	2.50	200	25.00	192	3.00
213	0.63	212	13.48	216	5.50	212	14.50	201	0.50	200	22.00
216	3.90	213	0.63	217	12.00	213	1.00	203	1.00	201	0.50
217	11.21	216	3.90	218	3.50	216	5.50	205	6.50	203	1.00
218	2.27	217	11.21	222	13.50	217	11.50	209	2.00	205	6.50
222	12.97	218	2.27	233	2.50	218	3.00	211	0.50	209	2.00
223	0.63	222	12.97	239	3.50	222	14.00	212	15.00	211	0.50
233	2.64	223	0.63	240	11.50	224	0.50	213	0.50	212	15.00
237	0.25	237	0.25	243	1.00	233	2.50	216	4.50	213	0.50
239	4.29	239	4.29	245	16.00	237	1.00	217	11.50	216	4.50
240	10.71	240	10.71	246	9.50	239	2.50	218	2.50	217	11.50
241	0.25	241	0.25	262	3.00	240	11.00	222	14.50	218	2.50
243	1.13	243	1.13	263	2.50	243	0.50	223	1.00	222	14.50
245	15.87	245	15.87	269	6.60	245	8.00	233	2.50	223	1.00
246	8.94	246	8.94	270	7.87	246	5.00	234	0.50	233	2.50

P-1		P-2		P-3		P-4		P-5		P-6	
DATE	MM	DATE	MM	DATE	MM	DATE	MM	DATE	MM	DATE	MM
252	0.25	252	0.25	271	24.64	262	3.00	237	1.50	234	0.50
262	3.02	262	3.02		**333.62**	263	2.50	239	2.00	237	1.50
263	2.40	263	2.40			269	6.60	240	11.50	239	2.00
269	6.60	269	6.60			270	7.87	243	1.50	240	11.50
270	7.87	270	7.87			271	24.64	245	14.50	243	1.50
271	24.64	271	24.64				**328.12**	246	9.00	245	14.50
	325.20		**314.59**					262	3.00	246	9.00
								263	2.50	262	3.00
								269	6.60	263	2.50
								270	7.87	264	0.50
								271	24.64	269	6.60
									326.62	270	7.87
										271	24.64
											329.12

Table 23. Rain (by Julian day) for center pivot 39 for 1999.

P-1		P-2		P-3		P-4		P-5		P-6	
DATE	MM	DATE	MM	DATE	MM	DATE	MM	DATE	MM	DATE	MM
112	9.9	112	12.5	112	12.0	112	9.0	112	10.5	112	10.5
113	3.0	113	2.7	113	6.7	113	3.7	113	5.7	113	5.7
114	0.1	117	12.7	117	12.7	117	11.2	116	1.0	117	8.7
115	7.0	118	7.2	118	8.2	118	8.2	117	12.7	118	8.2
117	6.9	119	7.5	119	10.5	119	10.5	118	7.7	119	11.0
118	7.7	120	16.5	120	22.0	120	20.5	119	10.5	120	21.0
119	10.3	121	9.5	121	10.5	121	6.0	120	10.0	121	11.0
120	19.7	122	5.0	122	5.5	122	3.0	121	5.0	122	5.5
121	9.7	126	4.5	134	5.0	126	4.5	122	4.5	126	4.5
122	5.2	134	1.0	135	3.0	134	1.0	126	4.5	134	1.0
126	4.5	135	3.5	136	11.0	135	4.5	134	1.5	135	6.0
134	1.3	136	10.0	137	3.0	136	10.0	135	3.5	136	10.5
135	5.1	137	1.0	138	1.0	137	1.0	136	9.0	137	1.0
136	10.5	138	0.5	147	2.0	140	2.0	137	0.5	140	2.5
137	0.6	140	2.0	148	0.5	141	0.5	140	2.5	142	0.5
140	2.1	142	0.5	149	1.0	142	0.5	141	1.5	144	1.0
142	0.9	144	0.5	150	1.0	144	0.5	144	1.0	147	2.5
144	0.6	147	2.0	151	1.0	147	2.5	147	2.0	149	2.0
147	2.3	148	0.5	152	0.5	148	0.5	148	0.5	150	0.5
148	0.1	149	1.5	156	0.5	149	1.5	149	1.5	151	2.0
149	1.8	151	2.0	160	5.5	150	0.5	150	1.0	153	1.5
150	1.0	152	0.5	161	6.0	151	1.5	151	1.5	155	0.5
151	1.3	153	0.5	163	1.0	152	0.5	152	0.5	156	0.5
152	0.3	156	0.5	165	10.0	153	1.5	153	1.5	161	6.0
153	0.9	160	5.5	166	0.5	156	0.5	156	0.5	163	1.0
156	0.5	161	6.0	167	1.0	160	5.5	160	5.5	165	9.0
160	3.0	164	1.0	168	3.5	161	6.5	161	6.0	166	0.5
161	5.8	165	8.5	173	0.5	163	1.0	163	0.5	167	0.5
163	0.9	166	0.5	181	2.0	164	10.0	164	0.5	168	3.0

P-1 DATE	MM
165	8.4
166	0.5
167	0.6
168	2.6
171	0.3
173	0.5
181	2.0
182	0.1
189	0.3
192	1.4
200	11.9
201	0.8
203	2.3
204	0.5
205	21.4
209	2.3
212	21.2
213	2.0
214	0.5
215	0.8
216	1.4
217	7.0
218	0.9
222	19.6
223	0.6
233	0.6
237	7.6
239	10.7
240	2.7
243	0.5
245	1.8
246	7.2
262	2.1
263	3.1
264	0.6
269	5.1
270	5.3
271	22.4
	302.3

P-2 DATE	MM
167	1.0
168	2.0
173	0.5
181	2.0
192	1.5
200	12.0
201	0.5
203	2.5
204	0.5
205	21.0
209	2.5
211	1.0
212	17.0
213	2.0
214	1.5
215	0.5
216	1.5
217	2.5
218	1.0
222	19.5
224	1.0
233	0.5
235	0.5
237	6.5
239	11.0
240	3.0
244	1.0
246	2.5
262	2.0
263	2.0
264	2.0
269	5.1
270	5.3
271	22.4
	283.5

P-3 DATE	MM
192	1.5
200	13.0
201	1.0
203	3.0
204	0.5
205	23.0
209	2.0
210	0.5
211	0.5
212	17.0
213	2.0
214	1.0
216	0.5
217	6.0
218	1.0
222	15.0
223	0.5
233	0.5
237	3.0
238	0.5
239	5.5
246	2.5
262	2.0
263	3.5
264	0.5
269	5.1
270	5.3
271	22.4
	286.5

P-4 DATE	MM
165	0.5
166	0.5
167	3.5
171	1.0
181	2.0
192	1.5
200	13.5
201	1.0
203	2.5
204	1.0
205	22.0
209	2.5
210	0.5
211	0.5
212	17.0
213	2.5
214	0.5
216	1.5
217	7.5
218	1.0
222	19.5
223	0.5
233	0.5
235	0.5
237	5.0
239	12.0
240	3.0
243	0.5
244	2.5
246	7.5
262	2.0
263	3.5
264	0.5
269	5.1
270	5.3
271	22.4
	301.5

P-5 DATE	MM
165	9.5
166	0.5
167	0.5
168	3.5
171	0.5
173	0.5
181	1.5
182	0.5
189	0.5
192	1.0
200	8.5
201	5.5
203	2.5
204	0.5
205	22.5
209	2.5
210	0.5
211	0.5
212	17.0
213	2.0
214	1.0
216	0.5
217	6.0
218	1.0
222	14.5
223	0.5
233	0.5
237	4.5
239	11.5
240	3.5
243	0.5
244	1.5
246	8.0
262	2.0
263	3.5
264	0.5
269	5.1
270	5.3
271	22.4
	286.0

P-6 DATE	MM
171	0.5
173	0.5
181	2.0
192	1.5
200	13.0
201	1.0
203	3.0
204	1.0
205	10.5
209	2.5
210	0.5
211	9.0
212	17.0
213	2.0
214	1.0
216	0.5
217	6.0
218	1.0
222	14.5
223	0.5
233	0.5
237	4.5
239	11.5
245	1.5
246	8.0
262	2.0
263	3.5
264	0.5
269	5.1
270	5.3
271	22.4
	290.5

Appendix 5

Water samples data

5.1. Irrigation water samples

We can see in Tables 24 and 25 the nitrogen concentration (NO3-N) from the water samples collected on field during the irrigation season 1999 in each center pivot.

Table 24. Nitrogen concentration (ppm NO3-N) under sample point and calculated, for center pivot 39 for season 1999.

ID	LAT	LON	NO3_Nlab	Irr3_NO3-N cal
CP39 1	40.299932	-103.950186	230.50	251.70
CP39 2	40.300997	-103.950385	236.60	251.30

ID	LAT	LON	NO3_Nlab	Irr4_NO3-N cal
CP39 1	40.299932	-103.950186	212.30	251.70

ID	LAT	LON	NO3_Nlab	Irr5_NO3-N cal
CP39 3	40.303318	-103.946623	171.50	105.40
CP39 4	40.299712	-103.945865	150.60	159.60

**** NO3_Nlab = N concentration obtained from laboratory analysis. IrrX_NO3-N cal = N concentration obtained from CPED simulations.**

Table 25. Nitrogen concentration (ppm NO3-N) under sample point and calculated, for center pivot 6 for season 1999.

ID	LAT	LON	NO3_Nlab	Irr3_NO3-N cal
CP6 1	40.334475	-104.030527	245.80	285.42
CP6 2	40.334654	-104.032417	243.80	286.83
CP6 3	40.333614	-104.027463	106.20	253.26
CP6 4	40.330465	-104.028155	74.40	223.11

ID	LAT	LON	NO3_Nlab	Irr3_NO3-N cal
CP6 1	40.334475	-104.030527	166.10	247.10

**** NO3_Nlab = N concentration obtained from laboratory analysis. IrrX_NO3-N cal = N concentration obtained from CPED simulations.**

5.2. Ground water samples

We can see from tables 26 and 27 the nitrogen concentration (NO3-N) from the water samples collected from each center pivot well during the irrigation season 1999 and 1998.

Table 26. Nitrogen concentration of the ground water (mg/L NO3-N) under each center pivot well, for season 1998.

Date		NO3-N in sample (ppm)
6/25/98	C6	7.69
6/17/98	C6	13.18
	Average	**10.4**
Date		NO3-N in sample (ppm)
6/28/98	C39	7.59

Table 27. Nitrogen concentration of the ground water (mg/L NO3-N) under each center pivot well, for season 1999.

Date	Bottle No	Location	NO3-N mg/L
6/12/1999	203	C39	4.42
6/23/1999	204	C39	4.35
7/13/1999	205	C39	5.02
7/23/1999	262	C39	4.64
8/23/1999	269	C39	5.60
	Average		**4.81**
Date	Bottle No	Location	NO3-N mg/L
6/10/1999	200	C6	7.15
6/23/1999	201	C6	5.46
7/13/1999	202	C6	8.03
7/23/1999	258	C6	7.87
8/23/1999	250	C6	8.37
	Average		**7.38**

Appendix 6

Soil Chemical and Physical Data

In this chapter I will present the soil physical and chemical data (including the approximation made for center pivot 6 for 1999). Due to, the extent of the data, I going to present only the figures.

6.1. Soil saturated hydraulic conductivity

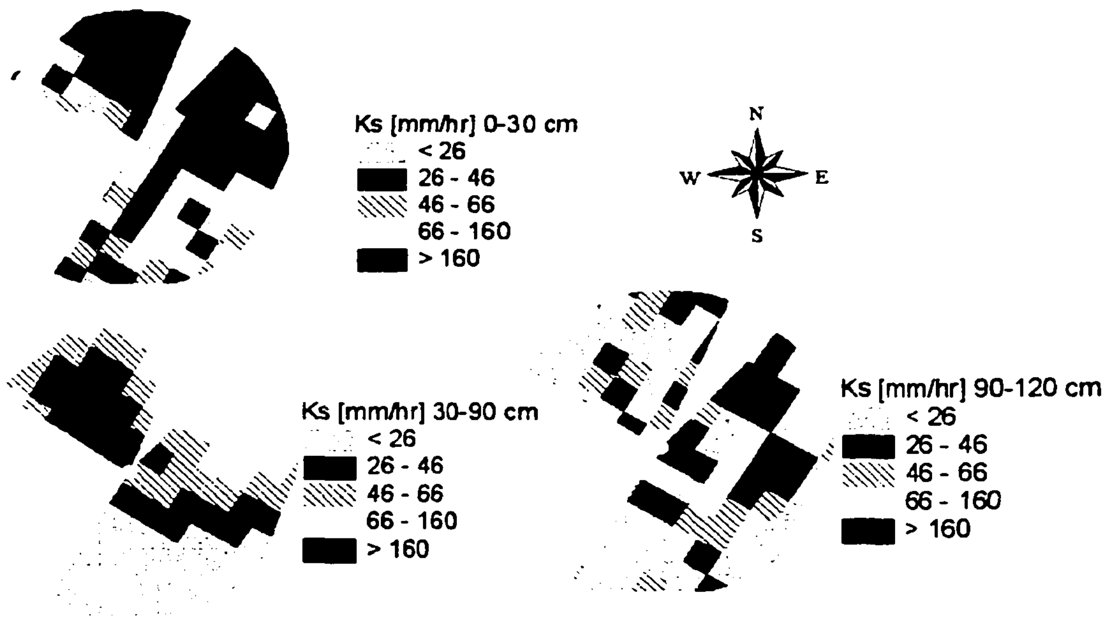


Figure 63. Saturated hydraulic conductivity [mm/hr] per layer for center pivot 6.

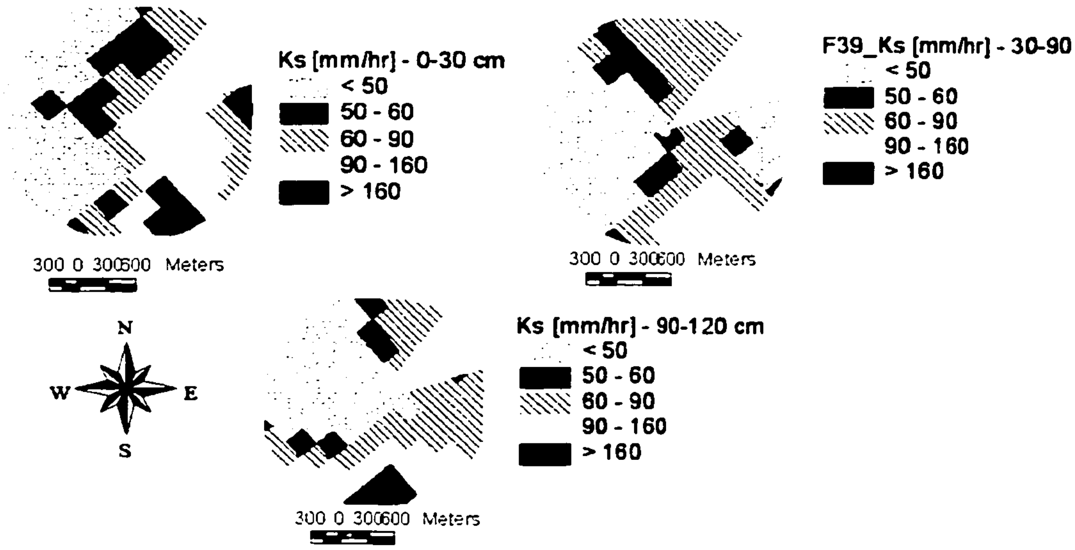


Figure 64. Saturated hydraulic conductivity [mm/hr] per layer for center pivot 39.

6.2. Soil Chemical characteristic

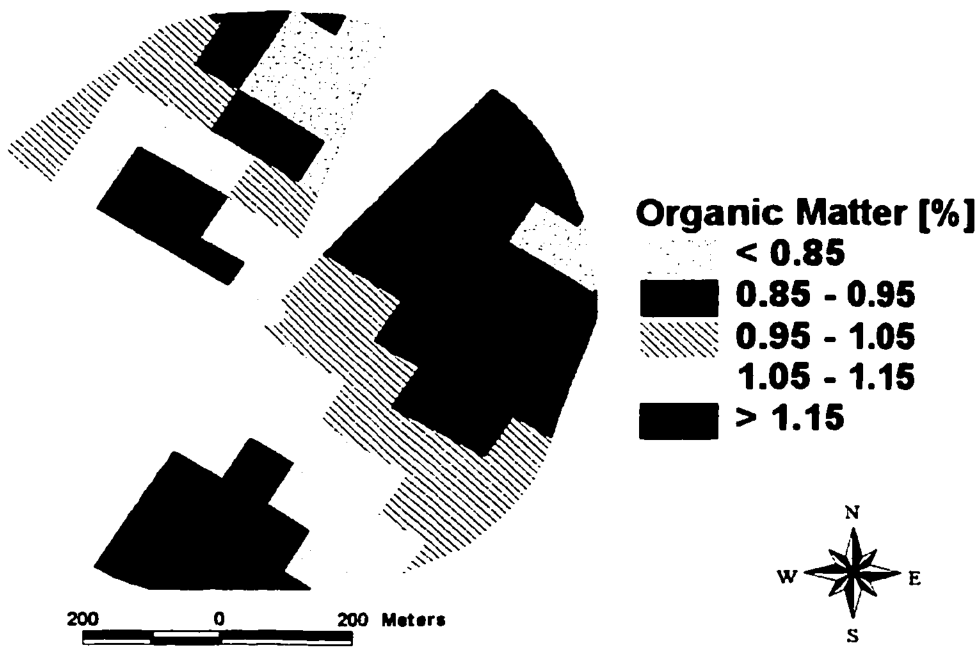


Figure 65. Organic matter content (%) for center pivot 6 in the first foot of depth.

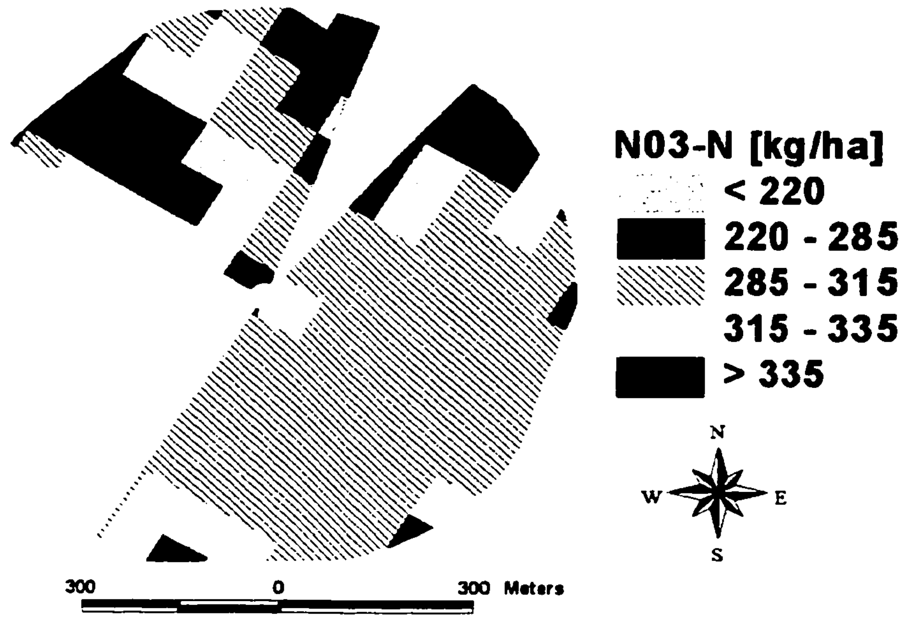


Figure 66. Nitrogen potentially available for center pivot 6, 1998.

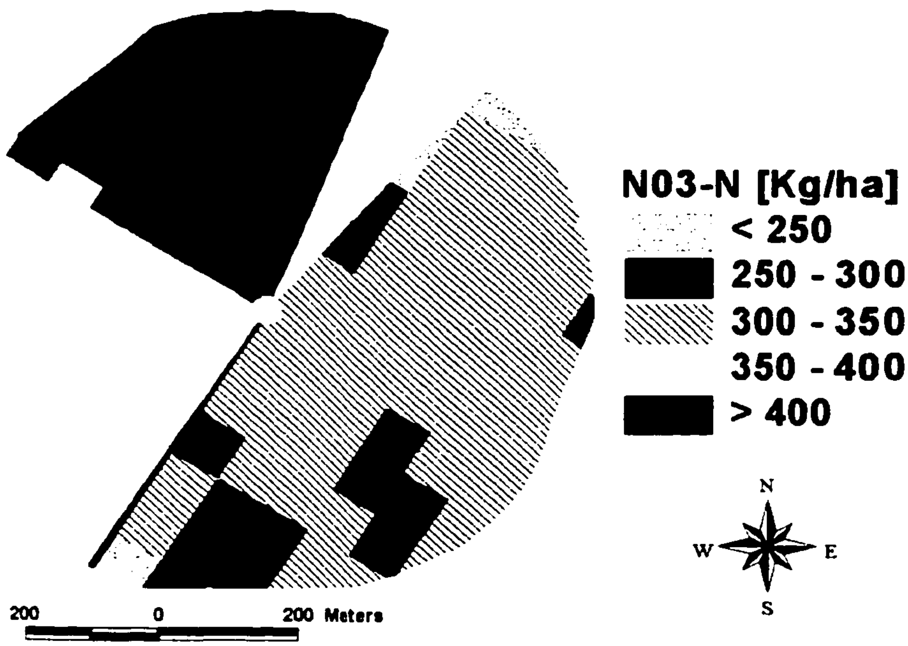


Figure 67. Nitrogen available for center pivot 6, 1999.

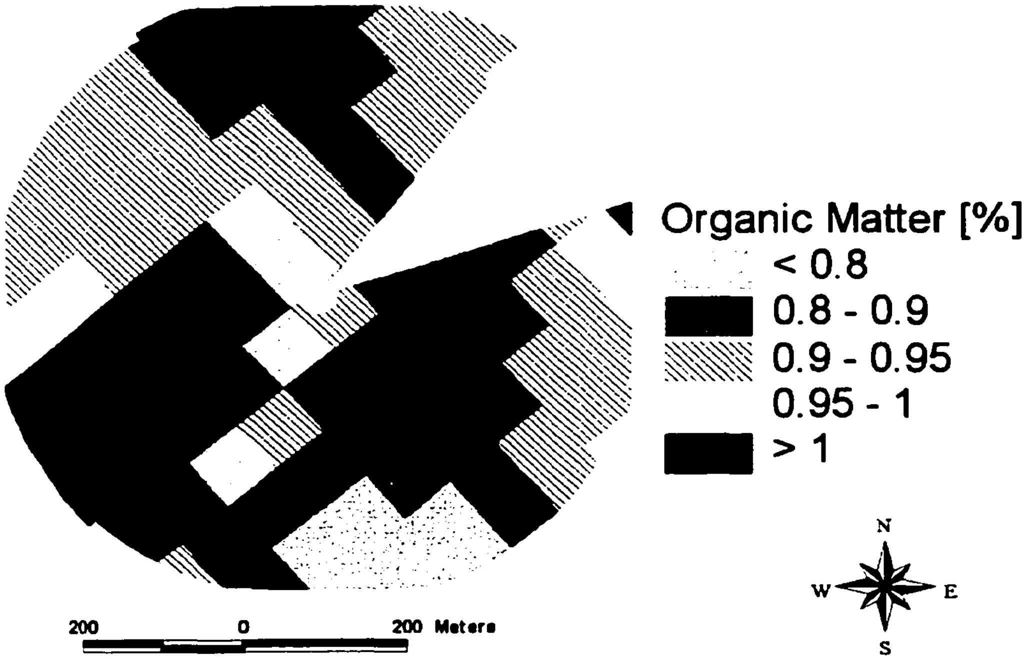


Figure 68. Organic matter content (%) for center pivot 39 in the first foot of depth.

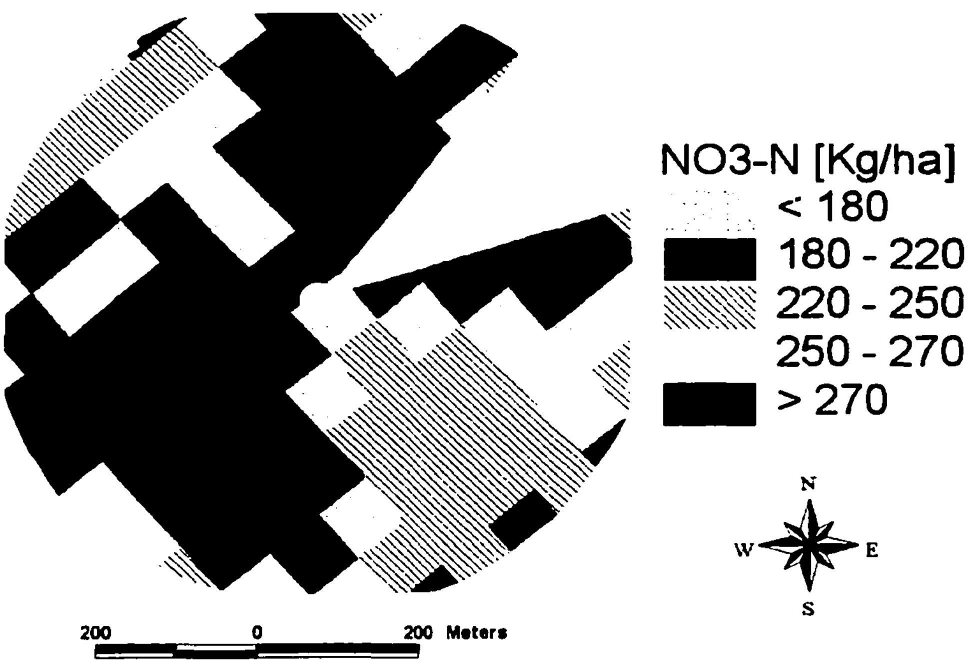


Figure 69. Nitrogen available for center pivot 39, 1999.

Appendix 7

Chemical Injection

7.1. UAN solution applied

Table 28. Example UAN solution (32 % nitrogen with a distribution of 25% NH4+25%NO3+ 50% Urea) applied, center pivot 6 for 1999.

GRIDCELL_I	LONG_CG	LAT_CG	AREA	AVE_N_R_4_					AVE_N_R8_L					AVE_N_R11_					AVE_N_R13_					AVE_N_R15_					AVE_N_SEASON				
				lb/ac	kg/ha	NO3	NH4	Urea	lb/ac	kg/ha	NO3	NH4	Urea	lb/ac	kg/ha	NO3	NH4	Urea	lb/ac	kg/ha	NO3	NH4	Urea	lb/ac	kg/ha	NO3	NH4	Urea	lb/ac	kg/ha	NO3	NH4	Urea
I16	-104.033	40.329	6491.9	28.56	32.01	7.80	7.80	16.40	27.76	31.12	7.59	7.59	15.95	31.43	35.23	8.59	8.59	18.05	26.76	30.00	7.31	7.31	15.37	27.20	30.49	7.43	7.43	15.62	141.70	158.86	38.73	38.73	81.40
J16	-104.032	40.328	48369.5	30.13	33.78	8.23	8.23	17.31	33.17	37.18	9.07	9.07	19.05	36.14	40.52	9.88	9.88	20.76	28.23	31.65	7.72	7.72	16.22	28.69	32.17	7.84	7.84	16.48	156.36	175.30	42.74	42.74	89.82
K16	-104.032	40.326	23771.9	31.40	35.20	8.58	8.58	18.04	37.47	42.01	10.24	10.24	21.53	40.10	44.96	10.96	10.96	23.03	29.42	32.98	8.04	8.04	16.90	29.90	33.52	8.17	8.17	17.18	168.29	188.67	46.00	46.00	96.67
L16	-104.031	40.328	167.7	26.11	29.27	7.14	7.14	15.00	30.52	34.22	8.34	8.34	17.53	36.89	41.36	10.08	10.08	21.19	24.47	27.43	6.69	6.69	14.06	24.87	27.88	6.80	6.80	14.28	142.86	160.16	39.05	39.05	82.07
I15	-104.033	40.329	7251.6	31.37	35.17	8.57	8.57	18.02	30.50	34.19	8.34	8.34	17.52	34.52	38.71	9.44	9.44	19.83	29.39	32.95	8.03	8.03	16.88	29.87	33.49	8.17	8.17	17.16	155.65	174.50	42.54	42.54	89.41
J15	-104.032	40.329	62488.8	30.96	34.71	8.46	8.46	17.79	34.51	38.69	9.43	9.43	19.82	37.19	41.69	10.16	10.16	21.36	29.01	32.53	7.93	7.93	16.67	29.49	33.06	8.06	8.06	16.94	161.16	180.67	44.05	44.05	92.58
K15	-104.031	40.329	62489.1	29.05	32.57	7.94	7.94	16.69	34.83	39.05	9.52	9.52	20.01	38.10	42.71	10.41	10.41	21.89	27.22	30.52	7.44	7.44	15.64	27.67	31.02	7.56	7.56	15.89	156.87	175.86	42.88	42.88	90.11
L15	-104.030	40.328	46968.2	28.25	31.67	7.72	7.72	16.23	33.21	37.23	9.08	9.08	19.08	38.50	43.17	10.52	10.52	22.12	26.47	29.67	7.23	7.23	15.20	26.90	30.16	7.35	7.35	15.45	153.32	171.89	41.91	41.91	88.08
M15	-104.030	40.328	10001.1	28.76	32.24	7.86	7.86	16.52	34.27	38.43	9.37	9.37	19.69	39.45	44.23	10.78	10.78	22.66	26.95	30.21	7.37	7.37	15.48	27.39	30.71	7.49	7.49	15.73	156.83	175.82	42.86	42.86	90.09
I14	-104.032	40.330	6620.2	31.31	35.10	8.56	8.56	17.99	30.44	34.13	8.32	8.32	17.49	34.46	38.64	9.42	9.42	19.80	29.34	32.89	8.02	8.02	16.66	29.82	33.43	8.15	8.15	17.13	155.38	174.19	42.47	42.47	89.26
J14	-104.031	40.330	62488.2	30.58	34.28	8.36	8.36	17.56	34.67	38.87	9.48	9.48	19.92	36.90	41.37	10.09	10.09	21.20	28.65	32.12	7.83	7.83	16.46	29.12	32.65	7.96	7.96	16.73	159.92	179.29	43.71	43.71	91.87
K14	-104.031	40.329	62488.6	29.30	32.85	8.01	8.01	16.83	34.89	39.12	9.54	9.54	20.04	38.80	43.49	10.60	10.60	22.29	27.46	30.78	7.50	7.50	15.77	27.90	31.28	7.63	7.63	16.03	158.35	177.52	43.28	43.28	90.96
L14	-104.030	40.329	62488.9	28.62	32.09	7.82	7.82	16.44	33.92	38.02	9.27	9.27	19.48	38.90	43.61	10.63	10.63	22.35	26.82	30.07	7.33	7.33	15.41	27.26	30.56	7.45	7.45	15.66	155.52	174.36	42.51	42.51	89.34
M14	-104.029	40.329	60771.3	28.46	31.90	7.78	7.78	16.35	35.83	40.17	9.79	9.79	20.58	39.37	44.14	10.76	10.76	22.62	26.67	29.90	7.29	7.29	15.32	27.10	30.38	7.41	7.41	15.57	157.43	176.49	43.03	43.03	90.43
N14	-104.028	40.328	25513.1	29.35	32.90	8.02	8.02	16.86	41.91	46.99	11.46	11.46	24.08	40.98	45.94	11.20	11.20	23.54	27.50	30.83	7.52	7.52	15.80	27.95	31.33	7.64	7.64	16.06	167.69	188.00	45.83	45.83	96.33
I13	-104.032	40.331	5988.1	31.48	35.30	8.61	8.61	18.09	30.61	34.32	8.37	8.37	17.58	34.65	38.85	9.47	9.47	19.91	29.50	33.08	8.06	8.06	16.95	29.98	33.61	8.20	8.20	17.22	156.23	175.15	42.70	42.70	89.75
J13	-104.031	40.330	62487.7	29.30	32.85	8.01	8.01	16.83	33.51	37.57	9.16	9.16	19.25	36.27	40.66	9.91	9.91	20.83	27.46	30.78	7.51	7.51	15.77	27.91	31.29	7.63	7.63	16.03	154.45	173.15	42.21	42.21	88.72
I05	-104.028	40.335	6004.7	34.66	38.86	9.47	9.47	19.91	38.44	43.10	10.51	10.51	22.08	0.00	0.00	0.00	0.00	0.00	32.48	36.42	8.88	8.88	18.66	33.01	37.01	9.02	9.02	18.96	138.60	155.38	37.88	37.88	79.62
J05	-104.027	40.335	7537.2	17.00	19.06	4.65	4.65	9.77	21.21	23.78	5.80	5.80	12.18	25.47	28.55	6.96	6.96	14.63	15.93	17.86	4.35	4.35	9.15	16.19	18.15	4.43	4.43	9.30	95.80	107.40	26.18	26.18	55.03
K05	-104.026	40.334	62483.9	33.14	37.15	9.06	9.06	19.04	39.31	44.07	10.74	10.74	22.58	47.65	53.42	13.02	13.02	27.37	31.05	34.81	8.49	8.49	17.84	31.56	35.38	8.63	8.63	18.13	182.71	204.84	49.94	49.94	104.96
L05	-104.026	40.334	62193.9	32.31	36.22	8.83	8.63	19.56	37.98	42.58	10.38	10.38	21.82	41.88	46.95	11.45	11.45	24.06	30.27	33.94	8.27	8.27	17.39	30.77	34.49	8.41	8.41	17.67	173.21	194.18	47.34	47.34	99.50
M05	-104.025	40.334	37683.4	28.58	32.04	7.81	7.81	16.42	35.85	40.19	9.80	9.80	20.59	36.33	40.73	9.93	9.93	20.87	26.78	30.02	7.32	7.32	15.38	27.22	30.51	7.44	7.44	15.63	154.76	173.50	42.30	42.30	88.90
N05	-104.024	40.333	1868.2	13.48	15.11	3.68	3.68	7.74	17.45	19.56	4.77	4.77	10.02	17.37	19.47	4.75	4.75	9.98	12.63	14.16	3.45	3.45	7.26	12.84	14.39	3.51	3.51	7.37	73.76	82.69	20.16	20.16	42.37
G04	-104.029	40.337	13074.9	31.34	35.13	8.56	8.56	18.00	32.72	36.69	8.94	8.94	18.80	42.08	47.17	11.50	11.50	24.17	29.37	32.92	8.03	8.03	16.87	29.84	33.46	8.16	8.16	17.14	165.35	185.37	45.19	45.19	94.98
H04	-104.028	40.336	34119.8	32.52	36.45	8.89	8.89	18.68	35.21	39.47	9.62	9.62	20.22	20.23	22.68	5.53	5.53	11.62	30.47	34.16	8.33	8.33	17.50	30.97	34.72	8.46	8.46	17.79	149.39	167.48	40.83	40.83	85.82
J04	-104.027	40.335	124.7	16.73	18.76	4.57	4.57	9.61	20.85	23.38	5.70	5.70	11.98	25.07	28.10	6.85	6.85	14.40	15.68	17.58	4.29	4.29	9.01	15.93	17.86	4.36	4.36	9.15	94.27	105.68	25.77	25.77	54.15
K04	-104.026	40.335	30493.9	15.12	16.95	4.13	4.13	8.69	18.55	20.80	5.07	5.07	10.66	22.57	25.30	6.17	6.17	12.96	14.17	15.89	3.87	3.87	8.14	14.40	16.15	3.94	3.94	8.27	84.82	95.09	23.18	23.18	48.72
L04	-104.025	40.335	11088.1	21.78	24.41	5.95	5.95	12.51	24.72	27.71	6.76	6.76	14.20	29.35	32.91	8.02	8.02	16.86	20.41	22.88	5.58	5.58	11.72	20.74	23.25	5.67	5.67	11.91	116.99	131.16	31.98	31.98	67.21

Appendix 8

Statistical analysis of variables and results

8.1. Regression Analysis between variables

8.1.1. Center Pivot 6 – season 98

a) Total water applied and Yield

** > mark are edges areas and were take out from the analysis.

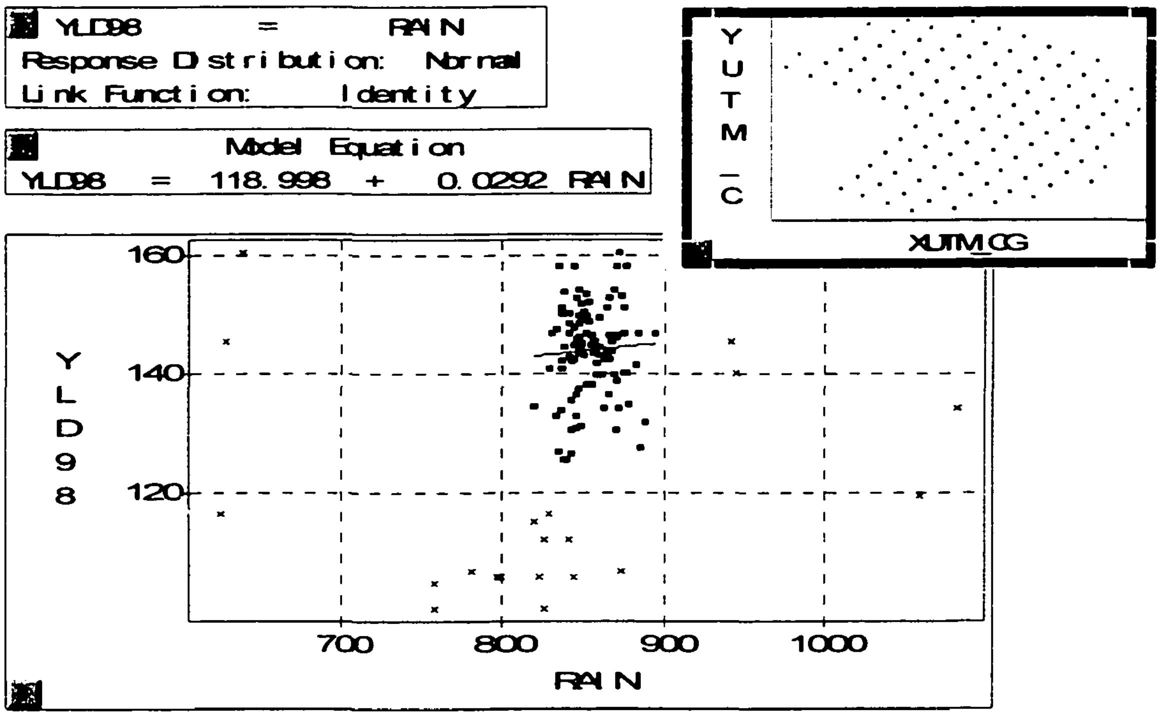


Figure 70. Relationships between total water applied and yield – center pivot 6.

Parametric Regression Fit								
		Model		Error				
Curv	Degree(Pol	DF	Mean	DF	Mean	R-Squ	F Sta	Pr
——	1.000	1.000	18.14	94.00	65.11	3E-3	.2786	.60

Summary of Fit			
Mean of Response	143.9681	R-Square	0.0030
Root MSE	8.0692	Adj R-Sq	0.003

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	18.1411	18.1411	0.28	0.5989
Error	94	6120.5870	65.1126		
C Total	95	6138.7282			

Type III Tests

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
RAIN	1	18.1411	18.1411	0.28	0.5989

Parameter Estimates

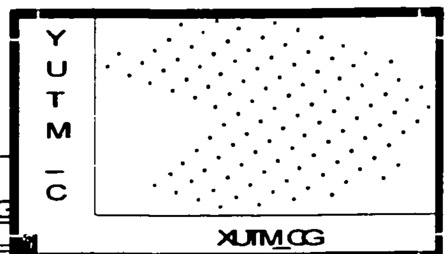
Variabl	DF	Estimate	Std Erro	t Stat	Pr >|t|	Toleranc	Var Inflat
Interce	1	118.9980	47.3137	2.52	0.0136	.	0
RAIN	1	0.0292	0.0554	0.53	0.5989	1.0000	1.0000

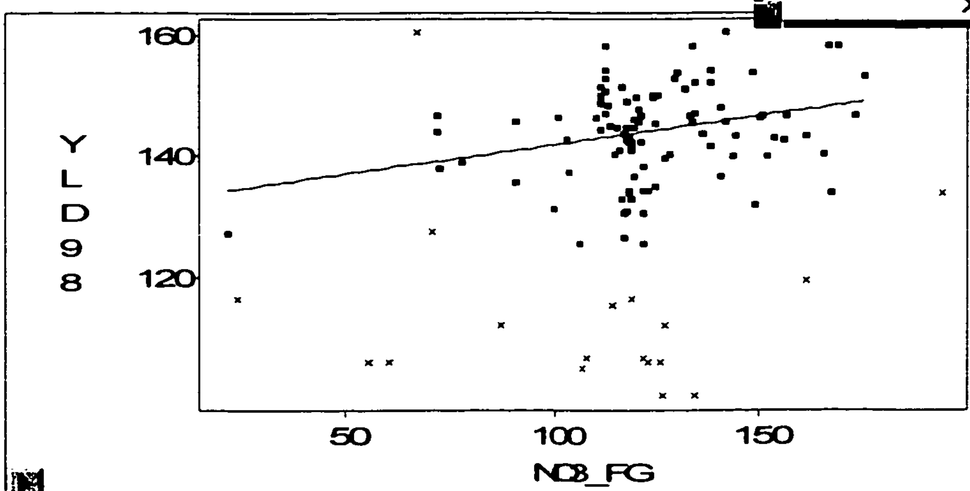
B) Nitrogen Applied and Yield

B.1. Nitrogen applied through fertigation

YLD98 = NO3_FG
Response Distribution: Normal
Link Function: Identity

Model Equation
YLD98 = 132.240 + 0.0952 NO3_FG





** > mark are edges areas and were take out from the analysis.

Figure 71. Relationships between nitrogen applied through fertigation and yield – center pivot 6.

Parametric Regression Fit

Curve	Degree(Polyn	Model DF	Model Mean Squ	Error DF	Error Mean Squ	R-Squ	F Stat	Pr > F
———	1	1	477.660	96	56.4164	.0810	8.47	45E-4

Summary of Fit

Mean of Response	144.1420	R-Square	0.0810
Root MSE	7.5111	Adj R-Sq	0.0715

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	477.6598	477.6598	8.47	0.0045
Error	96	5415.9782	56.4164		
C Total	97	5893.6380			

Type III Tests

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
NCB_FG	1	477.6598	477.6598	8.47	0.0045

Parameter Estimates

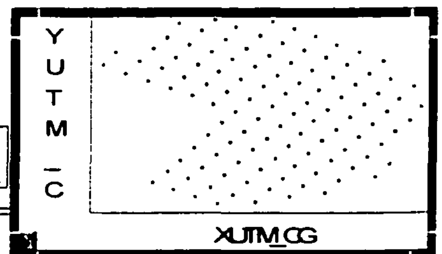
Variabl	DF	Estimate	Std Erro	t Stat	Pr >|t|	Toleranc	Var Inflati
Interce	1	132.2397	4.1603	31.79	93E-54	.	0
NCB_FG	1	0.0952	0.0327	2.91	0.0045	1.0000	1.0000

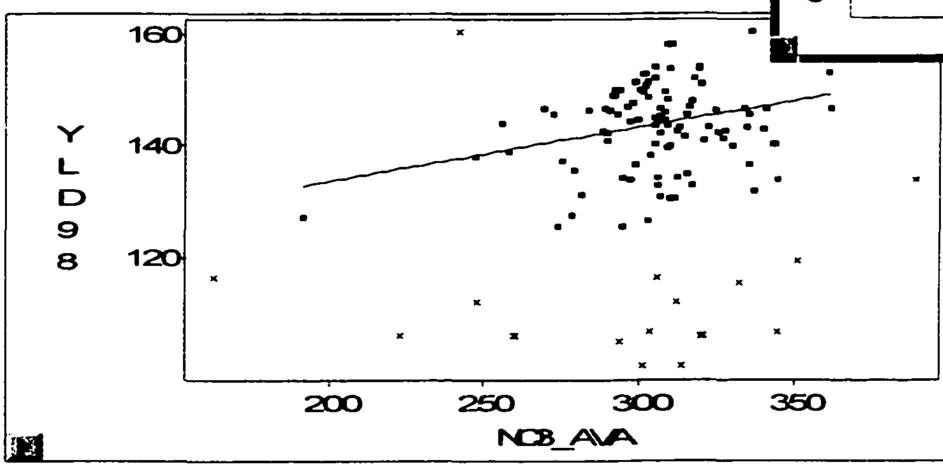
B.2. Total nitrogen applied

YLD98	=	NCB_AVA
Response Distribution:		Normal
Link Function:		Identity

Model Equation

YLD98 = 114.353 + 0.0963 NCB_AVA





** > mark are edges areas and were take out from the analysis.

Figure 72. Relationships between total nitrogen applied and yield – center pivot 6.

Parametric Regression Fit									
			Model		Error				
Curve	Degree(Polyno		DF	Mean Squ	DF	Mean Squ	R-Squa	F Stat	Pr > F
———	1	[redacted]	1	529.9237	97	58.0257	0.0860	9.13	3.E-03

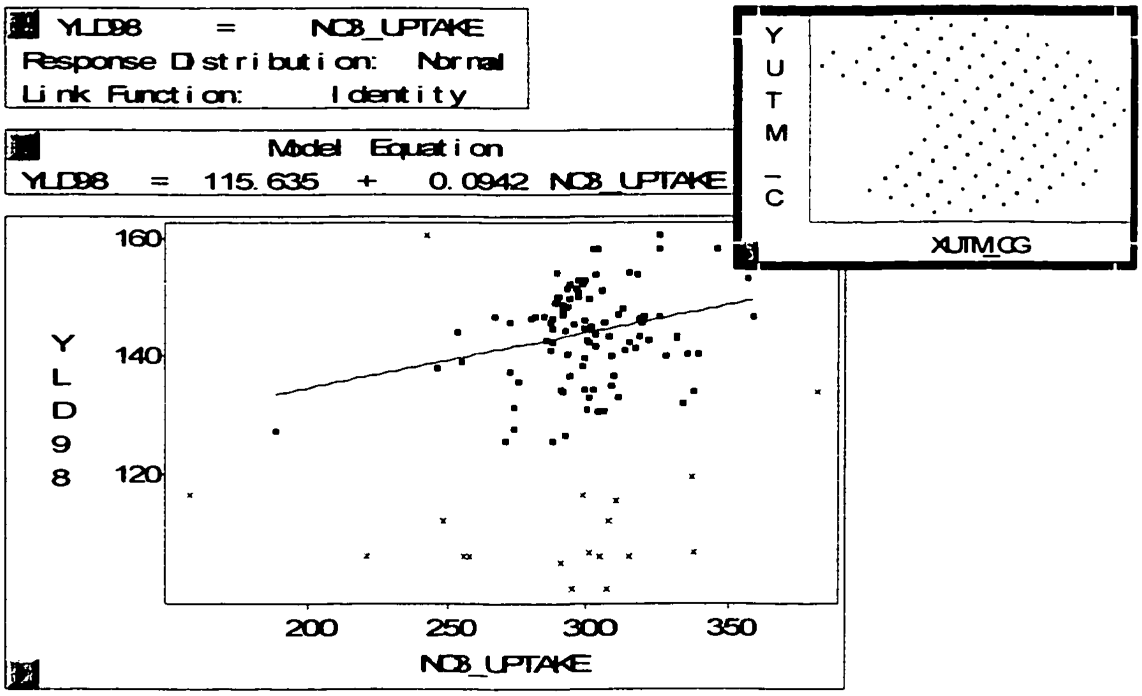
Summary of Fit			
Mean of Response	143.9768	R-Square	0.0860
Root MSE	7.6175	Adj R-Sq	0.0766

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	529.9237	529.9237	9.13	0.0032
Error	97	5628.4975	58.0257		
C Total	98	6158.4212			

Type III Tests					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
NO3_AVA	1	529.9237	529.9237	9.13	0.0032

Parameter Estimates							
Variable	DF	Estimate	Std Error	t Stat	Pr >|t|	Tolerance	Var Inflation
Intercep	1	114.3527	9.8326	11.63	<.0001	.	0
NO3_AVA	1	0.0963	0.0319	3.02	0.0032	1.0000	1.0000

C) Nitrogen uptake and Yield



** > mark are edges areas and were take out from the analysis.

Figure 73. Relationships between nitrogen uptake and yield – center pivot 6.

Parametric Regression Fit								
		Model		Error				
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F
———	1	1	457.834	97	58.7689	.0743	7.79	63E-4

Summary of Fit			
Mean of Response	143.9768	R-Square	0.0743
Root MSE	7.6661	Adj R-Sq	0.0648

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	457.8339	457.8339	7.79	0.0063
Error	97	5700.5873	58.7689		
C Total	98	6158.4212			

Type III Tests					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
NO3_UPTAKE	1	457.8339	457.8339	7.79	0.0063

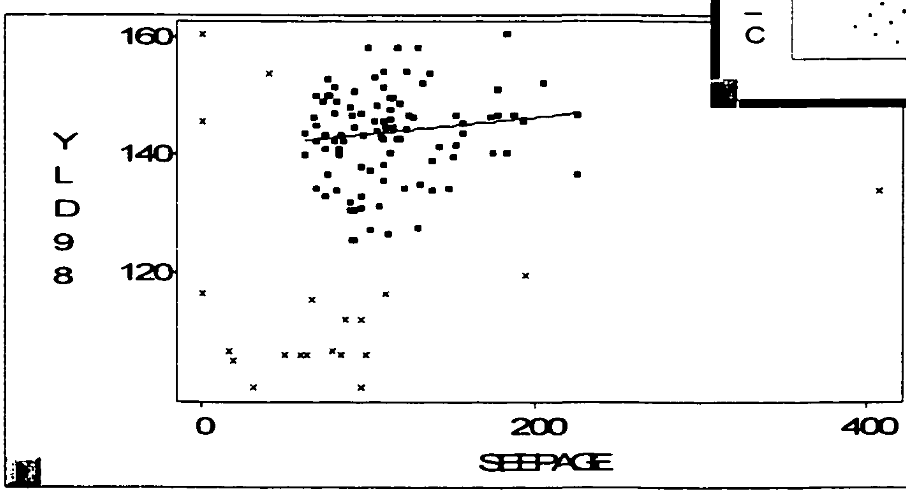
Parameter Estimates							
Variable	DF	Estimate	Std Error	t Stat	Pr > |t|	Tolerance	Var Inflation
Intercept	1	115.6354	10.1833	11.36	164E-21	.	0
NO3_UPTAK	1	0.0942	0.0338	2.79	0.0063	1.0000	1.0000

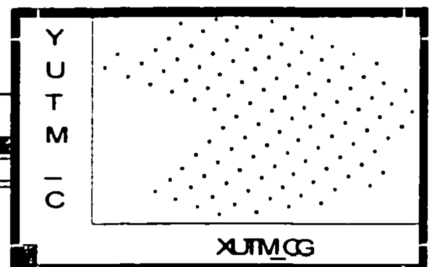
D) Deep percolation (seepage) and Yield

YLD98	=	SEEPAGE
Response Distribution:		Normal
Link Function:		Identity

Model Equation

YLD98 = 140.568 + 0.0287 SEEPAGE





** > mark are edges areas and were take out from the analysis.

Figure 74. Relationships between deep percolation (seepage) and yield – center pivot 6.

Parametric Regression Fit									
		Model		Error					
Curve	Degree(Polyno	DF	Mean Squ	DF	Mean Squ	R-Squa	F Stat	Pr > F
———	1	1	105.1372	95	62.5790	0.0174	1.68	2.E-01

Summary of Fit			
Mean of Response	143.8513	R-Square	0.0174
Root MSE	7.9107	Adj R-Sq	0.0070

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	105.1372	105.1372	1.68	0.1981
Error	95	5945.0021	62.5790		
C Total	96	6050.1393			

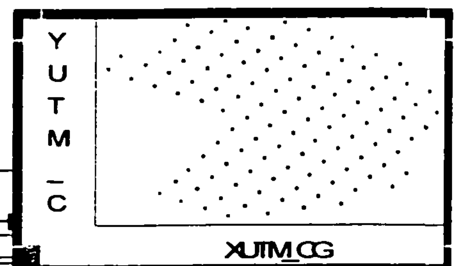
Type III Tests					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
SEEPAGE	1	105.1372	105.1372	1.68	0.1981

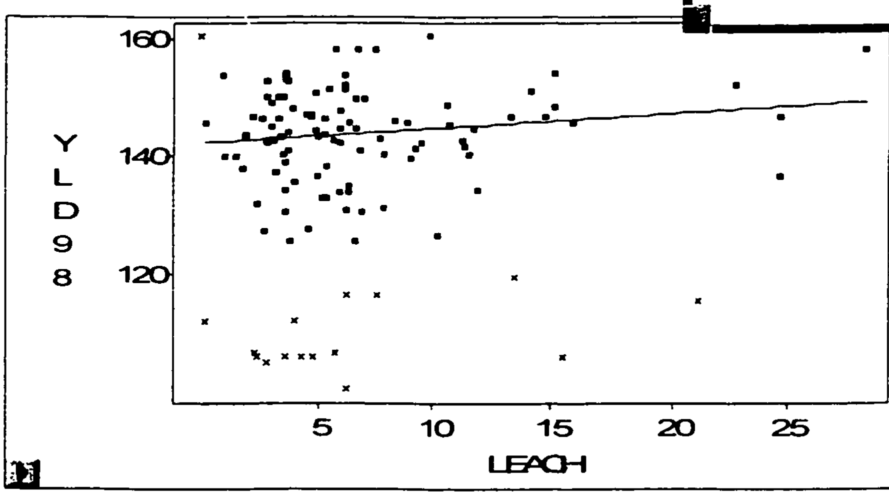
Parameter Estimates							
Variable	DF	Estimate	Std Error	t Stat	Pr >|t|	Tolerance	Var Inflation
Intercept	1	140.5681	2.6573	52.90	<.0001	.	0
SEEPAGE	1	0.0287	0.0221	1.30	0.1981	1.0000	1.0000

E) Leaching and Yield

YLD98 = LEACH
Response Distribution: Normal
Link Function: Identity

Model Equation
YLD98 = 142.190 + 0.2510 LEACH





** > marks are edges areas and were take out from the analysis.

Figure 75. Relationships between Leaching and yield – center pivot 6.

Parametric Regression Fit									
		Model		Error					
Curve	Degree(Polyn	DF	Mean Squ	DF	Mean Squ	R-Squa	F Stat	Pr > F	
———	1 [redacted]	1	162.291	98	62.1006	.0260	2.61	11E-2	

Summary of Fit			
Mean of Response	143.8816	R-Square	0.0260
Root MSE	7.8804	Adj R-Sq	0.0160

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	162.2908	162.2908	2.61	0.1092
Error	98	6085.8615	62.1006		
C Total	99	6248.1522			

Type III Tests					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
LEACH	1	162.2908	162.2908	2.61	0.1092

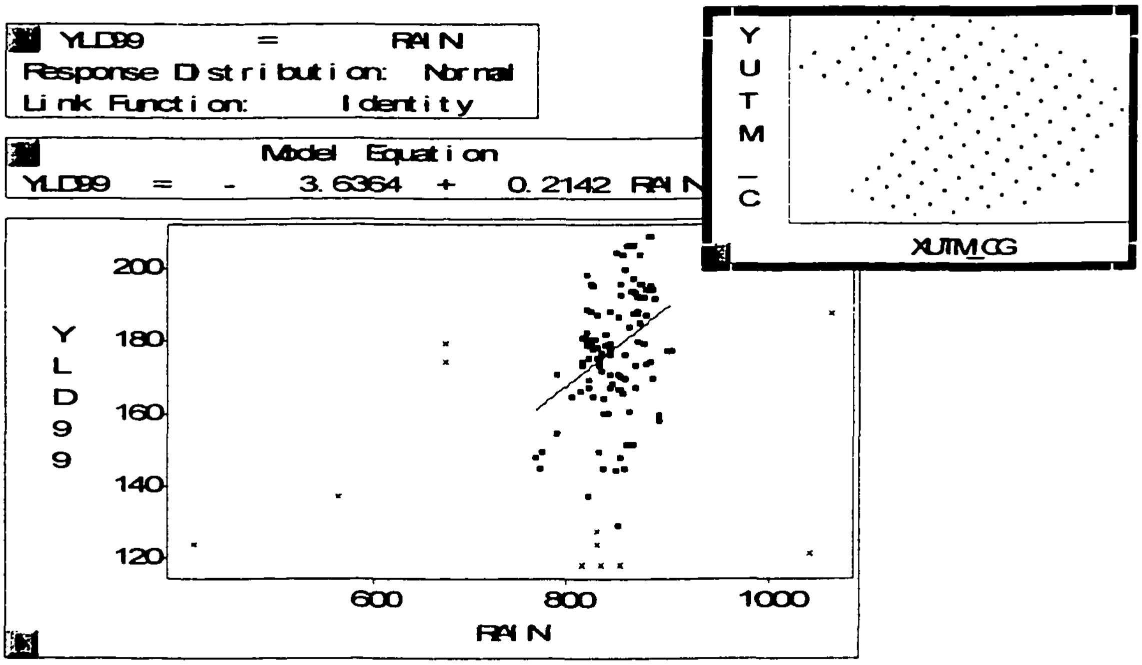
Parameter Estimates							
Variable	DF	Estimate	Std Error	t Stat	Pr >|t|	Tolerance	Var Inflation
Intercep	1	142.1905	1.3097	108.57	<.0001	.	0
LEACH	1	0.2510	0.1553	1.62	0.1092	1.0000	1.0000

8.1.2. Center Pivot 6 – season 99

a) Total water applied and Yield

YLD99 = RAIN
Response Distribution: Normal
Link Function: Identity

Model Equation
YLD99 = - 3.6364 + 0.2142 RAIN



** > marks are edges areas and were take out from the analysis.

Figure 76. Relationships between total water applied and yield – center pivot 6.

Parametric Regression Fit								
		Model		Error				
Curve	Degree(Polynom	DF	Mean Squa	DF	Mean Squa	R-Squar	F Stat	Pr > F
———	1	1	3664.6354	103	255.0345	0.1224	14.37	3.E-04

Summary of Fit			
Mean of Response	178.0202	R-Square	0.1224
Root MSE	15.9698	Adj R-Sq	0.1139

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	3664.6354	3664.6354	14.37	0.0003
Error	103	26268.5535	255.0345		
C Total	104	29933.1890			

Type III Tests

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
RAIN	1	3664.6354	3664.6354	14.37	0.0003

Parameter Estimates

Variable	DF	Estimate	Std Error	t Stat	Pr >|t|	Tolerance	Var Inflation
Intercept	1	-3.6364	47.9474	-0.08	0.9397	.	0
RAIN	1	0.2142	0.0565	3.79	0.0003	1.0000	1.0000

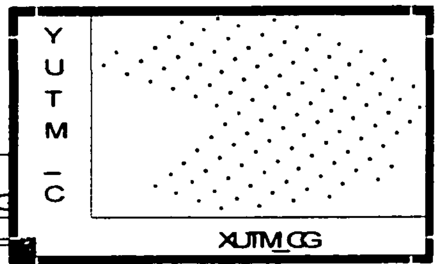
B) Nitrogen Applied and Yield

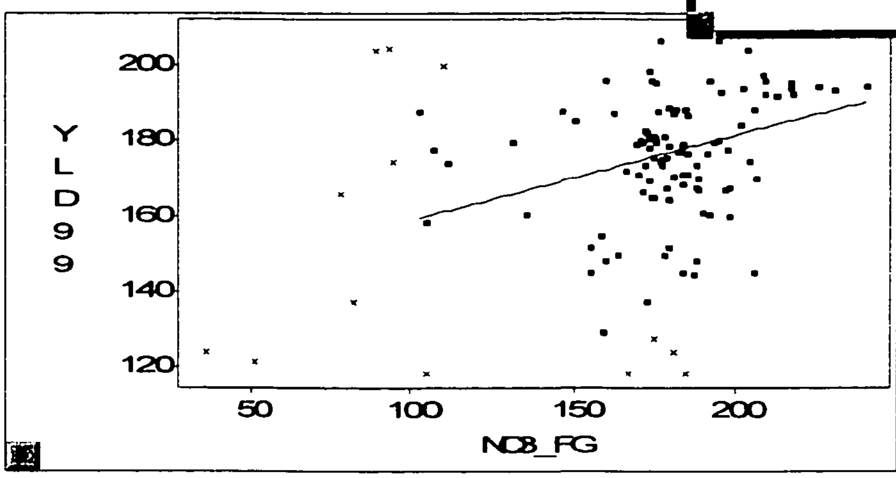
B.1. Nitrogen applied through fertigation

YLD99	=	NO3_FG
Response Distribution:		Normal
Link Function:		Identity

Model Equation

YLD99 = 135.976 + 0.2283 NO3_FG





** > marks are edges areas and were take out from the analysis.

Figure 77. Relationships between nitrogen applied through fertigation and yield-center pivot 6.

Parametric Regression Fit								
		Model		Error				
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F
————	1 [redacted]	1	3222.1431	101	244.1768	0.1156	13.20	4.4E-04

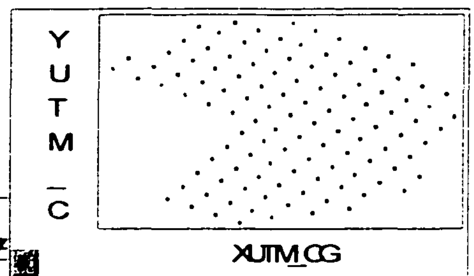
Summary of Fit			
Mean of Response	177.5058	R-Square	0.1156
Root MSE	15.6262	Adj R-Sq	0.1068

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	3222.1431	3222.1431	13.20	0.0004
Error	101	24661.8526	244.1768		
C Total	102	27883.9957			

Type III Tests					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
NCB_FG	1	3222.1431	3222.1431	13.20	0.0004

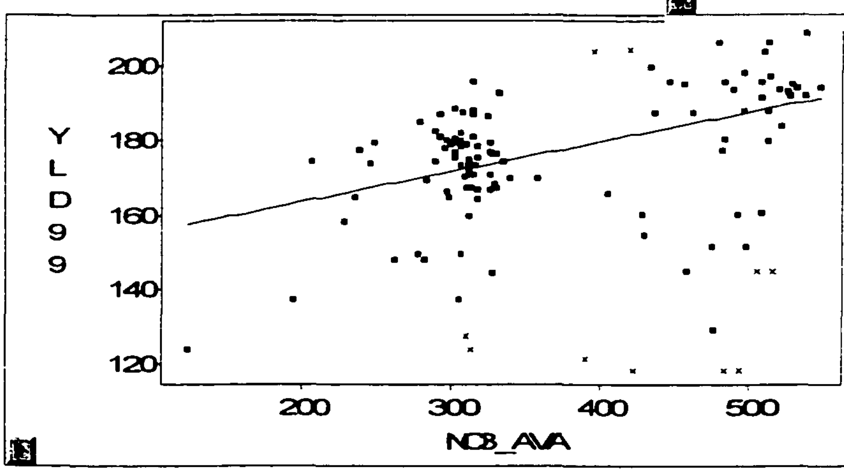
Parameter Estimates							
Variable	DF	Estimate	Std Error	t Stat	Pr >|t|	Tolerance	Var Inflation
Intercept	1	135.9760	11.5357	11.79	<.0001	.	0
NCB_FG	1	0.2283	0.0628	3.63	0.0004	1.0000	1.0000

B.2. Total nitrogen applied



YLD99	=	NCB_AVA
Response Distribution:		Normal
Link Function:		Identity

Model Equation				
YLD99	=	147.352	+	0.0812 NCB_AVA



** > marks are edges areas and were take out from the analysis.

Figure 78. Relationships between total nitrogen applied and yield – center pivot 6.

Parametric Regression Fit

Curve	Degree(Polynomi	Model DF	Model Mean Squ	Error DF	Error Mean Squ	R-Squa	F Stat	Pr > F
———	1	1	6953	104	230	2.E-01	30	3.E-07

Summary of Fit

Mean of Response	177.3394	R-Square	0.2253
Root MSE	15.1633	Adj R-Sq	0.2178

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	6953.0354	6953.0354	30.24	<.0001
Error	104	23912.1364	229.9244		
C Total	105	30865.1718			

Type III Tests

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
NO3_AVA	1	6953.0354	6953.0354	30.24	<.0001

Parameter Estimates

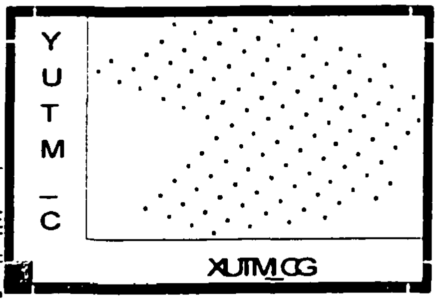
Variable	DF	Estimate	Std Error	t Stat	Pr >|t|	Tolerance	Var Inflation
Intercept	1	147	6	26	<.0001	.	0
NO3_AVA	1	8.1E-02	1.5E-02	5	<.0001	1	1

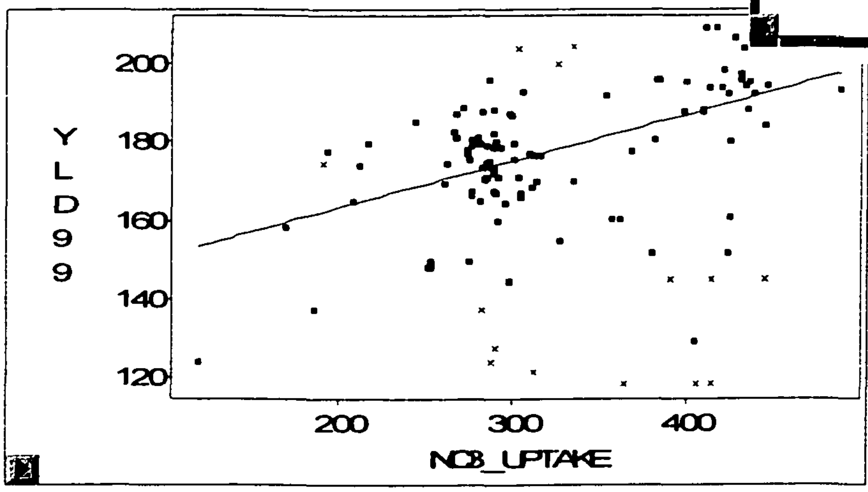
C) Nitrogen uptake and yield

YLD99 = NO3_UPTAKE
Response Distribution: Normal
Link Function: Identity

Model Equation

YLD99 = 139.582 + 0.1183 NO3_UPTAKE





** > marks are edges areas and were take out from the analysis.

Figure 79. Relationships between nitrogen uptake and yield – Center pivot 6.

Parametric Regression Fit									
		Model		Error					
Curve	Degree(Polynom	DF	Mean Squ	DF	Mean Squ	R-Squa	F Stat	Pr > F
———	1	1	7884	100	198	3.E-01	40	78E-10

Summary of Fit			
Mean of Response	177.8245	R-Square	0.2845
Root MSE	14.0816	Adj R-Sq	0.2773

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	7883.8875	7883.8875	39.76	<.0001
Error	100	19829.1096	198.2911		
C Total	101	27712.9971			

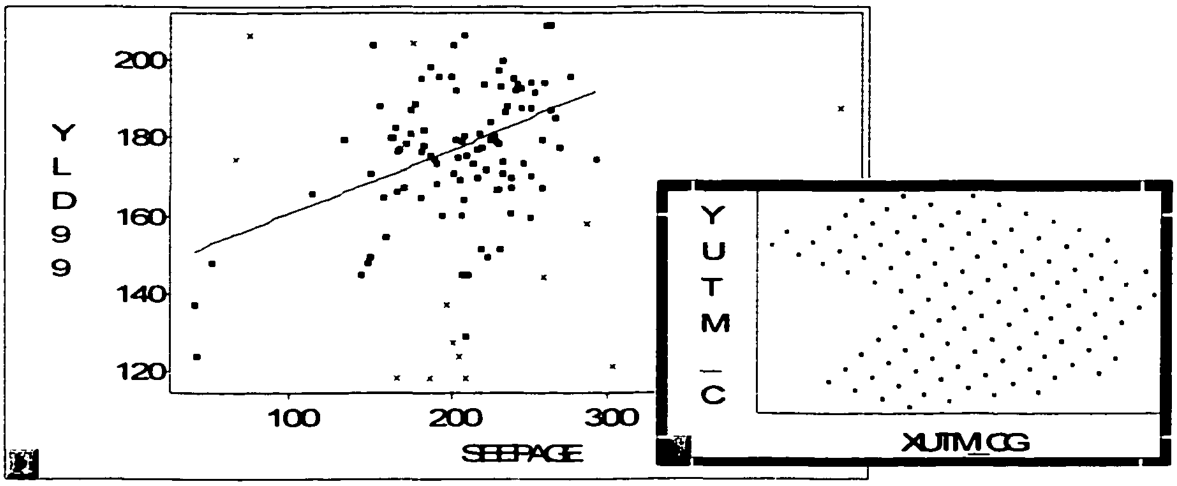
Type III Tests					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
NO3_UPTAKE	1	7883.8875	7883.8875	39.76	<.0001

Parameter Estimates							
Variable	DF	Estimate	Std Error	t Stat	Pr >|t|	Tolerance	Var Inflation
Intercept	1	140	6	22	834E-43	.	0
NO3_UPTAK	1	1.2E-01	1.9E-02	6	7.85E-9	1	1

D) Deep percolation (seepage) and yield

YLD99 = SEEPAGE
Response Distribution: Normal
Link Function: Identity

Model Equation
YLD99 = 144.223 + 0.1641 SEEPAGE



** > marks are edges areas and were take out from the analysis.

Figure 80. Relationships between deep percolation (seepage) and yield – center pivot 6.

Parametric Regression Fit

Curve	Degree(Polynom	Model DF	Model Mean Squ	Error DF	Error Mean Squ	R-Squa	F Stat	Pr > F
———	1	1	5618	100	218	21E-2	26	17E-7

Summary of Fit

Mean of Response	177.9460	R-Square	0.2062
Root MSE	14.7505	Adj R-Sq	0.1973

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	5618.1018	5618.1018	25.82	<.0001
Error	100	21757.7289	217.5773		
C Total	101	27375.8307			

Type III Tests

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
SEEPAGE	1	5618.1018	5618.1018	25.82	<.0001

Parameter Estimates

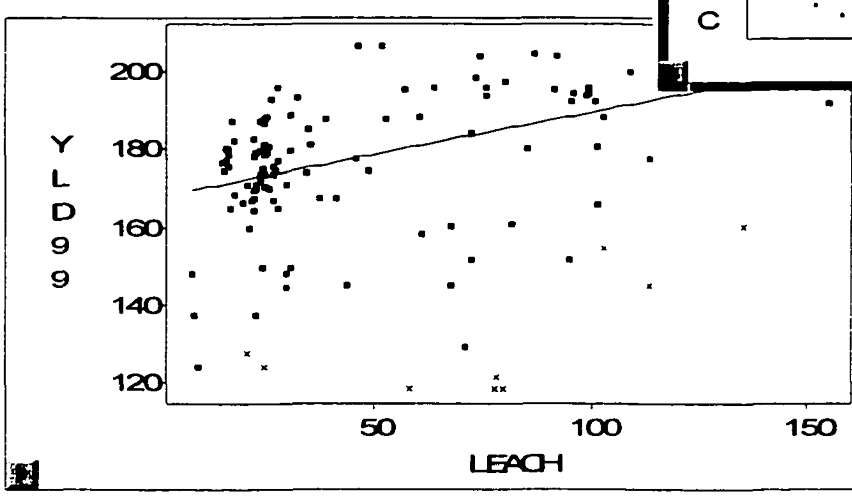
Variable	DF	Estimate	Std Error	t Stat	Pr >|t|	Tolerance	Var Inflation
Intercep	1	144	7	21	808E-41	.	0
SEEPAGE	1	1.6E-01	3.2E-02	5	1.7E-06	1	1

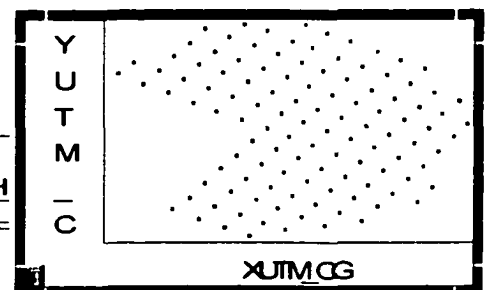
E) Leaching and Yield

YLD99	=	LEACH
Response Distribution:		Normal
Link Function:		Identity

Model Equation

YLD99 = 167.807 + 0.2184 LEACH





** > marks are edges areas and were take out from the analysis.

Figure 81. Relationships between leaching and yield – center pivot 6.

Parametric Regression Fit								
		Model		Error				
Curve	Degree(Polynomi	DF	Mean Squ	DF	Mean Squ	R-Squa	F Stat	Pr > F
———	1	1	5349	105	260	2.E-01	21	2.E-05

Summary of Fit			
Mean of Response	177.9244	R-Square	0.1638
Root MSE	16.1269	Adj R-Sq	0.1558

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	5349.0962	5349.0962	20.57	<.0001
Error	105	27307.9718	260.0759		
C Total	106	32657.0680			

Type III Tests					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
LEACH	1	5349.0962	5349.0962	20.57	<.0001

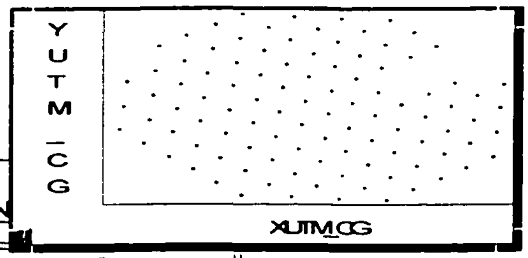
Parameter Estimates							
Variable	DF	Estimate	Std Error	t Stat	Pr > |t|	Tolerance	Var Inflation
Intercep	1	168	3	62	275E-86	.	0
LEACH	1	2.2E-01	4.8E-02	5	1.5E-05	1	1

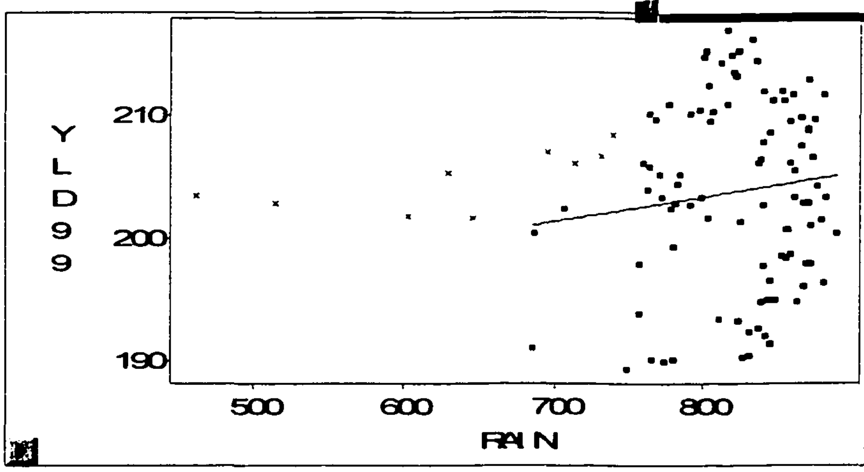
8.1.3. Center Pivot 39 – season 99

a) Total water applied and Yield

YLD99 = RAIN
Response Distribution: Normal
Link Function: Identity

Model Equation
YLD99 = 187.163 + 0.0202 RAIN





** > marks are edges areas and were take out from the analysis.

Figure 82. Relationships between total water applied and yield–center pivot 39.

Curve	Degree(Polynomial)	Model DF	Model Mean Square	Error DF	Error Mean Square	R-Square	F Stat	Pr > F
———	1	1	71	92	58	1.E-02	1	3.E-01

Parametric Regression Fit

Summary of Fit			
Mean of Response	203.8049	R-Square	0.0131
Root MSE	7.6335	Adj R-Sq	0.0023

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	70.8891	70.8891	1.22	0.2729
Error	92	5360.8156	58.2697		
C Total	93	5431.7047			

Type III Tests

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
RAIN	1	70.8891	70.8891	1.22	0.2729

Parameter Estimates

Variable	DF	Estimate	Std Error	t Stat	Pr >|t|	Tolerance	Var Inflation
Intercept	1	187	15	12	<.0001	.	0
RAIN	1	2.0E-02	1.8E-02	1	0.2729	1	1

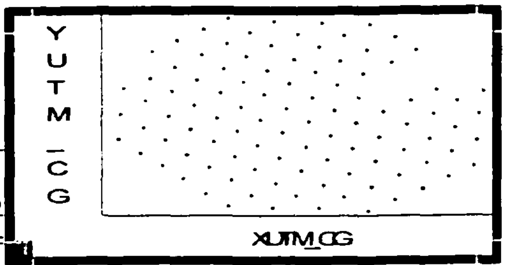
B) Nitrogen Applied and Yield

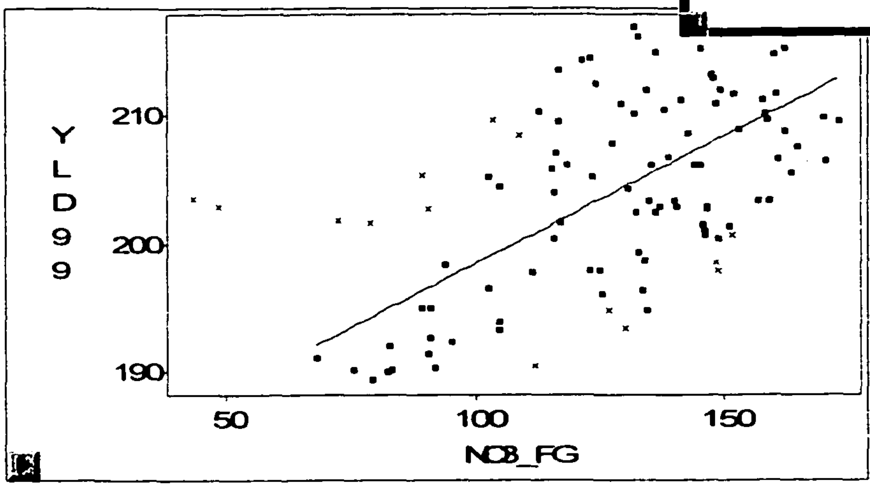
B.1. Nitrogen applied through fertigation

YLD99	=	NO3_FG
Response Distribution:		Normal
Link Function:		Identity

Model Equation

YLD99 = 178.325 + 0.2000 NO3_FG





** > marks are edges areas and were take out from the analysis.

Figure 83. Relationships between nitrogen applied through fertigation and yield – center pivot 39.

Parametric Regression Fit								
		Model		Error				
Curve	Degree(Polynomi	DF	Mean Squa	DF	Mean Squa	R-Squa	F Stat	Pr > F
————	1 [redacted]	1	2188	87	32	4.E-01	69	13E-13

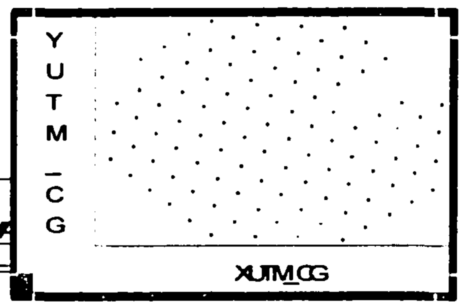
Summary of Fit			
Mean of Response	204.3678	R-Square	0.4406
Root MSE	5.6511	Adj R-Sq	0.4342

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	2188.1719	2188.1719	68.52	<.0001
Error	87	2778.2943	31.9344		
C Total	88	4966.4662			

Type III Tests					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
NO3_FG	1	2188.1719	2188.1719	68.52	<.0001

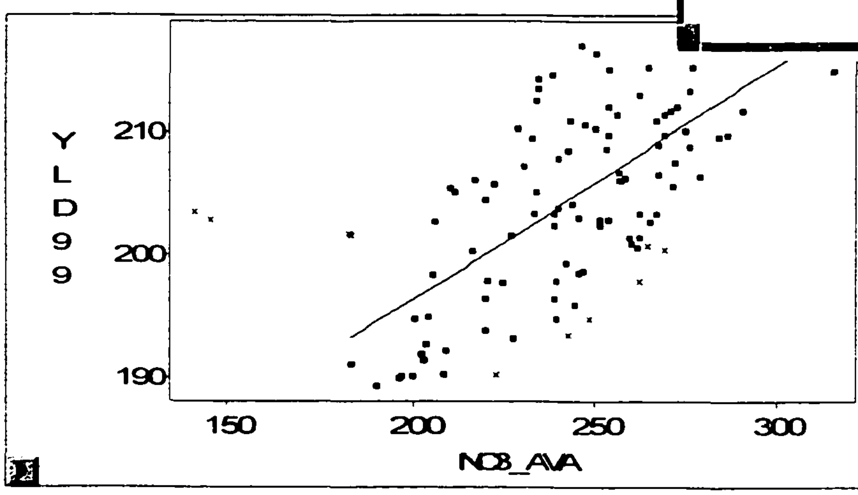
Parameter Estimates							
Variable	DF	Estimate	Std Error	t Stat	Pr >|t|	Tolerance	Var Inflation
Intercept	1	178	3	56	<.0001	.	0
NO3_FG	1	2.0E-01	2.4E-02	8	<.0001	1	1.0E+00

B.2. Total nitrogen applied



YLD99	=	NO3_AVA
Response Distribution:		Normal
Link Function:		Identity

Model Equation				
YLD99	=	157.911	+	0.1917 NO3_AVA



** > marks are edges areas and were take out from the analysis.

Figure 84. Relationships between total nitrogen applied and yield – center pivot 39.

Parametric Regression Fit									
		Model		Error					
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F	
————	1 [redacted]	1	**	91	30	.5	78	708E-16	

Summary of Fit			
Mean of Response	204.4516	R-Square	0.4616
Root MSE	5.4599	Adj R-Sq	0.4557

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	2325.5192	2325.5192	78.01	<.0001
Error	91	2712.7525	29.8105		
C Total	92	5038.2717			

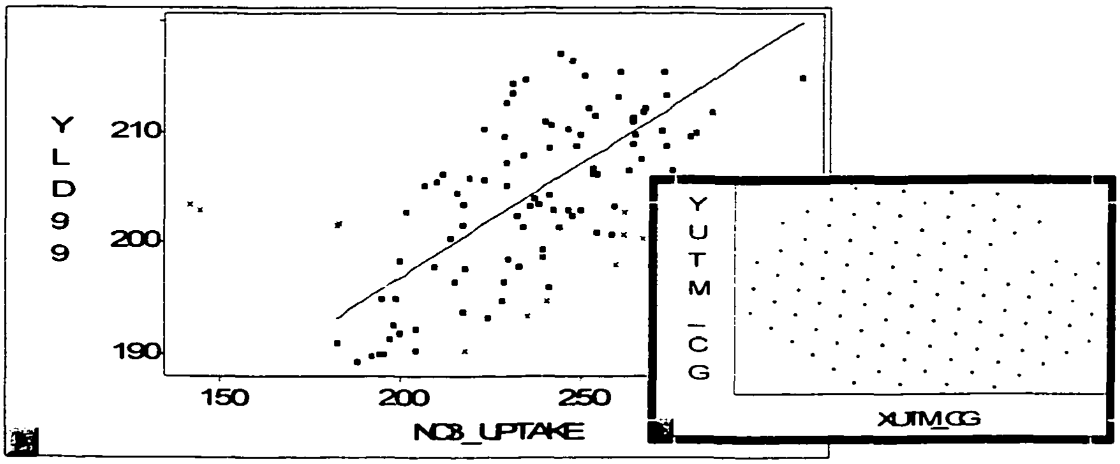
Type III Tests					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
NCB_AVA	1	2325.5192	2325.5192	78.01	<.0001

Parameter Estimates							
Variable	DF	Estimate	Std Error	t Stat	Pr >|t|	Tolerance	Var Inflation
Intercept	1	158	5	30	<.0001	.	0
NCB_AVA	1	1.9E-01	2.2E-02	9	<.0001	1	1

C) Nitrogen uptake and yield

YLD99 = NCB_UPTAKE	
Response Distribution:	Normal
Link Function:	Identity

Model Equation
YLD99 = 155.417 + 0.2066 NCB_UPTAKE



** > marks are edges areas and were take out from the analysis.

Figure 85. Relationships between nitrogen uptake and yield – center pivot 39.

Parametric Regression Fit								
		Model		Error				
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F
———	1 [redacted]	1	**	90	27	.5	96	707E-18

Summary of Fit			
Mean of Response	204.4677	R-Square	0.5168
Root MSE	5.1999	Adj R-Sq	0.5114

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	2602.5202	2602.5202	96.25	<.0001
Error	90	2433.5324	27.0392		
C Total	91	5036.0526			

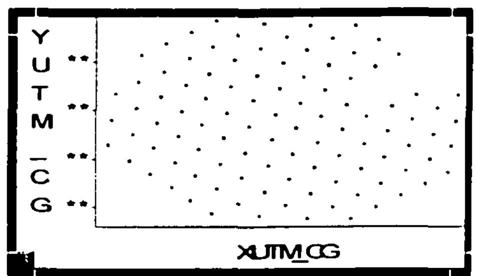
Type III Tests					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
NO3_UPTAKE	1	2602.5202	2602.5202	96.25	<.0001

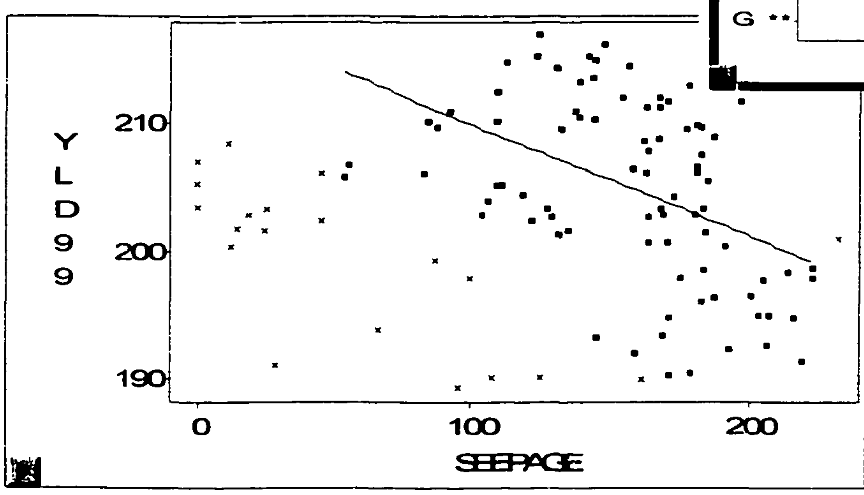
Parameter Estimates							
Variable	DF	Estimate	Std Error	t Stat	Pr >|t|	Tolerance	Var Inflation
Intercept	1	155	5	31	<.0001	.	0
NO3_UPTAKE	1	2.1E-01	2.1E-02	10	<.0001	1	1

D) Deep percolation (seepage) and yield

YLD99 = SEEPAGE
Response Distribution: Normal
Link Function: Identity

Model Equation
YLD99 = 218.766 - 0.0876 SEEPAGE





** > marks are edges areas and were take out from the analysis.

Figure 86. Relationships between deep percolation (seepage) and yield – center pivot 39.

Parametric Regression Fit

Curve	Degree(Polynomia	Model DF	Model Mean Squar	Error DF	Error Mean Squar	R-Square	F Stat	Pr > F
———	1	1	*	*	*	0	*	1.3E-05

Summary of Fit

Mean of Response	204.9905	R-Square	0.2106
Root MSE	6.4215	Adj R-Sq	0.2009

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	891.1249	891.1249	21.61	<.0001
Error	81	3340.0653	41.2354		
C Total	82	4231.1902			

Type III Tests

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
SEEPAGE	1	891.1249	891.1249	21.61	<.0001

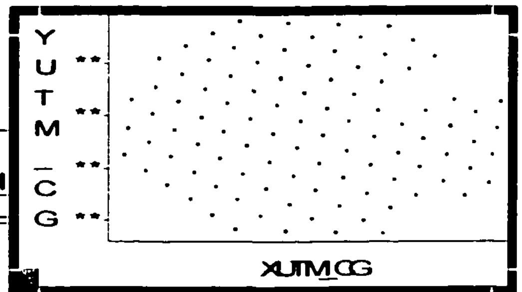
Parameter Estimates

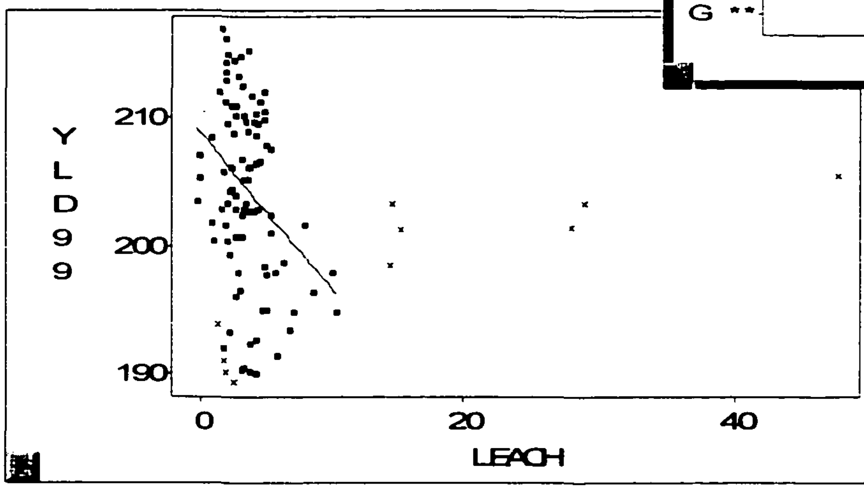
Variable	DF	Estimate	Std Error	t Stat	Pr >|t|	Tolerance	Var Inflation
Intercept	1	218.77	3.046	71.821	<.0001	.	0
SEEPAGE	1	-88E-3	2 E-02	-4.649	<.0001	1	1.E+00

E) Leaching and Yield

YLD99 = LEACH
Response Distribution: Normal
Link Function: Identity

Model Equation
YLD99 = 209.029 - 1.2039 LEACH





** > marks are edges areas and were take out from the analysis.

Figure 87. Relationships between deep percolation (seepage) and yield – center pivot 39.

Parametric Regression Fit									
		Model		Error					
Curve	Degree(Polynom	DF	Mean Squa	DF	Mean Squa	R-Squa	F Stat	Pr > F	
———	1	1	498.1894	91	46.7839	0.1048	10.65	2E-03	

Summary of Fit			
Mean of Response	204.5545	R-Square	0.1048
Root MSE	6.8399	Adj R-Sq	0.0949

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	498.1894	498.1894	10.65	0.0016
Error	91	4257.3383	46.7839		
C Total	92	4755.5277			

Type III Tests					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
LEACH	1	498.1894	498.1894	10.65	0.0016

Parameter Estimates							
Variable	DF	Estimate	Std Error	t Stat	Pr >|t|	Tolerance	Var Inflation
Intercep	1	209.0290	1.5438	135.40	96E-108	.	0
LEACH	1	-1.2039	0.3689	-3.26	0.0016	1.0000	1.0000

8.2. Cluster analysis

8.2.1. Center Pivot 6 - season 98

A) Cluster analysis procedure used to run in SAS 8.0 with sand percentages per layer (0-1, 1-3, 3-4 ft) and total leaching as variables.

GRIDCELL_I GRID_ID LOCATION COL ROW LONG_CG LAT_CG XUTM_CG YUTM_CG TOPO06 O_M SAND_01 KS_01 SAND_13 KS__13 SAND_34 KS__34 RAIN ET SEEPAGE APR MAY JUN JUL AUG SEP OCT NOV DEC LEACH NO3_GW NO3_FG NO3_SUF N03_1_98 N03_2_98 N03_3_98 NO3_4_98 AVE_LAY_98 N03_1_99 N03_2_99 N03_3_99 NO3_4_99 AVE_LAY_99 NO3_AVA NO3_UPTAKE YLD98;

```
PROC cluster data =PC06_CL_98 method=centroid trim = 1 k= 8 std
outtree=outtest;
var SAND_01 SAND_13 SAND_34 LEACH;
copy GRIDCELL_I GRID_ID LOCATION COL ROW LONG_CG LAT_CG
XUTM_CG YUTM_CG TOPO06 O_M SAND_01 KS_01 SAND_13 KS__13
SAND_34 KS__34 RAIN ET SEEPAGE APR MAY JUN JUL AUG SEP OCT
NOV DEC LEACH NO3_GW NO3_FG NO3_SUF N03_1_98 N03_2_98
N03_3_98 NO3_4_98 AVE_LAY_98 N03_1_99 N03_2_99 N03_3_99
NO3_4_99 AVE_LAY_99 NO3_AVA NO3_UPTAKE YLD98;
run;
```

The CLUSTER procedure results

Centroid Hierarchical Cluster Analysis
Eigenvalues of the Correlation Matrix

	Eigenvalue	Difference	Proportion	Cumulative
1	2.54073686	1.45755506	0.5081	0.5081
2	1.08318180	0.38081419	0.2166	0.7248
3	0.70236761	0.23482555	0.1405	0.8653
4	0.46754207	0.26137041	0.0935	0.9588
5	0.20617166		0.0412	1.0000

The data have been standardized to mean 0 and variance = 1
Root-Mean-Square Total-Sample Standard Deviation = 1
Root-Mean-Square Distance Between Observations = 3.16

Table 29. The CLUSTER procedure centroid hierarchical cluster analysis for leach and texture, center pivot 6 for 1998.

Cluster History

				Norm	T
				Cent	i
NCL	--Clusters	Joined---	FREQ	Dist	e
15	CL23	CL47	10	0.5682	
14	CL16	CL17	17	0.5768	
13	CL19	OB38	11	0.5962	
12	OB28	CL21	4	0.6062	
11	CL13	CL64	13	0.6437	
10	CL11	CL24	71	0.6392	
9	CL12	OB56	5	0.6573	
8	CL72	OB96	3	0.6656	
7	CL14	CL18	23	0.6729	
6	CL7	CL15	33	0.7545	
5	CL6	CL9	38	0.7246	
4	**CL10**	**OB98**	**72**	**0.8168**	
3	CL5	OB11	39	0.8419	
2	CL3	CL4	111	0.8939	
1	CL2	CL8	114	1.3434	

I decide to run the analysis with only 4 cluster (see table above) due to fit better with the data.

```
Proc tree data =outtest n=4 out=clstr4;
copy GRIDCELL_I GRID_ID LOCATION COL ROW LONG_CG LAT_CG
XUTM_CG YUTM_CG TOPO06 O_M SAND_01 KS_01 SAND_13 KS__13
SAND_34 KS__34 RAIN ET SEEPAGE APR MAY JUN JUL AUG SEP OCT
NOV DEC LEACH NO3_GW NO3_FG NO3_SUF N03_1_98 N03_2_98
N03_3_98 NO3_4_98 AVE_LAY_98 N03_1_99 N03_2_99 N03_3_99
NO3_4_99 AVE_LAY_99 NO3_AVA NO3_UPTAKE YLD98;
run;
```

B) Cluster analysis procedure used to run in SAS 8.0 with topography levels and nitrogen applied through fertigation as variables.

```
*GRIDCELL_I GRID_ID LOCATION COL ROW LONG_CG LAT_CG
XUTM_CG YUTM_CG TOPO06 O_M SAND_01 KS_01 SAND_13 KS__13
SAND_34 KS__34 RAIN ET SEEPAGE APR MAY JUN JUL AUG SEP OCT
NOV DEC LEACH NO3_GW NO3_FG NO3_SUF N03_1_98 N03_2_98
N03_3_98 NO3_4_98 AVE_LAY_98 N03_1_99 N03_2_99 N03_3_99
NO3_4_99 AVE_LAY_99 NO3_AVA NO3_UPTAKE YLD98;

PROC cluster data =PC06_CL_98 method=centroid trim = 1 k= 8 std
outtree=outtest;
var TOPO06 NO3_FG;
copy GRIDCELL_I GRID_ID LOCATION COL ROW LONG_CG LAT_CG
XUTM_CG YUTM_CG TOPO06 O_M SAND_01 KS_01 SAND_13 KS__13
SAND_34 KS__34 RAIN ET SEEPAGE APR MAY JUN JUL AUG SEP OCT
NOV DEC LEACH NO3_GW NO3_FG NO3_SUF N03_1_98 N03_2_98
N03_3_98 NO3_4_98 AVE_LAY_98 N03_1_99 N03_2_99 N03_3_99
NO3_4_99 AVE_LAY_99 NO3_AVA NO3_UPTAKE YLD98;
run;
```

The CLUSTER procedure results
centroid hierarchical cluster analysis
Eigenvalues of the correlation matrix

	Eigenvalue	Difference	Proportion	Cumulative
1	4.54511622	3.49905697	0.6493	0.6493
2	1.04605925	0.27023789	0.1494	0.7987
3	0.77582136	0.32122063	0.1108	0.9096
4	0.45460073	0.35067377	0.0649	0.9745
5	0.10392696	0.04421626	0.0148	0.9894
6	0.05971070	0.04494593	0.0085	0.9979
7	0.01476477		0.0021	1.0000

The data have been standardized to mean 0 and variance = 1
Root-Mean-Square Total-Sample Standard Deviation = 1
Root-Mean-Square Distance Between Observations = 3.74

Table 30. The CLUSTER procedure centroid hierarchical cluster analysis for topography and fertigation, center pivot 6 for 1998.

Cluster History

				Norm	T
				Cent	i
NCL	--Clusters Joined---		FREQ	Dist	e
15	CL17	CL37	14	0.3808	
14	CL20	CL27	50	0.3849	
13	CL14	CL21	63	0.385	
12	CL39	CL19	5	0.3993	
11	CL33	CL18	8	0.4091	
10	OB106	OB116	2	0.419	
9	CL28	CL11	20	0.4451	
8	CL12	CL24	9	0.4718	
7	CL9	CL25	22	0.5434	
6	CL15	CL13	77	0.5616	
5	OB38	CL8	10	0.7117	
4	**CL5**	**CL10**	**12**	**0.781**	
3	CL4	CL16	15	0.792	
2	CL6	CL7	99	1.0124	
1	CL2	CL3	114	1.3564	

As I did before, I decide to run the analysis with only 4 cluster (see table above) due to fit better with the data.

```
proc tree data =outtest n=4 out=clstr4;
copy GRIDCELL_I GRID_ID LOCATION COL ROW LONG_CG LAT_CG XUTM_CG YUTM_CG TOPO06 O_M SAND_01 KS_01 SAND_13 KS__13 SAND_34 KS__34 RAIN ET SEEPAGE APR MAY JUN JUL AUG SEP OCT NOV DEC LEACH NO3_GW NO3_FG NO3_SUF N03_1_98 N03_2_98 N03_3_98 NO3_4_98 AVE_LAY_98 N03_1_99 N03_2_99 N03_3_99 NO3_4_99 AVE_LAY_99 NO3_AVA NO3_UPTAKE YLD98;
run;
```

8.2.2. Center Pivot 6 - season 99

A) Cluster analysis procedure used to run in SAS 8.0 with sand percentages per layer and total leaching as variables.

```
*GRIDCELL_I GRID_ID LOCATION COL ROW LONG_CG LAT_CG
XUTM_CG YUTM_CG TOPO06 O_M SAND_01 KS_01 SAND_13 KS__13
SAND_34 KS__34 RAIN ET SEEPAGE JAN FEB MAR APR MAY JUN JUL
AUG SEP OCT NOV DEC LEACH NO3_GW NO3_FG NO3_SUF N03_1_00
N03_2_00 N03_3_00 NO3_4_00 AVE_LAY_00 N03_1_99 N03_2_99
N03_3_99 NO3_4_99 AVE_LAY_99 NO3_AVA NO3_UPTAKE YLD99;

PROC cluster data =PC06_CL_99 method=centroid noprint trim = 1 k= 8 std
outtree=outtest;
var SAND_01 SAND_13 SAND_34 Leach;
copy GRIDCELL_I GRID_ID LOCATION COL ROW LONG_CG LAT_CG
XUTM_CG YUTM_CG TOPO06 O_M SAND_01 KS_01 SAND_13 KS__13
SAND_34 KS__34 RAIN ET SEEPAGE JAN FEB MAR APR MAY JUN JUL
AUG SEP OCT NOV DEC LEACH NO3_GW NO3_FG NO3_SUF N03_1_00
N03_2_00 N03_3_00 NO3_4_00 AVE_LAY_00 N03_1_99 N03_2_99
N03_3_99 NO3_4_99 AVE_LAY_99 NO3_AVA NO3_UPTAKE YLD99;
run;
```

The CLUSTER procedure results
centroid hierarchical cluster analysis
Eigenvalues of the correlation matrix

	Eigenvalue	Difference	Proportion	Cumulative
1	4.15373792	2.82513807	0.5934	0.5934
2	1.32859986	0.57369746	0.1898	0.7832
3	0.75490239	0.36015566	0.1078	0.8910
4	0.39474673	0.15954472	0.0564	0.9474
5	0.23520201	0.14828404	0.0336	0.9810
6	0.08691798	0.04102487	0.0124	0.9934
7	0.04589310		0.0066	1.0000

The data have been standardized to mean 0 and variance = 1
Root-Mean-Square Total-Sample Standard Deviation = 1
Root-Mean-Square Distance Between Observations = 3.74

Table 31. The CLUSTER procedure centroid hierarchical cluster analysis for leach and texture, center pivot 6 for 1999

Cluster History

Norm	T				
				Cent	i
NCL	--Clusters Joined---		FREQ	Dist	e
14	CL29	CL30	36	0.543	
13	CL14	CL27	40	0.550	
12	CL15	OB64	27	0.592	
11	CL36	CL20	26	0.596	
10	CL17	CL53	5	0.608	
9	CL10	CL19	9	0.615	
8	CL9	CL13	49	0.589	
7	CL11	CL32	29	0.670	
6	CL8	CL18	52	0.686	
5	CL12	CL21	30	0.689	
4	**CL6**	**OB98**	**53**	**0.724**	
3	CL4	CL7	82	0.738	
2	CL3	CL62	84	0.820	
1	CL2	CL5	114	0.986	

As I did before, I decide to run the analysis with only 4 cluster (see table above) due to fit better with the data.

```
proc tree data =outtest n=4 out=clstr4;
copy GRIDCELL_I GRID_ID LOCATION COL ROW LONG_CG LAT_CG
XUTM_CG YUTM_CG TOPO06 O_M SAND_01 KS_01 SAND_13 KS__13
SAND_34 KS__34 RAIN ET SEEPAGE JAN FEB MAR APR MAY JUN JUL
AUG SEP OCT NOV DEC LEACH NO3_GW NO3_FG NO3_SUF N03_1_00
N03_2_00 N03_3_00 NO3_4_00 AVE_LAY_00 N03_1_99 N03_2_99
N03_3_99 NO3_4_99 AVE_LAY_99 NO3_AVA NO3_UPTAKE YLD99;
run;
```

B) Cluster analysis procedure used to run in SAS 8.0 with topography levels and nitrogen applied through fertigation as variables.

```
*GRIDCELL_I GRID_ID LOCATION COL ROW LONG_CG LAT_CG
XUTM_CG YUTM_CG TOPO06 O_M SAND_01 KS_01 SAND_13 KS__13
SAND_34 KS__34 RAIN ET SEEPAGE JAN FEB MAR APR MAY JUN JUL
AUG SEP OCT NOV DEC LEACH NO3_GW NO3_FG NO3_SUF N03_1_00
N03_2_00 N03_3_00 NO3_4_00 AVE_LAY_00 N03_1_99 N03_2_99
N03_3_99 NO3_4_99 AVE_LAY_99 NO3_AVA NO3_UPTAKE YLD99;

PROC cluster data =PC06_CL_99 method=centroid trim = 1 k= 8 std
outtree=outtest;
var TOPO06 NO3_FG;
```

copy GRIDCELL_I GRID_ID LOCATION COL ROW LONG_CG LAT_CG XUTM_CG YUTM_CG TOPO06 O_M SAND_01 KS_01 SAND_13 KS__13 SAND_34 KS__34 RAIN ET SEEPAGE JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC LEACH NO3_GW NO3_FG NO3_SUF N03_1_00 N03_2_00 N03_3_00 NO3_4_00 AVE_LAY_00 N03_1_99 N03_2_99 N03_3_99 NO3_4_99 AVE_LAY_99 NO3_AVA NO3_UPTAKE YLD99;
run;

The CLUSTER procedure results
centroid hierarchical cluster analysis
Eigenvalues of the correlation matrix

	Eigenvalue	Difference	Proportion	Cumulative
1	2.54073686	1.45755506	0.5081	0.5081
2	1.08318180	0.38081419	0.2166	0.7248
3	0.70236761	0.23482555	0.1405	0.8653
4	0.46754207	0.26137041	0.0935	0.9588
5	0.20617166		0.0412	1.0000

The data have been standardized to mean 0 and variance = 1
Root-Mean-Square Total-Sample Standard Deviation = 1
Root-Mean-Square Distance Between Observations = 3.16

Table 32. The CLUSTER procedure centroid hierarchical cluster analysis for topography and fertigation, center pivot 6 for 1999.
Cluster History

				Norm	T
				Cent	i
NCL	--Clusters	Joined---	FREQ	Dist	e
15	CL68	OB85	3	0.3338	
14	CL18	CL24	55	0.3445	
13	CL23	CL28	13	0.3647	
12	CL13	CL30	18	0.405	
11	CL20	CL93	12	0.4377	
10	CL16	CL11	25	0.4221	
9	CL17	CL31	6	0.4531	
8	OB101	CL19	5	0.5035	
7	CL14	CL15	58	0.5168	
6	CL9	CL8	11	0.5645	
5	CL10	CL7	83	0.7112	
4	**CL12**	**OB52**	**19**	**0.7875**	
3	CL6	OB95	12	1.0212	
2	CL5	CL3	95	1.0271	
1	CL2	CL4	114	1.2892	

As I did before, I decide to run the analysis with only 4 cluster (see table above) due to fit better with the data.

```
proc tree data =outtest n=4 out=clstr4;
copy GRIDCELL_I GRID_ID LOCATION COL ROW LONG_CG LAT_CG
XUTM_CG YUTM_CG TOPO06 O_M SAND_01 KS_01 SAND_13 KS__13
SAND_34 KS__34 RAIN ET SEEPAGE JAN FEB MAR APR MAY JUN JUL
AUG SEP OCT NOV DEC LEACH NO3_GW NO3_FG NO3_SUF N03_1_00
N03_2_00 N03_3_00 NO3_4_00 AVE_LAY_00 N03_1_99 N03_2_99
N03_3_99 NO3_4_99 AVE_LAY_99 NO3_AVA NO3_UPTAKE YLD99;
run;
```

8.2.3. Center Pivot 39 - season 99

A) Cluster analysis procedure used to run in SAS 8.0 with sand percentages per layer and total leaching as variables.

```
*GRIDCELL_I GRID_ID LOCATION COL ROW LONG_CG LAT_CG
XUTM_CG YUTM_CG TOPO06 O_M SAND_01 KS_01 SAND_13 KS__13
SAND_34 KS__34 RAIN ET SEEPAGE JAN FEB MAR APR MAY JUN JUL
AUG SEP OCT NOV DEC LEACH NO3_GW NO3_FG NO3_SUF N03_1_00
N03_2_00 N03_3_00 NO3_4_00 AVE_LAY_00 N03_1_99 N03_2_99
N03_3_99 NO3_4_99 AVE_LAY_99 NO3_AVA NO3_UPTAKE YLD99;

PROC cluster data =PC06_CL_99 method=centroid trim = 1 k= 8 std
outtree=outtest;
var TOPO06 NO3_FG;
copy GRIDCELL_I GRID_ID LOCATION COL ROW LONG_CG LAT_CG
XUTM_CG YUTM_CG TOPO06 O_M SAND_01 KS_01 SAND_13 KS__13
SAND_34 KS__34 RAIN ET SEEPAGE JAN FEB MAR APR MAY JUN JUL
AUG SEP OCT NOV DEC LEACH NO3_GW NO3_FG NO3_SUF N03_1_00
N03_2_00 N03_3_00 NO3_4_00 AVE_LAY_00 N03_1_99 N03_2_99
N03_3_99 NO3_4_99 AVE_LAY_99 NO3_AVA NO3_UPTAKE YLD99;
run;
```

The CLUSTER procedure results
centroid hierarchical cluster analysis
Eigenvalues of the correlation matrix

	Eigenvalue	Difference	Proportion	Cumulative
1	4.54511622	3.49905697	0.6493	0.6493
2	1.04605925	0.27023789	0.1494	0.7987
3	0.77582136	0.32122063	0.1108	0.9096
4	0.45460073	0.35067377	0.0649	0.9745
5	0.10392696	0.04421626	0.0148	0.9894
6	0.05971070	0.04494593	0.0085	0.9979
7	0.01476477		0.0021	1.0000

The data have been standardized to mean 0 and variance = 1
Root-Mean-Square Total-Sample Standard Deviation = 1
Root-Mean-Square Distance Between Observations = 3.74

Table 33. The CLUSTER procedure centroid hierarchical cluster analysis for leach and texture, center pivot 39 for 1999.

Cluster History

NCL	--Clusters Joined---		FREQ	Norm Cent Dist	Tie
15	OB23	CL16	3	0.4351	
14	CL17	CL31	34	0.436	
13	CL19	CL60	8	0.4663	
12	CL33	CL20	7	0.4707	
11	OB13	OB94	2	0.5026	
10	CL12	CL18	30	0.5188	
9	CL10	CL23	36	0.5049	
8	CL9	CL24	44	0.5265	
7	CL14	CL52	39	0.5441	
6	CL15	CL13	11	0.6538	
5	CL7	CL8	83	0.7315	
4	**CL5**	**CL22**	**87**	**0.7379**	
3	CL4	CL11	89	0.9794	
2	CL3	CL6	100	1.3198	
1	CL2	OB89	101	1.8641	

As I did before, I decide to run the analysis with only 4 cluster (see table above) due to fit better with the data.

proc tree data =outtest n=**4** out=clstr4;
copy GRIDCELL_I GRID_ID LOCATION COL ROW LONG_CG LAT_CG XUTM_CG YUTM_CG TOPO06 O_M SAND_01 KS_01 SAND_13 KS__13 SAND_34 KS__34 RAIN ET SEEPAGE JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC LEACH NO3_GW NO3_FG NO3_SUF N03_1_00 N03_2_00 N03_3_00 NO3_4_00 AVE_LAY_00 N03_1_99 N03_2_99 N03_3_99 NO3_4_99 AVE_LAY_99 NO3_AVA NO3_UPTAKE YLD99;
run;

B) Cluster analysis procedure used to run in SAS 8.0 with topography levels and nitrogen applied through fertigation as variables.

*GRIDCELL_I GRID_ID COL ROW LONG_CG LAT_CG XUTM_CG YUTM_CG TOPO39 SAND_01 Ks_01 SAND_13 KS__13 SAND_34 KS__34 RAIN ET SEEPAGE JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC LEACH NO3_GW NO3_FG NO3_SUF NO3_INI_99 NO3_INI_00 NO3_DIF_ST NO3_AVA NO3_UPTAKE YLD99;

PROC cluster data =Pc39_cl_99 method=centroid trim = **1** k= **8** std outtree=outtest;
var TOPO39 NO3_FG;
copy GRIDCELL_I GRID_ID COL ROW LONG_CG LAT_CG XUTM_CG YUTM_CG TOPO39 SAND_01 Ks_01 SAND_13 KS__13 SAND_34 KS__34 RAIN ET SEEPAGE JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC LEACH NO3_GW NO3_FG NO3_SUF NO3_INI_99 NO3_INI_00 NO3_DIF_ST NO3_AVA NO3_UPTAKE YLD99;
run;

The CLUSTER Procedure results

Centroid hierarchical cluster analysis
Eigenvalues of the correlation matrix

	Eigenvalue	Difference	Proportion	Cumulative
1	4.54511622	3.49905697	0.6493	0.6493
2	1.04605925	0.27023789	0.1494	0.7987
3	0.77582136	0.32122063	0.1108	0.9096
4	0.45460073	0.35067377	0.0649	0.9745
5	0.10392696	0.04421626	0.0148	0.9894
6	0.05971070	0.04494593	0.0085	0.9979
7	0.01476477		0.0021	1.0000

The data have been standardized to mean 0 and variance = 1
Root-Mean-Square Total-Sample Standard Deviation = 1
Root-Mean-Square Distance Between Observations = 3.74

Table 34. The CLUSTER procedure centroid hierarchical cluster analysis for topography and fertigation, center pivot 39 for 1999.

Cluster History

NCL	--Clusters Joined---		FREQ	Norm Cent Dist	Tie
15	CL94	CL22	7	0.3544	
14	CL19	OB102	5	0.3817	
13	CL27	CL23	26	0.3826	
12	CL26	CL20	16	0.4048	
11	CL21	CL44	12	0.4189	
10	CL15	CL32	11	0.4339	
9	CL18	CL24	22	0.4509	
8	CL13	CL9	48	0.4639	
7	CL10	CL17	15	0.5133	
6	CL42	CL11	14	0.5836	
5	CL12	CL6	30	0.6571	
4	**CL8**	**CL16**	**51**	**0.682**	
3	CL5	CL4	81	0.8437	
2	CL7	CL14	20	1.0267	
1	CL3	CL2	101	1.0668	

As I did before, I decide to run the analysis with only 4 cluster (see table above) due to fit better with the data.

```
proc tree data =outtest n=4 out=clstr4;
copy GRIDCELL_I GRID_ID COL ROW LONG_CG LAT_CG XUTM_CG
YUTM_CG TOPO39 SAND_01 Ks_01 SAND_13 KS__13 SAND_34 KS__34
RAIN ET SEEPAGE JAN FEB MAR APR MAY JUN JUL AUG SEP OCT
NOV DEC LEACH NO3_GW NO3_FG NO3_SUF NO3_INI_99 NO3_INI_00
NO3_DIF_ST NO3_AVA NO3_UPTAKE YLD99;
run;
```

Appendix 9

Coarse Grid Data Figures

9.1. Spatial irrigation maps (based on coarse grid).

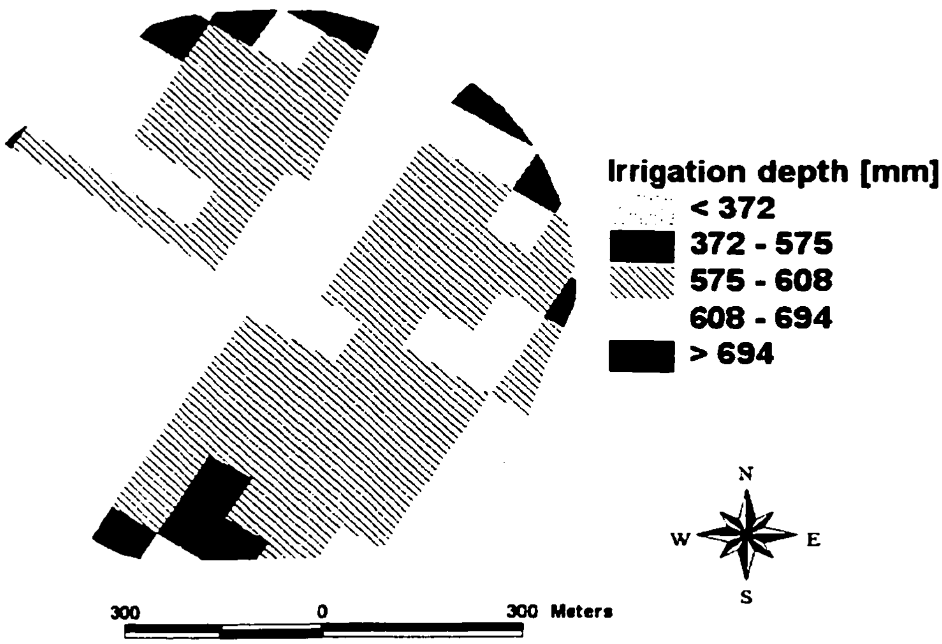


Figure 88. Season irrigation distribution (based in coarse grid) for center pivot 6 - 1998.

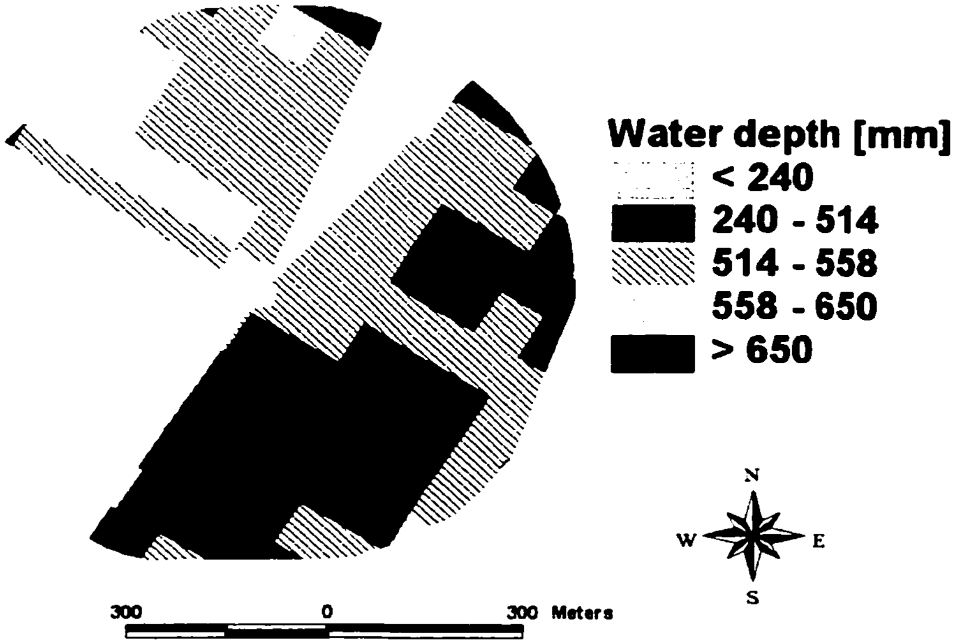


Figure 89. Season irrigation distribution (based in coarse grid) for center pivot 6 - 1999.

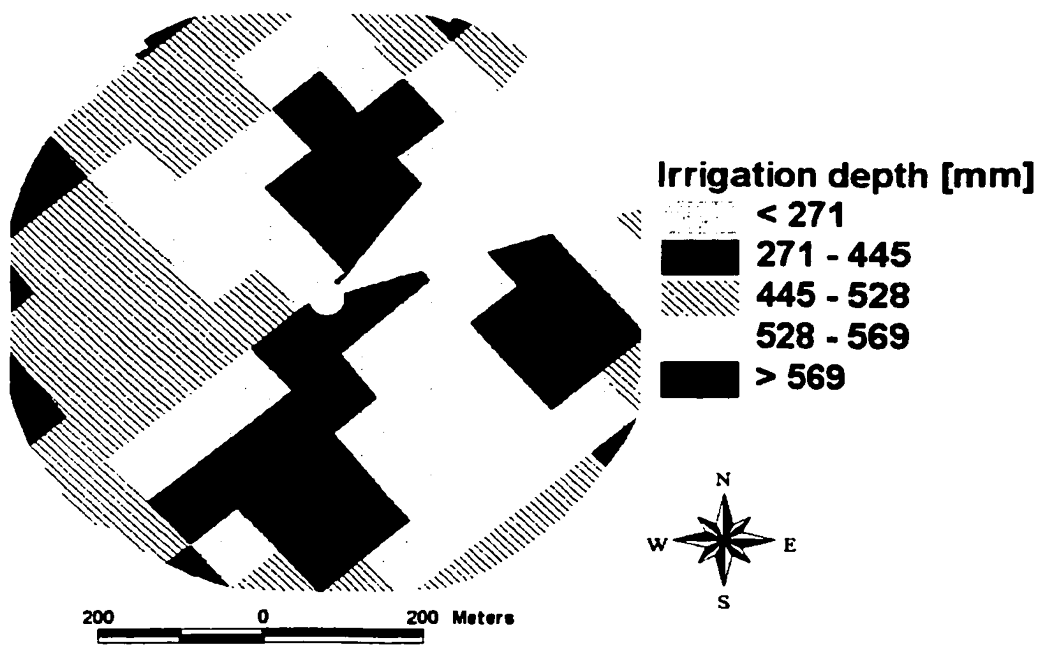


Figure 90. Season irrigation distribution (based in coarse grid) for center pivot 39 - 1999.

9.2. Spatial nitrogen application maps (based on coarse grid).

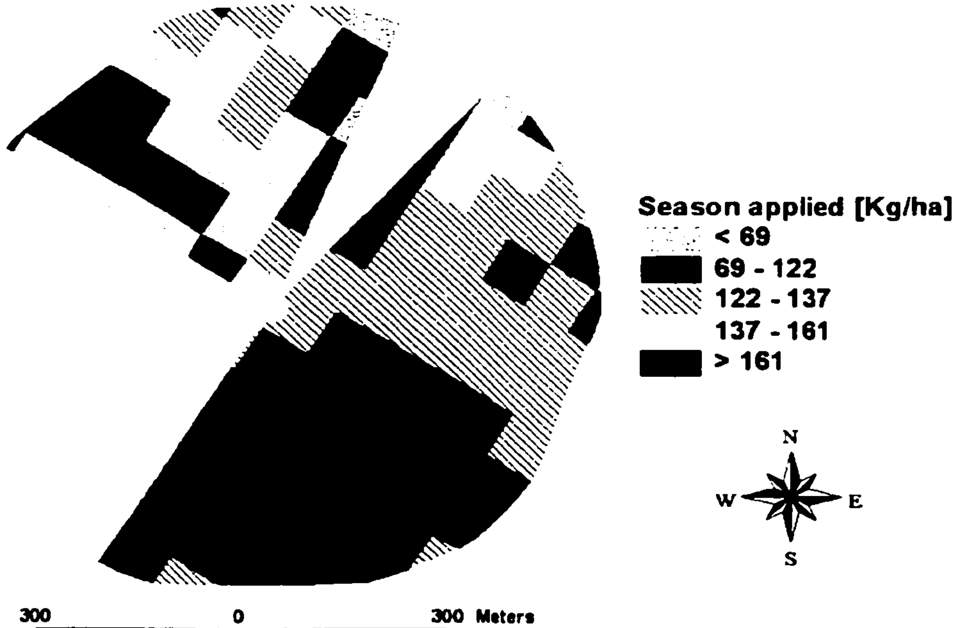


Figure 91. Season nitrogen apply (based in coarse grid) for center pivot 6 - 1998.

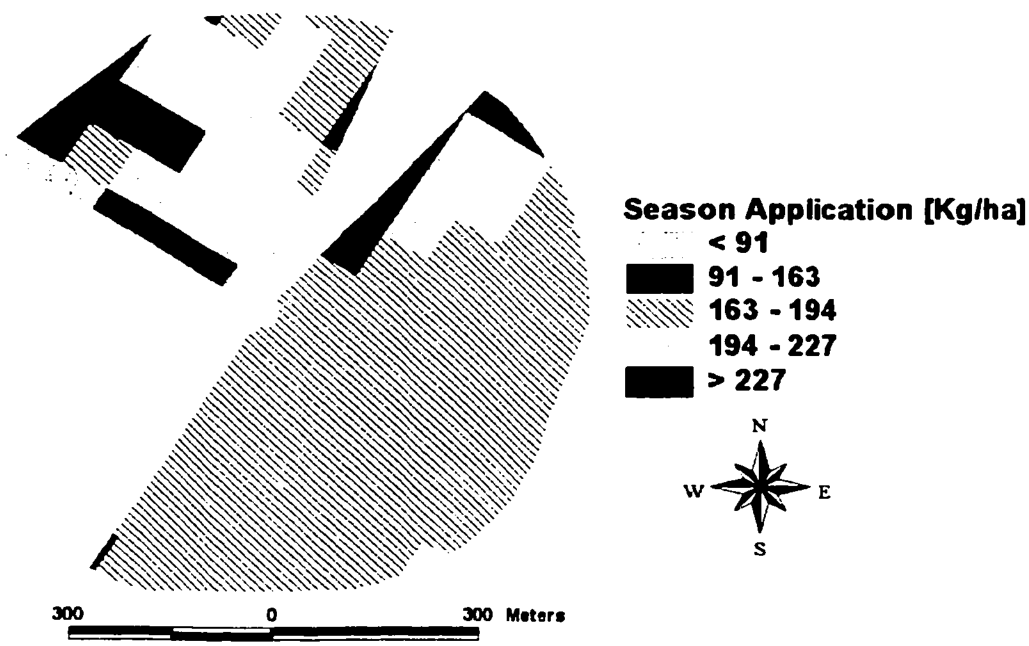


Figure 92. Season nitrogen apply (based in coarse grid) for center pivot 6 - 1999.

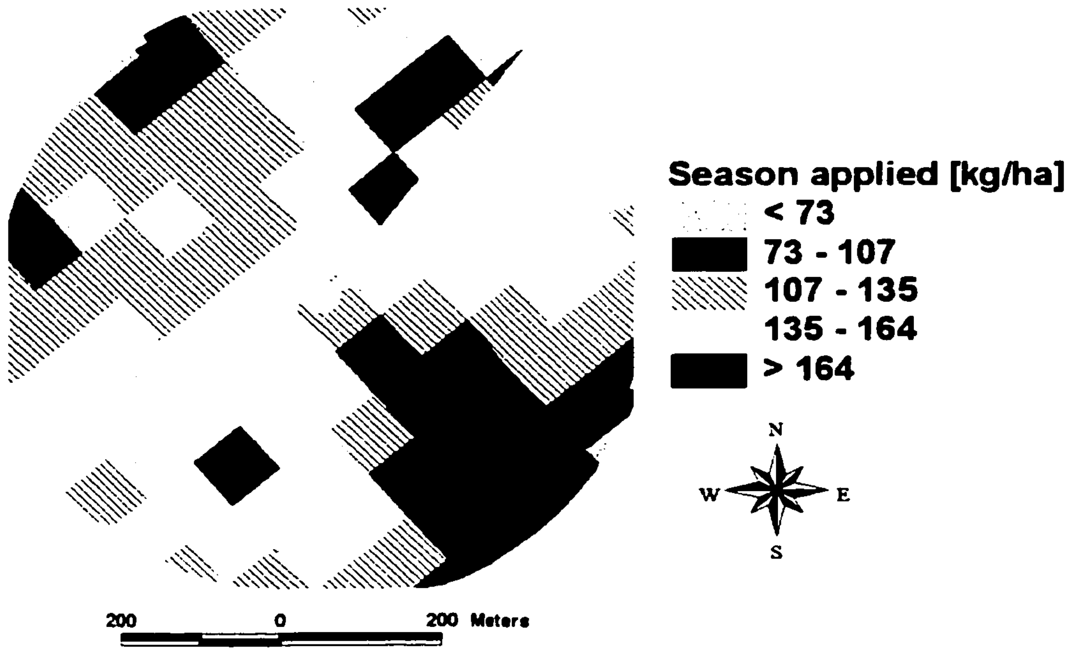


Figure 93. Season nitrogen apply (based in coarse grid) for center pivot 39 - 1999.

9.3. Evapotranspiration maps

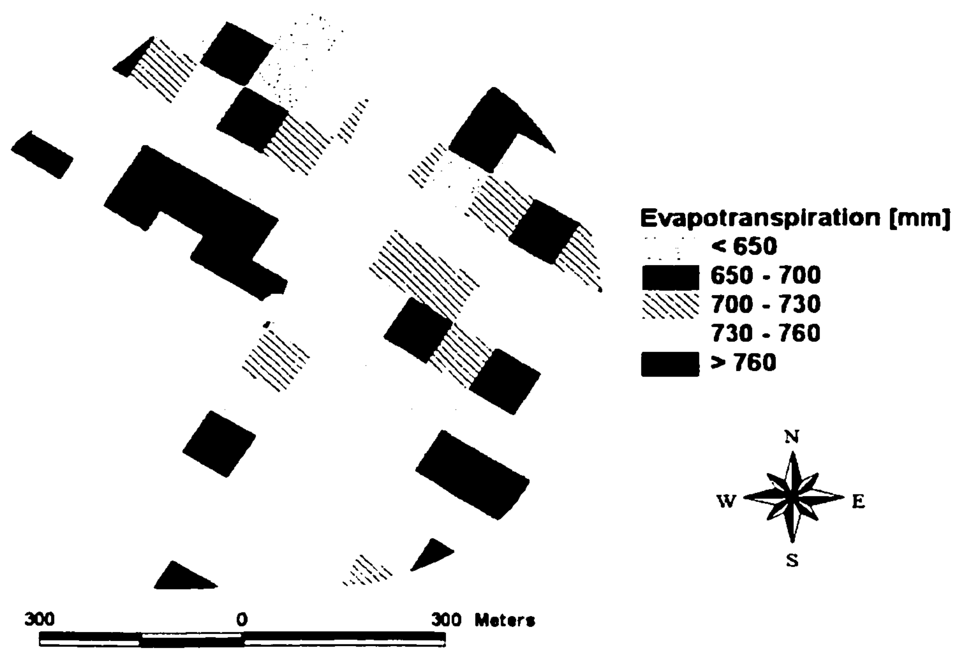


Figure 94. Evapotranspiration season 1998, center pivot 6.

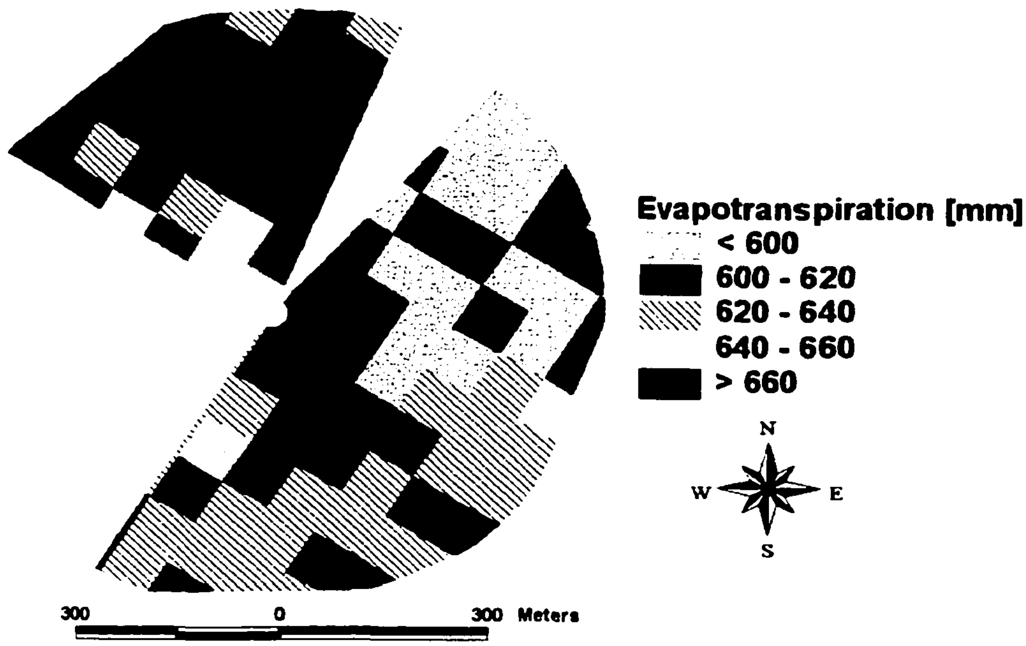


Figure 95. Evapotranspiration season 1999, center pivot 6.

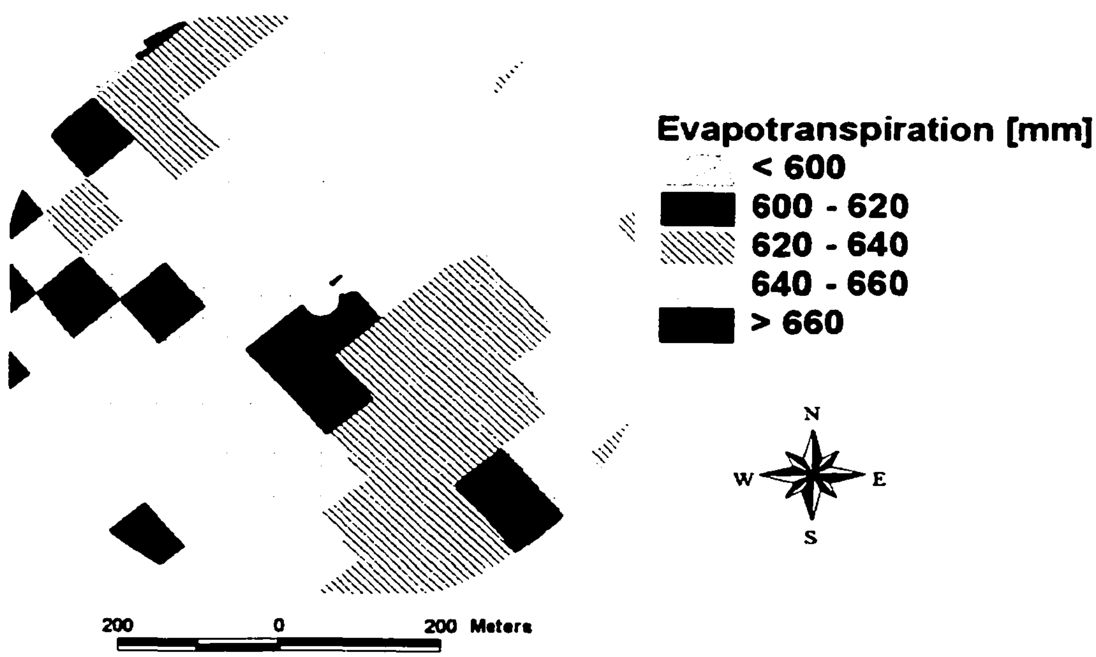


Figure 96. Evapotranspiration season 1999, center pivot 39.