DEVELOPMENT AND APPLICATION OF AN AGRICULTURAL SOIL PRODUCTIVITY EQUATION FOR RECLAIMED SURFACE MINES IN CLAY COUNTY, MINNESOTA

by

JON BRYAN BURLEY, ASLA

A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Masters of Landscape Architecture
in
Department of Landscape Architecture

Winnipeg, Manitoba, 1988

ISBN 0-315-47841-1

DEVELOPMENT AND APPLICATION OF AN AGRICULTURAL SOIL PRODUCTIVITY EQUATION FOR RECLAIMED SURFACE MINES IN CLAY COUNTY, MINNESOTA

BY

JON BRYAN BURLEY

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF LANDSCAPE ARCHITECTURE

I hereby declare that I am the sole author of this thesis. I authorize the University of Manitoba to lend this thesis to other institutions or individuals for the purpose of scholarly research.

Jon Bryan Burley

I further authorize the University of Manitoba to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

Jon Bryan Burley

The University of Manitoba requires the signatures of all persons using or photocopying this thesis. Please sign below, and give address and date.

ACKNOWLEDGEMENTS

The author wishes to express his sincerest appreciation to Malvern N. Jacobson for his correspondence concerning the collection of field data and to E. Doll for his inspirational work concerning soil productivity.

In addition, I wish to thank Dr. N. Kenkel, Dr. J. Stewart and C. H. Thomsen for their relentless and critical review of technical issues, procedures and writing clarity.

I would also like to thank A. E. Rattray for his foresight in developing a landscape architecture graduate program at the University of Manitoba and creating scholarly opportunities for practicing landscape architects to encounter scientific study. As creators of built-form, landscape architects are pursuing research topics that measure the effects various landscape treatments have upon the performance of designed space. I have greatly appreciated the opportunity to participate in this type of academic atmosphere.

Finally, I would like to thank my wife, Cheryl for her patience and understanding and to Paul Burley, P.E. (my brother) who was willing to participate in the reviewing of a graduate student's rough manuscript.

ABSTRACT OF THESIS

DEVELOPMENT AND APPLICATION OF AN
AGRICULTURAL SOIL PRODUCTIVITY EQUATION
FOR RECLAIMED SURFACE MINES
IN CLAY COUNTY, MINNESOTA

by JON BRYAN BURLEY, ASLA

This thesis addresses the development and application of an agricultural productivity equation for predicting neo-sol plant growth potential in Clay County, Minnesota. Soil factors examined in the study include percent organic matter, percent slope, percent rock fragments, hydraulic conductivity, electrical conductivity, pH, topographic position, available water holding capacity, bulk density and percent clay. Squared terms and two-factor interaction terms were also examined as possible regressors. A best equation was selected that had a multiple coefficient of determination of 0.7399 and has five significant regressors and intercept with $p<.0001$. The regressors are hydraulic conductivity, percent slope squared, bulk density times percent rock fragments, electrical conductivity times percent rock fragments and electrical conductivity times percent organic matter. The regressors predict soil suitability for a general crop model. The crops included in the model are wheat, oats, barley, soybeans, sugar beets, sunflowers and grasses/legumes.

The equation has been applied to a sand and gravel surface mine in Clay County, Minnesota. Four reclamation alternatives were examined for their ability to improve plant growth and for cost effectiveness. To improve the site's post-mining agricultural productivity, removing rock fragments, and grading the post-mine landscape to a 3% slope was determined to be the most effective and cost efficient reclamation approach. Soil compaction, increasing organic matter, increasing electrical conductivity and saving the topsoil were determined less cost effective. Soil productivity was significantly increased in all alternatives ($p<.05$).

TABLE OF CONTENTS

TABLE OF CONTENTS CONTINUED

TABLE OF CONTENTS CONTINUED

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

INTRODUCTION

PURPOSE/TOPIC

This thesis presents a mathematical equation to predict the degree of success in reclaiming gravel pits within Clay County, Minnesota, for agricultural purposes. In addition, the thesis presents step by step instructions to develop productivity equations for other regions or counties. It also illustrates how the equation can be applied.

LITERATURE REVIEW

Since surface mining can drastically alter the vegetation cover, soil profiles, landforms and hydrological characteristics of the post-mining landscape (Toy and Hadley 1987), post-mining land-use design professionals (Schellie and Rogier 1963 and Jenson 1967) have suggested that pre-mining planning and design is highly desirable. To reclaim surface mined lands, predictive reclamation modelling has been suggested as a tool to assist in post-mining landscape planning (Doll 1985). This pre-mining process can assist in the avoidance of rendering the post-mining landscape unsuitable for many post-mining land-uses.

In the past, despite this professional awareness, many surface mines were abandoned. These abandoned landscapes were unsuitable for most land-uses. Therefore laws were developed in some regions of the world to prevent the abandonment of surface mining lands and reclaim the landscape. Many of the current reclamation laws, regulations and standards have recently been reviewed by several authors. McLellan (1985) examined reclamation policies in Ontario, while Hall (1987) compared reclamation effectiveness between Montana and West Germany. Simpson (1985) discusses the issues surrounding the United States Public Law 95-87 which requires that the mined landscape be restored to its original contours. Cardwell (1985) describes the historical developments that led to reclamation legislation in the Kentucky surface coal mining industry. Each of these reclamation laws are relatively new. Many nations and states/provinces do not have reclamation laws.

In general, these reclamation laws are perceived to be relatively successful. However, these laws have presented a new problem. How does one quantitatively demonstrate reclamation success?

In some regions, reclamation regulations present criteria to determine reclamation success. For example, in North Dakota, reclamation regulations require that the reclaimed land contain vegetation productivity levels equal to or greater than productivity levels prior to mining (Doll, et al., 1984a). Yet during pre-mining planning and design, determining post-mining production levels has been difficult.

Predicting these post-mining productivity levels is difficult because, during the reconstruction of the land, soil profiles and soil patterns are created that did not exist in the past. These new soils (neo-sols) have unknown vegetation production potential. In an attempt to understand the problems associated with reconstructing soils, Plotkin (1986) reviewed the technical issues and difficulties concerning neo-sols. During reconstruction, the reclamation specialist can manipulate the physical and chemical attributes of these neo-sols; but there are only a few general guidelines for building productive neo-sols. The reclamation specialist is confronted with generating neo-sols in a situation where the neo-sol prescriptions are unspecific.

Several authorities have recently developed sets of neo-sol agricultural productivity guidelines. One set of guidelines to generate neo-sol prescriptions is the National Soils Handbook (1983), mentioned by Munn, et al., (1987). Several papers have been published suggesting criteria for neo-sol agricultural productivity (Omodt, et al 1975, Power, et al., 1978, Schafer 1979, Hargis 1984 and Schafer 1984). A western United States regional neo-sol surface mining reference is available, edited by Williams and Schuman (1987). In another effort, Lyle (1987) published a reclamation manual for surface mines. The criteria established by these authors are primarily simple and basic suggestions and not numerical quantitative prescriptions.

These guidelines are relatively recent because reclamation research is also only a relatively recent activity as documented by Gandt's (1984) historical review of reclamation research. During this period, neo-sols have been studied to some extent. Snarski, et al., (1981) described the physical and chemical characteristics between pre-mine and post-mine Illinois soils. They found that post-mine chemical and physical soil properties (pH, particle size distribution, phosphorus, cation exchange capacity, calcium carbonate equivalent and organic carbon) could be predicted. In east-central Texas, Chichester (1983) examined the usefulness of various soil horizons for incorporation into neo-sols. Schafer (1984) reported on the agricultural productivity of selected neo-sols in the Northern Great Plains. He found that some reclaimed landscapes may have greater agricultural capability than pre-mining landscapes. Toy and Shay (1987) recently compared the physical properties of neo-sols and native soils in Wyoming; they found few differences. McSweeney, et al., (1987) examined corn and soy bean productivity for eight neo-sol treatments. They recommend a mining wheel-conveyor-spreader system to place A-horizon material over 1 meter of soil material. At present, not all crops and surface mine regions are examined in the existing body of literature. However, neo-sol prescriptions are made with the current body of knowledge.

Once the neo-sol soil prescription has been made and the soil material is in place, the performance of the neo-sol is determined. In the past, post-mining crop yields were compared to reference areas to determine post-mining agricultural capability. The approach is a numerical comparison. The neo-sol must produce at least 90 percent vegetation cover, 90 percent diversity levels and 90 percent biomass productivity of the reference area. There must be a 90 percent statistical confidence level (Sindelar and Murdock 1985). In addition to the reference area method, Sindelar and Murdock (1985) described a similar method (historical use analysis) where the post-mining landscape yields were compared to pre-mining baseline conditions. In both the reference area method and historical use approach, the land was considered reclaimed once adequate or comparable crop yields were achieved. Approval meant that the surface mine operator had fulfilled reclamation obligations and reclamation bonds could be released. However, if the neo-sols do not meet performance standards, opportunities to amend the soils are often lost. Kline (1985) described the current problems with bond release programs and issues surrounding the Surface Mining Control and Reclamation Act (SMCRA).

Doll and Wollenhaupt (1985) suggested that comparing reclaimed land productivity levels to reference areas is unreliable and expensive. Walsh (1985) recommended the development of better quantitative models. He stated there needs to be a high quality baseline study, better soil overburden evaluation criteria and better monitoring data. Further, he believes these improvements would lead to a more reliable predictive model. To develop a more reliable evaluation, Vories (1985) described the current research required, and he suggested:

(1) that a standard must be established to evaluate crop productivity,

(2) statistical validation of indirect tests,

(3) the determination of which crops should be used to assess productivity potential.

These suggestions have led to a different soil evaluation approach. Doll, et al., (1984) suggest that neo-sol productivity must be determined from the actual physical and chemical properties of the neo-sol. Based upon this concept, Doll and Wollenhaupt (1985) have presented a numerical productivity index to assess the post-mining productivity level of neo-sols. The index attempts to mathematically predict soil productivity potential.

Neill (1979) proposed one of the first productivity index models; this model was later modified by Pierce, et al., (1983). Lohse, et al., (1985) described a land productivity formula for Illinois agricultural areas.

Based upon Pierce, et al., and Neill's models plus experience and extensive research, Doll (1985) and Doll and Wollenhaupt (1985) proposed the following productivity equation for the western North Dakota coal mining region (equation 1).

$$PI = 100\ TOP \sum_{i=1}^{n} (AWC_i \times SAR_i \times EC_i \times BD_i \times HC_i \times Wf_i) \quad \text{Eq 1}$$

Where

PI= Productivity Index
TOP= Topographic position
AWC= Available Water Holding Capacity
SAR= Sodium Absorption Ratio
EC= Electrical Conductivity
BD= Bulk Density
HC= Hydraulic Conductivity
WF= Rooting Depth Weighting Factor
i= Soil Depth

The equation attempts to predict soil productivity potential by assessing specific soil attributes. In Doll's and Wollenhaupt's (1985) equation, these measurable properties were selected based upon the experimentation and experience of the authors. Other soil properties could be selected; however soil factors not found in the equation were considered insignificant for western North Dakota soils.

Only root zone factors were considered for the equation. While it can be argued that climate, insects and other factors affect crop productivity, on a year to year basis these factors are highly variable and are only meaningful when one is attempting to quantify actual crop yield. Since climate is not being altered, it should not be included in the model. Soil productivity equations examine the portion of the landscape that is actually being disturbed. The portion being disturbed is the rooting zone (soil). These soil productivity equations are attempts to predict the agricultural potential of only the rooting zone.

Doll's equation is strictly a hypothetical equation. Presently, the equation is in the development process. For instance, the measuring scale and standardization of the soil properties have not yet been established. In addition, the equation building process to determine the best mathematical equation with a predicted stastistical reliability has not been conducted. Therefore the model cannot yet be mathematically applied to a real situation.

Within the present body of literature, equations with the ability to predict the optimum soil configurations require further development. Existing soil productivity indexes, while promising, have certain theoretical and statistical weaknesses. Specifically, they fail to address the following:

(1) Factor (attributes) interactions. According to Hicks (1982) factors in a multiple regression study may be:

(A) independent of other factors, interacting independently with a dependent variable,

(B) partially grouped with several factors interacting collectively but independent of other soil factors, or

C) completely interdependent.

In multiple regression equations, independent interactions are mathematically represented by an addition sign between variables. Factor interactions are represented mathematically by multiplication signs between the variables.

In the equation presented by Doll (1985) the productivity index is treated as though it were one large interaction model with all soil variables multiplied together.

(2) Quadratic expression of a factor. Soil factors affecting crop production may have quadratic forms. Quadratic forms are expressed mathematically by a second degree exponent (Nichols, et al., 1969).

(3) Slope constants. Soil factors affecting crop production may have intercept and slope values. In an equation, these values are termed beta coefficients.

(4) Interaction with specific crop types. Soil factors may affect various crop types differently. This means that numerous equations may be required to represent various crop types. For example, sugar beets and corn may not covary according to soil type. A separate equation for each crop may be necessary.

(5) Regional interaction. Soil factors may affect various crops differently in different regions. This means that a different equation may be required for each growing region. Each new equation may require new soil factors not necessary in other models. For example, Sodium Absorption Ratio may not be important in Eastern North American soils, but may be significant in Western Soils (Doll, et al., 1984b).

(6) Significant soil factors. Not all soil factors may be significant to the model. Each new soil factor may not

add significant refinements to the model and should not be used. For example, the factor pH can affect crop productivity. pH values that are either too low or too high may reduce yields. However, when combined with other factors such as electrical conductivity and % organic matter, pH may not contribute any improved accuracy to the prediction equation.

By addressing these six points, modern multivariate and regression statistical procedures can assist in overcoming the shortcomings of existing productivity models.

The importance of this approach lies in its ability to accurately and reliably predict the influences of soil disturbance and crop productivity. By predicting post-mining agricultural productivity during the pre-mining process, numerous post-mining site plan iterations can be generated to determine the optimum soil configuration. The landscape engineer can test various hypothetical neo-sol profiles and develop a post-mining reclamation plan that produces the most productive neo-sol possible. This means the effectiveness of reclamation activities can be improved. Typically, many post-mining reclamation plans treat the mining operation as one distinct process and the reclamation operation as another. Overburden, topsoil, excess sand and flumed fines are often handled twice, once during the mining operation itself and again during reclamation. Bauer (1982) suggests tht much of this double handling can be avoided.

Theoretically, the optimum soil configuration can be incorporated into the actual mining operation leading to cost savings by eliminating the second soil handling.

RESEARCH OBJECTIVES

The objectives of this study are:

(1) to review the development of neo-sol productivity models,

(2) investigate and produce a neo-sol productivity model for Clay County, Minnesota, and

(3) apply the derived model to a site in Clay County.

RESEARCH ASSUMPTIONS

The assumptions necessary to conduct the study are:

(1) the necessary field data to develop the model have already been collected (note: The data cannot be productivity values derived from an index. The data must be actual field data. Data derived from an index will only reveal an equation that approximates the index.),

(2) a multiple regression model is the type of model desired,

(3) a multiple regression model will yield significant results ($p<.05$ for factors in model),

(4) a significant multiple regression model can be used to demonstrate the development of a surface mining site in Clay County.

RESEARCH METHODOLOGY

The general approach to this study is as follows:

(1) review literature to understand the current body of knowledge concerning predictive reclamation modelling for neo-sols,

(2) describe study area,

(3) input relevant dependent and independent variables from study area into the Higher Education Computer Network (HECN) of the state of North Dakota,

(4) standardize all variables,

(5) perform principal component analysis upon the dependent variables to search for a linear combination of variables that can be expressed in univariate form,

(6) eliminate unlikely regressors through the RSReg procedure (a multiple regression procedure) in SAS (Statistical Analysis System) (cut-off value $p<.25$),

(7) perform maximum R-squared improvement analysis to select the best combination of regressors to predict crop productivity,

(8) perform multicollinearity and C-plot checks of the best model(s),

(9) plot observed versus predicted productivity scores of best model,

(10) compute predicted productivity of pre-mining study site,

(11) compute predicted productivity of post-mining study site in an abandoned state,

(12) compute predicted productivity of post-mining study site under various landscape configuration scenarios,

(13) search for most cost effective scenario,

(14) state conclusions.

Figure 1 is a flowchart describing the flow of data through the process. In the flowchart, one critical decision point is highlighted. At this point, the model is rejected or accepted. If the model is rejected, the next best equation is selected from diagnostics and C-Plot criteria.

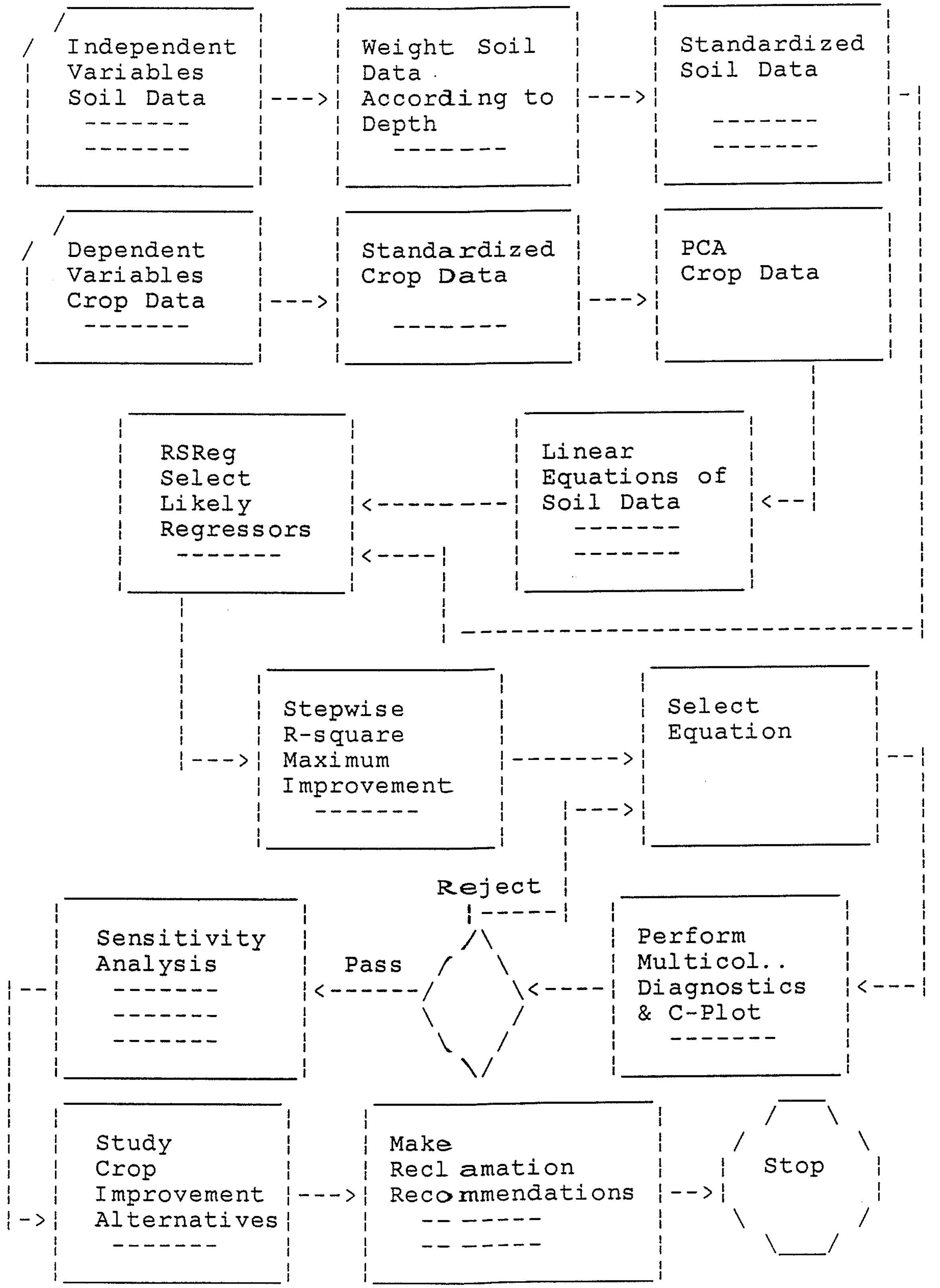


Figure 1. FLOWCHART OF EQUATION BUILDING AND RECLAMATION RECOMMENDATION PROCESS.

STUDY AREA

In Clay County, surface mining and agriculture are closely related land-uses. By examining the geological formations, surface mining history and agricultural patterns one can develop a clear relationship between sand and gravel surface mining and post-mining agricultural land-uses.

LOCATION

The study area is Clay County, Minnesota (Figure 2). Clay County is located in the Upper Midwest, along the west-central boundary of Minnesota adjacent to North Dakota. The county is approximately 1,693 square kilometers (1,052 square miles) in area with about 8 square kilometers (five square miles) of surface water (Jacobsen 1982).

The surface mining site chosen for application of the productivity model is located along the eastern edge of Clay County (Figure 3). The site is 36.45 hectares (90 acres) in size. It is operated by Kost Brothers of Moorhead, Minnesota. The original owners at the time of the sand and gravel lease agreement were Marvin and Pearl Spillum (Clay County 1968). The original agreement was for 60 acres of the site (NW 1/4 of NE 1/4 and E 1/4 of NE 1/4 of NW 1/4 in Section 35 T138N R44W). Also included in the study is the NE 1/4 of the NE 1/4 in Section 35 T138N R44W. This site is referred to as the Spillum site. Appendix A describes the Spillum site study area in detail.

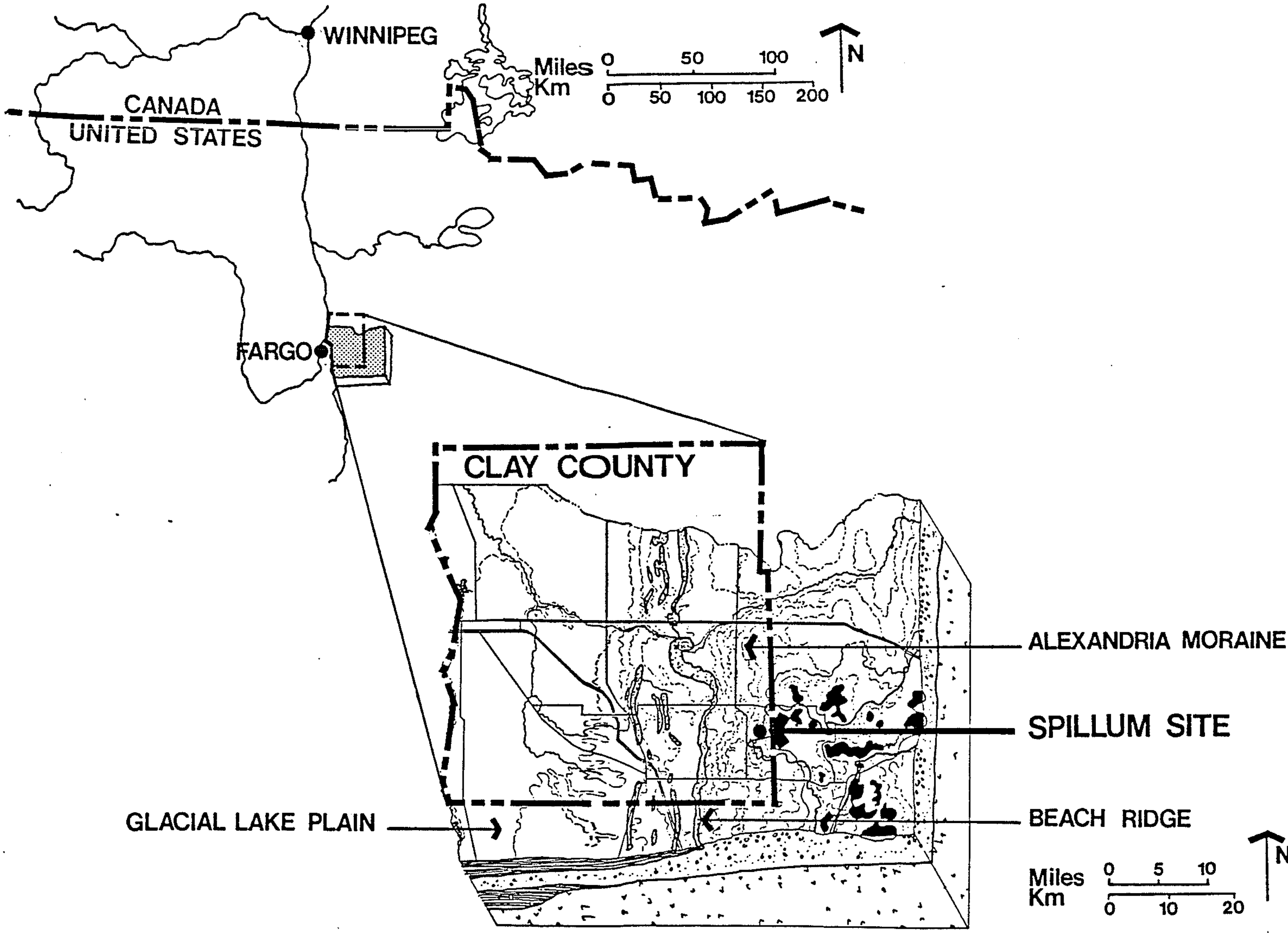


FIGURE 2. MAP OF CLAY COUNTY AND REGION

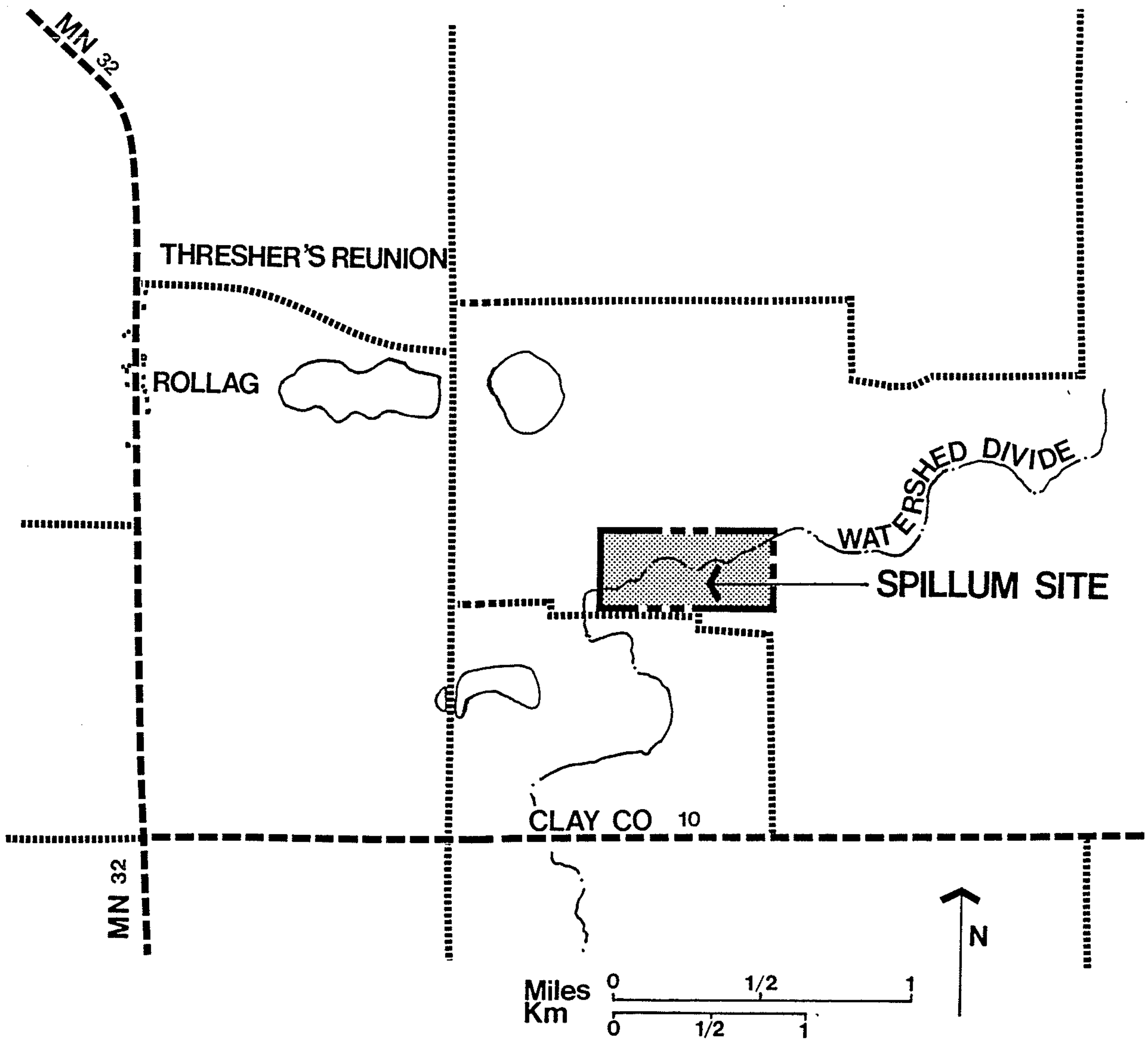


FIGURE 3. MAP OF SPILLUM SITE AND SURROUNDING AREA

CLIMATE AND AGRICULTURAL CROP SELECTION

Clay County is in the humid continental-cool summer climatic region (Espenshade 1974). This means that the summer has occasionally cool days and the winter is very cold with arctic air surging over the county (Jacobsen 1982). The warmest recorded temperature for Clay County is 38.89 degrees C. (102 degrees F.), recorded on 30 July 1975 (Jacobsen 1982). In summer (as defined by Jacobsen 1982), at Hawley, Minnesota (a town located approximately in the center of the county) the average temperature is 20 degrees C. (68 degrees F.). The average summer maximum temperature is 27.22 degrees C. (81 degrees F.). The coldest recorded temperature for Hawley is -37.22 degrees C. (-35 degrees F.), recorded on 15 January, 1972. During winter (as defined be Jacobsen 1982), the average minimum temperature is -12.78 degrees C. (9 degrees F.) and the average minimum low is -18.33 degrees C. (-1 degree F.). The average daily January temperature is -15.72 degrees C. (3.7 degrees F.), while the average daily July temperature is 21.56 degrees C. (70.8 degrees F.).

Cool temperatures limit the selection of possible crops grown in Clay County. For example, there are only 4,062 average growing degree-days in Hawley, Minnesota (Jacobsen 1982). This cool climate allows the production of wheat, barley, oats, potatoes, sunflowers, soybeans, sugarbeets and native prairie grass hay. The last spring frost occurs between May 16th and May 29th. The first fall frost will typically occur between September 4 and September 22. The growing season will last between 110 and 147 days (Jacobsen 1982). Crops such as corn and melons have difficulty maturing under such short and cool summers.

Low precipitation levels may also limit crop selection. The average precipitation is 57.43 cm (22.61 inches) with two years in ten having less than 47.12 cm (18.55 inches) and two years in ten having more than 64.08 cm (25.23 inches) (Jacobsen 1982). During summer, hail occurs in small scattered patches. Average yearly snowfall is 86.87 cm (34.2 inches). Snowfall occurs from October to April.

NATIVE VEGETATION AND AGRICULTURAL CROP PRODUCTION

Prior to European settlement, the Clay County landscape was dominated by mesic prairie, wet prairie and marsh (Marschner 1974). The woodlands were composed of wet forests (defined by Curtis 1959) located along the rivers and oak savannas (defined by Curtis 1959) in the hills. After European settlement, most of the land was converted to agricultural croplands. Today, 16,050 acres of Clay County land remains in woodland (Jacobsen 1982).

The crops selected for 1977 production within the county included wheat (217,300 acres), sugar beets (46,800 acres), sunflowers (52,000 acres), corn (25,000 acres), potatoes (7,800 acres), soybeans (26,500 acres), other small grains (124,500 acres) and hay (24,000 acres) (Jacobsen 1982).

While most of the native vegetation in the county is gone, Clay County remains primarily a rural region producing agronomic crops.

SURFACE MINING RELATIONSHIP TO GEOLOGICAL HISTORY

Surface mining and Clay County's relatively recent gelogical history are closely related. Surface mining within the county is primarily conducted to obtain sand and gravel. Glacial activity has determined the location of these sand and gravel surficial deposits.

In Clay County, many of the best glacial deposits are located on the beach ridges of Glacial Lake Agassiz. The deposits supply sand and gravel for building construction and road building in urban centers as well as rual areas within in the glacial lake plain.

Other deposits exist in the Alexandria Moraine (Figure 2). Crum and Rust (1986) have characterized the soils of this moraine at a location south of Clay County. The glacial moraine is physically situated upon the Pre-cambrian Shield (Maclay et al., 1969). This Pre-cambrian Shield gradually dips to the west and is eventually covered by sedimentary rocks. At the convergence of the Shield with the sedimentary rocks a slight depression or basin is formed. This basin was the path of least resistance for southward glacial advancement. During the retreat of the glaciers, Glacial Lake Agassiz was formed. Teller and Clayton (1983) recently edited a review of Glacial Lake Agassiz's geological formations and geological history. Large deposits of clay are encountered in the lake basin. Along the lake's perimeter, sandy and gravelly beaches were formed. To the east of these beach ridges lies the Alexandria moraine.

CLAY COUNTY SURFACE MINING HISTORY

The demand for sand and gravel is primarily in the Fargo-Moorhead urban center and in the glacial lake plain. Appendix B illustrates a procedure for estimating demand. To support this demand, sand and gravel is mined. Since the surface of the glacial lake plain is composed of clay, sand and gravel had to be obtained elsewhere. The beach ridges contained an abundance of sand and gravel.

Beginning in the 1920's the beach ridges were mined to support a growing Fargo-Moorhead urban center and to build an extensive roadway system in the glacial lake plain. In the 1960's the beach ridge sand and gravel deposits near Fargo-Moorhead were being exhausted by constructing an interstate highway system, improving federal highways and developing North Dakota's largest metropolitan area (Fargo/Moorhead).

Some beach ridge deposits could not be utilized by the sand and gravel industry, since they were contaminated with Cretaceous shale. This forced operators to consider sand and gravel deposits in the glacial moraine. Both contaminated deposits and exhausted deposits led to the development of the Alexandria Moraine surface mines.

As illustrated by the demand index, the major market for the sand and gravel is to the west in the glacial lake plain. Unlike many sand and gravel operations which are very close to urban land, sand and gravel operations in Clay County are relatively far away. Thus the post-mining land-use for most reclaimed mining sites will probably not be urban, but rural.

In the rural landscape, agriculture is the predominate land-use. Thus reclaiming the landscape for agriculture can be considered a logical post-mining land-use decision. The development of a predictive equation could assist in constructing neo-sols for productive cropland.

METHODS

TIME AND EQUIPMENT

To accomplish the steps described in this thesis, access to a statistical computing package is required. The statistical methods needed include principal components analysis and multiple regression analysis. The procedures described in this paper were accomplished using the Statistical Analysis System (SAS) software (SAS 1983). The database to conduct the analysis contains over 48720 numbers. This database precludes the use of some micro-computers with small storage capacities.

The time necessary to complete the equation development is approximately 200 man hours (160 man hours for data input, 40 man hours for statistical testing). Prior to equation development, five to ten years of field data gathering is necessary. The 200 hour estimate also assumes the computer user is familiar with the statistics package and the necessary job control language. This estimation allows the input of approximately 80 soil types and statistical testing of numerous models.

REQUIRED BASELINE DATA

To develop the model, two sets of variables are required. One set is the dependent variable list (response variables); the other set is the independent variable list (factor variables). The independent variables will be used to predict the outcomes of the dependent variables. The independent variables are physical and chemical soil properties. The dependent variables are crop yields. The physical and chemical soil properties will be used to develop an equation to predict crop yields.

The lists of potential variables are found in the United States Soil Conservation Service County Soils Surveys. In those surveys, the independent variables are described in the physical and chemical soil characteristics table(s). The dependent variables are described in the crop yield tables.

There were seven crop variables (dependent variables) selected for the study. These variables were spring wheat, barley, oats, sunflowers, soybeans, sugar beets and grasses/ legumes yields. The data set consisted of actual U. S. Soil Conservation Service crop yields from the year 1975 to 1979 (Jacobsen 1986 and Jacobsen 1982). During those years a severe drought was experienced in 1977 and a severe flood experienced in 1975. The data was expressed as an average yield that included normal growing seasons, drought years and flooding conditions.

There were ten soil characteristics (independent variables) selected for the study. These variables included topographic position, % slope, % rock fragments > 3 inches, % clay, bulk density, available water holding capacity, hydraulic conductivity, pH, electrical conductivity and % organic matter. The soil data consisted of soil profile measurements at one inch increments to a depth of 60 inches. Eighty soil types (mapping units) were represented in the study.

PRE-DATA ANALYSIS

Weighting Soil Characteristics According to Depth. Once the original data set is entered into the computer, each chemical and physical soil factor has a value for each 2.54 cm (1 inch) in the soil profile. For a soil profile of 121.92 cm, there would be forty-eight values per soil factor per soil mapping unit. Each soil factor per mapping unit needs to be combined into one value.

The weighting of these values follows research conducted and reviewed by Doll et al., (1984a). The research suggests that various soils depths contribute to crop productivity in different proportions. According to their research, the first 30.48 cm (12 inches) of a soil profile contribute 40 % of a crop's yield. 30 % is attributed to the level between 30.48 cm to 60.96 cm (12 to 24 inches). The 60.96 cm to 91.44 cm (24 to 36 inches) level contributes 20 %. 10 % is attributed to the level between 91.44 cm to 121.92 cm (36 to 48 inches). None is attributed to levels below 121.92 cm (forty-eight inches). Therefore, the soil mapping unit's physical and chemical properties are weighted according to depth.

To accomplish this weighting, each factor per soil mapping unit is assessed separately. For example, if there were fifty soils and ten factors, the weighting would have to be conducted a total of 500 times (50 x 10). A soil mapping unit factor's values are grouped into 30.48 cm (one foot) intervals and the values for each interval summed. Each summation is then multiplied by the appropriate weighting criteria (.4 for the first level, .3 for the second level, .2 for the third level, .1 for the fourth level and zero for any reading below 121.92 cm). Finally, the weighted sums for each interval are added and divided by 12. The resulting value represents that soil mapping unit's weighted physical or chemical score (equation 2).

Standardizing the Data Set. In most data sets, both the dependent variables and independent variables are noncommensurable (measured in different units). For example, one crop may be expressed in terms of metric tons per hectare, while another crop may be expressed in bushels per hectare. Alternatively, one soil characteristic may be expressed in Mmhos while another may be expressed in cm/hour. If the variables remain unstandardized, those crops or soil variables whose units contain larger real numbers will dominate the analysis (Kendall, 1980). Therefore, that data for each crop and weighted soil property must be standardized to zero mean and unit variance.

ANALYSIS

At this point, there still are several crop types (dependent variables) and soil characteristics (independent variables) per soil type. One approach to model development would be to develop a regression equation for each crop type. However, this may not be necessary. If several or all of the crops covary, individual equations might be redundant and inefficient. By examining the multivariate relationships between the crops, it may be possible to develop one equation which may serve for all crops. In this study, principal components analysis was used to identify those combinations of crops with the potential for grouped model development.

<u>Principal Component Analysis</u>. This step attempts to reduce a list of dependent variables (crop productivity values) into a single value which represents overall crop productivity at a given site. This step is accomplished by principal component analysis (PCA). The numerical strategy examines the latent underlying structure of a multivariate variable set (Tabachnick and Fidell 1983). For example, if ten dependent variables are examined, the data can be vectorized into an orthogonal ten-dimensional space. If the variables co-vary primarily along several or one axis, the information contained in the crop productivity scores can be reduced with little loss of information. Such a procedure for developing aggregate crop productivity scores has been previously suggested and described by Kendall (1939) and Banks (1954). Wonnacott and Wonnacott (1981) illustrate the application of PCA to regression analysis.

The site (soil mapping units) by variable (crop productivity) matrix led to the calculation of a seven by seven covariance matrix between variables. A PCA of this matrix produces two sets of related values. The first set consists of eigenvalues. Each eigenvalue is the variance of a given principal component axis in the multidimensional variable space. Both the proportional sum of the eigenvalues and the number of principal components will be equal to the number of dependent variables selected in the study. Eigenvalues are generally sorted from largest (first principal component) to smallest (last principal component).

Each eigenvalue divided by the sum of eigenvalues indicates the proportion of variance explained by each assigned principal component. Principal components with proportional eigenvalues greater than one are likely candidates for model development (McCuen 1985).

The second set of values are the eigenvectors. There is one eigenvector assigned to each principal component axis per dependent variable. For example, if there are ten dependent variables, there will be ten principal component axes and a total of 100 eigenvectors, ten for each component axis. Eigenvector values are normally standardized so as to range from -1.0 to 1.0. Positive values indicate positive variable covariance with the associated principal component axis while negative values indicate a negative one. Values near zero indicate low association along the axis.

The rules for interpreting the significance of principal component axes are not well defined (McCuen 1985); however, some general suggested guidelines are possible. When examining eigenvectors, examine one significant principal axis row at one time starting with the row associated with the largest eigenvalue. The examination of the eigenvectors is as follows:

1. If the eigenvector elements associated with the first principal component axis are all positive (negative), the variables covary monotonically. In this case a single value may represent crop productivity for all crops in a soil mapping unit. This single value may be used as the only dependent variable necessary for regression modelling.

To illustrate further, the eigenvector elements associated with a given component axis represent weights (slope coefficients) for associated variables in a linear equation. By computing the linear equation, an overall crop productivity score can be obtained (equation 2). If the eigenvector elements are from the first principal component axis, this crop productivity score maximizes the variance of the overall score and is preferred over other linear combinations (Kendall 1980). However, other linear combinations may still be worth examining.

2. If some eigenvector elements are positive and others negative, a linear combination can be formed that will contrast positively weighted variables versus negatively weighted variables.

3. If only one number is positive and all the others are negative or near zero, then a model can be developed for that crop alone.

Once the linear combinations have been identified and computed, the computed productivity scores are ready for multiple regression analysis. These productivity scores represent a single dependent grouped crop score for a set of independent soil observations.

To produce the regression equation scores, one will use a procedure to eliminate independent variables that are poor predictors and select those independent variables that are likely candidates to predict crop productivity scores. Then regression equation combinations can be tested to find the most efficient and effective fit.

REGRESSION MODELLING

Multiple Regression Analysis. Regression analysis includes the search for the best predictor variables. However, when there are numerous variables to be considered (main effects, interactions and quadratic forms) and when there are limitations upon time and limitations upon the abilities of the computing mechanism, it is very helpful to eliminate the least promising variables and select the most promising variables. Montgomery and Peck (1982) call this search for a subset of regressors the variable selection problem. The RSReg procedure is a statistical analysis tool that can help to select the most promising variables (SAS 1983). The procedure examines the ability of independent variables to predict a dependent variable. This means that the procedure will compare weighted standardized soil mapping unit characteristics to predict standardized crop productivity scores. The method examines main effects, first order interaction terms (cross products) and squared terms. Those soil variables (regressors) with a maximum p value between 0.25 to 0.5 are suggested by various multiple regression texts to be selected for further regression modelling. In preliminary runs of the RSReg procedure for the data set in this study, a $p<.5$ would still leave approximately 35 to 40 regressors for further testing and $p<.25$ would leave approximately 20 to 25 regressors for further testing. Since twenty-five regressors were considered the maximum that the computer could evaluate in further regression modelling, a $p<.25$ was selected.

Stepwise Procedure. In SAS, the stepwise procedure attempts to find the best set of regressors that most accurately describes the relationship between the soil characteristics and crops. Within the stepwise procedure the Maximum-R squared improvement technique (MAXR) has been determined to be the most effective (SAS 1983). The selection process will produce a list of regression equations. This list will describe the best one variable equation possible, then the best two variable equation and so forth. From this list of equations, one must examine each equation to find the best equation.

In the search for the best equation, there are two types of equations to search for. The first equation has the highest r-squared value possible and yet contains all independent variables with p-values less than .01. If that type of model does not exist, search for the second type of model. This model must also contain the highest r-squared value possible and yet contain all independent variables with probability values less than .05. These two model types are the leading candidates for further model testing.

MODEL TESTING

The selected equations require further testing. Equations should be tested for multicollinearity and C-plot values (Freund and Minton 1979).

When regressors are correlated, they are said to be multicollinear (Younger 1979) . This means that the regressors are related with some or all of the other regressors. In multicollinearity, slope coefficients are confounded with their associated predictor variable and other predictor variables. This makes the coefficients unreliable. The magnitudes and signs of the coefficients may actually be quite different from the predicted values.

In selecting the best model, one desires to find a model that is not underspecified (does not optimize the information in the data) or is not overspecified (inefficient). The C-plot test uses variance estimators and the number of regressors in an equation to find the most effective and efficient equation. The C-plot test is a procedure that searches for the candidate equation with the error mean square from the sample that is closest to the unbiased estimator of the population error mean square (Younger 1979). In the actual test, the calculated C-plot value with a number just slightly less than the number of regressors plus one is the most likely candidate.

If the models pass the tests, confidence intervals should be plotted for the regression equations.

RESULTS

Table 1 lists the eigenvalues for the standardized crop data resulting from PCA of the covariance matrix. Since only the first eigenvalue is greater than one, only the first principal component is used for further model development.

Table 2 lists the eigenvector elements associated with each of the eigenvalues in Table 1. In the first principal component column, the set of eigenvectors all contain positive values. The values place almost equal weighting upon spring wheat, barley, oats, sunflowers and soybeans. Sugar beets and grasses/legumes have smaller positive values. As suggested by Kendall (1980), the eigenvector elements associated with the first principal component are used to develop a linear equation to predict the sum of crop productivity (Equation 2):

$$\begin{aligned}\text{PLANT}=&(0.4355*\text{SWZ})+(0.4364*\text{BAZ})+(0.4329*\text{OTZ})+\\&(0.4042*\text{SFZ})+(0.2600*\text{SBZ})+(0.4239*\text{SNZ})+\\&(0.1474*\text{GEZ})\end{aligned} \qquad \text{Eq 2}$$

Where

PLANT = Total Plant Productivity
SWZ = Spring Wheat Z-Score
BAZ = Barley Z-Score
OTZ = Oat Z-Score
SFZ = Sunflower Z-Score
SBZ = Sugar Beet Z-Score
SNZ = Soybean Z-Score
GEZ = Grasses/Legumes Z-Score

TALBE 1. EIGENVALUES FOR STANDARDIZED CROP DATA

	EIGENVALUE	DIFFERENCE	PROPORTION	CUMULATIVE
PRIN1	5.02818	4.07480	0.718308	0.71831
PRIN2	0.95335	0.26735	0.136193	0.85450
PRIN3	0.68600	0.49207	0.098001	0.95250
PRIN4	0.19393	0.09226	0.027705	0.98021
PRIN5	0.10167	0.06896	0.014524	0.99473
PRIN6	0.03271	0.02855	0.004673	0.99940
PRIN7	0.00417	.	0.000596	1.00000

TABLE 2. EIGENVECTOR ELEMENTS FOR STANDARDIZED CROP DATA.

EIGENVECTORS

	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5	PRIN6	PRIN7
SWZ	0.435532	-.054099	-.020933	-.307358	0.153460	-.827362	0.066333
BAZ	0.436400	-.065967	-.091187	-.339488	-.236614	0.258646	-.747498
OTZ	0.432932	-.077968	-.133284	-..91178	-.421420	0.318631	0.651783
SFZ	0.404207	-.167694	-.118357	0.826758	-.294915	-.140346	-.065475
SBZ	0.260032	0.313989	0.907465	0.063538	-.042860	0.063449	0.020065
SNZ	0.423905	-.148007	-.066107	0.107647	0.807351	0.351124	0.085652
GEZ	0.147450	0.915438	-.362783	0.079633	0.047335	0.006180	0.000540

To illustrate the application of the linear equation, the total plant productivity score for soil S33B is calculated in Equation 3. Soil S33B (33B in Jacobsen 1982) is a Barnes loam, 1 to 3 percent slope. It is a neutral to calcareous soil found on upland areas in Clay County. The soil is heavily cultivated, supporting crops of small grains, sunflowers, corn, soybeans and hay.

$$\begin{aligned} PLANT = & (0.4355*1.0372)+(0.4364*0.8069)+ \\ & (0.4329*0.9136)+(0.4042*0.7021)+ \\ & (0.2600*(-0.6874))+(0.4239*1.2145)+ \\ & (0.1474*0.0388) \end{aligned} \qquad \text{Eq 3}$$

$$PLANT=1.8288$$

Where

PLANT	=	Total Plant Productivity for soil S33B
1.0372	=	Spring Wheat Z-Score for soil S33B
0.8069	=	Barley Z-Score for soil S33B
0.9136	=	Oat Z-Score for soil S33B
0.7021	=	Sunflower Z-Score for soil S33B
-0.6874	=	Sugar Beet Z-Score for soil S33B
1.2145	=	Soybean Z-Score for soil S33B
0.0388	=	Grasses/Legumes Z-Score for soil S33B

The total plant productivity score derived from Equation 4 was computed for each soil profile in the data set. These scores were the dependent variables in the regression analysis.

To begin the procedures identified with regression analysis, RSReg was employed. Table 3 lists the results from the RSReg procedure. The procedure identifies twenty-five variables with a $p \leq .25$ (Table 4).

TABLE 3. RSREG RESULTS.

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	10	51.51388753	0.6521	96.49	0.0001
QUADRATIC	10	13.78498381	0.1745	25.82	0.0001
CROSSPRODUCT	45	12.95337014	0.1640	5.39	0.0007
TOTAL REGRESS	65	78.25224149	0.9905	22.55	0.0001

RESIDUAL	DF	SS	MEAN SQUARE
TOTAL ERROR	14	0.74739676	0.05338548

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	-0.10742542	1.49954229	-0.07	0.9439
TPZ	1	1.44683590	1.28662593	1.12	0.2797
SLZ	1	-0.97374210	0.99759842	-0.98	0.3456
FRZ	1	0.35557110	4.43759335	0.08	0.9373
CLZ	1	2.43359995	1.19095949	2.04	0.0603
BDZ	1	2.59460929	2.85344315	0.91	0.3786
ECZ	1	1.05704375	0.84466302	1.25	0.2313
OMZ	1	3.89248382	3.14725406	1.24	0.2365
HCZ	1	1.46570162	0.87307713	1.68	0.1154
AWZ	1	-1.86020781	7.53475319	-0.25	0.8086
PHZ	1	-1.15693247	0.63002574	-1.84	0.0876
TPZTPZ	1	-0.008649515	0.12055624	-0.07	0.9438
SLZTPZ	1	-0.37585030	0.34525402	-1.09	0.2947
SLZSLZ	1	-0.10663093	0.06880551	-1.55	0.1435
FRZTPZ	1	0.59207607	0.89809643	0.66	0.5204
FRZSLZ	1	-0.79183401	0.82972432	-0.95	0.3561
FRZFRZ	1	0.02689417	1.01175718	0.03	0.9792
CLZTPZ	1	0.56489114	0.72881441	0.78	0.4512
CLZSLZ	1	-0.25029687	0.60146274	-0.42	0.6836
CLZFRZ	1	1.02915107	0.72276834	1.42	0.1764
CLZCLZ	1	1.03227944	0.51818971	1.99	0.0662
BDZTPZ	1	1.08276765	1.11193886	0.97	0.3467
BDZSLZ	1	0.16649-12	1.10144834	0.15	0.8820
BDZFRZ	1	7.88468767	4.13097110	1.91	0.0770
BDZCLZ	1	2.36776111	1.44538253	1.64	0.1237
BDZBDZ	1	2.43651082	1.38851647	1.75	0.1012
ECZTPZ	1	-0.30107173	0.20643668	-1.46	0.1668
ECZSLZ	1	0.02442896	0.22577058	0.11	0.9154
ECZFRZ	1	-1.65176326	1.19626974	-1.38	0.1887
ECZCLZ	1	-0.60429166	0.56866102	-1.06	0.3059
ECZBDZ	1	-0.33181540	1.14946271	-0.29	0.7771
ECZECZ	1	0.10881947	0.16193447	0.67	0.5125
OMZTPZ	1	-0.21771137	1.77877002	-0.12	0.9043
OMZSLZ	1	-1.22436235	2.01732503	-0.61	0.5536
OMZFRZ	1	10.72520091	11.47252285	0.93	0.3657

TABLE 3, CONTINUED

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
OMZCLZ	1	2.26236171	1.30112167	1.74	0.1040
OMZBDZ	1	4.97245437	3.18238846	1.56	0.1405
OMZECZ	1	4.42545746	2.07768254	2.13	0.0514
OMZOMZ	1	1.23302016	1.84626273	0.67	0.5151
HCZTPZ	1	0.53770080	0.88141379	0.61	0.5516
HCZSLZ	1	-0.22552808	0.57801127	-0.39	0.7023
HCZFRZ	1	0.13656537	1.83857277	0.07	0.9418
HCZCLZ	1	1.67230653	1.03096333	1.62	0.1271
HCZBDZ	1	1.65732030	1.42127970	1.17	0.2631
HCZECZ	1	0.00651706	0.41724034	0.02	0.9878
HCZOMZ	1	2.04456961	1.51400505	1.35	0.1983
HCZHCZ	1	0.83658988	0.45965656	1.82	0.0902
AWZTPZ	1	12.40731171	11.96844174	1.04	0.3175
AWZSLZ	1	-3.59541266	6.50995623	-0.55	0.5895
AWZFRZ	1	10.18355139	19.98187157	0.51	0.6182
AWZCLZ	1	21.28751748	9.33632407	2.28	0.0388
AWZBDZ	1	11.40784794	16.60498938	0.69	0.5033
AWZECZ	1	-0.26450081	9.12336476	-0.03	0.9773
AWZOMZ	1	12.58608403	10.61874785	1.19	0.2556
AWZHCZ	1	15.56848358	6.46820397	2.41	0.0305
AWZAWZ	1	0.73615358	2.12721571	0.35	0.7344
PHZTPZ	1	0.05852067	0.22689525	0.26	0.8002
PHZSLZ	1	-0.10411720	0.22196883	-0.47	0.6462
PHZFRZ	1	0.05951968	0.80935382	0.07	0.9424
PHZCLZ	1	-0.22671906	0.32194841	-0.70	0.4929
PHZBDZ	1	-2.18143866	0.59577024	-3.66	0.0026
PHZECZ	1	-0.45020086	0.33391878	-1.35	0.1990
PHZOMZ	1	-3.93413671	1.01779234	-3.87	0.0017
PHZHCZ	1	-0.02254861	0.31178044	-0.07	0.9434
PHZAWZ	1	-4.14872161	5.20664956	-0.80	0.4389
PHZPHZ	1	0.19167849	0.13267768	1.44	0.1706

TABLE 4. POTENTIAL REGRESSORS FROM RSREG

Main Effects

- % Clay
- Electrical Conductivity
- % Organic Matter
- Hydraulic Conductivity
- pH

Squared Terms

- % Slope
- % Clay
- Bulk Density
- Hydraulic Conductivity
- pH

Interaction Terms

- % Clay, % Rock Fragments
- Bulk Density, % Rock Fragments
- Electrical Conductivity, Topographic Position
- Electrical Conductivity, % Rock Fragments
- % Organic Matter, % Clay
- % Organic Matter, Bulk Density
- % Organic Matter, Electrical Conductivity
- Hydraulic Conductivity, % Clay
- Hydraulic Conductivity, % Organic Matter
- Available Water Holding Capacity, % Clay
- Available Water Holding Capacity, Hydraulic Conductivity
- pH, Bulk Density
- pH, Electrical Conductivity
- pH, % Organic Matter

These twenty-five variables (Table 4) were entered into the Stepwise Maximum R-Squared selection procedure to find an efficient and effective regression equation (Equation 4). Table 5 lists the results of the optimum regression equation with a $p \leq 0.0001$ for each variable.

TABLE 5. BEST EQUATION FROM STEPWISE R-SQUARE IMPROVEMENT PROCEDURE.

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE PLANT

R SQUARE = 0.73987201 C(P) = 21.83218626

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	5	293.89333360	58.77866672	42.10	0.0001
ERROR	74	103.32852364	1.39633140		
TOTAL	79	397.22185724			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.62056451				
HCZ	-1.18051872	0.13668694	104.15502747	74.59	0.0001
SLZSLZ	-0.35746843	0.05254259	64.63100583	46.29	0.0001
BDZFRZ	-1.93755091	0.30923954	54.81566745	39.26	0.0001
ECZFRZ	-2.34196309	0.30371693	83.02532676	59.46	0.0001
OMZECZ	1.24238777	0.27557903	28.37987725	20.32	0.0001

$$PLANTS = .6206 + (-1.1805*HCZ) + (-0.3575*SLZ*SLZ) + (-1.9376*BDZ*FRZ) + (-2.3420*ECZ*FRZ) + (1.2424*OMZ*ECZ) \quad \text{Eq 4}$$

Where

PLANTS = Predicted Productivity Score
HCZ = Hydraulic Conductivity Z-Score
SLZ = % Slope Z-Score
BDZ = Bulk Density Z-Score
FRZ = % Rock Fragments Z-Score
ECZ = Electrical Conductivity Z-Score
OMZ = % Organic Matter

C-PLOT VALUES

Equation 4 is slightly underspecified. The C-plot value for this equation is 21.83, while k+1 is 6. Thus if there were an equation with good statistical probability values (at least $p<0.05$) for each of its collection of regressors, plus had a C-plot value closer to k+1, then this new equation would be selected over Equation 4. However, in the stepwise computer output, equations containing other collections of regressors with better C-plot values had at least one probability value which is not significant ($p<.05$). This means that Equation 4 has the best C-plot value in the study.

MULTICOLLINEARITY DIAGNOSTICS

The condition index for the five regressors and the intercept were less than 3.0. Montgomery and Peck (1982) indicate that condition numbers between 100 and 1000 suggest strong multicollinearity and condition numbers greater than 1000

TABLE 6. MULTICOLLINEARITY DIAGNOSTICS.

NUMBER	EIGENVALUE	CONDITION NUMBER
1	2.170378	1.000000
2	1.238529	1.323776
3	0.946231	1.514499
4	0.871799	1.577827
5	0.466164	2.157737
6	0.306898	2.659319

imply severe multicollinearity. Therefore the selected best equation in this study does not have strong multicollinearity (Table 6).

PRODUCTIVITY PREDICTION

The equation selected for this study contains an intercept, one main effects term, one squared term and three interaction terms (Table 7). In addition, the coefficient of multiple determination in the equation is 0.739872. This means that the regressors explain 74% of the variation in the regression model.

To predict the agricultural productivity of a particular soil, the best equation can be slightly modified. Instead of having to calculate the z-score for each regressor before calculating the predicted plant productivity score, Equation 6 can be rewritten as illustrated by Equations 5 and 6 to allow direct soil readings to be entered into the equation. Equation 6 is similar to Equation 5. In Equation 6 the values for the sample means and variance have been entered into the equation.

TABLE 7. GLM DESCRIPTION OF BEST EQUATION.

GLM LINEAR MODELS PROCEDURE

R SQUARE = 0.739872 C(P) = 21.83238123

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	5	293.89333360	58.77866672	42.10	0.0001
ERROR	74	103.32852364	1.39633140		
TOTAL	79	397.22185724			

	B VALUE	STD ERROR	TYPE I SS	F	PROB>F
INTERCEPT	0.62056451				
HCZ	-1.18051872	0.14404167	75.03291001	53.74	0.0001
SLZSLZ	-0.35746843	0.13668694	81.40506702	58.30	0.0001
BDZFRZ	-1.93755091	0.05254259	22.09943815	15.83	0.0002
ECZFRZ	-2.34196309	0.30923954	86.97604118	62.29	0.0001
OMZECZ	1.24238777	0.27557903	28.37987725	20.32	0.0001

	TYPE III SS	F	PROB>F
HCZ	104.15502747	74.59	0.0001
SLZSLZ	66.63100583	46.29	0.0001
BDZFRZ	54.81566745	39.26	0.0001
ECZFRZ	83.02532676	59.46	0.0001
OMZECZ	28.37987725	20.32	0.0001

```
PLANTS=.6206+(-1.1805*((HC-HCX)/HCS))+
          (-0.3575*(((SL-SLX)/SLS)**2))+
          (-1.9375*((BD-BDX)/BDS)((FR-FRX)/FRS))+
          (-2.3420*((EC-ECX)/ECS)((FR-FRX)/FRS))+
           (1.2424*((OM-OMX)/OMS)((EC-ECX)/ECS))          Eq 5
```

Where

PLANTS = Predicted Productivity Score
HC = Hydraulic Conductivity
HCX = Hydraulic Conductivity Mean
HCS = Hydraulic Conductivity Variance
SL = % Slope
SLX = % Slope Mean
SLS = % Slope Variance
BD = Bulk Density
BDX = Bulk Density Mean
BDS = Bulk Density Variance
FR = % Rock Fragments
FRX = % Rock Fragments Mean
FRS = % Rock Fragments Variance
EC = Electrical Conductivity
ECX = Electrical Conductivity Mean
ECS = Electrical Conductivity Variance
OM = % Organic Matter
OMX = % Organic Matter Mean
OMS = % Organic Matter Variance

```
PLANTS=.6206+(-1.1805*((HC-3.9296)/4.0030))+            Eq 6
      (-0.3575*(((SL-3.0000)/4.6810)**2))+
      (-1.9375*((BD-1.3584) /0.2644)((FR-0.9075/3.4929))+
      (-2.3420*((EC-2.526)/1.0947)((FR-0.9075)/3.4929))+
      (1.2424*((OM-3.9512)/0.6638)((EC-2.5269)/1.0947))
```

Where

PLANTS = Predicted Productivity Score
HC = Hydraulic Conductivity
SL = % Slope
BD = Bulk Density
FR = % Rock Fragments
EC = Electrical Conductivity
OM = % Organic Matter

The computation of the plant productivity score for a specific soil profile such as soil S33B is illustrated in Equation 7. Table 8 illustrates the predicted productivity scores and 95% confidence intervals for all 80 soils.

$$\begin{aligned}PLANTS=&.6206+(-1.1805*((1.3-3.9296)/4.0030))+ \\ &(-0.3575*(((2.0-3.0000)/4.6810)**2))+ \\ &(-1.9375*((1.52-1.3584)/0.2644)((2.5-0.9075/3.4929))+ \\ &(-2.3420*((2.9-2.526)/1.0947)((2.5-0.9075)/3.4929))+ \\ &(1.2424*((1.05-3.9512)/0.6638)((2.9-2.5269)/1.0947))\end{aligned} \qquad \text{Eq 7}$$

PLANTS= 0.3343

TALBE 8. 95% CONFIDENCE INTERVAL FOR PREDICTED PRODUCTIVITY SCORES.

SOIL NAME	PREDICTED VALUE	LOWER 95% MEAN	UPPER 95% MEAN
S33B	0.3341	-0.0439	0.7122
S33B2	0.3341	-0.0439	0.7122
S33C2	-0.2369	-0.5987	0.1250
S36	1.4796	1.1108	1.8484
S38B	1.1567	0.8148	1.4986
S38B2	1.3707	1.0045	1.7369
S38C	0.5233	0.2285	0.9103
S38C2	0.7997	0.4341	1.1654
S38D	-1.1926	-1.8775	-0.5076
S38D2	-0.9622	-1.6587	-0.2657
S38E	-5.9386	-7.9874	-3.8898
S45B	-2.0577	-2.7445	-1.3710
S45C	-2.4493	-3.1310	-1.7675
S46	0.3371	-0.1362	0.8104
S47	1.2843	0.9139	1.6547
S50	1.4122	1.0331	1.7913
S52	0.7248	0.4288	1.0208
S56	1.3723	0.9692	1.7754
S57A	1.3321	0.9337	1.7305
S57B	1.3811	0.9793	1.7828
S58A	1.2945	0.9505	1.6386
S58B	1.6418	1.2619	2.0217
S59	0.3640	0.0555	0.6725
S60A	0.9940	0.6144	1.3736
S60B2	1.0430	0.6613	1.4246
S61	0.2223	-0.0695	0.5141
S63	0.3507	0.0469	0.6544
S64	-1.2785	-1.9794	-0.5776
S65	-0.1195	-0.4634	0.2245
S66	-1.8506	-2.5334	-1.1677
S67A	2.4891	1.5479	3.4302
S67B2	2.5380	1.5972	3.4788
S68	-0.2772	-0.5956	0.0401
S71	-1.9803	-2.6612	-1.2995
S93	2.6577	1.8542	3.4611
S127B	-0.2171	-0.6067	0.1725
S127C	-0.6209	-1.0069	-0.2349
S148	-1.8486	-2.5316	-1.1656
S157A	0.7217	0.3730	1.0705
S157B	0.7707	0.4181	1.1232
S157C	0.1997	-0.1452	0.5445
S180B	1.6747	1.2933	2.0562
S184B	1.8808	1.4802	2.2813
S236	2.3008	1.8302	2.7714
S245B	-1.3196	-2.0185	-0.6206
S293B	0.7466	0.4485	1.0446

TABLE 8, CONTINUED

SOIL NAME	PREDICTED VALUE	LOWER 95% MEAN	UPPER 95% MEAN
S335	-2.2651	-3.0252	-1.5051
S343A	1.4041	1.0228	1.7853
S343B2	1.4530	1.0693	1.8367
S344	1.1001	0.7284	1.4718
S402B	-0.6629	-1.1433	-0.1825
S402C	-1.2461	-1.6898	-0.8025
S402D	-3.2499	-3.9296	-2.5702
S402E	-6.4068	-8.6847	-4.1289
S403	2.1590	1.7334	2.5845
S413	-0.3634	-0.7488	0.0221
S425	1.0634	0.6534	1.4734
S426	-1.1876	-1.7102	-0.6650
S429	1.8738	1.4404	2.3072
S435	-0.3158	-0.6912	0.0596
S494	0.9832	0.6547	1.3116
S506	1.3940	1.0047	1.7833
S509	-4.9967	-6.5549	-3.4384
S510	0.5773	0.2798	0.8748
S540	-3.2358	-4.0724	-2.3991
S543	-5.1133	-6.5661	-3.6605
S544	-3.0658	-4.2428	-1.8888
S545	-2.4395	-3.2797	-1.5993
S609	-0.9923	-1.4901	-0.4946
S903BB	0.1431	-0.2469	0.5330
S903BL	1.7005	1.3159	2.0850
S987	0.3945	0.0930	0.6969
S1819	1.6461	1.2623	2.0300
S1871	1.2183	0.8107	1.6259
S1872	1.3855	0.9759	1.7951
S1873	1.3466	0.9407	1.7525
S1874	-1.5133	-2.1449	-0.8816
S1875	1.4796	1.1108	1.8484
S1876	1.7949	1.3993	2.1904

```
------------------------------------------------------------------
                                                S93 |---*----|
                                              S67B2 |-----*----|
       *  = PREDICTED MEAN SCORE                S67A |----*-----|
    |----| = 95% CONFIDENCE INTERVAL              S236 |--*-|
                                                  S403 |--*--|
                                              S429 |-*--|
                                             S184B |-*--|
                                             S1876 |--*-|
                                            S903BL |--*-|
                                             S180B |-*--|
                                             S1819 |-*--|
                                              S58B |-*--|
                                              S36 |-*--|
                                           S343B2 |-*--|
                                            S1875 |-*--|
                                              S50 |-*-|
                                            S343A |-*-|
                                             S506 |-*-|
                                          S1872 |--*-|
                                           S57B |--*-|
                                             S56|--*-|
                                          S38B2 |-*-|
                                         S1873 |--*-|
                                          S57A |--*-|
                                          S58A |-*--|
                                           S47 |-*--|
                                         S1871 |-*--|
                                          S38B |-*-|
                                         S425 |-*--|
                                         S344 |-*--|
                                        S60B2 |-*--|
                                         S60A |-*-|
                                         S494 |-*-|
                                      S38C2 |-*-|
                                      S157B |-*-|
                                      S293B |-*-|
                                        S52 |-*-|
                                    S157A |--*-|
                                     S510 |-*-|
                                     S38C |-*-|
                                    S987 |-*-|
                                     S59 |-*-|
                                     S63 |-*-|
                                    S46 |--*--|
                                   S33B |--*-|
                                  S33B2 |--*-|
 ________________________________________________________________
 |    |    |    |    |    |    |    |    |    |    |    |    |    |
-9   -8   -7   -6   -5   -4   -3   -2   -1    0    1    2    3    4
                     SOIL PRODUCTIVITY SCORES
------------------------------------------------------------------
```

FIGURE 4. GRAPH OF 95% CONFIDENCE INTERVAL FOR MEAN OF PREDICTED PRODUCTIVITY SCORES.

```
-------------------------------------------------------------
                                          S61  |-*-|
                                        S157C  |-*-|
                                      S903BB  |--*-|
                                         S65  |-*--|
                                      S127B  |--*-|
                                       S33C2  |-*-|
                                         S68  |-*-|
                                       S435  |-*-|
                                       S413  |-*-|
                                    S127C  |--*-|
                                    S402B  |--*--|
                                 S38D2  |---*---|
                                   S609  |--*--|
                                  S426  |--*--|
                                 S38D  |---*---|
                                 S402C  |--*-|
                                  S64  |---*---|
                              S245B  |---*---|
                              S1874  |---*---|
                             S148  |---*---|
                              S66  |---*--|
                             S71  |---*---|
                            S45B  |---*---|
                          S403  |----*---|
                         S545  |----*---|
                          S45C  |---*---|
                    S544  |------*-----|
                     S540  |----*----|
                     S402D  |---*---|
         S509  |-------*-------|
         S543  |------*-------|
  S38E  |---------*----------|
S402E  |-----------*-----------|
 ____________________________________________________________________
  |    |    |    |    |    |     |    |    |    |    |    |    |    |
 -9   -8   -7   -6   -5   -4    -3   -2   -1    0    1    2    3    4
                         SOIL PRODUCTIVITY SCORES
----------------------------------------------------------------------
FIGURE  4, CONTINUED
```

DISCUSSION

EQUATION INTERPRETATION

In the selected equation, there were five regressors that were significant ($p<0.0001$). Each regressor can be interpreted and assessed for its importance and meaning in the construction of neo-sols.

Hydraulic Conductivity. In the model, hydraulic conductivity is the only main effects regressor. Hydraulic conductivity varies negatively with soil productivity. This means that as soil productivity increases, the hydraulic conductivity decreases. The objective in neo-sol construction would be to keep hydraulic conductivity values low.

Two physical soil properties contribute to hydraulic conductivity rates. The first property is the size of soil void spaces; the second property is the configuration of void spaces (Brady 1974). Together, large connected voids will allow water to quickly percolate through the soil. Another property related to hydraulic conductivity is the water-holding capacity of the soil (Brady 1974). When rainfall entering the soil is greater than the water-holding capacity of the soil, soil moisture useful for plant growth will be lost as the water quickly moves beyond the four foot root zone.

In neo-sol construction, two recommendations are pertinent to reducing hydraulic conductivity:

(A) pore spaces should be small, and

(B) water-holding capacity should be maximized.

This means that sandy soils should be avoided at the surface. Loams and clays should be introduced as the first four feet of reconstructed soil. If there is not enough clay or loam to constitute the first four feet, then the clay or loam should be at the top of the neo-sol profile.

Percent Slope. In the model, percent slope squared is a significant factor indicating soil productivity. As the soil productivity increases, the percent slope approaches an optimum value of 3%.

Steep slopes have a higher rate of precipitation runoff. This means that less water is allowed to penetrate into the soil, resulting in dry soil.

On very flat terrain, too much water can be trapped. This means that the soil can become waterlogged and anaerobic, drowning the root system of plants.

In neo-sol construction, steep slopes and very flat terrain should be avoided. Any existing steep slopes or flat terrain created by mining operations should be eliminated. For increased agricultural productivity, the landscape should be approximately a 3% slope).

Bulk Density and Percent Rock Fragments. In the model, the interaction term consisting of bulk density and percent rock fragments is a direct measure of soil productivity. If bulk density and percent rock fragments are numerically above the mean, the value of the term will be low. If bulk density and percent rock fragments are numerically below the mean, the value of the term will also be low. However, if percent rock fragments is numerically low and the bulk density is numerically high or if percent rock fragments is high and the bulk density is low, the value of the term will be high. High values for the term are associated with good soil productivity; low values are associated with poor soil productivity.

Soils can contain two features to make their bulk density lower. The first feature is an increase in void spaces. The second feature is an increase in organic matter. Both features can be beneficial for plant growth (Brady 1974). Void spaces allow air and water to occupy vadose zones. Organic matter provides nutrients and increases water holding capacity.

Munn, et al., (1987) recently reviewed the significance of rock fragments in reclaiming soils. Rock fragments reduce water-holding capacity and nutrient availability plus they increase hydraulic conductivity (a negative effect according to the model). Yet, rock fragments do make a positive contribution. Rock fragments can reduce erosion. In addition, some biological associations are positively associated with rocky soils. However for the crops examined in this study, rock fragments are not beneficial. In neo-sol construction for agronomic crops, rock fragments hinder mechanical establishment of vegetation. Therefore the percent of rock fragments should be low.

When the percentage of rock fragments is low, the equation indicates that higher bulk density levels will result in increased agricultural productivity. In general, soils should be kept dense and rock-free. If rocks are present, to compensate for numerous rock fragments, the soil should be constructed to be less dense.

Electrical Conductivity and Percent Rock Fragments. In the model, the interaction regressor of electrical conductivity and percent rock fragments is a direct measure of soil productivity. If both electrical conductivity and percent rock fragments are high or if both electrical conductivity and percent rock fragments are low, soil productivity will be low. If either one of the factors is high while the other is low, soil productivity will be high.

Jurinal, et al., (1987) recently reviewed the effects of electrical conductivity upon reclaimed soils. As electrical conductivity increases, the water holding capacity of the soil needs to be higher to compensate for increased saline conditions. If there is little water in the soil, plants cannot tolerate saline conditions. Since an increase in rock fragments decreases a soil's water holding capacity, it is reasonable to consider percent rock fragments and electrical conductivity to interact together negatively upon plant growth.

In neo-sol construction, rock fragments must be absent in the presence of high soil electrical conductivity.

Electrical Conductivity and Percent Organic Matter. In the model, the interaction of electrical conductivity and percent organic matter is a direct measure of soil productivity. If electrical conductivity and percent organic matter are high or if electrical conductivity and percent organic matter are low, soil productivity will be high. Conversely, if one factor is high and the other factor is low, soil productivity will be low.

Smith, et al., (1987) recently reviewed the effects of organic matter in reclaimed soils. Organic matter supplies nitrogen, increases water holding capacity and acts as a buffer from low and high pH reactions. Jurinal, et al., (1987) indicate that increased nitrogen supply increases plant tolerance to higher electrical conductivity levels. Also, since the water holding capacity is higher, more water may be available to increase plant tolerance to high electrical conductivity levels. In addition, the buffering properties of the organic matter can reduce the effects of a high pH contribution by high electrical conductivity levels. Providing that nitrogen is available, water is available and high pH levels are avoided, the nutrients provided by high electrical conductivity levels can be beneficial.

In neo-sol construction, high electrical conductivity levels require high organic matter levels. If organic matter is not present or if organic matter cannot be supplied, low electrical conductivity soil material should be placed in the top four feet of the neo-sol.

Ideal Soil. These five terms (one main effect, one squared term, three interaction terms) plus the beta-intercept are the only significant factors necessary for productivity prediction. All other factors do not add to the model's ability to predict crop productivity. While pH reaction, available water holding capacity, topographic position and other factors may be important alone, these factors as a group are not important.

Following the model, the ideal soil will contain the following features:

(A) hydraulic conductivities ranging from 3.3 mm/hr (.13 inches/hour) to 10.16 cm/hr (4.0 inches/hour),

(B) the soil will be placed on slopes approaching three percent,

(C) bulk densities ranging from 1.36 gm/cubic cm to 1.6 gm/cubic cm with no rock fragments,

(D) electrical conductivity ranging from 2.5 to 6.8 Mmhos/cm with four to ten percent organic matter.

An example of a soil with characteristics close to the ideal soil is Bearden silty clay loam (S93). This soil has the highest soil productivity level of the soils examined in the thesis. Sites consisting of Bearden silty clay loam have a hydraulic conductivity of 0.8072 inches/hour, an average slope of 0.5 percent, a bulk density of 1.39 gm/cubic cm, an electrical conductivity of 6.4 Mmhos/cm, zero percent rock fragments but only two percent organic matter. In contrast, Sioux bouldery loamy coarse sand with slope type E is a soil with a low predicted productivity value. Its characteristics include a hydraulic conductivity of 24.44 cm/hour (9.625 inches/hour), an average slope of 21 percent, bulk density of 1.52 gm/cubic cm, an electrical conductivity of 2 Mmhos/cm, 30 percent rock fragments and 0.2% organic matter.

Limitations of Model. The regressors in the equation have limits concerning the applicability of the soil productivity model.

First, the hydraulic conductivity levels examined in the study range from 3.3 cm/hr to 33 cm/hr, the bulk density levels examined in the study range from 0.175 gm/cubic cm to 1.6 gm/cubic cm, the electrical conductivity levels examined in the study range from less than 2 Mmohs to 6.8 Mmohs and the organic matter levels examined in the study range from 0.2 percent to 53.7 percent. This means the effects on plant growth above and below these ranges are beyond the predictive bounds of the equation. Second, the lower limit for both percent slope and percent rock fragments were encountered in the study. The lower limit has a bound of zero. Therefore, soils reaching the lower limit of these two regressors are still applicable. However, average slopes greater than 24 percent and percent rock fragments greater than 30 percent are also beyond the bounds of the equation.

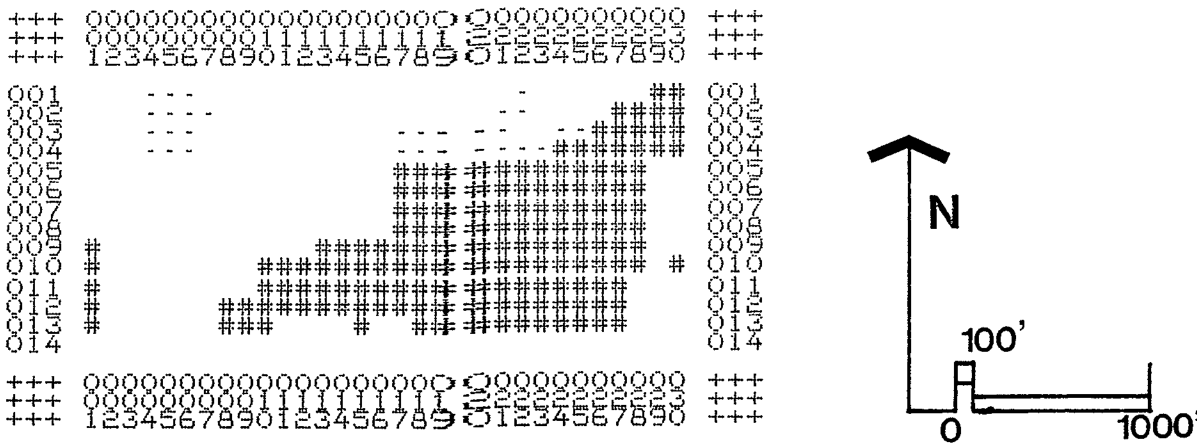
In addition to bounds placed upon the model by the regressors in the equation, the model is limited to location of applicability and origination of parent material. All soils studied were from Clay County, Minnesota. Therefore the model is effective for soil types found in Clay County only. The model is not applicable for any other region. Futhermore, the model should be applied in situations where the site soils originate from parent material examined in the study. Soils derived from other parent materials or site conditions are beyond the predictive applicability of the equation.

EQUATION APPLICATION

In this thesis, a model has been identified that can predict Clay County soil productivity for seven crops. This model can be applied to the Spillum site for development of a plant productivity post-mining land-use plan.

To assist in developing a post-mining land-use plan, a microcomputer mapping and analysis package was employed (Tomlin 1986). For convenient mapping and analysis purposes, the Spillum site was divided into 420 cells. Each cell represented a square area of land 30.48 m by 30.48 m (100 feet by 100 feet). Figure 5 is a soil productivity map for undisturbed portions of the Sioux soils series. The name of this map in the mapping package is, "EXSOILPR." The title is an abbreviation for "existing soil pre-mining."

Pre-mining Soil Productivity. Sand and gravel is extracted from the Sioux soil series, specifically soil 402E. At present, about half sand and gravel resources from the Spillum site have been extracted. The existing mine was in operation prior to the development of the Clay County soil survey. Therefore, the pre-mining plant productivity conditions for the existing mine site are difficult to estimate. One might speculate that the existing mining operations occupy soils that were previously from the Sioux series. However, the remaining portions of the Spillum site are easier to assess. For illustrative purposes, the unmined soil series 402E will be selected to demonstrate the



EXSOILPR

	0	NON-MINED SOILS	231 POINTS	55.0%
##########	4	402E SOILS	159 POINTS	37.9%
----------	9	402C SOILS	30 POINTS	7.1%

FIGURE 5. MAP OF SOILS TO BE MINED ON SPILLUM SITE

applicability of the agricultural productivity equation to develop a post-mining land-use plan. Table 9 illustrates the existing grand total site productivity scores for the eastern portions of unmined 402E soils.

The grand total productivity score allows the reclamation specialist the opportunity to develop a picture of the overall agricultural conditions associated with a given site. It also allows the reclamation specialist to compute total productivity across soil types. This method is similar to methods employed by Spindler and Downing (1986).

TABLE 9. EXISTING PLANT PRODUCTIVITY SCORES FOR PRE-MINED LAND.

Soil	Soil Productivity	Area	Grand Total Productivity
Gravel Pit	Unknown	31.45 Acres	
402E	-3.2501	35.12 Acres	-114.14
			-114.14

The objective of the equation application would be to create post-mining soils with equal or greater grand total crop productivity than pre-mining conditions. A $p<0.5$ will be used to compare the means of existing soil productivity and proposed soil productivity.

SENSITIVITY ANALYSIS

To select the best productivity condition, it is helpful to systematically study the equation. For example, to determine the optimum settings for several variables in an equation, linear programming is often employed (Ramalingam 1976); however, if the equation is not linear (squared terms, and overlapping interaction terms) linear programming is of little assistance. An alternative method is sensitivity analysis. Sensitivity analysis is performed to understand how the model (equation) behaves under a variety of environmental situations. Ramalingam (1976), McAllister (1982) and Westman (1985) discuss the importance of sensitivity analysis in model optimization. Sensitivity analysis is a process which seeks to discover whether decisions derived from the model would change with alterations in context. For example, sensitivity analysis is commonly performed in economic studies where varying rates of opportunity cost (discount rate) may affect decision making. In the case of soil productivity, there are landscape contexts which may affect the selection or choice of amendment prescriptions. For example, in this study, the context could be considered to be the general level of soil productivity: high, moderate and low. Each level may require a different approach to improve soil productivity.

A sensitivity analysis was performed on the equation by examining the equation under five general contexts: high productivity (2 standard deviations above the mean for all regressors), moderately high productivity (1 standard deviation above the mean for all regressors), moderate productivity (mean values for all regressors), moderately low productivity (1 standard deviation below the mean for all regressors) and low productivity (2 standard deviations below the mean for all regressors). Appendix C lists the combination of variables examined in the sensitivity analysis of the equation 5. There were twenty-one settings of each factor (HC, SL, FR, BD, EC and OM), examined under these five contexts. MathCAD 1.1 (MathSoft 1987) was utilized to perform the mathematical sequence of operations to conduct the sensitivity analysis. The sensitivity analysis was conducted by studying the equation within five equation conditions:

(A) all variables set at minus two standard deviations below their mean, with the exception of the variable being manipulated,

(B) all variables set at minus one standard deviation below their mean, with the exception of the variable being manipulated,

(C) all variables set at their mean, with the exception of the variable being manipulated,

(D) all variables set at plus one standard deviation above their mean, with the exception of the variable being manipulated,

(E) all variables set at plus two standard deviations above their mean, with the exception of the variable being manipulated.

This procedure resulted in 630 soil productivity calculations. The results of the sensitivity analysis indicated that the model was sensitive to different conteptual settings and that soil prescriptions must be adjusted to meet the specific environmental context of the particular soil. The following is a discussion of the results from the different settings.

2 Standard Deviations Below Mean. At this level, increases in percent rock fragments, bulk density and electrical conductivity increase soil productivity scores, while decreases in hydraulic conductivity, percent slope and percent organic matter increase soil scores.

Standard Deviation Below Mean. At this level, increases in percent rock fragments, bulk density and electrical conductivity increase soil productivity scores, while decreases in hydraulic conductivity, percent slope and percent organic matter increase soil productivity.

Mean. At mean values, changes in percent rock fragments, bulk density, electrical conductivity and percent organic matter result in no change in soil productivity scores. However, decreases in slope and hydraulic conductivity produce increases in soil productivity.

One Standard Deviation Above Mean. At one standard decreases in bulk density, hydraulic conductivity, percent slope, electrical conductivity and percent rock fragments increase soil productivity. Only an increase in percent organic matter increases soil productivity.

Two Standard Deviations Above Mean. Decreases in bulk density, hydraulic conductivity, percent slope, electrical conductivity and percent rock fragments increase soil productivity, while an increase in percent organic matter increases soil productivity.

Table 10 lists a general summary for the findings of the sensitivity analysis. Essentially, there are three strategies. First, if all the regressor variables for a particular soil are low in value, increases in percent rock fragments, bulk density and electrical conductivity plus decreases in percent slope, hydraulic conductivity and percent organic matter result in increased agricultural soil productivity. Second, if the regressor variables for a particular soil are near the mean in value, decreases in slope and decreases in hydraulic conductivity will increase soil productivity. Third, if the regressor variables for a particular soil are high in value, decreases in bulk density, hydraulic conductivity, percent rock fragments, percent slope and electrical conductivity plus increases in percent organic matter increase soil productivity.

TABLE 10. GENERAL STRATEGY FOR IMPROVING SOILS.

	Initial Regressor Values for a Soil			
	Low Values	Mean Values	High Values	Mixed Values
Hydraulic Conductivity	Decrease	Decrease	Decrease	Further Study
Percent Slope	Decrease	Decrease	Decrease	Further Study
Bulk Density	Increase	No Effect	Decrease	Further Study
Percent Rock Fragments	Increase	No Effect	Decrease	Further Study
Electrical Conductivity	Increase	No Effect	Decrease	Further Study
Percent Organic Matter	Decrease	No Effect	Increase	Further Study

It is highly unlikely that soil values for a neo-sol will be either all below their county means, all exactly near their county means, or all above their county means. Instead, neo-sols may exhibit a mixed condition. When soil variables exhibit a mixed condition, (meaning that some variables are above plus one standard deviation and others are below one standard deviation) further sensitivity analysis is recommended. An examination of the Spillum site will illustrate this.

SPILLUM SITE PROPOSED SOIL PRODUCTIVITY

The general strategy for improving soils can be used as a guide for examining potential improvements of the post-mining landscape at the Spillum site. The soil series that is being affected (Sioux series) is summarized in Table 10. The Sioux soil series are characteristic of sites with steep slopes. The soil exhibits high hydraulic conductivity, high percentage of rock fragments, high bulk density, low soil electrical conductivity and low soil organic matter. This suggests that the soil is mixed in values, having some values above the county mean and others below the mean.

When the Sioux soil values are placed into the equation, it is apparent that decreases in hydraulic conductivity, percent slope, percent rock fragments plus increases in bulk density, electrical conductivity and percent organic matter will increase productivity values. This suggests a basis for developing an approach to increase soil productivity.

Within the confines of these prescription suggestions there are many approaches to achieving increased soil productivity. Four basic approaches were examined in this study. The first approach is the sand and gravel extraction method. In this reclamation technique, post-mining boulders are buried and the landscape is graded level. (This approach was originally agreed to in the lease). The second approach adds another phase to the reclamation process by compacting the soil. The third approach is to add organic matter and salts (such as calcium carbonate) to the soil. The fourth approach is to carefully reconstruct soil profiles to achieve maximum productivity. Each of these alternatives will require further sensitivity analysis beyond the analysis performed in Appendix C to determine the optimum reclamation approach.

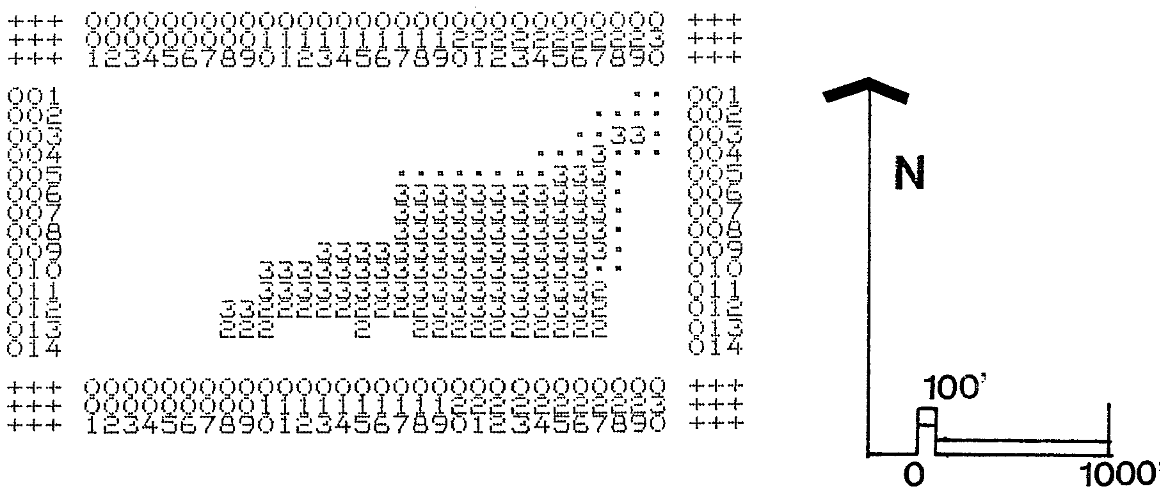
Extract, Grade and Level Alternative. Table 11 illustrates the three soil conditions under this alternative. With this alternative, a sandy and 3% sloped plain would exist in the center of the mining pit. At the edges, unmined earthen hills consisting of relatively uniform sandy slopes would surround the plain. Under this alternative, it is important to know which combination of slopes and plains will result in the highest total productivity for the site. To identify the best combination, iterations were generated (Appendix D). The results indicate that while steep side slopes allow a greater area of gentle slopes, the negative soil productivity scores on the steep slopes create a reduced grand total productivity for the entire site. The closer the entire site is graded to a three percent slope; the higher the overall productivity will be.

TABLE 11. PRODUCTIVITY SCORES FOR EXTRACT, GRADE AND LEVEL ALTERNATIVE.

Soil	Soil Productivity	Area	Grand Total Productivity
slope 30%	-2.239	6.89 Acres	-15.43
slope 10%	1.677	5.74 Acres	9.63
slope 3%	2.476	22.49 Acres	55.68
			49.88

Figure 6 is a map illustrating the soil productivity pattern for the reclaimed soils in the extract grade and level alternative.

Under normal conditions, removing rock and grading the landscape to a three percent slope would be a very expensive proposition. Bulk excavating and rough grading costs would be approximately $1.00 per bulk cubic yard (Kerr, et al., 1986). Rock removal would cost between approximately $1.00 and $2.50 per cubic yard of rocks collected. When moving hundreds of thousands of cubic yards of soil, the cost to improve soil productivity may be approximately $12,907.00 per acre (43560 feet squared * 4 feet deep * $2.00/cubic yard / 27 feet cubed per cubic yard). This means that under typical farming situations, it would be too costly to rehabilitate the soils by grading and rock removal. However, removing rocks and leveling the land is a typical process of sand and gravel surface mining. Therefore, the removal of rocks and



EXTRPOST

	0	_______________	267 POINTS	63.6%
....	8	30 % SLOPE	30 POINTS	7.1%
2222222222	12	10 % SLOPE	25 POINTS	6.0%
3333333333	13	3 % SLOPE	98 POINTS	23.3%

FIGURE 6. MAP OF SOIL PRODUCTIVITY SCORES FOR EXTRACT, GRADE AND LEVEL ALTERNATIVE

the regrading of the land is accomplished as a by-product of surface mining.

Under this alternative the post-mining landscape can be improved. The three predicted productivity scores listed in Table 11 are all above the 95% confidence region for soil S402E illustrated in Figure 4. Soil productivity scores from Figure 4 that are slightly less than the three predicted scores listed in Table 11 have 95% confidence tails that do not overlap with the 95% confidence region for soil S402E. Thus the open plain and pit walls have at least a 95% probability that they overlap with the pre-mining scores.

In this illustration, all of the post-mining predicted values are above the pre-mining values. Under other situations, there may be a mixture of conditions where some values are above previous values while other values may be below. Daniel (1978) describes non-parametric methods to determine which set of scores (ie. pre-mining versus post-mining) may be greater. The sign test of two related samples is a distribution free procedure that can be applied to comparing the two sets of scores.

<u>Compact Soil Alternative.</u> Compacting the soil (thereby reducing hydraulic conductivity and increasing bulk density) is another reclamation alternative. Under this alternative, machinery not normally used in the mine process would have to be driven over the site to compact the soils, and would be

therefore an added cost to reclamation. The results of this approach (Table 12) indicate modest increases in the soil productivity. The cost of compacting the soil is approximately $0.50 per compacted cubic yard (Kerr, et al., 1986). To compact one acre to a depth of four feet, would cost a minimum of approximately $3,227.00.

TABLE 12. PRODUCTIVITY SCORES FOR COMPACTED SOIL ALTERNATIVE

Soil	Soil Productivity	Area	Grand Total Productivity
slope 20%	-1.5087	6.89 Acres	-10.39
slope 10%	2.4082	5.74 Acres	13.82
slope 3%	3.256	22.49 Acres	73.23
			76.66

An alternative which suggests that compacting the soil will increase productivity at first glance appears contrary to research results reported by Graham, et al., (1986) and McSweeney, et al., (1987). They indicated that compacted neo-sols reduced plant productivity. However, they examined loam rather than sandy soils. Sandy soils can benefit from compaction to reduce hydraulic conductivity. Loamy soils will already have lower hydraulic conductivity and may not benefit from compaction.

<u>Add Organic Matter and Increase Electrical Conductivity Alternative.</u> Appendix D illustrates the results obtained by adding organic matter and increasing electrical conductivity.

Small portions of organic matter and the addition of ions (increasing electrical conductivity using materials such as calcium carbonate) will decrease soil productivity; however, only large amounts of organic matter and ions will lead to increased productivity.

Increasing the organic content of the first four feet of the soil would require approximately 7,000 loose cubic feet of peat moss or composted manure. The organic material costs between $2.00 to $4.00 per loose cubic foot to install (Kerr, et al., 1986). This would mean that the cost per acre would be approximately $14,000.00 to $28,000.00. In addition, the cost of increasing the electrical conductivity through the addition of adding limestone would be approximately $100.00 per ton (Kerr, et al., 1986). If 15.24 cm of limestone were added to the first four feet of soil, the cost could exceed $81,000.00 per acre. Table 13 illustrates the grand total productivity of the reclaimed land under this alternative.

TABLE 13. PRODUCTIVITY SCORES FOR ADDED ORGANIC MATTER AND INCREASE ELECTRICAL CONDUCTIVITY ALTERNATIVE.

Soil	Soil Productivity	Area	Grand Total Productivity
slope 20%	-1.801	6.89 Acres	-12.41
slope 10%	2.1159	5.74 Acres	12.15
slope 3%	2.915	22.49 Acres	65.56
			65.30

Soil Profile Alternative. Another approach would be to strip and save the topsoil portion and spread the topsoil over the post-mining landscape. This topsoil would have a plant productivity value of .8281 (Equation 8).

$$
\begin{aligned}
\text{PLANTS IN PIT BOTTOM}\\ \text{A HORIZON} &= .6206+(-1.1805(1.276))+ \\
&\quad (0)+ \\
&\quad -1.9375(0.536)(-0.26)+ \\
&\quad -2.3420(-0.48)(-0.26)+ \\
&\quad (1.2424*((2.0-3.9512)/0.6638)(-0.48) \\
&= .8281 \qquad \text{Eq 8}
\end{aligned}
$$

However, this value is not as high as the mean of the extract and grade alternative ($p<.05$), therefore, there is no productivity gain from saving the topsoil profile and placing the soil on top of the post-mining landscape. The cost to strip, remove rocks and replace the topsoil (30.48 cm deep) would be approximately $10,000 per acre.

Cost Comparison. Table 14 illustrates the cost comparison and productivity scores associated with each alternative. The compacted soil alternative, added organic matter and increased electrical conductivity alternative and soil profile alternative are expensive alternatives; while the extract, grade and level alternative improves the soil productivity score at a very low marginal cost.

TABLE 14. COMPARISON OF COST ALTERNATIVES.

ALTERNATIVE	PRODUCTIVITY SCORE ON OPEN PLAIN	COST PER ACRE	COST PER ACRE/ PRODUCTIVITY SCORE
EXTRACT, GRADE AND LEVEL	2.476	$100.00	$40.38/POINT
COMPACT SOIL W/ EXTRACT, GRADE AND LEVEL	3.256	$3,327.00	$1,021.81/POINT
ADD ORGANIC MATTER & INCREASE ELECTRICAL CONDUCTIVITY W/ EXTRACT, GRADE AND LEVEL	2.915	$101,767.00	$34,911.49/POINT
SAVE TOPSOIL W/ EXTRACT, GRADE AND LEVEL BENEATH	1.8168	$10,100.00	$5,559.22/POINT

Long Term Stability. Even if any of these prescriptions were properly executed, there is no guarantee that the neo-sol would retain its properties after several years. Long-term stability studies and examinations to determine soil productivity decline have only recently been considered for investigation (Toy and Shay 1987).

SUMMARY

For the Spillum site, the most promising alternative is the extract, grade and level approach. With this approach the costs above the normal costs associated with sand and gravel operations to improve soil productivity are very small. These small costs are for leveling rough portions of the post-mine landscape. Figure 7 illustrates a CADKEY (Micro

Control Systems 1986) computer representation of the landscape prior to mining the remaining portions of the Spillum site. Figure 8 illustrates a computer representation of the study during post-mining agricultural use. This image was drawn by applying the extract, grade and level approach using the volume of remaining material in Appendix B.

The prescription associated with the Spillum site is a site specific approach. As a result, applications of the equation to other Clay County sites may result in different recommendations.

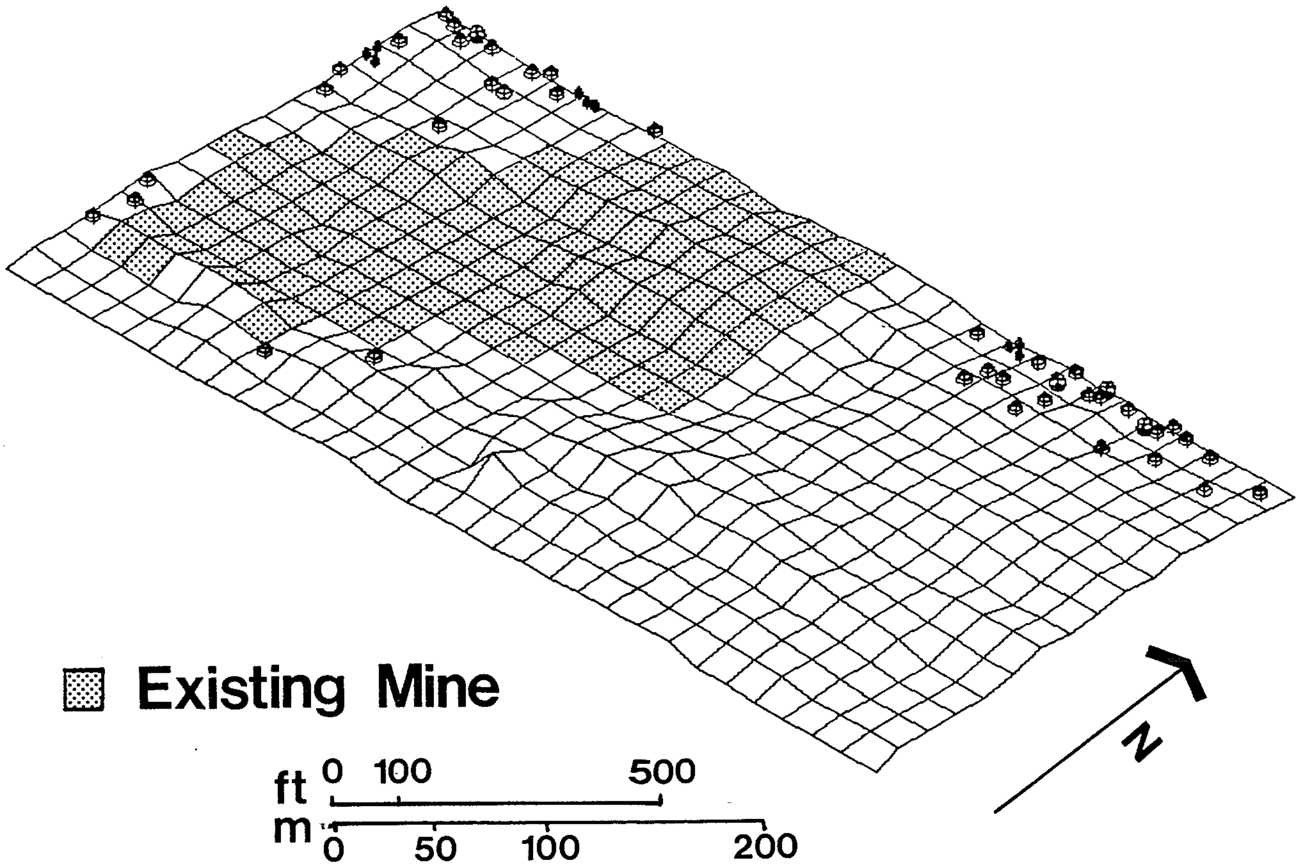


FIGURE 7. COMPUTER REPRESENTATION OF EXISTING MINE SITE

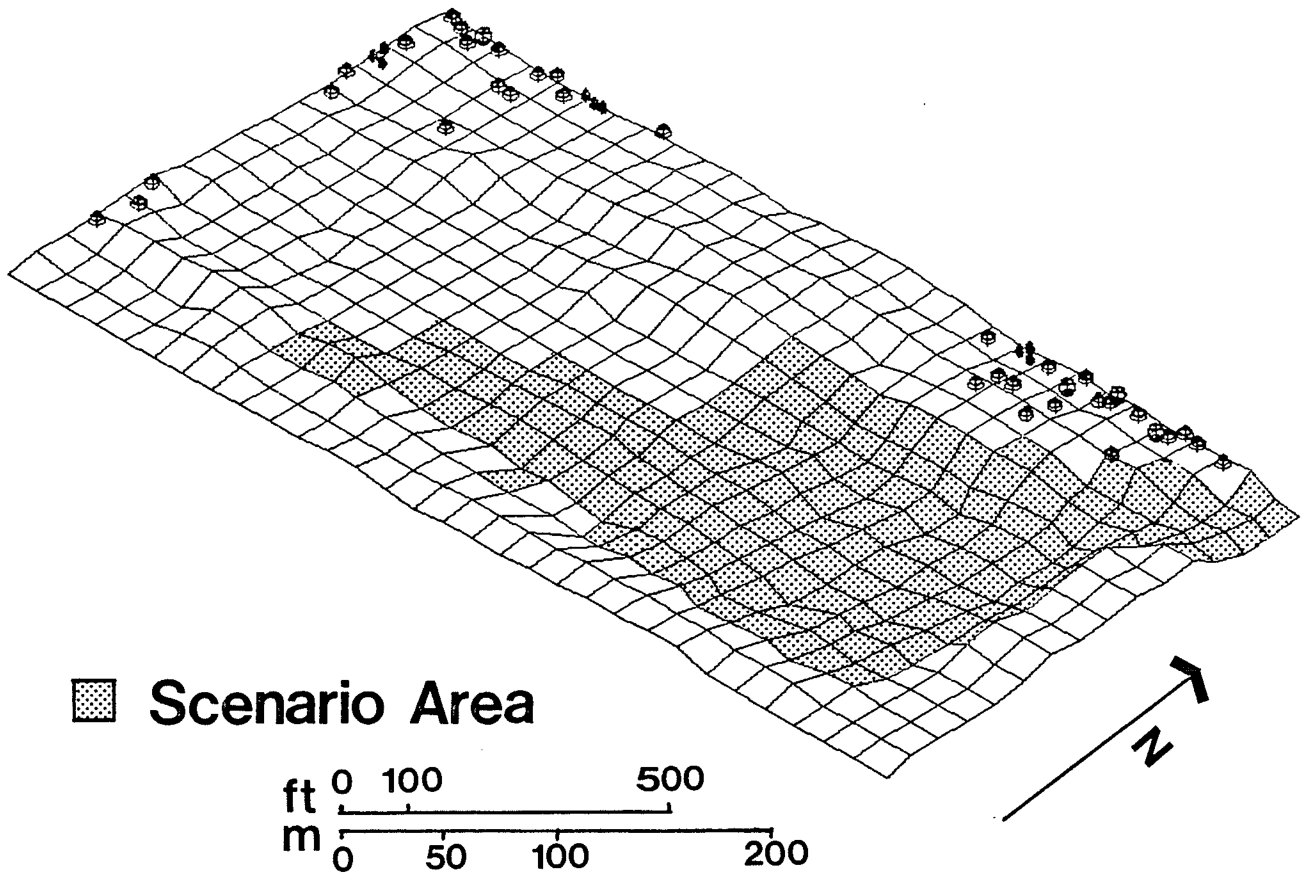


FIGURE 8. COMPUTER REPRESENTATION OF PROPOSED MINE SITE

CONCLUSION

An equation was developed from a data bank consisting of eighty soils in Clay County, Minnesota. Each soil had measurements for ten properties (independent soil factors) at each 2.54 cm interval in a 152.4 cm profile. Crop harvest data was available for seven vegetative crops (dependent variables). The crop harvest data was collected over a period of approximately ten years. Using Principal Components Analysis, a single crop production value for each soil was obtained. This single value was used to regress soil factors against crop production. An equation was made which had regressors at $p<.0001$, satisfied C-Plot requirements and multicollinearity requirements. This equation can predict soil productivity values and compare means between predicted soil productivity values with 95 % confidence levels.

This equations was applied to the Spillum site (a sand and gravel surface mine) in Clay County. Grading the post-mining landscape to a three precent slope, compacting the soil and having a rock-free soil profile for the first four feet of soil was determined the most cost effective solution. Adding organic matter or limestone and saving the topsoil for placement on the surface of the post-mining landscape were not identified as cost effective solutions for this site.

The equation is not applicable to areas outside Clay County. In addition the equation is not applicable to situations where chemical and physical soil properties are above or below the properties encountered in this study.

The equation can be applied to guide the development of surface mine reclamation plans. The model can determine landform and suggest appropriate soil admendments. However, as with most mathematical simplifications of the real world, caution should be exercised in the application of the equation. The equation is only as good as the original data set. Future data sets may generate revised editions of this equation.

In addition, the long-term stability of neo-sol configurations has not been determined. Future projects may address the long-term stability of agricultural productivity prescriptions.

APPENDIX A. SPILLUM SITE

The Spillum site is presently being mined for sand and gravel; however, the extent of the operations is small in comparison to the size of the deposit. This means that the mine may be used many years into the future. The mine has potential for demonstrating pre-mining applications of the equation to create post-mining landscapes.

PRE-MINING LANDSCAPE

Prior to mining, the site was relatively undisturbed and remained similar to its condition before European settlement. The site had a rolling topography with primarily dry prairie vegetation and bur oak (*Quercus macrocarpa*) savanna. Curtis (1959) describes the general composition of these plant associations.

MINING AGREEMENT AND OPERATIONS

In the late 1960's, a lease was obtained from the landowner by the mining operator (Clay County 1968). Under the terms of the original agreement, the operator was required to pay $0.32 (American currency) for each yard of material taken from the site and was required to remove at least $1,000.00 worth of materials each year. The lease contains a clause requiring the operator to reclaim the land once gravel pit operations have ceased.

Mining operations began by stripping the topsoil. A large excess sand stockpile was created during the early phases of operations. At this point during the mining operations, the landowner requested that the operator perform pit-run extraction.

Pit-run extraction is the direct placement of sand and gravel into trucks for hauling. The gravel is not separated from the sand and fines. The trucks haul the material to rock crushers and separators, to concrete plants and to construction sites.

At the Spillum site, over 50 % of the lease area remains unmined. Eventually the unmined areas will be mined for sand and gravel.

The size of the deposit beyond the Spillum site is extensive. The deposit extends to the east for several miles. Much of this deposit is presently under lease and purchase fee simple for future surface mining.

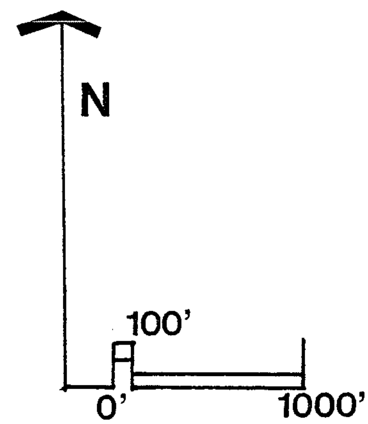
SOILS

The deposit is associated with the Sioux soil series (Jacobsen 1982) (Figure 9). The deposit has a large constituent of boulders, cobbles and gravel, approximately 55% (Figure 10). The soil is well graded and poorly sorted (Equations 9 and 10). In addition, the soils are very droughty. They are very suitable for construction material but very poor for septic tanks and pond reservoirs. The soil is very low in organic matter. The topsoil is only 3" thick.

```
+++ 000000000000000000000000000000 +++
+++ 000000000111111111122222222223 +++
+++ 123456789012345678901234567890 +++

001 AAAeeeAA        jjj##e######ꝏꝏ 001
002 AAAeeee         jjj#ee####ꝏꝏꝏꝏ 002
003 AAAeee          eeeee##eeꝏꝏꝏꝏꝏ 003
004 AAAeee          eeeeeeeꝏꝏꝏꝏꝏꝏꝏ 004
005 AAA             ꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏAA 005
006 AA              ꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏAA 006
007 A               ꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏAA 007
008                 ꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏAA 008
009 ꝏ           ꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏAA 009
010 ꝏ        ꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏAꝏ 010
011 ꝏ        ꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏAAA 011
012 ꝏ      ꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏ    012
013 ꝏ  jjj ꝏꝏꝏjjjjꝏjjꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏ    013
014 jjjjjjjjjjjjjjjjjjjjjjjjjjjjjj 014

+++ 000000000000000000000000000000 +++
+++ 000000000111111111122222222223 +++
+++ 123456789012345678901234567890 +++
```



POSPRPLA

	0	EXISTING MINE	137 POINTS	32.6%
##########	4	SOIL 893E	15 POINTS	3.6%
ꝏꝏꝏꝏꝏꝏꝏꝏꝏꝏ	6	SOIL 402E	159 POINTS	37.9%
AAAAAAAAAA	20	SOIL 966D	34 POINTS	8.1%
eeeeeeeeee	29	SOIL 402C	30 POINTS	7.1%
jjjjjjjjjj	39	SOILS 494 & 966C	45 POINTS	10.7%

FIGURE 9. MAP OF SOIL LOCATED ON SPILLUM SITE

Exposed substrate greatly exceeds recommended soil erosion rates to maintain soil fertility.

Other soils existing on the Spillum site include the Lohnes-Waukon complex, Darnen loam, Waukon-Sioux complex and the Sverdrup sandy loam. These well drained sandy and stoney soils are susceptible to erosion.

The size of the deposit to be removed on the Spillum site (Table 15) is estimated to be 0.290 million bulk cubic yards of boulders and cobbles, 0.900 million bulk cubic yards of gravel, 0.110 million bulk cubic yards of course and medium sand, 0.126 million bulk cubic yards of medium sand and 0.057 million bulk cubic yards of fine sand. Once operations are complete, approximately 0.89 million bulk cubic yards of sand and fines will remain.

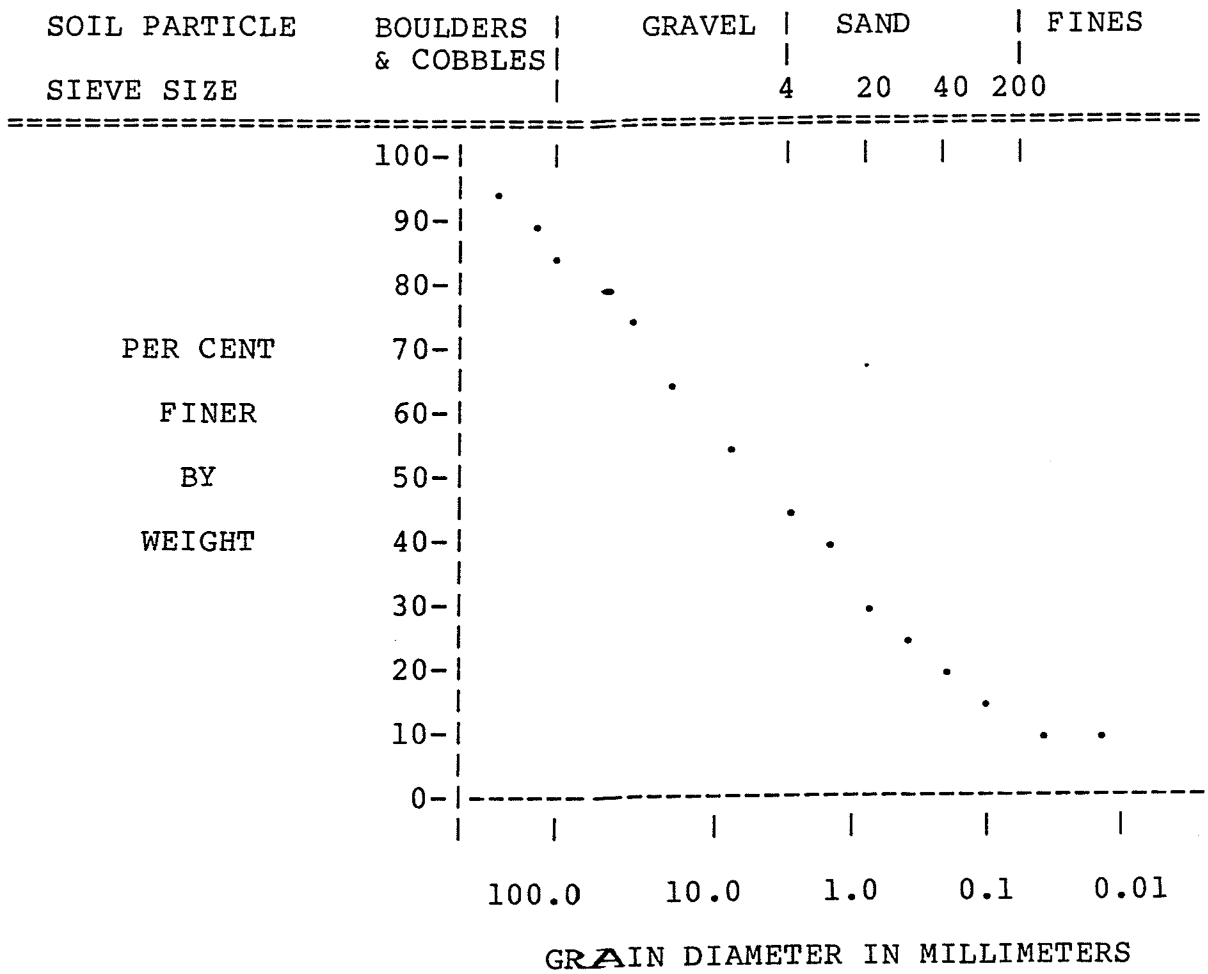


Figure 15. Graph of Particle Distribution in Sioux Soil Series.

$$\text{UNIFORMITY COEFFICIENT} = \frac{D60}{D10} = \frac{10.5}{.09} = 116 = \text{Well Graded Graded} \qquad \text{Eq 9}$$

Where

D60 = 60 % Grain Size

D10 = 10 % Grain Size

$$\text{SORTING COEFFICIENT} = (D75/D25)^{.05} \qquad \text{Eq 10}$$

$$= (90/0.9)^{0.5}$$

$$= 10 = \text{Poorly Sorted}$$

Where:

D75 = 75 % Grain Size

D25 = 25 % Grain Size

Table 15. Spillum site: volume of deposit materials sorted by size.

	TOTAL	BOULDERS & COBBLES	GRAVEL	COURSE SAND	MEDIUM SAND	FINE SAND	FINES	TOPSOIL
% OF SOIL		15%	43%	12%		13%	6%	11%
% FINER		85%	42%	30%		19%	11%	---
SOIL VOLUMES*								
WEST PARCEL	1.5	0.225	0.645	0.180	0.195	0.095	0.165	0.012
REMOVED		0.18	0.516	0.072	0.076	0.036	0.005	0.000
TO BE REMOVED		0.04	0.129	0.008	0.01	0.009	0.001	0.000
TO STAY		0.005	0.000	0.090	0.100	0.050	0.160	0.012
EAST PARCEL	1.7	0.255	0.731	0.204	0.221	0.102	0.190	0.014
TO BE REMOVED		0.250	0.731	0.102	0.107	0.048	0.006	0.000
TO STAY		0.005	0.000	0.102	0.114	0.054	0.184	0.014

* IN MILLIONS OF CUBIC YARDS

SURROUNDING LAND-USE

The site is surrounded by compatible land-uses. A large xeric forest is located to the north. Grazing lands are to the east and west. Grazing lands and cultivated cropland exist to the south. Presently, there are no adverse land-uses near the site such as residential housing or commercial offices to cause incompatibility. However, there exists a scenic incompatibility issue. The site is part of a scenic resource as one travels through the moraine dominated landscape to the lake country. To the east of the site, a substantial recreation industry with extensive lake homes and summer recreation has been developed in the area. Barren excess sand stockpiles detract from the scenic character of the landscape.

Visually, pit operations are hidden from the public. The pit is buffered by berms. The berms consist of sandy and loamy soils unsuitable to mine. The rolling landscape berms reduce noise pollution and contribute to dust control.

The first few miles of the hauling road are surfaced with gravel. The road requires dust reduction measures. Once yearly hauling operations are complete, the road in low-lying areas requires additional gravel. Hauling operations are conducted during the fall.

HYDROLOGY

The site has several important hydrological features. One unique feature is the site's watershed location. The site is at the watershed divide between the Buffalo River watershed and the Pelican/Ottertail river watershed (Maclay, et al., 1969 and Winter, et al., 1969).

Since the hydraulic conductivity of the soils are relatively high, surface water quickly penetrates the ground and recharges the groundwater. The Spillum site is an active groundwater recharge area. The water table is several hundred feet below the pit floor. The groundwater flows west into the Red River Valley Basin.

Groundwater supply from the east is an important resource for the Red River Valley Basin. The groundwater from the east is suitable for drinking. Groundwater that enters the basin from the west is highly alkaline and unsuitable for drinking. Therefore, the integrity of the recharge potential at the Spillum site should be maintained.

EXISTING VEGETATION

There is no reported study of the vegetation at the Spillum site in the literature. However, sites in Clay County, several nearby counties and North Dakota provide a representative description of the floristic composition and vegetation dynamics of the area. Medhaug (1985) studied selected mesic forests of Ottertail County, Minnesota. Ottertail County is directly east and southeast of Clay County. While these mesic forests are nearby, occasional fires and droughty soils may prevent mesic forest trees from invading the oak savanna. Hanson (1976) studied the oak savanna of the Sheyenne National Grasslands. This study is the closest floristic oak savanna comparative to the Spillum site. Dziadyk (1981) studied several stands of prairie grasslands in Clay County. Dziadyk's study is the closest floristic prairie comparative to the Spillum site. Wanek (1967) studied the gallery forests of the Red River Valley.

His study is the closest wet forest comparative to the Spillum site. These studies comprise descriptions of the major plant communities in the region.

The 1987 Spillum site vegetation is dominated by a xeric prairie matrix (defined by Curtis 1959). Dry-mesic prairie corridors exist in the swales. Xeric prairies are very robust and can withstand intense grazing, drought, trampling and low fertility. To the north of the xeric prairie is a xeric forest and bur oak savanna. The xeric forest (defined by Curtis 1959) is very sensitive to trampling and compaction. This bur oak savanna represents a transition zone between the forest and prairie. This transition forest has been recently reviewed by Dunham (1981). He studied the transition forests in Mahnomen County, Minnesota. Mahnomen County is located to the northeast of Clay County. The bur oaks indicate a droughty soil and a past history of occasional fires. The section in this appendix describing land-use and recreational potential suggests future site development opportunities for the bur oak savanna.

WILDLIFE

Hilly and sandy landscapes similar to the Spillum site are often left by default to the production of wildlife. These landscapes provide a savanna complex ideal for browsing and for providing cover. According to Shelford (1978), the Spillum site is on the western edge of the oak-deer-maple biome. This upland landscape supports terrestrial land mammals such as white-tailed deer (<u>Odocoileus virginianus</u>), thirteen-lined ground squirrels (<u>Spermophilus tridecemlineatus</u>), woodchucks (<u>Marmota monax</u>) and red fox (<u>Vulpes vulpes</u>). Hazard (1982) describes the life history and abundance of mammals found in Minnesota. Green and Janssen (1975) illustrate the location and abundance of birds in Minnesota, including Clay County. Phillips, et al., (1982) describe the life histories and habitats of fish in the Minnesota region.

In addition to the oak-deer-maple biome, the Spillum site is on the eastern edge of the northern temperate grassland biome and the southern tip of the aspen parkland contact margin (Shelford 1978).

<u>NON-MINING LAND-USE</u>

Portions of the site not currently being mined are used for grazing. The site is a transitional landscape from the intense agriculture in the Red River Valley and the recreational lands to the east.

The site does not offer water related recreational potential; however, the site does offer the opportunity for recreational lands associated with state or county park development. To the northwest of the Spillum site is Buffalo River State Park. This park offers recreation in a prairie and gallery forest landscape. To the southeast of the Spillum site is

Maplewood State Park. This park offers recreation in maple/basswood and aquatic landscapes. A transitional landscape featuring recreation in a bur oak savanna landscape at or near the Spillum site can complement the two existing parks.

Although the small town of Rollag, Minnesota is approximately two miles to the west of the Spillum site, demand for housing and industrial sites in the area is low. Therefore the potential for the Spillum site to be used as a future building location is low. In addition, recreational housing featuring golf or nature related activites are being developed in the region. In the future there may be a market for savanna related recreational activites. The probability of the Spillum site being developed for recreational activity is low.

At present, mining operations do not interfere with the town of Rollag. Hauling operations by-pass the town.

Approximately one and one-half miles to the northwest of the Spillum site is the location of the annual Western Minnesota Steam Threshers Reunion. The reunion is an annual three day activity that occurs during the Labor Day Weekend (Western Minnesota Steam Threshers Reunion 1987). Mining operations do not interfere with the reunion. The operations and hauling occur after the reunion is completed.

In the Rollag area white-tailed deer hunting occurs every fall. Stray hunter's bullets have posed a threat to the area's residents and visitors. This potential safety problem (mine operators being struck by stray bullets) is avoided by mining operations occurring prior to the deer hunting season.

SITE SUMMARY

In summary, the site has several important points:

(1) droughty soils and high soil erosion potential,

(2) aquifer recharge integrity should be maintained,

(3) xeric conditions and infertile soils are poorly suited for intense agriculture and are poor for plant growth in general,

(4) soils are structurally very stable for construction, but have septic tank limitations,

(5) upon completion of mining operations, the deep water table makes lake or pond creation unlikely,

(6) low recreation potential,

(7) low housing market potential,

(8) unique xeric forest and oak savanna,

(9) site used for upland wildlife production and for agricultural grazing,

(10) there are no land-use conflicts with the mining operation,

(11) the mining operation is visually buffered from surrounding land-uses.

APPENDIX B. SAND AND GRAVEL DEMAND INDEX

Appendix B illustrates a procedure to calculate and compare the relative demand for sand and gravel between various demand centers.

The procedure determined that the demand for sand and gravel is concentrated in the glacial lake plain. This demand was calculated by using a simple one-way primary index. Westman (1985) and McAllister (1982) described the application of these index procedures. The index contained three basic components.

The first component was a construction requirement for sand and gravel products to be placed upon landscape features. For example, clay soils are highly unsuitable for road beds and unsuitable as a sub-base for many construction elements and thus sand and gravel products are utilized to mitigate the effects of shrink and swell, frost action, ponding, and low soil strength. The fatty clays of the glacial lake plain in Clay County have a greater physical demand for sand and gravel than the loamy soils on Clay County's till plain. A till plain often contains many stable soils and will not require massive soil modifications covering all of the till plain.

The second component was the relative area of each landscape feature. Those landscape features with more area have greater weighting. For example, while an area with clay may physically demand more sand and gravel, if the clay area is small in comparison to an area with loam soils, a small portion of sand and gravel will be utilized to mitigate the negative construction effects of the clay soils. In comparison, a large portion of sand and gravel will be needed during construction over the loam soils. In this study, the glacial lake plain had the largest area and thus had the highest weighting.

The third component was the relative population number for each landscape feature. Sand and gravel products are associated with the building and construction needs of people; the greater the population, the greater the importance for sand and gravel products. High population figures receive high importance values, low population areas receive low importance values. The glacial lake plain had the largest population.

Upon computing the index, the relative sand and gravel demand between areas can be compared. In Clay county, demand is greatest in the glacial lake plain. Sand and gravel products are consistently required to mitigate adverse physical soil conditions in the glacial lake plain. In Clay County the glacial lake plain comprises 65 % of the land area. For Clay County, 96 % of the population inhabits the glacial lake plain. Thus the factors of physical landscape demand, square area of demand and population importance result in a relative demand for the glacial lake plain that greatly exceeds the demand for sand and gravel in the till plain, moraine or beach ridge.

TABLE 16. LANDSCAPE NEED FOR SAND AND GRAVEL

	A1 SHRINK SWELL	+ A2 FROST ACTION	+ A3 PONDING	+ A4 STRENGTH	= B1
GLACIAL LAKE PLAIN	SEVERE 3	SEVERE 3	SEVERE 3	SEVERE 3	12
TILL PLAIN	MODERATE 2	MODERATE 2	MODERATE 2	MODERATE 2	8
MORAINE	MODERATE 2	MODERATE 2	MODERATE 2	MODERATE 2	8
BEACH RIDGE	SLIGHT 1	SLIGHT 1	SLIGHT 1	SLIGHT 1	4

TABLE 17. COMPUTATION OF RELATIVE DEMAND

C * % AREA	D % POPULATION	= H DEMOGRAPHIC INDEX	B*H	= F DEMAND INDEX	G RELATIVE DEMAND
65	96	62		74.8	94.2
2	1	00.02		--	NIL
28	2	56		4.5	5.7
5	0.5	00.225		0.1	0.1
100	~100			79.4	100.0

$$G = \frac{\left(\sum_{i=1}^{4} Aji\right)(Cj * Dj)}{\left[\sum_{j=1}^{4} Lj\left(\sum_{i=1}^{4} Aji\,(Cj * Dj)\right)\right]}$$

Where:

Aji = Soil action in a particular row and column.
Lj = Landscape feature (row).
i = Soil action (column).
B = Sum of soil actions for a particular landscape feature (row) indicating the relative degree soil amendments (sand & gravel) are required.
Cj = % area in Clay County for a given landscape feature (row).
Dj = % population in Clay County for a given landscape feature (row).
F = Demand index (B*H) for sand and gravel for a given landscape in Clay county (row).
G = Relative demand for sand and gravel for a given landscape in Clay County (row).
H = Cj * Dj

APPENDIX C. SENSITIVITY ANALYSIS EQUATIONS, TABLES AND GRAPHS

SENSITIVITY ANALYSIS: HYDRAULIC CONDUCTIVITY

Vary HC, all other regressors set at two standard deviations. below mean.

$N := 20 \qquad i := 0 \,..\, N$

$$HCZ_i := \frac{.13 + (i \cdot .64) - 3.9296}{4.0030}$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + -2$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + -2$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + -2$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + -2$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + -2$$

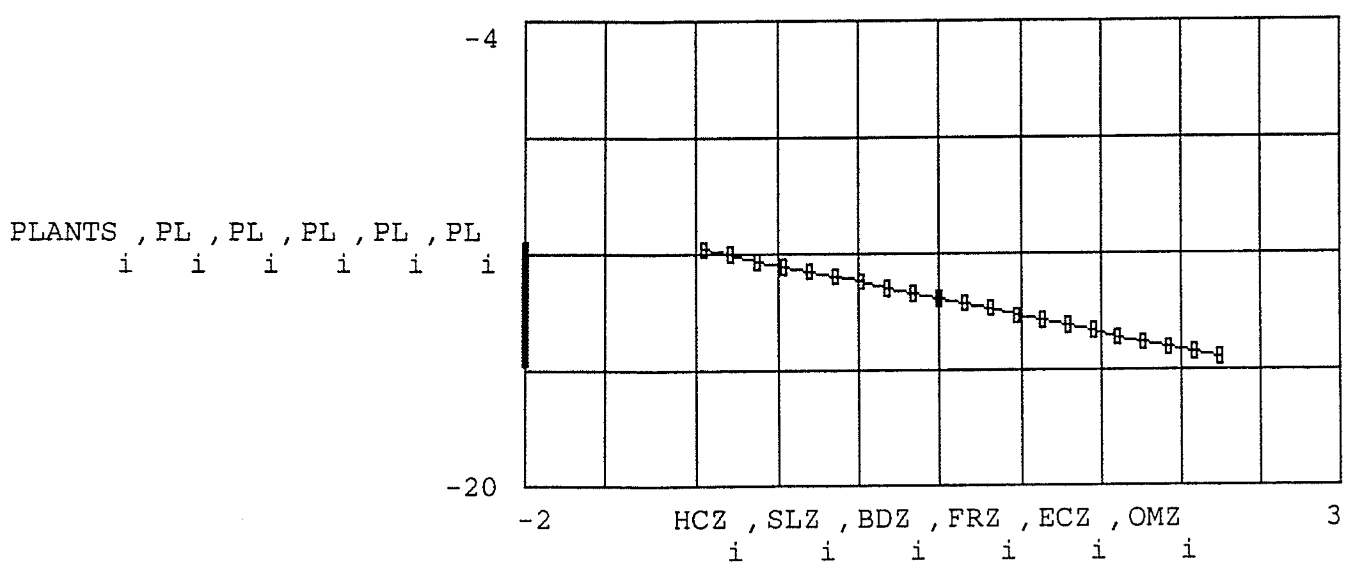
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$$

Table and graph of sensitivity analysis with HC varied and all other regressors set at two standard deviations below mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
-0.949	-2	-2	-2	-2	-2	-11.837
-0.789	-2	-2	-2	-2	-2	-12.026
-0.629	-2	-2	-2	-2	-2	-12.215
-0.47	-2	-2	-2	-2	-2	-12.403
-0.31	-2	-2	-2	-2	-2	-12.592
-0.15	-2	-2	-2	-2	-2	-12.781
0.01	-2	-2	-2	-2	-2	-12.97
0.17	-2	-2	-2	-2	-2	-13.158
0.33	-2	-2	-2	-2	-2	-13.347
0.49	-2	-2	-2	-2	-2	-13.536
0.65	-2	-2	-2	-2	-2	-13.725
0.809	-2	-2	-2	-2	-2	-13.913
0.969	-2	-2	-2	-2	-2	-14.102
1.129	-2	-2	-2	-2	-2	-14.291
1.289	-2	-2	-2	-2	-2	-14.48
1.449	-2	-2	-2	-2	-2	-14.668
1.609	-2	-2	-2	-2	-2	-14.857
1.769	-2	-2	-2	-2	-2	-15.046
1.929	-2	-2	-2	-2	-2	-15.235
2.089	-2	-2	-2	-2	-2	-15.423
2.248	-2	-2	-2	-2	-2	-15.612



SENSITIVITY ANALYSIS

Vary HC, all other regressors set at one standard deviation. below mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{.13 + (i \cdot .64) - 3.9296}{4.0030}$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + -1$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + -1$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + -1$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + -1$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + -1$$

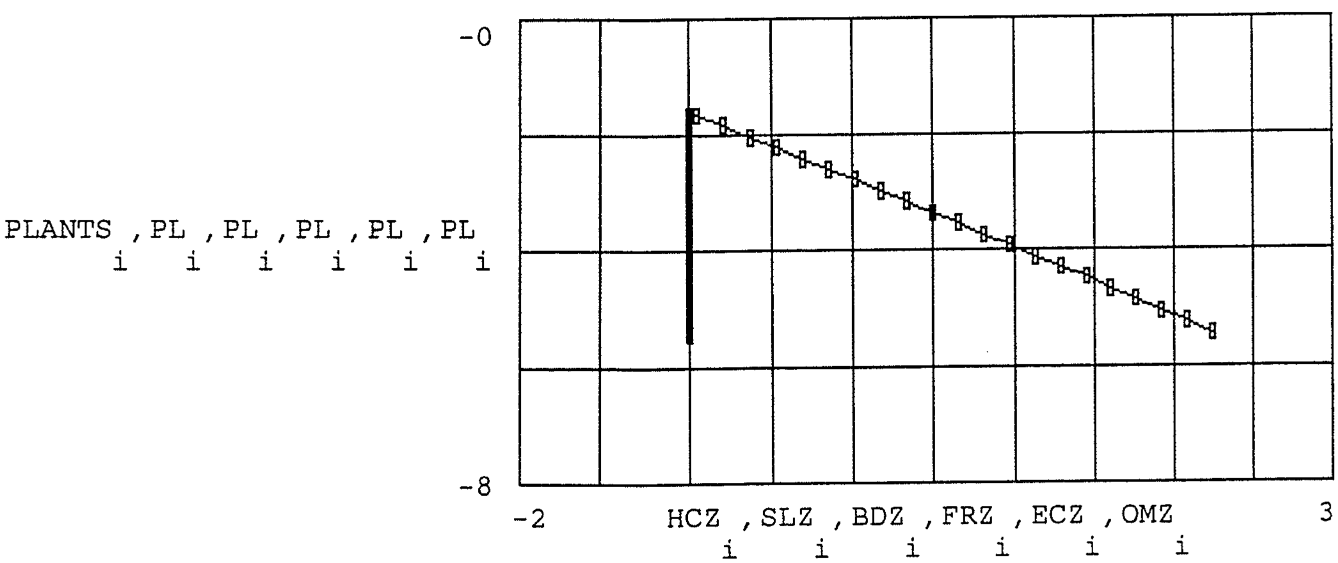
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot {SLZ_i}^2\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with HC varied and all other regressors set at one standard deviation below mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
-0.949	-1	-1	-1	-1	-1	-1.653
-0.789	-1	-1	-1	-1	-1	-1.842
-0.629	-1	-1	-1	-1	-1	-2.031
-0.47	-1	-1	-1	-1	-1	-2.22
-0.31	-1	-1	-1	-1	-1	-2.408
-0.15	-1	-1	-1	-1	-1	-2.597
0.01	-1	-1	-1	-1	-1	-2.786
0.17	-1	-1	-1	-1	-1	-2.975
0.33	-1	-1	-1	-1	-1	-3.163
0.49	-1	-1	-1	-1	-1	-3.352
0.65	-1	-1	-1	-1	-1	-3.541
0.809	-1	-1	-1	-1	-1	-3.73
0.969	-1	-1	-1	-1	-1	-3.918
1.129	-1	-1	-1	-1	-1	-4.107
1.289	-1	-1	-1	-1	-1	-4.296
1.449	-1	-1	-1	-1	-1	-4.485
1.609	-1	-1	-1	-1	-1	-4.673
1.769	-1	-1	-1	-1	-1	-4.862
1.929	-1	-1	-1	-1	-1	-5.051
2.089	-1	-1	-1	-1	-1	-5.24
2.248	-1	-1	-1	-1	-1	-5.428



SENSITIVITY ANALYSIS

Vary HC, all other regressors set at mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{.13 + (i \cdot .64) - 3.9296}{4.0030}$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810}$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929}$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947}$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644}$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638}$$

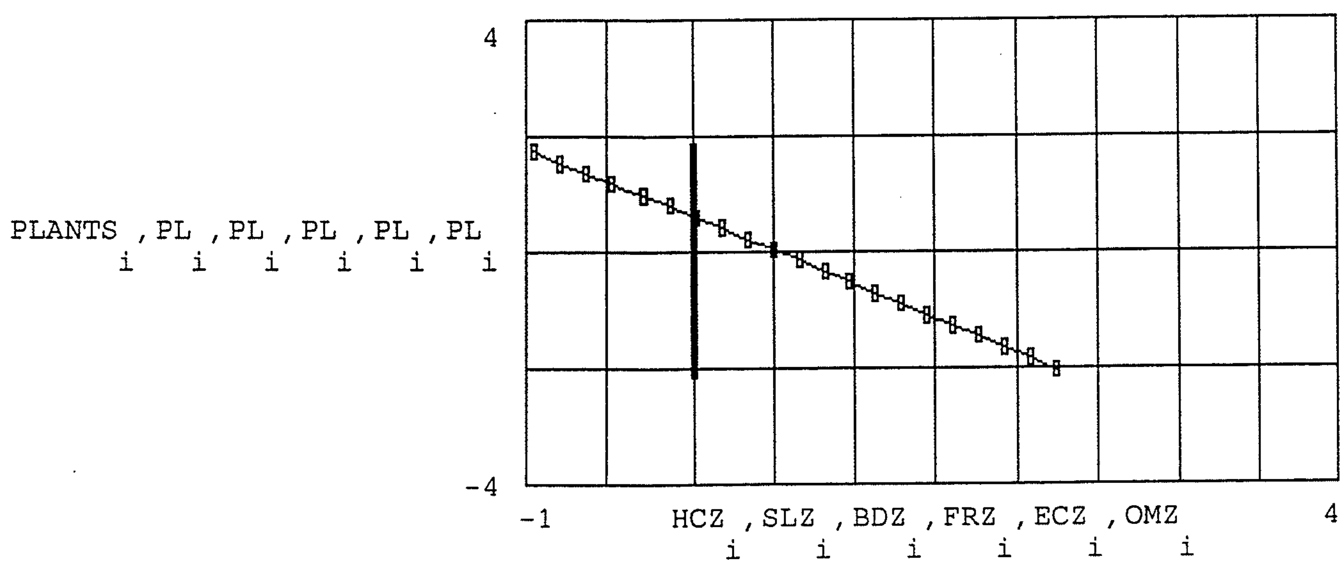
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$$

Table and graph of sensitivity analysis with HC varied and all other regressors set at mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
-0.949	0	0	0	0	0	1.741
-0.789	0	0	0	0	0	1.552
-0.629	0	0	0	0	0	1.364
-0.47	0	0	0	0	0	1.175
-0.31	0	0	0	0	0	0.986
-0.15	0	0	0	0	0	0.797
0.01	0	0	0	0	0	0.609
0.17	0	0	0	0	0	0.42
0.33	0	0	0	0	0	0.231
0.49	0	0	0	0	0	0.042
0.65	0	0	0	0	0	-0.146
0.809	0	0	0	0	0	-0.335
0.969	0	0	0	0	0	-0.524
1.129	0	0	0	0	0	-0.712
1.289	0	0	0	0	0	-0.901
1.449	0	0	0	0	0	-1.09
1.609	0	0	0	0	0	-1.279
1.769	0	0	0	0	0	-1.467
1.929	0	0	0	0	0	-1.656
2.089	0	0	0	0	0	-1.845
2.248	0	0	0	0	0	-2.034



SENSITIVITY ANALYSIS

Vary HC, all other regressors set at one standard deviation. above mean.

$N := 20 \qquad i := 0 \,..\, N$

$$HCZ_i := \frac{.13 + (i \cdot .64) - 3.9296}{4.0030}$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + 1$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + 1$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + 1$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + 1$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + 1$$

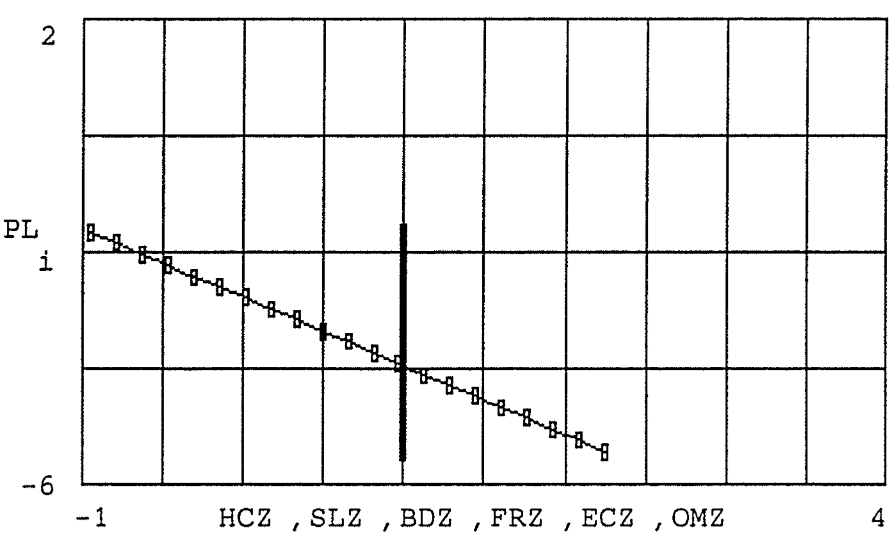
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with HC varied and all other regressors set at one standard deviation above mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
-0.949	1	1	1	1	1	-1.653
-0.789	1	1	1	1	1	-1.842
-0.629	1	1	1	1	1	-2.031
-0.47	1	1	1	1	1	-2.22
-0.31	1	1	1	1	1	-2.408
-0.15	1	1	1	1	1	-2.597
0.01	1	1	1	1	1	-2.786
0.17	1	1	1	1	1	-2.975
0.33	1	1	1	1	1	-3.163
0.49	1	1	1	1	1	-3.352
0.65	1	1	1	1	1	-3.541
0.809	1	1	1	1	1	-3.73
0.969	1	1	1	1	1	-3.918
1.129	1	1	1	1	1	-4.107
1.289	1	1	1	1	1	-4.296
1.449	1	1	1	1	1	-4.485
1.609	1	1	1	1	1	-4.673
1.769	1	1	1	1	1	-4.862
1.929	1	1	1	1	1	-5.051
2.089	1	1	1	1	1	-5.24
2.248	1	1	1	1	1	-5.428



SENSITIVITY ANALYSIS

Vary HC, all other regressors set at two standard deviations above mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{.13 + (i \cdot .64) - 3.9296}{4.0030}$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + 2$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + 2$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + 2$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + 2$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + 2$$

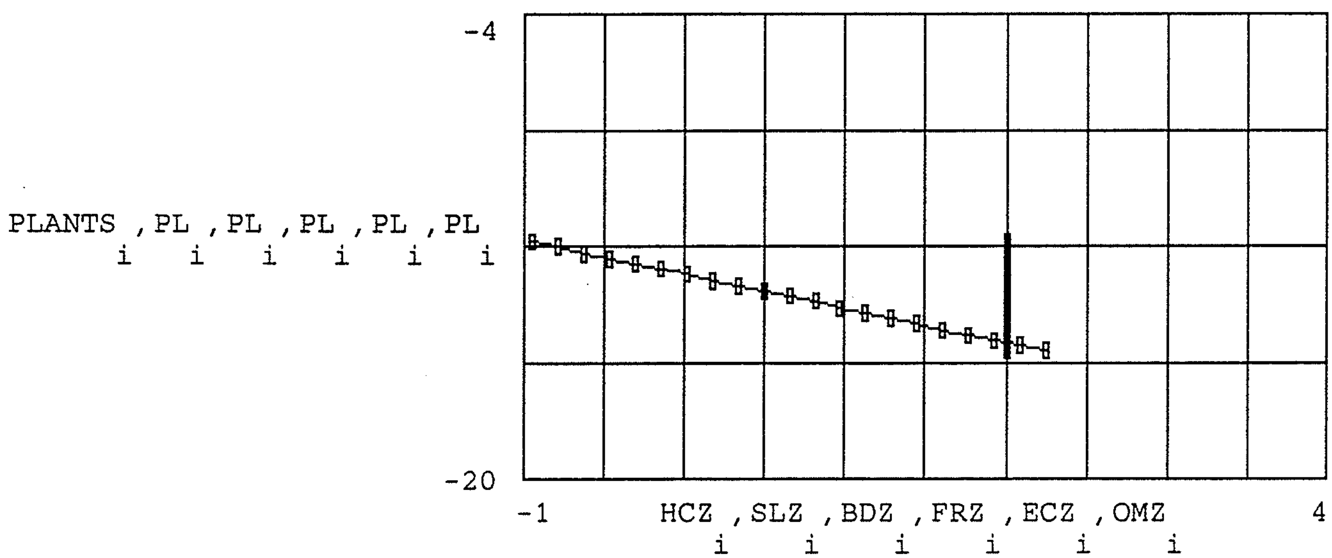
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with HC varied and all other regressors set at two standard deviations above mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
-0.949	2	2	2	2	2	-11.837
-0.789	2	2	2	2	2	-12.026
-0.629	2	2	2	2	2	-12.215
-0.47	2	2	2	2	2	-12.403
-0.31	2	2	2	2	2	-12.592
-0.15	2	2	2	2	2	-12.781
0.01	2	2	2	2	2	-12.97
0.17	2	2	2	2	2	-13.158
0.33	2	2	2	2	2	-13.347
0.49	2	2	2	2	2	-13.536
0.65	2	2	2	2	2	-13.725
0.809	2	2	2	2	2	-13.913
0.969	2	2	2	2	2	-14.102
1.129	2	2	2	2	2	-14.291
1.289	2	2	2	2	2	-14.48
1.449	2	2	2	2	2	-14.668
1.609	2	2	2	2	2	-14.857
1.769	2	2	2	2	2	-15.046
1.929	2	2	2	2	2	-15.235
2.089	2	2	2	2	2	-15.423
2.248	2	2	2	2	2	-15.612



SENSITIVITY ANALYSIS: % SLOPE

Vary SL, all other regressors set at two standard deviations below mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + -2$$

$$SLZ_i := \frac{0 + (i) - 3.000}{4.6810}$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + -2$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + -2$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + -2$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + -2$$

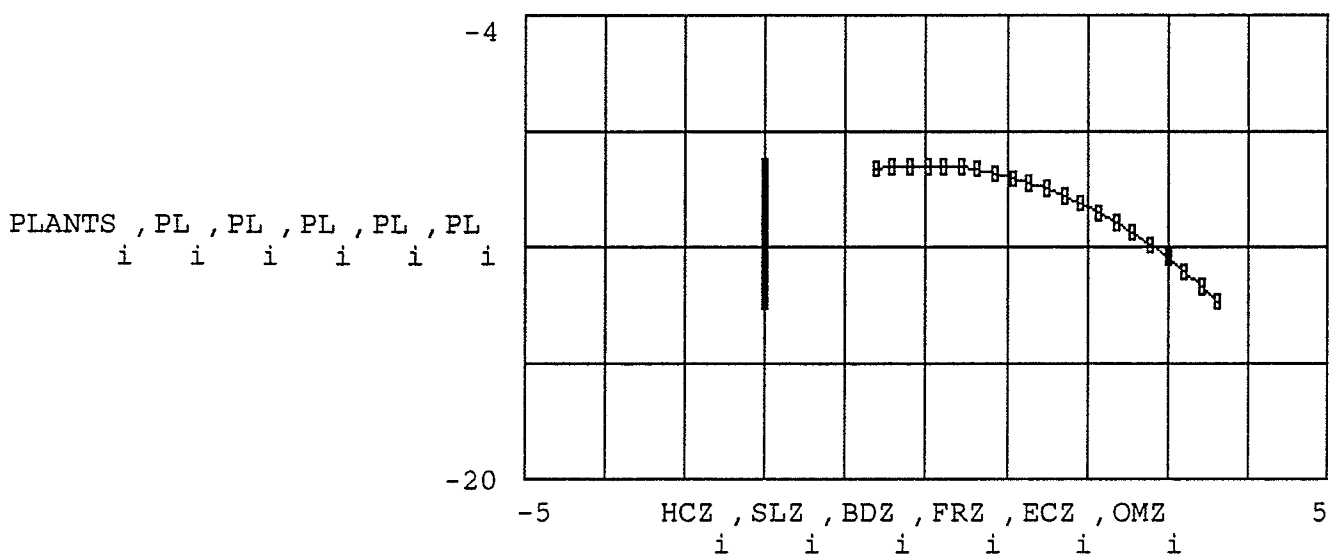
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with SL varied and all other regressors set at two standard deviations below mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
-2	-0.641	-2	-2	-2	-2	-9.314
-2	-0.427	-2	-2	-2	-2	-9.232
-2	-0.214	-2	-2	-2	-2	-9.183
-2	0	-2	-2	-2	-2	-9.167
-2	0.214	-2	-2	-2	-2	-9.183
-2	0.427	-2	-2	-2	-2	-9.232
-2	0.641	-2	-2	-2	-2	-9.314
-2	0.855	-2	-2	-2	-2	-9.428
-2	1.068	-2	-2	-2	-2	-9.575
-2	1.282	-2	-2	-2	-2	-9.754
-2	1.495	-2	-2	-2	-2	-9.966
-2	1.709	-2	-2	-2	-2	-10.211
-2	1.923	-2	-2	-2	-2	-10.488
-2	2.136	-2	-2	-2	-2	-10.798
-2	2.35	-2	-2	-2	-2	-11.141
-2	2.564	-2	-2	-2	-2	-11.516
-2	2.777	-2	-2	-2	-2	-11.924
-2	2.991	-2	-2	-2	-2	-12.365
-2	3.204	-2	-2	-2	-2	-12.838
-2	3.418	-2	-2	-2	-2	-13.344
-2	3.632	-2	-2	-2	-2	-13.882



SENSITIVITY ANALYSIS

Vary SL, all other regressors set at one standard deviation below mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + -1$$

$$SLZ_i := \frac{0 + (i) - 3.000}{4.6810}$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + -1$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + -1$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + -1$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + -1$$

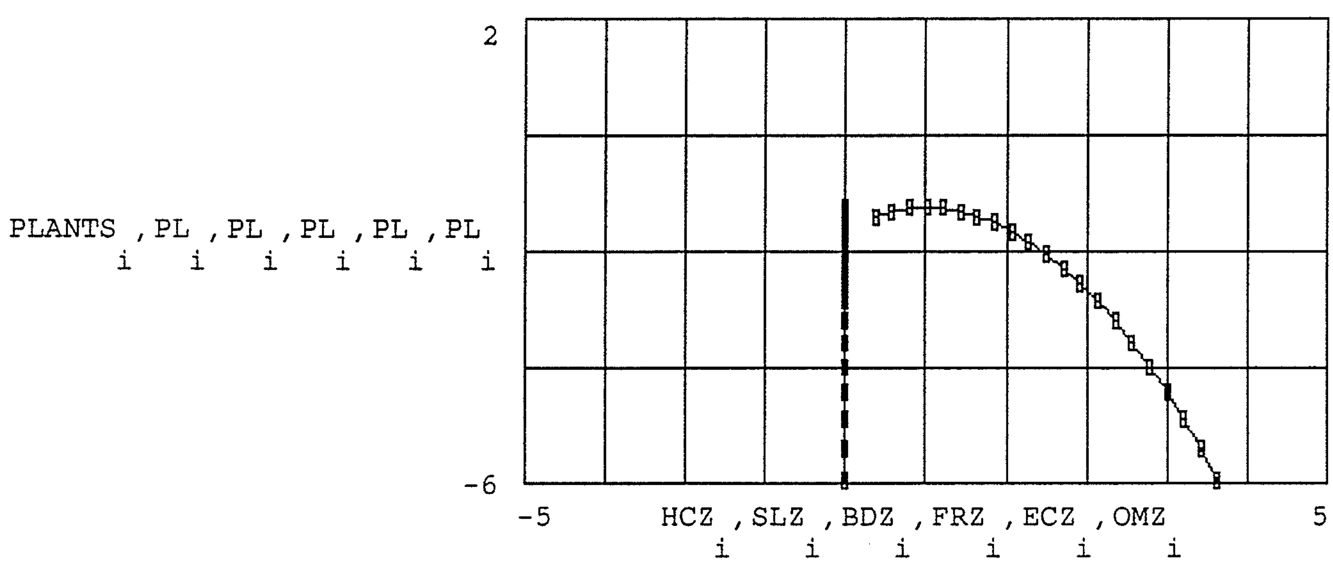
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with SL varied and all other regressors set at one standard deviation below mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
-1	-0.641	-1	-1	-1	-1	-1.383
-1	-0.427	-1	-1	-1	-1	-1.301
-1	-0.214	-1	-1	-1	-1	-1.252
-1	0	-1	-1	-1	-1	-1.236
-1	0.214	-1	-1	-1	-1	-1.252
-1	0.427	-1	-1	-1	-1	-1.301
-1	0.641	-1	-1	-1	-1	-1.383
-1	0.855	-1	-1	-1	-1	-1.497
-1	1.068	-1	-1	-1	-1	-1.644
-1	1.282	-1	-1	-1	-1	-1.823
-1	1.495	-1	-1	-1	-1	-2.035
-1	1.709	-1	-1	-1	-1	-2.28
-1	1.923	-1	-1	-1	-1	-2.558
-1	2.136	-1	-1	-1	-1	-2.868
-1	2.35	-1	-1	-1	-1	-3.21
-1	2.564	-1	-1	-1	-1	-3.585
-1	2.777	-1	-1	-1	-1	-3.993
-1	2.991	-1	-1	-1	-1	-4.434
-1	3.204	-1	-1	-1	-1	-4.907
-1	3.418	-1	-1	-1	-1	-5.413
-1	3.632	-1	-1	-1	-1	-5.951



SENSITIVITY ANALYSIS

Vary SL, all other regressors set at mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030}$$

$$SLZ_i := \frac{0 + (i) - 3.000}{4.6810}$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929}$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947}$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644}$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638}$$

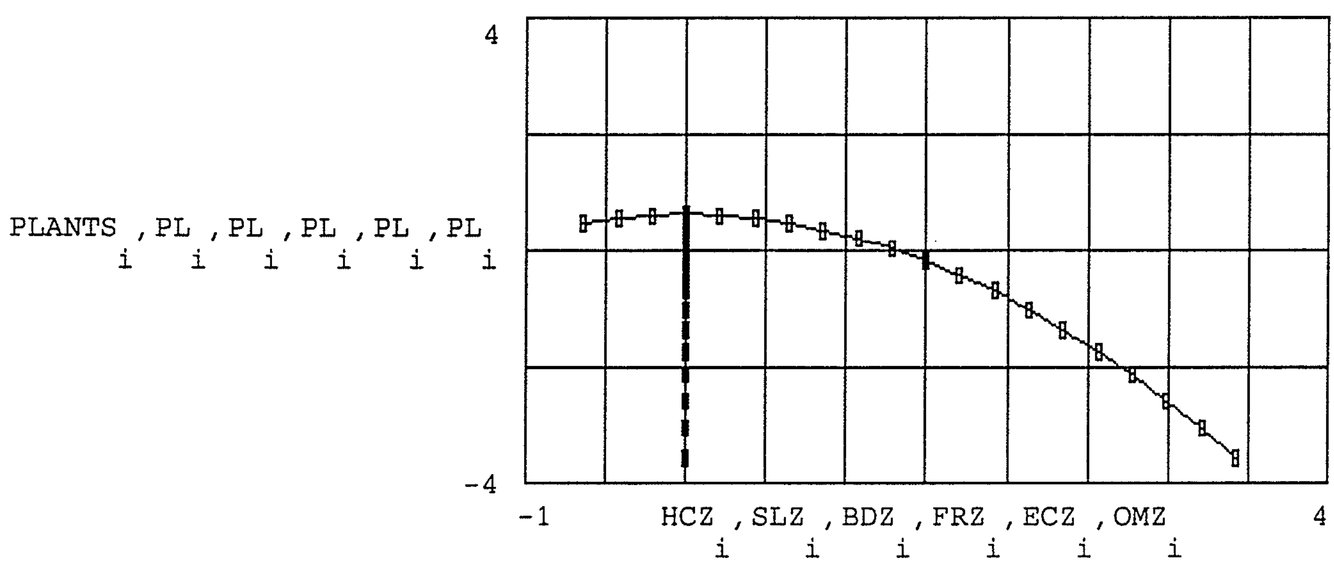
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot {SLZ_i}^2\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with SL varied and all other regressors set at mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
0	-0.641	0	0	0	0	0.474
0	-0.427	0	0	0	0	0.555
0	-0.214	0	0	0	0	0.604
0	0	0	0	0	0	0.621
0	0.214	0	0	0	0	0.604
0	0.427	0	0	0	0	0.555
0	0.641	0	0	0	0	0.474
0	0.855	0	0	0	0	0.36
0	1.068	0	0	0	0	0.213
0	1.282	0	0	0	0	0.033
0	1.495	0	0	0	0	-0.179
0	1.709	0	0	0	0	-0.424
0	1.923	0	0	0	0	-0.701
0	2.136	0	0	0	0	-1.011
0	2.35	0	0	0	0	-1.354
0	2.564	0	0	0	0	-1.729
0	2.777	0	0	0	0	-2.137
0	2.991	0	0	0	0	-2.577
0	3.204	0	0	0	0	-3.05
0	3.418	0	0	0	0	-3.556
0	3.632	0	0	0	0	-4.095



SENSITIVITY ANALYSIS

Vary SL, all other regressors set at one standard deviation above mean.

$N := 20 \qquad i := 0 \,..\, N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + 1$$

$$SLZ_i := \frac{0 + (i) - 3.000}{4.6810}$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + 1$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + 1$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + 1$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + 1$$

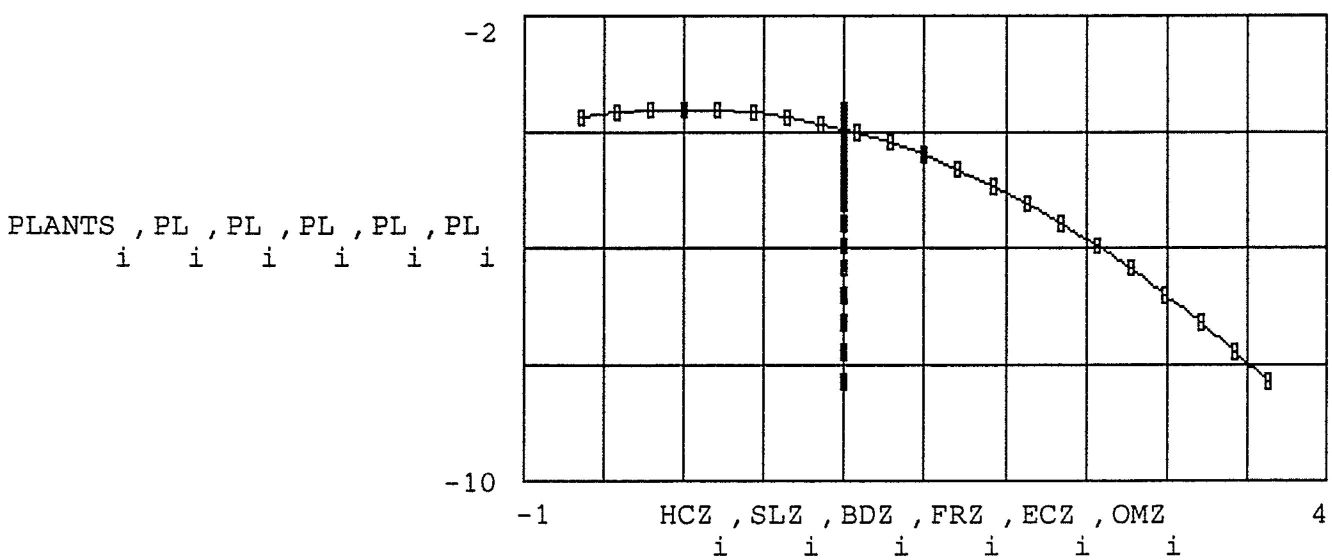
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with SL varied and all other regressors set at one standard deviation above mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
1	-0.641	1	1	1	1	-3.744
1	-0.427	1	1	1	1	-3.662
1	-0.214	1	1	1	1	-3.613
1	0	1	1	1	1	-3.597
1	0.214	1	1	1	1	-3.613
1	0.427	1	1	1	1	-3.662
1	0.641	1	1	1	1	-3.744
1	0.855	1	1	1	1	-3.858
1	1.068	1	1	1	1	-4.005
1	1.282	1	1	1	1	-4.184
1	1.495	1	1	1	1	-4.396
1	1.709	1	1	1	1	-4.641
1	1.923	1	1	1	1	-4.919
1	2.136	1	1	1	1	-5.229
1	2.35	1	1	1	1	-5.571
1	2.564	1	1	1	1	-5.946
1	2.777	1	1	1	1	-6.354
1	2.991	1	1	1	1	-6.795
1	3.204	1	1	1	1	-7.268
1	3.418	1	1	1	1	-7.774
1	3.632	1	1	1	1	-8.312



SENSITIVITY ANALYSIS

Vary SL, all other regressors set at two standard deviations above mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + 2$$

$$SLZ_i := \frac{0 + (i) - 3.000}{4.6810}$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + 2$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + 2$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + 2$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + 2$$

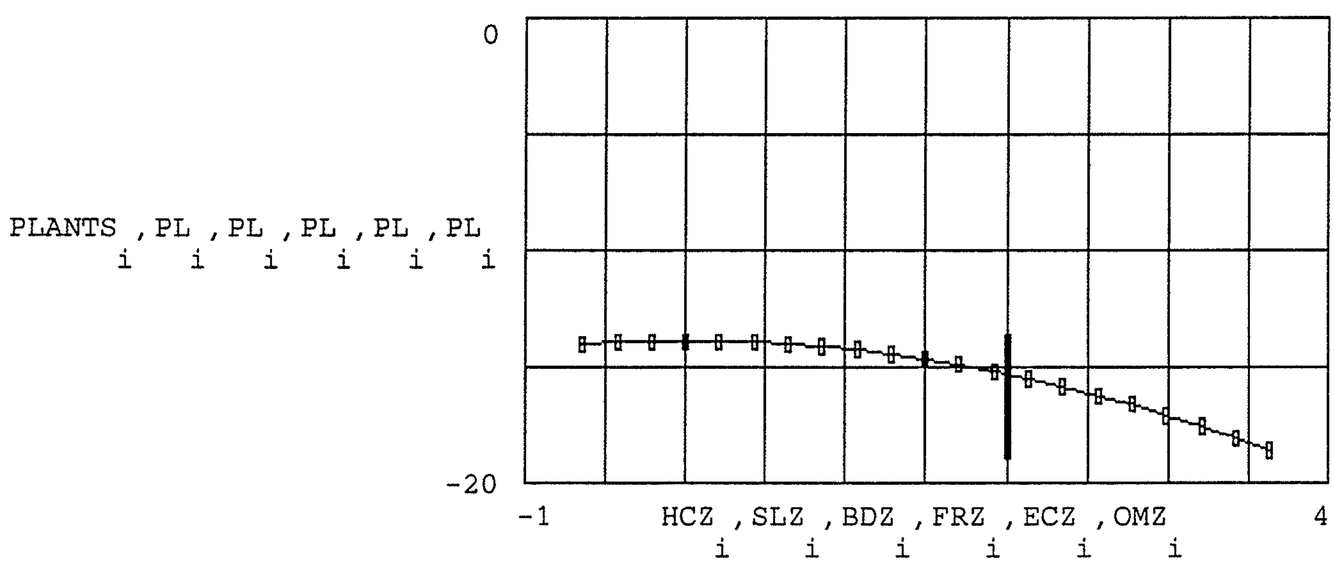
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot {SLZ_i}^2\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with SL varied and all other regressors set at two standard deviations above mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
2	-0.641	2	2	2	2	-14.036
2	-0.427	2	2	2	2	-13.954
2	-0.214	2	2	2	2	-13.905
2	0	2	2	2	2	-13.889
2	0.214	2	2	2	2	-13.905
2	0.427	2	2	2	2	-13.954
2	0.641	2	2	2	2	-14.036
2	0.855	2	2	2	2	-14.15
2	1.068	2	2	2	2	-14.297
2	1.282	2	2	2	2	-14.476
2	1.495	2	2	2	2	-14.688
2	1.709	2	2	2	2	-14.933
2	1.923	2	2	2	2	-15.21
2	2.136	2	2	2	2	-15.52
2	2.35	2	2	2	2	-15.863
2	2.564	2	2	2	2	-16.238
2	2.777	2	2	2	2	-16.646
2	2.991	2	2	2	2	-17.087
2	3.204	2	2	2	2	-17.56
2	3.418	2	2	2	2	-18.066
2	3.632	2	2	2	2	-18.604



SENSITIVITY ANALYSIS: % ROCK FRAGMENTS

Vary FR, all other regressors set at two standard deviations below mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + -2$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + -2$$

$$FRZ_i := \frac{0.0000 + (i \cdot 2) - 0.9075}{3.4929}$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + -2$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + -2$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + -2$$

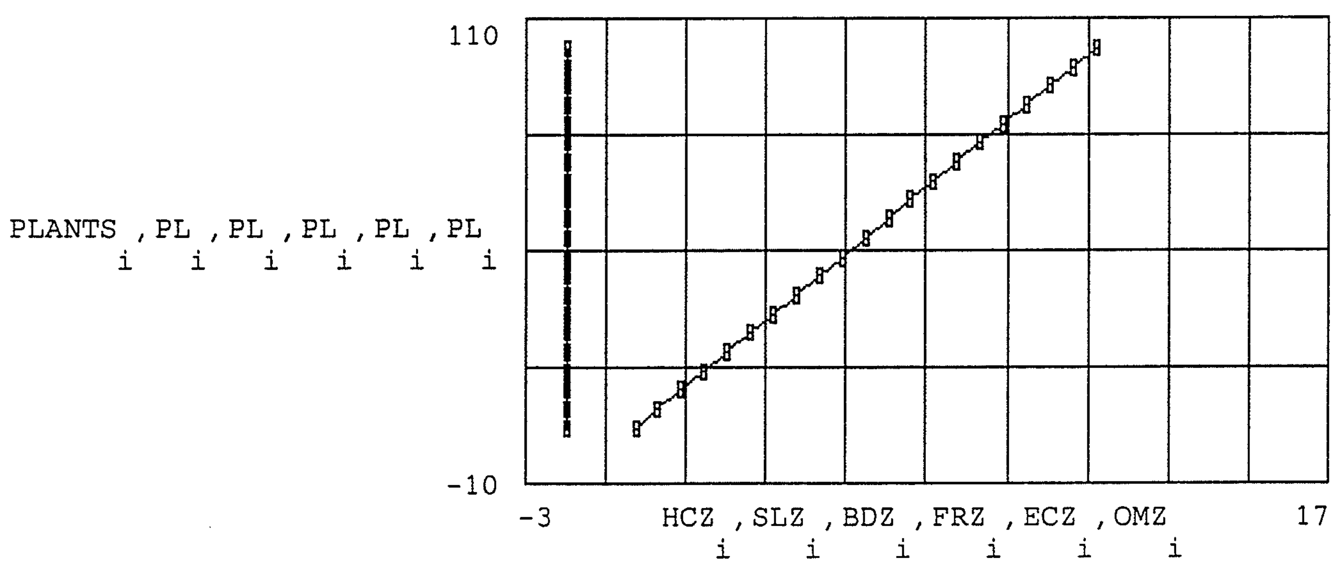
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with FR varied and all other regressors set at two standard deviations below mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
-2	-2	-2	-0.26	-2	-2	4.297
-2	-2	-2	0.313	-2	-2	9.198
-2	-2	-2	0.885	-2	-2	14.099
-2	-2	-2	1.458	-2	-2	19
-2	-2	-2	2.031	-2	-2	23.901
-2	-2	-2	2.603	-2	-2	28.801
-2	-2	-2	3.176	-2	-2	33.702
-2	-2	-2	3.748	-2	-2	38.603
-2	-2	-2	4.321	-2	-2	43.504
-2	-2	-2	4.893	-2	-2	48.405
-2	-2	-2	5.466	-2	-2	53.305
-2	-2	-2	6.039	-2	-2	58.206
-2	-2	-2	6.611	-2	-2	63.107
-2	-2	-2	7.184	-2	-2	68.008
-2	-2	-2	7.756	-2	-2	72.909
-2	-2	-2	8.329	-2	-2	77.809
-2	-2	-2	8.902	-2	-2	82.71
-2	-2	-2	9.474	-2	-2	87.611
-2	-2	-2	10.047	-2	-2	92.512
-2	-2	-2	10.619	-2	-2	97.413
-2	-2	-2	11.192	-2	-2	102.313



SENSITIVITY ANALYSIS

Vary FR, all other regressors set at one standard deviation below mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + -1$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + -1$$

$$FRZ_i := \frac{0.0000 + (i \cdot 2) - 0.9075}{3.4929}$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + -1$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + -1$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + -1$$

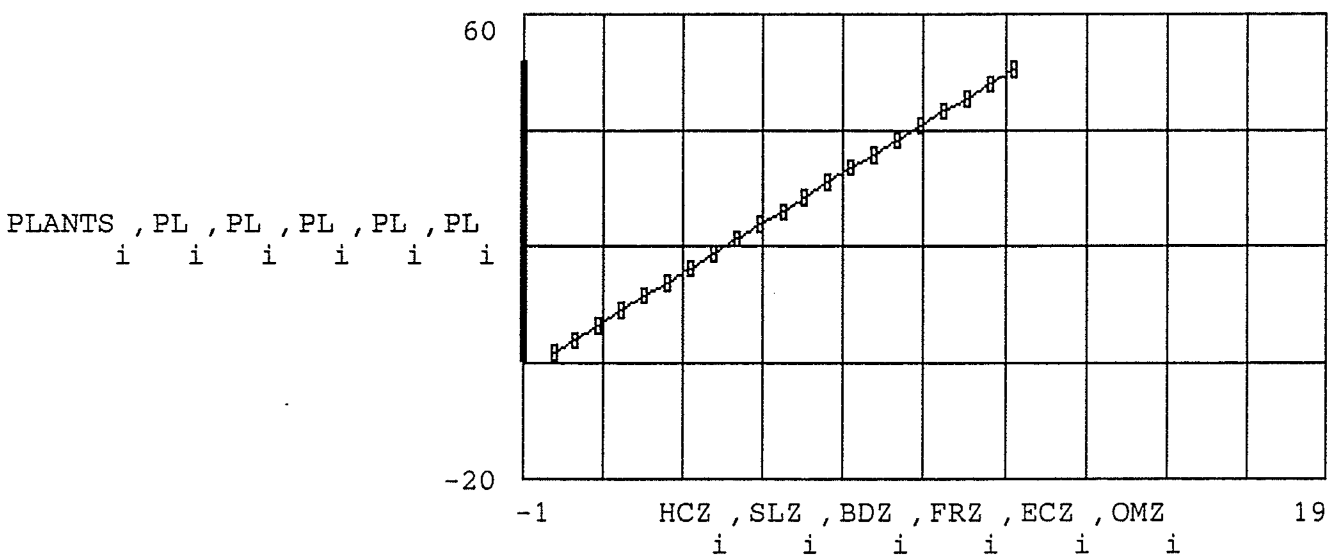
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with FR varied and all other regressors set at one standard deviation below mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
-1	-1	-1	-0.26	-1	-1	1.574
-1	-1	-1	0.313	-1	-1	4.025
-1	-1	-1	0.885	-1	-1	6.475
-1	-1	-1	1.458	-1	-1	8.925
-1	-1	-1	2.031	-1	-1	11.376
-1	-1	-1	2.603	-1	-1	13.826
-1	-1	-1	3.176	-1	-1	16.277
-1	-1	-1	3.748	-1	-1	18.727
-1	-1	-1	4.321	-1	-1	21.177
-1	-1	-1	4.893	-1	-1	23.628
-1	-1	-1	5.466	-1	-1	26.078
-1	-1	-1	6.039	-1	-1	28.529
-1	-1	-1	6.611	-1	-1	30.979
-1	-1	-1	7.184	-1	-1	33.429
-1	-1	-1	7.756	-1	-1	35.88
-1	-1	-1	8.329	-1	-1	38.33
-1	-1	-1	8.902	-1	-1	40.781
-1	-1	-1	9.474	-1	-1	43.231
-1	-1	-1	10.047	-1	-1	45.681
-1	-1	-1	10.619	-1	-1	48.132
-1	-1	-1	11.192	-1	-1	50.582



SENSITIVITY ANALYSIS

Vary FR, all other regressors set at mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030}$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810}$$

$$FRZ_i := \frac{0.0000 + (i \cdot 2) - 0.9075}{3.4929}$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947}$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644}$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638}$$

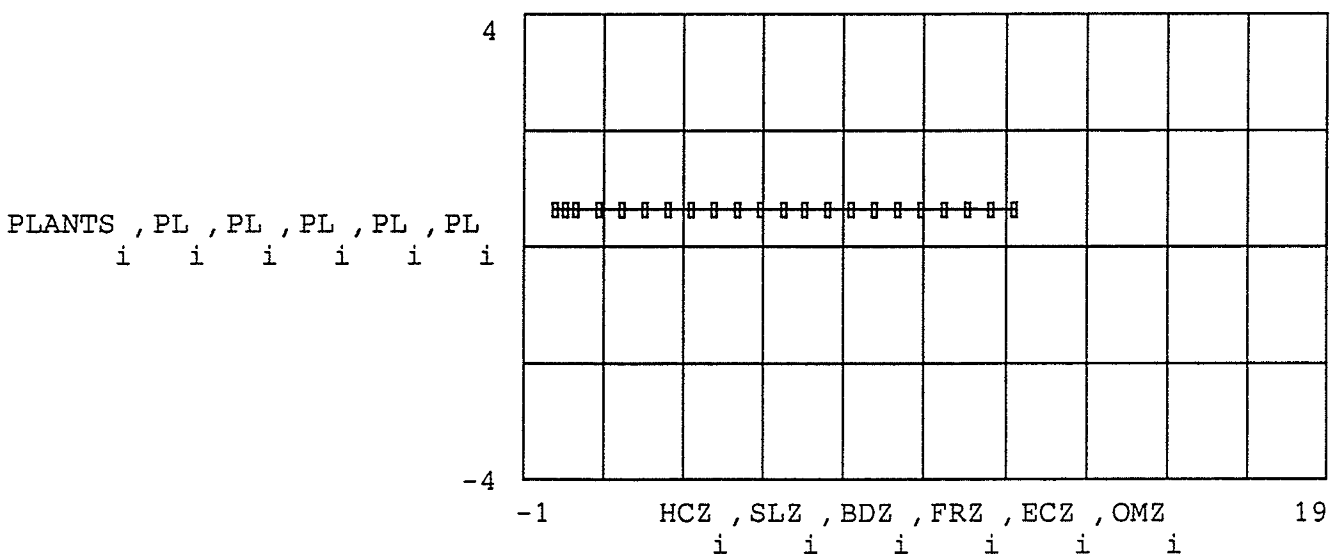
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with FR varied and all other regressors set at mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
0	0	0	-0.26	0	0	0.621
0	0	0	0.313	0	0	0.621
0	0	0	0.885	0	0	0.621
0	0	0	1.458	0	0	0.621
0	0	0	2.031	0	0	0.621
0	0	0	2.603	0	0	0.621
0	0	0	3.176	0	0	0.621
0	0	0	3.748	0	0	0.621
0	0	0	4.321	0	0	0.621
0	0	0	4.893	0	0	0.621
0	0	0	5.466	0	0	0.621
0	0	0	6.039	0	0	0.621
0	0	0	6.611	0	0	0.621
0	0	0	7.184	0	0	0.621
0	0	0	7.756	0	0	0.621
0	0	0	8.329	0	0	0.621
0	0	0	8.902	0	0	0.621
0	0	0	9.474	0	0	0.621
0	0	0	10.047	0	0	0.621
0	0	0	10.619	0	0	0.621
0	0	0	11.192	0	0	0.621



SENSITIVITY ANALYSIS

Vary FR, all other regressors set at one standard deviation above mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + 1$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + 1$$

$$FRZ_i := \frac{0.0000 + (i \cdot 2) - 0.9075}{3.4929}$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + 1$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + 1$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + 1$$

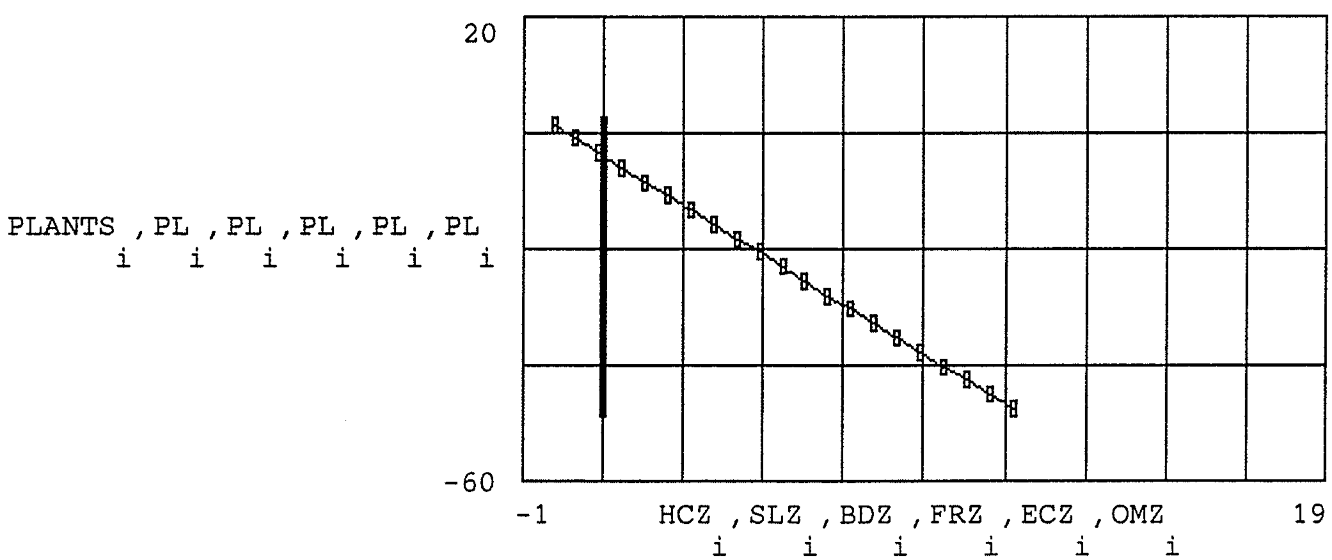
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot {SLZ_i}^2\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with FR varied and all other regressors set at one standard deviation above mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
1	1	1	-0.26	1	1	1.437
1	1	1	0.313	1	1	-1.014
1	1	1	0.885	1	1	-3.464
1	1	1	1.458	1	1	-5.914
1	1	1	2.031	1	1	-8.365
1	1	1	2.603	1	1	-10.815
1	1	1	3.176	1	1	-13.266
1	1	1	3.748	1	1	-15.716
1	1	1	4.321	1	1	-18.166
1	1	1	4.893	1	1	-20.617
1	1	1	5.466	1	1	-23.067
1	1	1	6.039	1	1	-25.518
1	1	1	6.611	1	1	-27.968
1	1	1	7.184	1	1	-30.418
1	1	1	7.756	1	1	-32.869
1	1	1	8.329	1	1	-35.319
1	1	1	8.902	1	1	-37.77
1	1	1	9.474	1	1	-40.22
1	1	1	10.047	1	1	-42.67
1	1	1	10.619	1	1	-45.121
1	1	1	11.192	1	1	-47.571



SENSITIVITY ANALYSIS

Vary FR, all other regressors set at two standard deviations above mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + 2$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + 2$$

$$FRZ_i := \frac{0.0000 + (i \cdot 2) - 0.9075}{3.4929}$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + 2$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + 2$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + 2$$

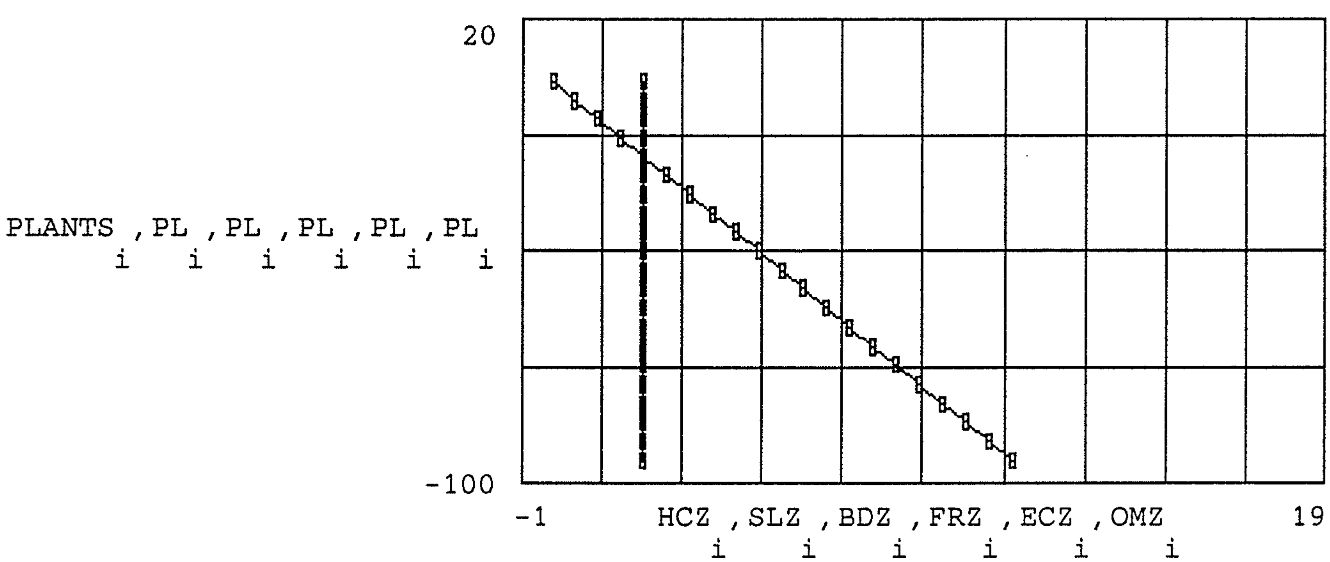
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^2\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with FR varied and all other regressors set at two standard deviations above mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
2	2	2	-0.26	2	2	4.023
2	2	2	0.313	2	2	-0.878
2	2	2	0.885	2	2	-5.779
2	2	2	1.458	2	2	-10.679
2	2	2	2.031	2	2	-15.58
2	2	2	2.603	2	2	-20.481
2	2	2	3.176	2	2	-25.382
2	2	2	3.748	2	2	-30.283
2	2	2	4.321	2	2	-35.183
2	2	2	4.893	2	2	-40.084
2	2	2	5.466	2	2	-44.985
2	2	2	6.039	2	2	-49.886
2	2	2	6.611	2	2	-54.787
2	2	2	7.184	2	2	-59.687
2	2	2	7.756	2	2	-64.588
2	2	2	8.329	2	2	-69.489
2	2	2	8.902	2	2	-74.39
2	2	2	9.474	2	2	-79.291
2	2	2	10.047	2	2	-84.191
2	2	2	10.619	2	2	-89.092
2	2	2	11.192	2	2	-93.993



SENSITIVITY ANALYSIS: ELECTRICAL CONDUCTIVITY

Vary EC, all other regressors set at two standard deviations below mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + -2$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + -2$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + -2$$

$$ECZ_i := \frac{0 + (i \cdot .3) - 2.526}{1.0947}$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + -2$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + -2$$

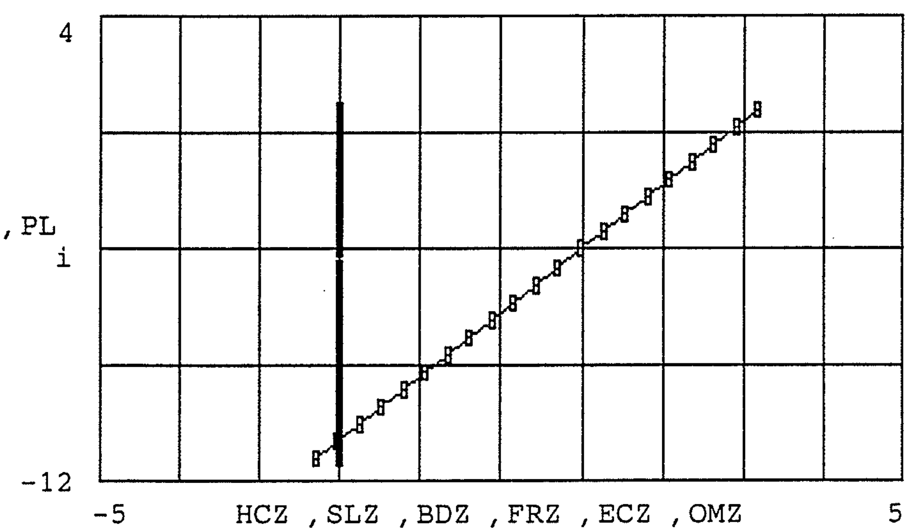
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$$

Table and graph of sensitivity analysis with EC varied and all other regressors set at two standard deviations below mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
-2	-2	-2	-2	-2.307	-2	-11.273
-2	-2	-2	-2	-2.033	-2	-10.67
-2	-2	-2	-2	-1.759	-2	-10.068
-2	-2	-2	-2	-1.485	-2	-9.465
-2	-2	-2	-2	-1.211	-2	-8.862
-2	-2	-2	-2	-0.937	-2	-8.26
-2	-2	-2	-2	-0.663	-2	-7.657
-2	-2	-2	-2	-0.389	-2	-7.054
-2	-2	-2	-2	-0.115	-2	-6.452
-2	-2	-2	-2	0.159	-2	-5.849
-2	-2	-2	-2	0.433	-2	-5.246
-2	-2	-2	-2	0.707	-2	-4.643
-2	-2	-2	-2	0.981	-2	-4.041
-2	-2	-2	-2	1.255	-2	-3.438
-2	-2	-2	-2	1.529	-2	-2.835
-2	-2	-2	-2	1.803	-2	-2.233
-2	-2	-2	-2	2.077	-2	-1.63
-2	-2	-2	-2	2.351	-2	-1.027
-2	-2	-2	-2	2.625	-2	-0.425
-2	-2	-2	-2	2.899	-2	0.178
-2	-2	-2	-2	3.173	-2	0.781



SENSITIVITY ANALYSIS

Vary EC, all other regressors set at one standard deviation below mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + -1$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + -1$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + -1$$

$$ECZ_i := \frac{0 + (i \cdot .3) - 2.526}{1.0947}$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + -1$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + -1$$

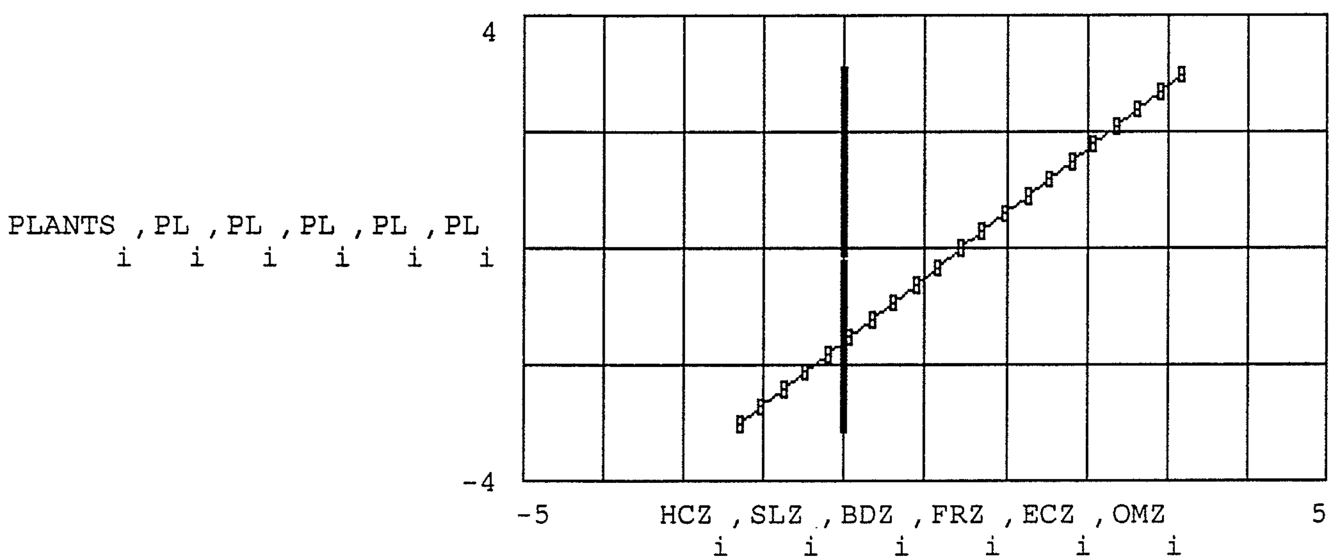
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with EC varied and all other regressors set at one standard deviation below mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
-1	-1	-1	-1	-2.307	-1	-3.031
-1	-1	-1	-1	-2.033	-1	-2.73
-1	-1	-1	-1	-1.759	-1	-2.429
-1	-1	-1	-1	-1.485	-1	-2.127
-1	-1	-1	-1	-1.211	-1	-1.826
-1	-1	-1	-1	-0.937	-1	-1.524
-1	-1	-1	-1	-0.663	-1	-1.223
-1	-1	-1	-1	-0.389	-1	-0.922
-1	-1	-1	-1	-0.115	-1	-0.62
-1	-1	-1	-1	0.159	-1	-0.319
-1	-1	-1	-1	0.433	-1	-0.018
-1	-1	-1	-1	0.707	-1	0.284
-1	-1	-1	-1	0.981	-1	0.585
-1	-1	-1	-1	1.255	-1	0.886
-1	-1	-1	-1	1.529	-1	1.188
-1	-1	-1	-1	1.803	-1	1.489
-1	-1	-1	-1	2.077	-1	1.79
-1	-1	-1	-1	2.351	-1	2.092
-1	-1	-1	-1	2.625	-1	2.393
-1	-1	-1	-1	2.899	-1	2.694
-1	-1	-1	-1	3.173	-1	2.996



SENSITIVITY ANALYSIS

Vary EC, all other regressors set at mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030}$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810}$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929}$$

$$ECZ_i := \frac{0 + (i \cdot .3) - 2.526}{1.0947}$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644}$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638}$$

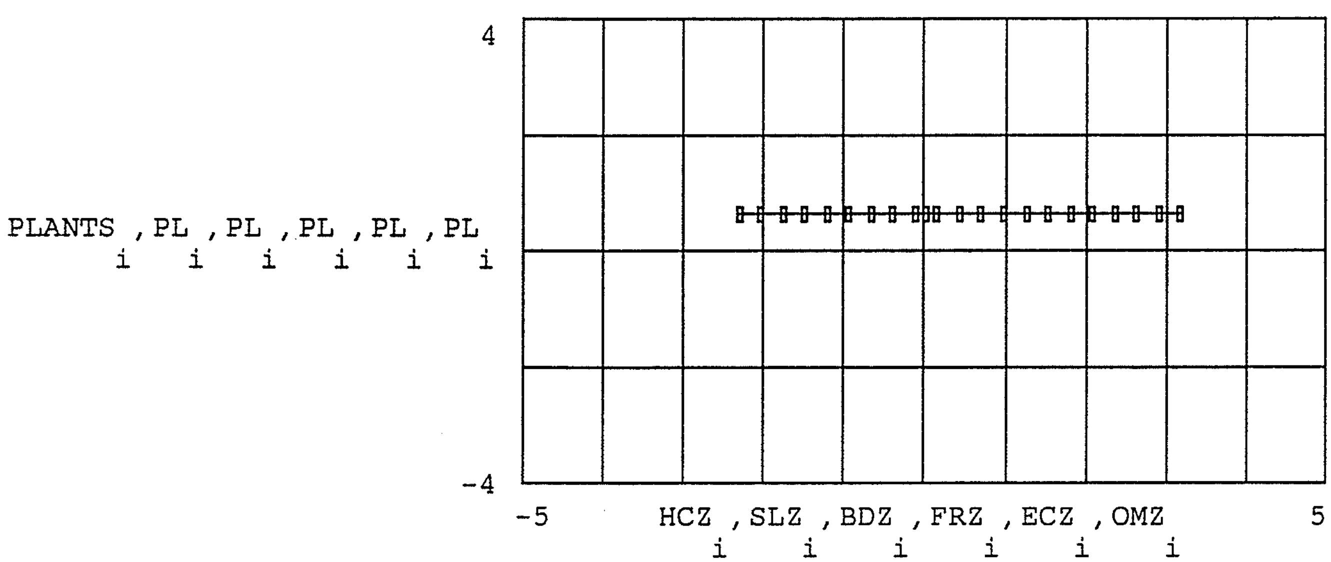
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$$

Table and graph of sensitivity analysis with EC varied and all other regressors set at mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
0	0	0	0	-2.307	0	0.621
0	0	0	0	-2.033	0	0.621
0	0	0	0	-1.759	0	0.621
0	0	0	0	-1.485	0	0.621
0	0	0	0	-1.211	0	0.621
0	0	0	0	-0.937	0	0.621
0	0	0	0	-0.663	0	0.621
0	0	0	0	-0.389	0	0.621
0	0	0	0	-0.115	0	0.621
0	0	0	0	0.159	0	0.621
0	0	0	0	0.433	0	0.621
0	0	0	0	0.707	0	0.621
0	0	0	0	0.981	0	0.621
0	0	0	0	1.255	0	0.621
0	0	0	0	1.529	0	0.621
0	0	0	0	1.803	0	0.621
0	0	0	0	2.077	0	0.621
0	0	0	0	2.351	0	0.621
0	0	0	0	2.625	0	0.621
0	0	0	0	2.899	0	0.621
0	0	0	0	3.173	0	0.621



SENSITIVITY ANALYSIS

Vary EC, all other regressors set at one standard deviation above mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + 1$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + 1$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + 1$$

$$ECZ_i := \frac{0 + (i \cdot .3) - 2.526}{1.0947}$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + 1$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + 1$$

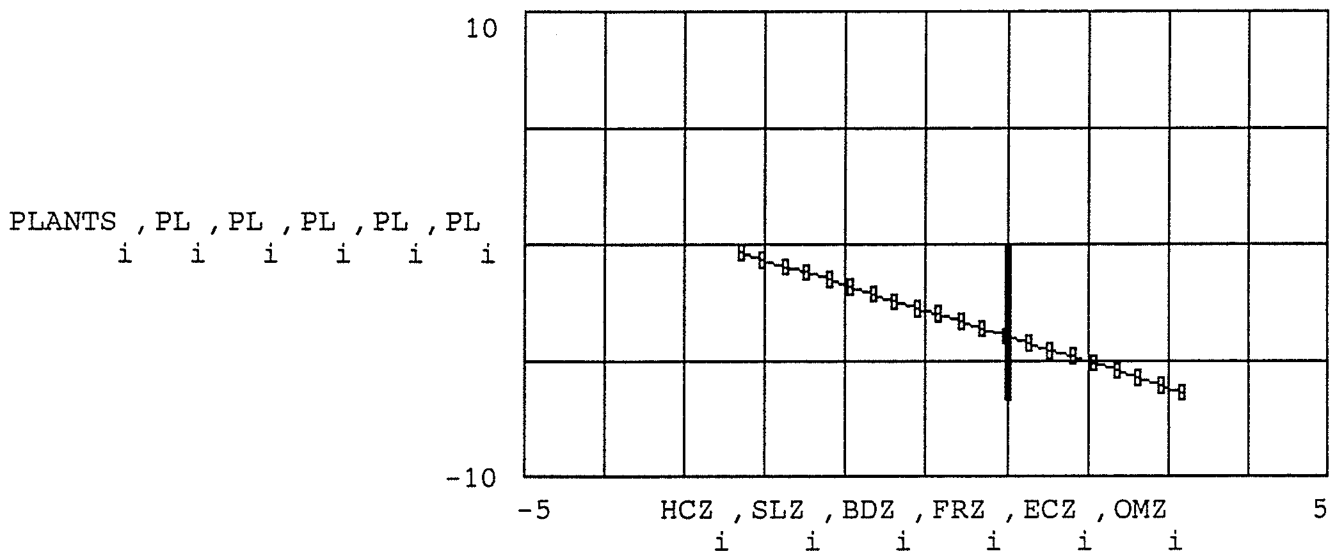
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$$

Table and graph of sensitivity analysis with EC varied and all other regressors set at one standard deviation above mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
1	1	1	1	-2.307	1	-0.318
1	1	1	1	-2.033	1	-0.619
1	1	1	1	-1.759	1	-0.92
1	1	1	1	-1.485	1	-1.222
1	1	1	1	-1.211	1	-1.523
1	1	1	1	-0.937	1	-1.824
1	1	1	1	-0.663	1	-2.126
1	1	1	1	-0.389	1	-2.427
1	1	1	1	-0.115	1	-2.728
1	1	1	1	0.159	1	-3.03
1	1	1	1	0.433	1	-3.331
1	1	1	1	0.707	1	-3.632
1	1	1	1	0.981	1	-3.934
1	1	1	1	1.255	1	-4.235
1	1	1	1	1.529	1	-4.536
1	1	1	1	1.803	1	-4.838
1	1	1	1	2.077	1	-5.139
1	1	1	1	2.351	1	-5.44
1	1	1	1	2.625	1	-5.742
1	1	1	1	2.899	1	-6.043
1	1	1	1	3.173	1	-6.344



SENSITIVITY ANALYSIS

Vary EC, all other regressors set at 2 standard deviations above mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + 2$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + 2$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + 2$$

$$ECZ_i := \frac{0 + (i \cdot .3) - 2.526}{1.0947}$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + 2$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + 2$$

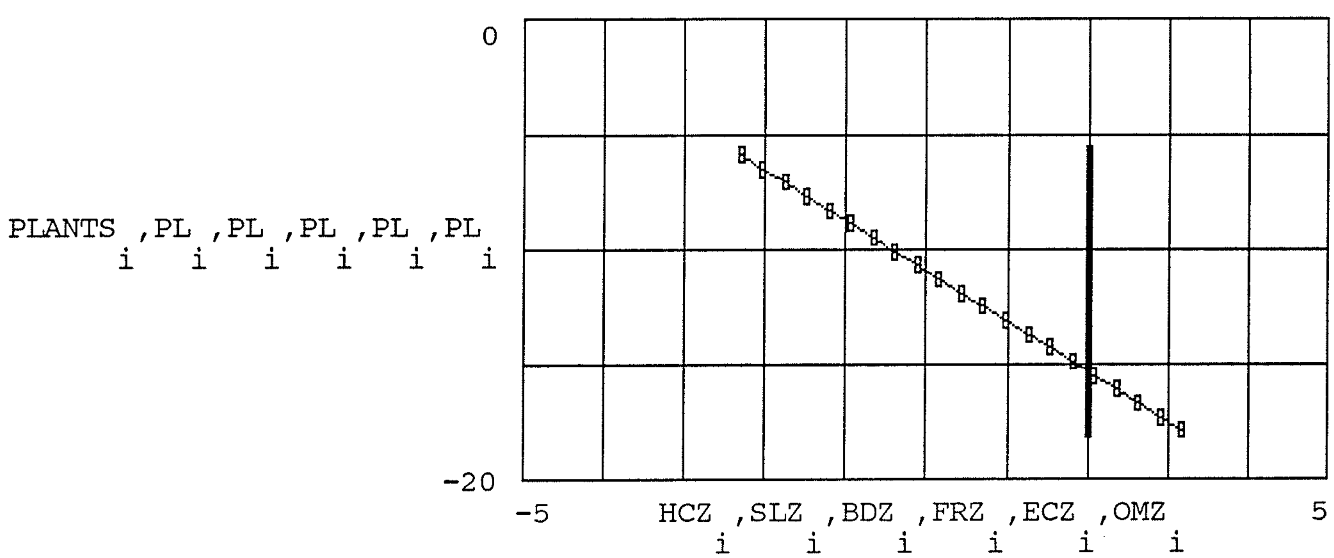
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot {SLZ_i}^2\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with EC varied and all other regressors set at two standard deviations above mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
2	2	2	2	-2.307	2	-5.846
2	2	2	2	-2.033	2	-6.448
2	2	2	2	-1.759	2	-7.051
2	2	2	2	-1.485	2	-7.654
2	2	2	2	-1.211	2	-8.257
2	2	2	2	-0.937	2	-8.859
2	2	2	2	-0.663	2	-9.462
2	2	2	2	-0.389	2	-10.065
2	2	2	2	-0.115	2	-10.667
2	2	2	2	0.159	2	-11.27
2	2	2	2	0.433	2	-11.873
2	2	2	2	0.707	2	-12.475
2	2	2	2	0.981	2	-13.078
2	2	2	2	1.255	2	-13.681
2	2	2	2	1.529	2	-14.283
2	2	2	2	1.803	2	-14.886
2	2	2	2	2.077	2	-15.489
2	2	2	2	2.351	2	-16.091
2	2	2	2	2.625	2	-16.694
2	2	2	2	2.899	2	-17.297
2	2	2	2	3.173	2	-17.9



SENSITIVITY ANALYSIS: BULK DENSITY

Vary BD, all other regressors set at two standard deviations below mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + -2$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + -2$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + -2$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + -2$$

$$BDZ_i := \frac{.175 + (i \cdot .08) - 1.3584}{0.2644}$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + -2$$

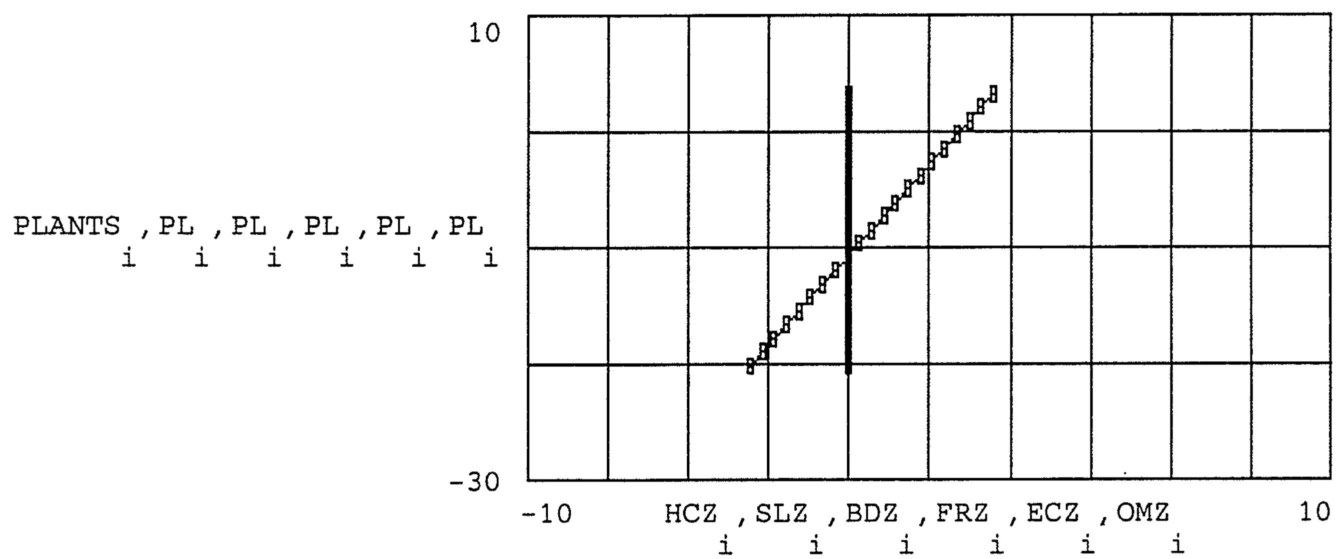
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with BD varied and all other regressors set at two standard deviations below mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
-2	-2	-4.476	-2	-2	-2	-20.191
-2	-2	-4.173	-2	-2	-2	-19.018
-2	-2	-3.871	-2	-2	-2	-17.846
-2	-2	-3.568	-2	-2	-2	-16.673
-2	-2	-3.266	-2	-2	-2	-15.501
-2	-2	-2.963	-2	-2	-2	-14.328
-2	-2	-2.66	-2	-2	-2	-13.156
-2	-2	-2.358	-2	-2	-2	-11.983
-2	-2	-2.055	-2	-2	-2	-10.811
-2	-2	-1.753	-2	-2	-2	-9.638
-2	-2	-1.45	-2	-2	-2	-8.466
-2	-2	-1.148	-2	-2	-2	-7.293
-2	-2	-0.845	-2	-2	-2	-6.121
-2	-2	-0.542	-2	-2	-2	-4.948
-2	-2	-0.24	-2	-2	-2	-3.776
-2	-2	0.063	-2	-2	-2	-2.604
-2	-2	0.365	-2	-2	-2	-1.431
-2	-2	0.668	-2	-2	-2	-0.259
-2	-2	0.97	-2	-2	-2	0.914
-2	-2	1.273	-2	-2	-2	2.086
-2	-2	1.576	-2	-2	-2	3.259



SENSITIVITY ANALYSIS

Vary BD, all other regressors set at one standard deviation below mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + -1$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + -1$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + -1$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + -1$$

$$BDZ_i := \frac{.175 + (i \cdot .08) - 1.3584}{0.2644}$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + -1$$

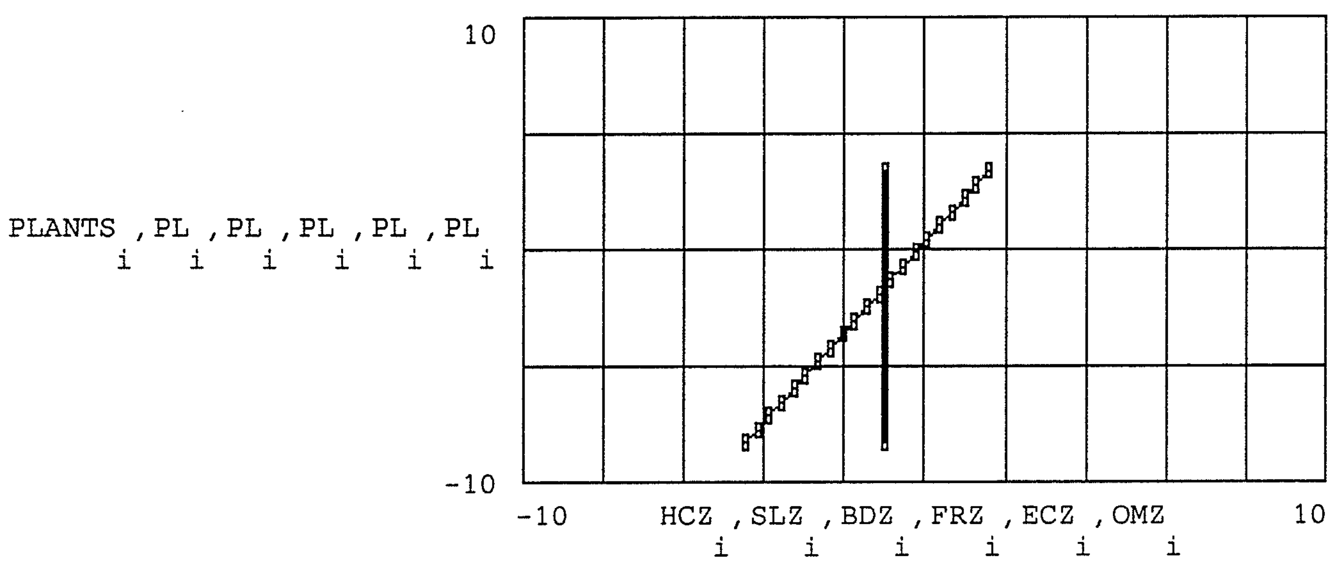
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$$

Table and graph of sensitivity analysis with BD varied and all other regressors set at one standard deviation below mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
-1	-1	-4.476	-1	-1	-1	-8.328
-1	-1	-4.173	-1	-1	-1	-7.742
-1	-1	-3.871	-1	-1	-1	-7.155
-1	-1	-3.568	-1	-1	-1	-6.569
-1	-1	-3.266	-1	-1	-1	-5.983
-1	-1	-2.963	-1	-1	-1	-5.397
-1	-1	-2.66	-1	-1	-1	-4.81
-1	-1	-2.358	-1	-1	-1	-4.224
-1	-1	-2.055	-1	-1	-1	-3.638
-1	-1	-1.753	-1	-1	-1	-3.052
-1	-1	-1.45	-1	-1	-1	-2.466
-1	-1	-1.148	-1	-1	-1	-1.879
-1	-1	-0.845	-1	-1	-1	-1.293
-1	-1	-0.542	-1	-1	-1	-0.707
-1	-1	-0.24	-1	-1	-1	-0.121
-1	-1	0.063	-1	-1	-1	0.466
-1	-1	0.365	-1	-1	-1	1.052
-1	-1	0.668	-1	-1	-1	1.638
-1	-1	0.97	-1	-1	-1	2.224
-1	-1	1.273	-1	-1	-1	2.811
-1	-1	1.576	-1	-1	-1	3.397



SENSITIVITY ANALYSIS

Vary BD, all other regressors set at mean.

$N := 20 \qquad i := 0..N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030}$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810}$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929}$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947}$$

$$BDZ_i := \frac{.13 + (i \cdot .05) - 1.3584}{0.2644}$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638}$$

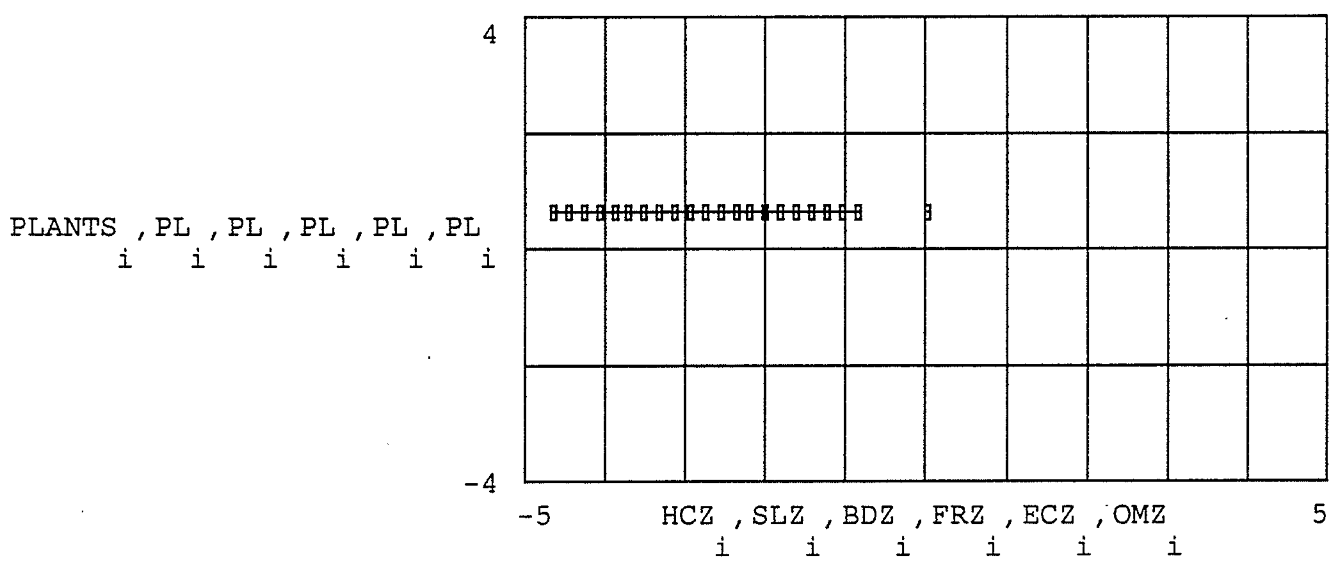
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with BD varied and all other regressors set at mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
0	0	-4.646	0	0	0	0.621
0	0	-4.457	0	0	0	0.621
0	0	-4.268	0	0	0	0.621
0	0	-4.079	0	0	0	0.621
0	0	-3.89	0	0	0	0.621
0	0	-3.7	0	0	0	0.621
0	0	-3.511	0	0	0	0.621
0	0	-3.322	0	0	0	0.621
0	0	-3.133	0	0	0	0.621
0	0	-2.944	0	0	0	0.621
0	0	-2.755	0	0	0	0.621
0	0	-2.566	0	0	0	0.621
0	0	-2.377	0	0	0	0.621
0	0	-2.188	0	0	0	0.621
0	0	-1.998	0	0	0	0.621
0	0	-1.809	0	0	0	0.621
0	0	-1.62	0	0	0	0.621
0	0	-1.431	0	0	0	0.621
0	0	-1.242	0	0	0	0.621
0	0	-1.053	0	0	0	0.621
0	0	-0.864	0	0	0	0.621



SENSITIVITY ANALYSIS

Vary BD, all other regressors set at one standard deviation above mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + 1$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + 1$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + 1$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + 1$$

$$BDZ_i := \frac{.175 + (i \cdot .08) - 1.3584}{0.2644}$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + 1$$

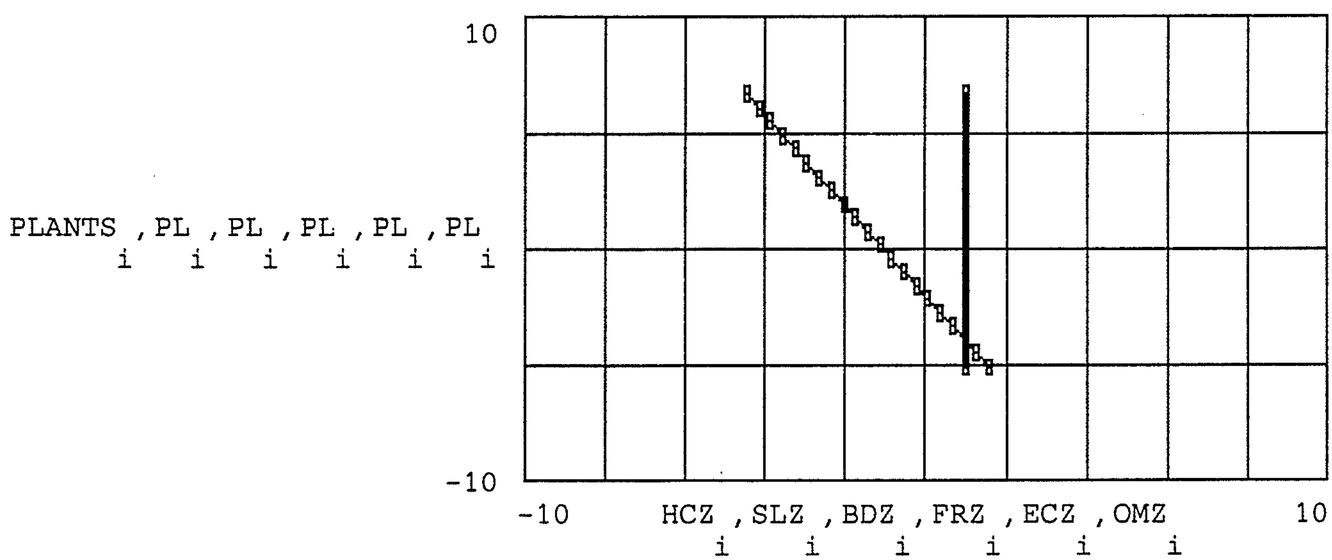
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with BD varied and all other regressors set at one standard deviation above mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
1	1	-4.476	1	1	1	6.655
1	1	-4.173	1	1	1	6.069
1	1	-3.871	1	1	1	5.482
1	1	-3.568	1	1	1	4.896
1	1	-3.266	1	1	1	4.31
1	1	-2.963	1	1	1	3.724
1	1	-2.66	1	1	1	3.137
1	1	-2.358	1	1	1	2.551
1	1	-2.055	1	1	1	1.965
1	1	-1.753	1	1	1	1.379
1	1	-1.45	1	1	1	0.793
1	1	-1.148	1	1	1	0.206
1	1	-0.845	1	1	1	-0.38
1	1	-0.542	1	1	1	-0.966
1	1	-0.24	1	1	1	-1.552
1	1	0.063	1	1	1	-2.139
1	1	0.365	1	1	1	-2.725
1	1	0.668	1	1	1	-3.311
1	1	0.97	1	1	1	-3.897
1	1	1.273	1	1	1	-4.484
1	1	1.576	1	1	1	-5.07



SENSITIVITY ANALYSIS

Vary BD, all other regressors set at two standard deviations above mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + 2$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + 2$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + 2$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + 2$$

$$BDZ_i := \frac{.175 + (i \cdot .08) - 1.3584}{0.2644}$$

$$OMZ_i := \frac{3.9512 + (i \cdot .5 \cdot 0) - 3.9512}{0.6638} + 2$$

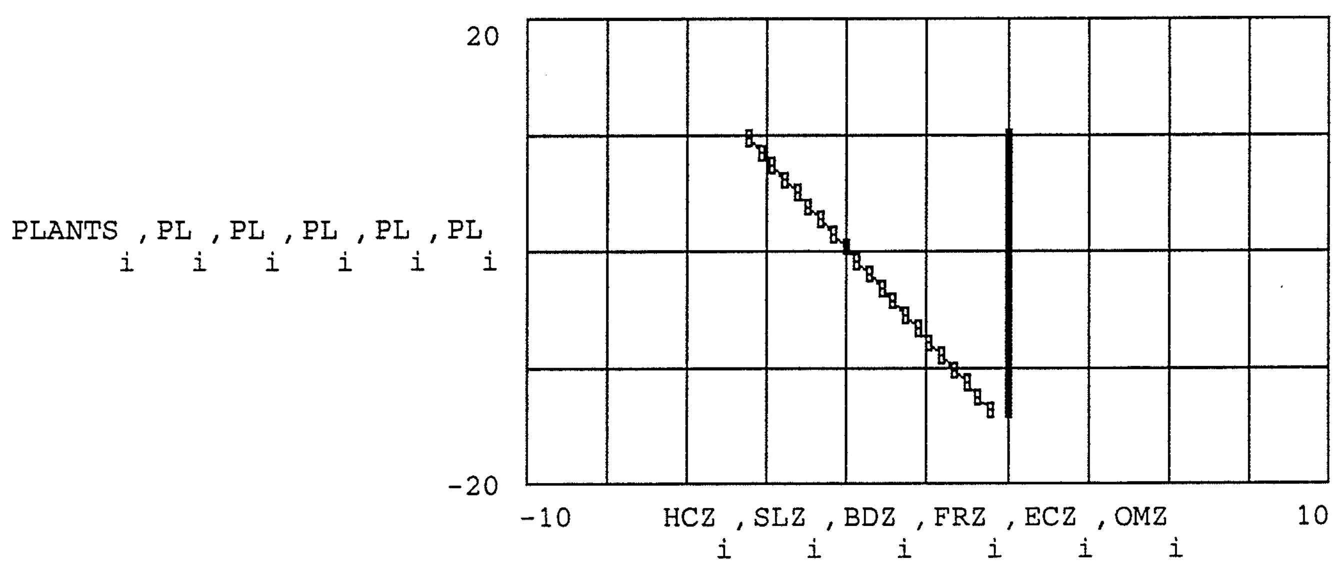
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with BD varied and all other regressors set at two standard deviations above mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
2	2	-4.476	2	2	2	9.775
2	2	-4.173	2	2	2	8.602
2	2	-3.871	2	2	2	7.43
2	2	-3.568	2	2	2	6.258
2	2	-3.266	2	2	2	5.085
2	2	-2.963	2	2	2	3.913
2	2	-2.66	2	2	2	2.74
2	2	-2.358	2	2	2	1.568
2	2	-2.055	2	2	2	0.395
2	2	-1.753	2	2	2	-0.777
2	2	-1.45	2	2	2	-1.95
2	2	-1.148	2	2	2	-3.122
2	2	-0.845	2	2	2	-4.295
2	2	-0.542	2	2	2	-5.467
2	2	-0.24	2	2	2	-6.64
2	2	0.063	2	2	2	-7.812
2	2	0.365	2	2	2	-8.985
2	2	0.668	2	2	2	-10.157
2	2	0.97	2	2	2	-11.329
2	2	1.273	2	2	2	-12.502
2	2	1.576	2	2	2	-13.674



SENSITIVITY ANALYSIS: % ORGANIC MATTER

Vary OM, all other regressors set at two standard deviations below mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + -2$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + -2$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + -2$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + -2$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + -2$$

$$OMZ_i := \frac{0 + (i \cdot .5) - 3.9512}{0.6638}$$

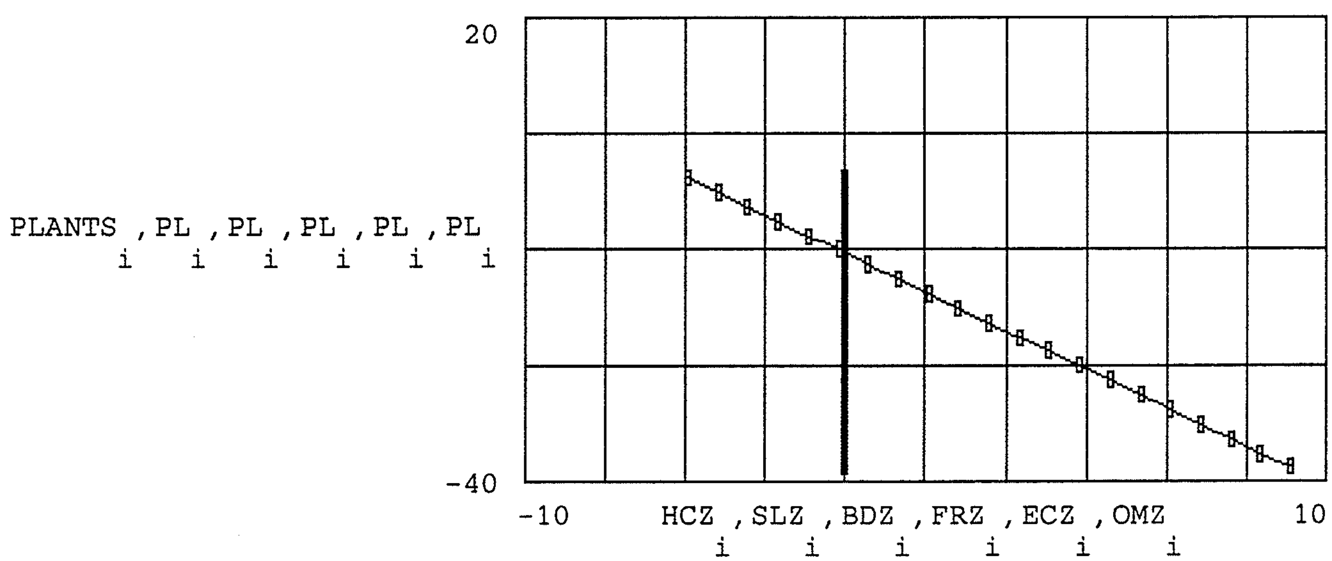
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$$

Table and graph of sensitivity analysis with OM varied and all other regressors set at two standard deviations below mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
-2	-2	-2	-2	-2	-5.952	-0.776
-2	-2	-2	-2	-2	-5.199	-2.648
-2	-2	-2	-2	-2	-4.446	-4.519
-2	-2	-2	-2	-2	-3.693	-6.391
-2	-2	-2	-2	-2	-2.939	-8.262
-2	-2	-2	-2	-2	-2.186	-10.134
-2	-2	-2	-2	-2	-1.433	-12.006
-2	-2	-2	-2	-2	-0.68	-13.877
-2	-2	-2	-2	-2	0.074	-15.749
-2	-2	-2	-2	-2	0.827	-17.621
-2	-2	-2	-2	-2	1.58	-19.492
-2	-2	-2	-2	-2	2.333	-21.364
-2	-2	-2	-2	-2	3.086	-23.236
-2	-2	-2	-2	-2	3.84	-25.107
-2	-2	-2	-2	-2	4.593	-26.979
-2	-2	-2	-2	-2	5.346	-28.851
-2	-2	-2	-2	-2	6.099	-30.722
-2	-2	-2	-2	-2	6.853	-32.594
-2	-2	-2	-2	-2	7.606	-34.466
-2	-2	-2	-2	-2	8.359	-36.337
-2	-2	-2	-2	-2	9.112	-38.209



SENSITIVITY ANALYSIS

Vary OM, all other regressors set at one standard deviation below mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + -1$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + -1$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + -1$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + -1$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + -1$$

$$OMZ_i := \frac{0 + (i \cdot .5) - 3.9512}{0.6638}$$

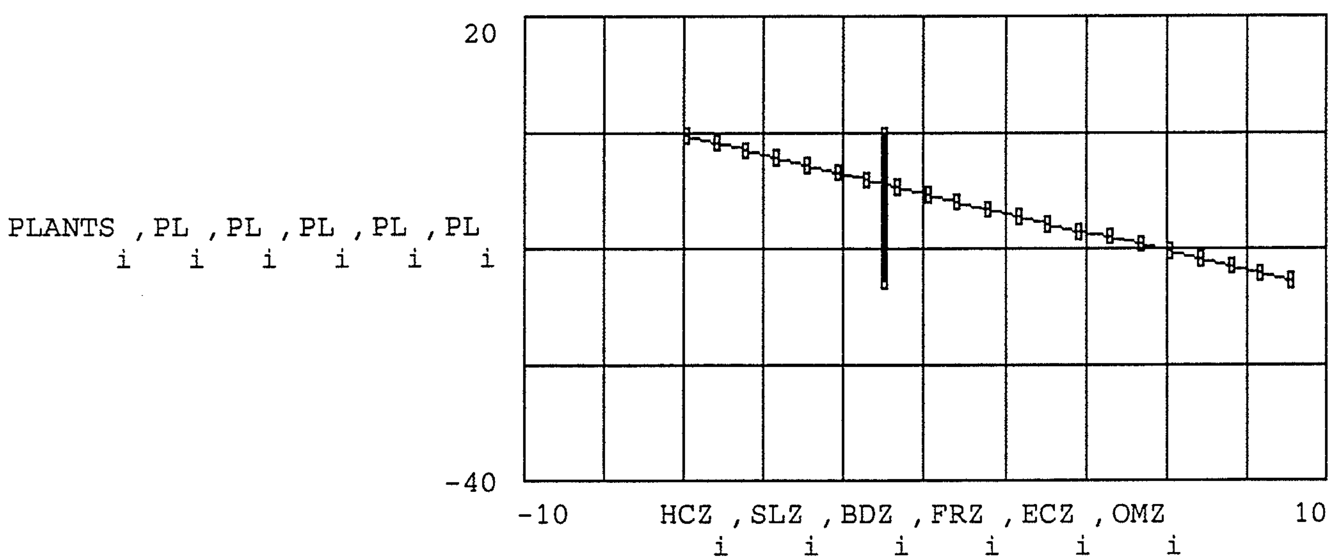
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$$

Table and graph of sensitivity analysis with OM varied and all other regressors set at one standard deviation below mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
-1	-1	-1	-1	-1	-5.952	4.559
-1	-1	-1	-1	-1	-5.199	3.624
-1	-1	-1	-1	-1	-4.446	2.688
-1	-1	-1	-1	-1	-3.693	1.752
-1	-1	-1	-1	-1	-2.939	0.816
-1	-1	-1	-1	-1	-2.186	-0.12
-1	-1	-1	-1	-1	-1.433	-1.056
-1	-1	-1	-1	-1	-0.68	-1.991
-1	-1	-1	-1	-1	0.074	-2.927
-1	-1	-1	-1	-1	0.827	-3.863
-1	-1	-1	-1	-1	1.58	-4.799
-1	-1	-1	-1	-1	2.333	-5.735
-1	-1	-1	-1	-1	3.086	-6.671
-1	-1	-1	-1	-1	3.84	-7.606
-1	-1	-1	-1	-1	4.593	-8.542
-1	-1	-1	-1	-1	5.346	-9.478
-1	-1	-1	-1	-1	6.099	-10.414
-1	-1	-1	-1	-1	6.853	-11.35
-1	-1	-1	-1	-1	7.606	-12.285
-1	-1	-1	-1	-1	8.359	-13.221
-1	-1	-1	-1	-1	9.112	-14.157



SENSITIVITY ANALYSIS

Vary OM, all other regressors set at mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030}$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810}$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929}$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947}$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644}$$

$$OMZ_i := \frac{0 + (i \cdot .5) - 3.9512}{0.6638}$$

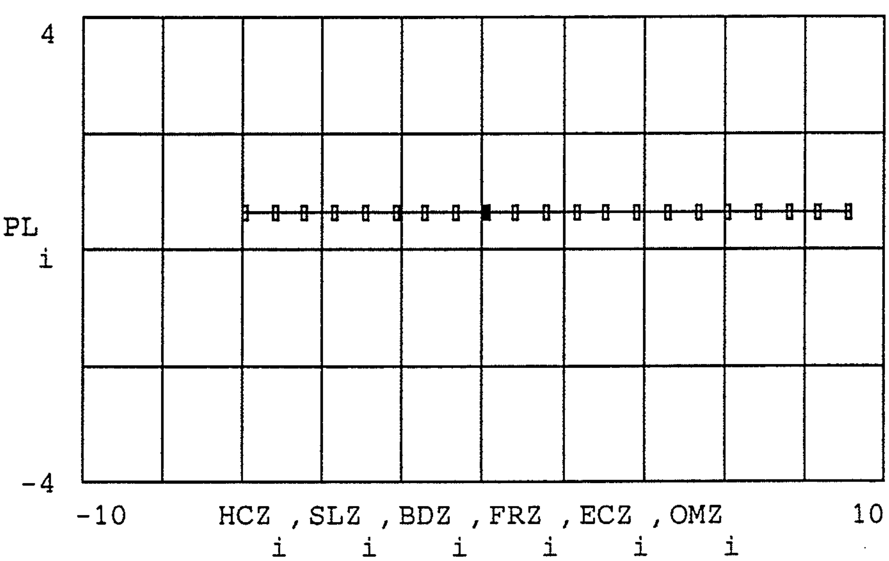
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot {SLZ_i}^2\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of sensitivity analysis with OM varied and all other regressors set at mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
0	0	0	0	0	-5.952	0.621
0	0	0	0	0	-5.199	0.621
0	0	0	0	0	-4.446	0.621
0	0	0	0	0	-3.693	0.621
0	0	0	0	0	-2.939	0.621
0	0	0	0	0	-2.186	0.621
0	0	0	0	0	-1.433	0.621
0	0	0	0	0	-0.68	0.621
0	0	0	0	0	0.074	0.621
0	0	0	0	0	0.827	0.621
0	0	0	0	0	1.58	0.621
0	0	0	0	0	2.333	0.621
0	0	0	0	0	3.086	0.621
0	0	0	0	0	3.84	0.621
0	0	0	0	0	4.593	0.621
0	0	0	0	0	5.346	0.621
0	0	0	0	0	6.099	0.621
0	0	0	0	0	6.853	0.621
0	0	0	0	0	7.606	0.621
0	0	0	0	0	8.359	0.621
0	0	0	0	0	9.112	0.621



SENSITIVITY ANALYSIS

Vary OM, all other regressors set at one standard deviation above mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + 1$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + 1$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + 1$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + 1$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + 1$$

$$OMZ_i := \frac{0 + (i \cdot .5) - 3.9512}{0.6638}$$

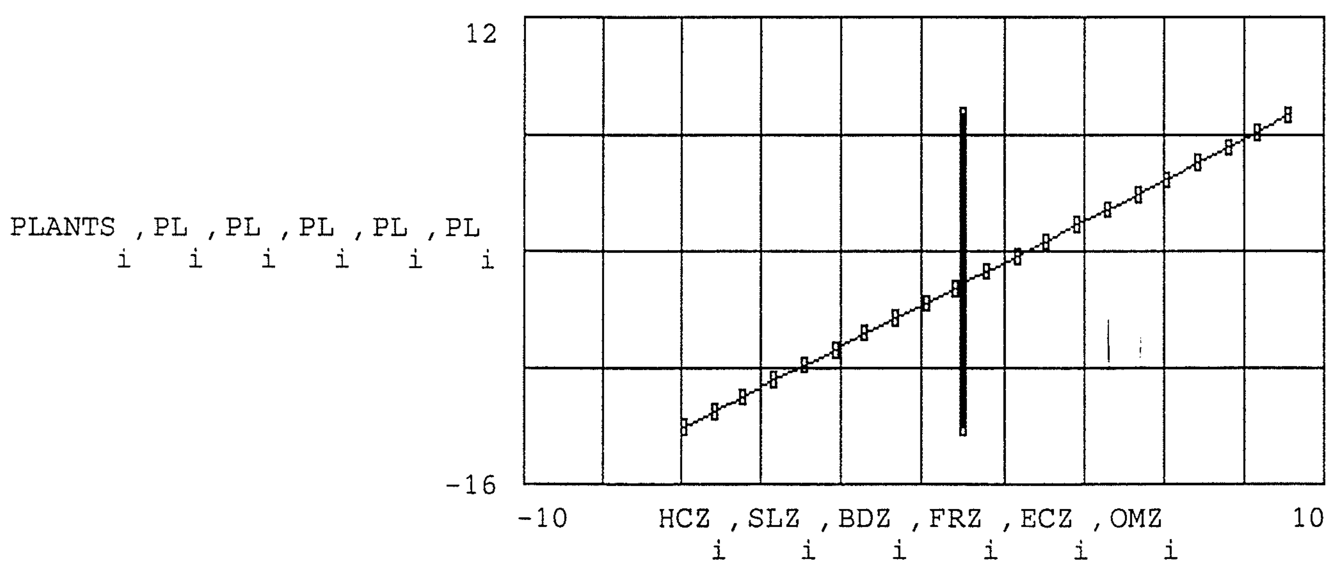
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$$

Table and graph of sensitivity analysis with OM varied and all other regressors set at one standard deviation above mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
1	1	1	1	1	-5.952	-12.592
1	1	1	1	1	-5.199	-11.656
1	1	1	1	1	-4.446	-10.721
1	1	1	1	1	-3.693	-9.785
1	1	1	1	1	-2.939	-8.849
1	1	1	1	1	-2.186	-7.913
1	1	1	1	1	-1.433	-6.977
1	1	1	1	1	-0.68	-6.041
1	1	1	1	1	0.074	-5.106
1	1	1	1	1	0.827	-4.17
1	1	1	1	1	1.58	-3.234
1	1	1	1	1	2.333	-2.298
1	1	1	1	1	3.086	-1.362
1	1	1	1	1	3.84	-0.426
1	1	1	1	1	4.593	0.509
1	1	1	1	1	5.346	1.445
1	1	1	1	1	6.099	2.381
1	1	1	1	1	6.853	3.317
1	1	1	1	1	7.606	4.253
1	1	1	1	1	8.359	5.189
1	1	1	1	1	9.112	6.124



SENSITIVITY ANALYSIS

Vary OM, all other regressors set at two standard deviations above mean.

$N := 20 \qquad i := 0 .. N$

$$HCZ_i := \frac{3.9296 + (i \cdot .64 \cdot 0) - 3.9296}{4.0030} + 2$$

$$SLZ_i := \frac{3.000 + (i \cdot 0) - 3.000}{4.6810} + 2$$

$$FRZ_i := \frac{0.9075 + (i \cdot 2 \cdot 0) - 0.9075}{3.4929} + 2$$

$$ECZ_i := \frac{2.526 + (i \cdot .3 \cdot 0) - 2.526}{1.0947} + 2$$

$$BDZ_i := \frac{1.3584 + (i \cdot .05 \cdot 0) - 1.3584}{0.2644} + 2$$

$$OMZ_i := \frac{0 + (i \cdot .5) - 3.9512}{0.6638}$$

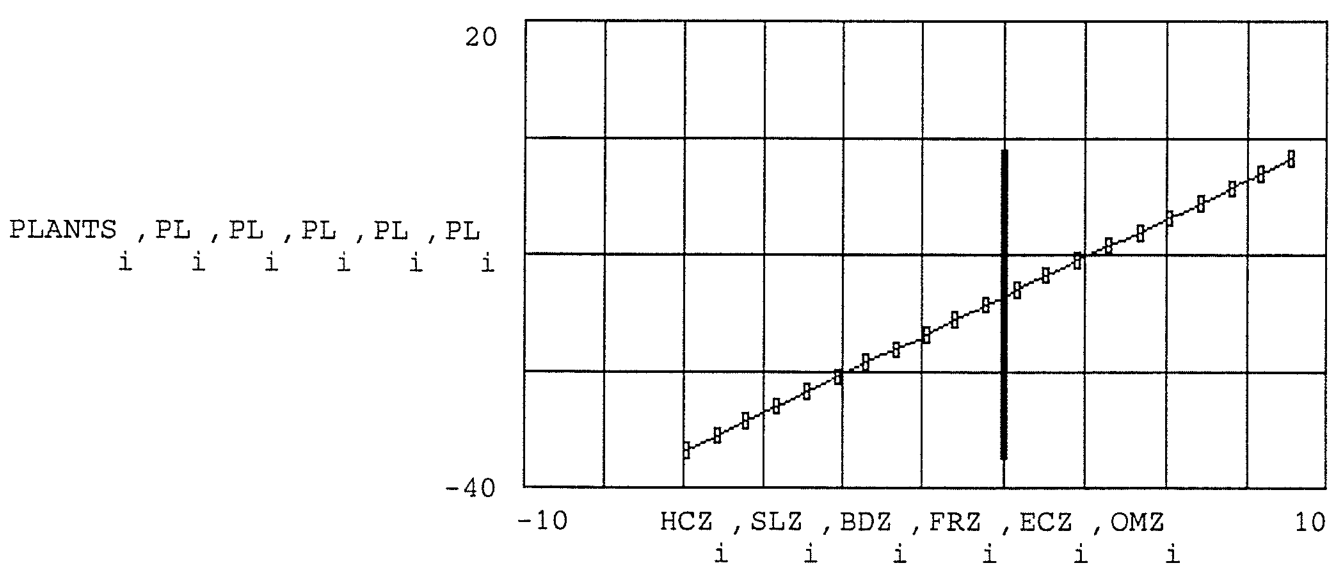
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$$

Table and graph of sensitivity analysis with OM varied and all other regressors set at two standard deviations above mean.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
2	2	2	2	2	-5.952	-35.079
2	2	2	2	2	-5.199	-33.207
2	2	2	2	2	-4.446	-31.336
2	2	2	2	2	-3.693	-29.464
2	2	2	2	2	-2.939	-27.592
2	2	2	2	2	-2.186	-25.721
2	2	2	2	2	-1.433	-23.849
2	2	2	2	2	-0.68	-21.977
2	2	2	2	2	0.074	-20.106
2	2	2	2	2	0.827	-18.234
2	2	2	2	2	1.58	-16.362
2	2	2	2	2	2.333	-14.491
2	2	2	2	2	3.086	-12.619
2	2	2	2	2	3.84	-10.747
2	2	2	2	2	4.593	-8.876
2	2	2	2	2	5.346	-7.004
2	2	2	2	2	6.099	-5.133
2	2	2	2	2	6.853	-3.261
2	2	2	2	2	7.606	-1.389
2	2	2	2	2	8.359	0.482
2	2	2	2	2	9.112	2.354



APPENDIX D. SENSITIVITY ANALYSIS OF SPILLUM SITE SOIL RECLAMATION ALTERNATIVES

DESIGN ANALYSIS: EXTRACT & GRADE ALTERNATIVE

Vary slope, HC=9, BD=1.5, FR=0, EC=2, OM=.2.

$N := 35 \qquad i := 0 .. N$

$$HCZ_i := \frac{9 - 3.9296}{4.0030}$$

$$SLZ_i := \frac{i - 3.000}{4.6810}$$

$$FRZ_i := \frac{0.0 - 0.9075}{3.4929}$$

$$ECZ_i := \frac{2 - 2.526}{1.0947}$$

$$BDZ_i := \frac{1.5 - 1.3584}{0.2644}$$

$$OMZ_i := \frac{0.2 - 3.9512}{0.6638}$$

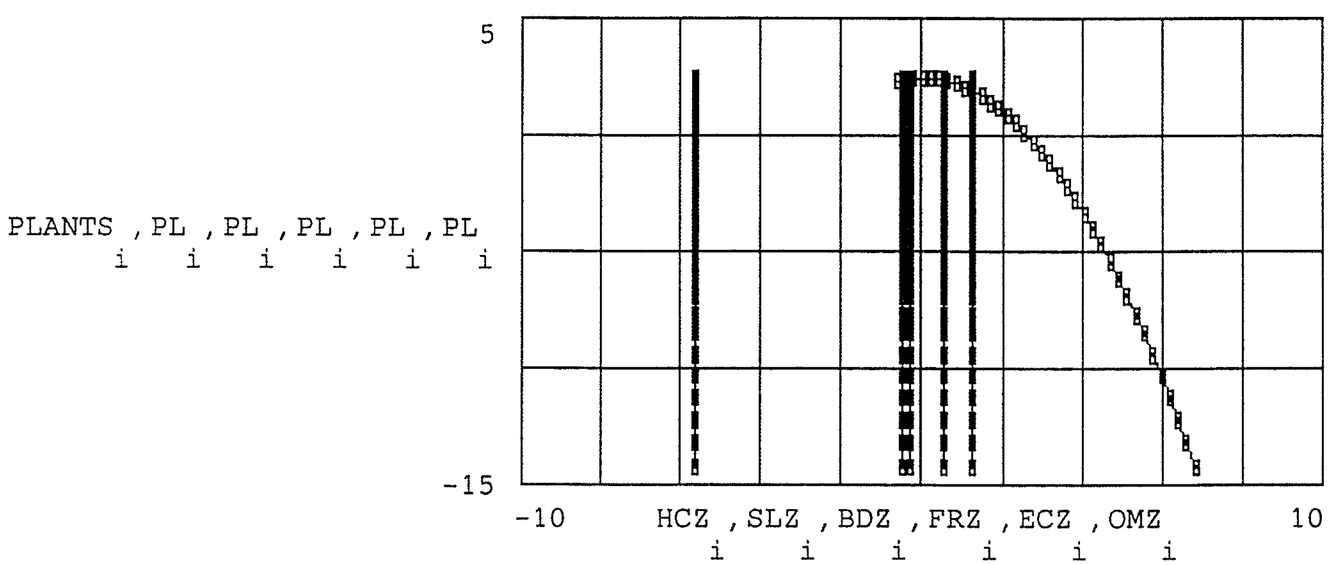
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^2\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

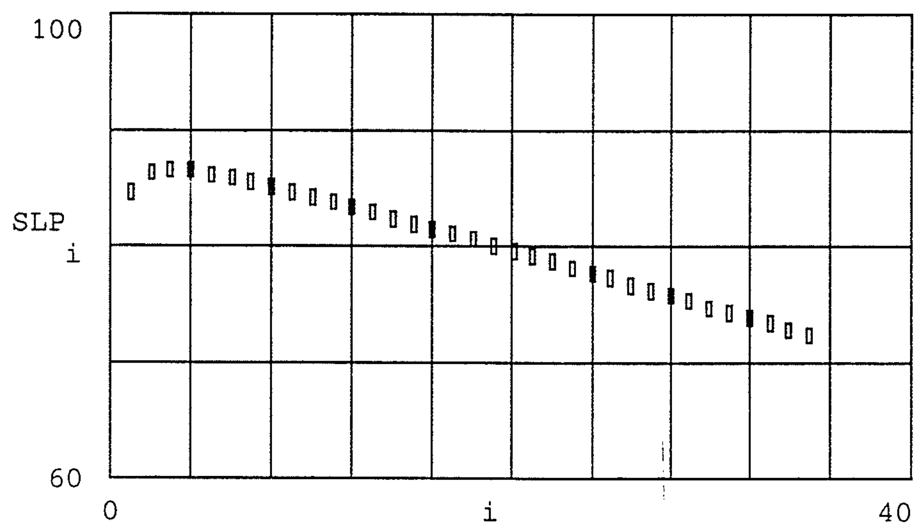
$$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$$

Table and graph of design analysis with slope varied, HC=9, BD=1.5, FR=0 EC=2, OM=.2.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
1.267	-0.641	0.536	-0.26	-0.48	-5.651	2.329
1.267	-0.427	0.536	-0.26	-0.48	-5.651	2.411
1.267	-0.214	0.536	-0.26	-0.48	-5.651	2.46
1.267	0	0.536	-0.26	-0.48	-5.651	2.476
1.267	0.214	0.536	-0.26	-0.48	-5.651	2.46
1.267	0.427	0.536	-0.26	-0.48	-5.651	2.411
1.267	0.641	0.536	-0.26	-0.48	-5.651	2.329
1.267	0.855	0.536	-0.26	-0.48	-5.651	2.215
1.267	1.068	0.536	-0.26	-0.48	-5.651	2.068
1.267	1.282	0.536	-0.26	-0.48	-5.651	1.889
1.267	1.495	0.536	-0.26	-0.48	-5.651	1.677
1.267	1.709	0.536	-0.26	-0.48	-5.651	1.432
1.267	1.923	0.536	-0.26	-0.48	-5.651	1.155
1.267	2.136	0.536	-0.26	-0.48	-5.651	0.845
1.267	2.35	0.536	-0.26	-0.48	-5.651	0.502
1.267	2.564	0.536	-0.26	-0.48	-5.651	0.127
1.267	2.777	0.536	-0.26	-0.48	-5.651	-0.281
1.267	2.991	0.536	-0.26	-0.48	-5.651	-0.722
1.267	3.204	0.536	-0.26	-0.48	-5.651	-1.195
1.267	3.418	0.536	-0.26	-0.48	-5.651	-1.701
1.267	3.632	0.536	-0.26	-0.48	-5.651	-2.239
1.267	3.845	0.536	-0.26	-0.48	-5.651	-2.81
1.267	4.059	0.536	-0.26	-0.48	-5.651	-3.414
1.267	4.273	0.536	-0.26	-0.48	-5.651	-4.05
1.267	4.486	0.536	-0.26	-0.48	-5.651	-4.719
1.267	4.7	0.536	-0.26	-0.48	-5.651	-5.421
1.267	4.913	0.536	-0.26	-0.48	-5.651	-6.155
1.267	5.127	0.536	-0.26	-0.48	-5.651	-6.922
1.267	5.341	0.536	-0.26	-0.48	-5.651	-7.721
1.267	5.554	0.536	-0.26	-0.48	-5.651	-8.553
1.267	5.768	0.536	-0.26	-0.48	-5.651	-9.418
1.267	5.982	0.536	-0.26	-0.48	-5.651	-10.315
1.267	6.195	0.536	-0.26	-0.48	-5.651	-11.245
1.267	6.409	0.536	-0.26	-0.48	-5.651	-12.208
1.267	6.623	0.536	-0.26	-0.48	-5.651	-13.203
1.267	6.836	0.536	-0.26	-0.48	-5.651	-14.231



$$x_i := \frac{30}{i + .001} \qquad y_i := 35 - x_i \qquad SLP_i := y_i \cdot 2.476 + \left[x_i \cdot PLANTS_i\right]$$



x_i	y_i	SLP_i	$PLANTS_i$
$3 \cdot 10^4$	$-2.997 \cdot 10^4$	$-4.316 \cdot 10^3$	2.329
29.97	5.03	84.706	2.411
14.993	20.007	86.416	2.46
9.997	25.003	86.661	2.476
7.498	27.502	86.538	2.46
5.999	29.001	86.269	2.411
4.999	30.001	85.926	2.329
4.285	30.715	85.542	2.215
3.75	31.25	85.131	2.068
3.333	31.667	84.703	1.889
3	32	84.262	1.677
2.727	32.273	83.813	1.432
2.5	32.5	83.357	1.155
2.308	32.692	82.895	0.845
2.143	32.857	82.43	0.502
2	33	81.962	0.127
1.875	33.125	81.49	-0.281
1.765	33.235	81.017	-0.722
1.667	33.333	80.542	-1.195
1.579	33.421	80.066	-1.701
1.5	33.5	79.588	-2.239
1.429	33.571	79.109	-2.81
1.364	33.636	78.629	-3.414
1.304	33.696	78.148	-4.05
1.25	33.75	77.667	-4.719
1.2	33.8	77.184	-5.421
1.154	33.846	76.702	-6.155
1.111	33.889	76.219	-6.922
1.071	33.929	75.735	-7.721
1.034	33.966	75.251	-8.553
1	34	74.767	-9.418
			-10.315

0.968	34.032	74.282	-11.245
0.937	34.063	73.797	-12.208
0.909	34.091	73.311	-13.203
0.882	34.118	72.826	-14.231
0.857	34.143	72.34	

DESIGN ANALYSIS: COMPACT SOIL ALTERNATIVE

Vary bulk density and hydraulic conductivity, SL=3, FR=0, EC=2, OM=.2.

$N := 35 \qquad i := 0 .. N$

$$HCZ_i := \frac{13 - (i \cdot 0.2) - 3.9296}{4.0030}$$

$$SLZ_i := \frac{3 - 3.000}{4.6810}$$

$$FRZ_i := \frac{0.0 - 0.9075}{3.4929}$$

$$ECZ_i := \frac{2 - 2.526}{1.0947}$$

$$BDZ_i := \frac{1.3 + (i \cdot .01) - 1.3584}{0.2644}$$

$$OMZ_i := \frac{0.2 - 3.9512}{0.6638}$$

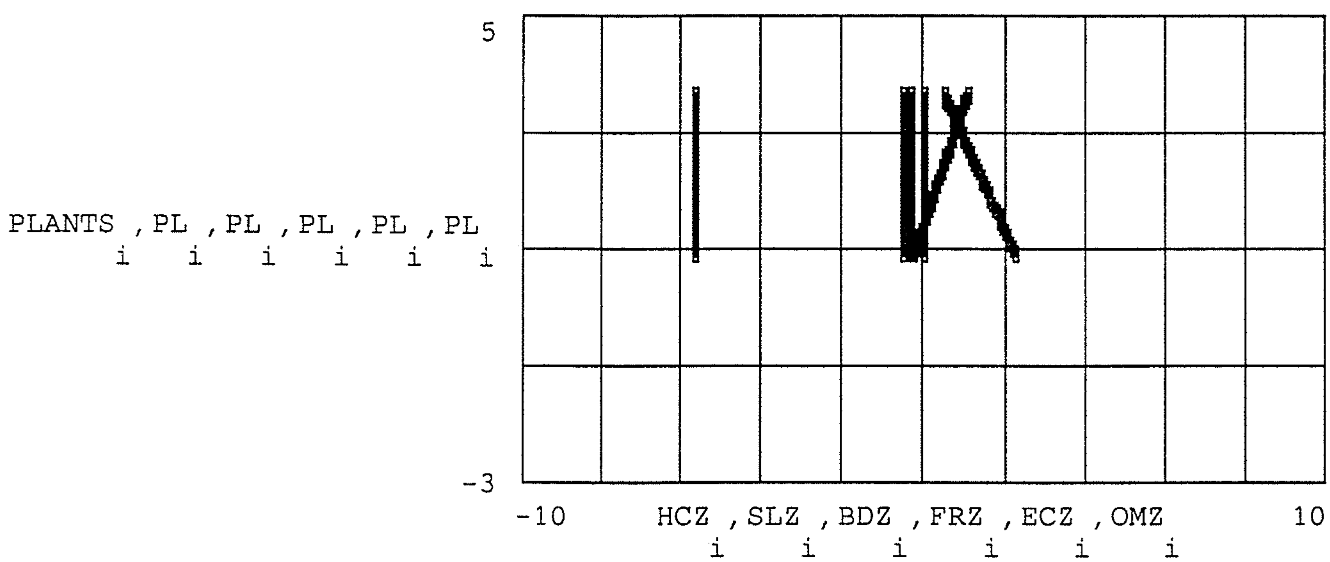
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of design analysis with hydraulic conductivity and bulk density varied, SL=3, FR=0 EC=2, OM=.2.

HCZ_i	SLZ_i	BDZ_i	FRZ_i	ECZ_i	OMZ_i	$PLANTS_i$
2.266	0	-0.221	-0.26	-0.48	-5.651	0.916
2.216	0	-0.183	-0.26	-0.48	-5.651	0.994
2.166	0	-0.145	-0.26	-0.48	-5.651	1.072
2.116	0	-0.107	-0.26	-0.48	-5.651	1.15
2.066	0	-0.07	-0.26	-0.48	-5.651	1.228
2.016	0	-0.032	-0.26	-0.48	-5.651	1.306
1.966	0	0.006	-0.26	-0.48	-5.651	1.384
1.916	0	0.044	-0.26	-0.48	-5.651	1.462
1.866	0	0.082	-0.26	-0.48	-5.651	1.54
1.816	0	0.12	-0.26	-0.48	-5.651	1.618
1.766	0	0.157	-0.26	-0.48	-5.651	1.696
1.716	0	0.195	-0.26	-0.48	-5.651	1.774
1.666	0	0.233	-0.26	-0.48	-5.651	1.852
1.616	0	0.271	-0.26	-0.48	-5.651	1.93
1.566	0	0.309	-0.26	-0.48	-5.651	2.008
1.516	0	0.346	-0.26	-0.48	-5.651	2.086
1.467	0	0.384	-0.26	-0.48	-5.651	2.164
1.417	0	0.422	-0.26	-0.48	-5.651	2.242
1.367	0	0.46	-0.26	-0.48	-5.651	2.32
1.317	0	0.498	-0.26	-0.48	-5.651	2.398
1.267	0	0.536	-0.26	-0.48	-5.651	2.476
1.217	0	0.573	-0.26	-0.48	-5.651	2.554
1.167	0	0.611	-0.26	-0.48	-5.651	2.632
1.117	0	0.649	-0.26	-0.48	-5.651	2.71
1.067	0	0.687	-0.26	-0.48	-5.651	2.788
1.017	0	0.725	-0.26	-0.48	-5.651	2.866
0.967	0	0.762	-0.26	-0.48	-5.651	2.944
0.917	0	0.8	-0.26	-0.48	-5.651	3.022
0.867	0	0.838	-0.26	-0.48	-5.651	3.1
0.817	0	0.876	-0.26	-0.48	-5.651	3.178
0.767	0	0.914	-0.26	-0.48	-5.651	3.256
0.717	0	0.952	-0.26	-0.48	-5.651	3.334
0.667	0	0.989	-0.26	-0.48	-5.651	3.412
0.617	0	1.027	-0.26	-0.48	-5.651	3.49
0.567	0	1.065	-0.26	-0.48	-5.651	3.568
0.517	0	1.103	-0.26	-0.48	-5.651	3.646



DESIGN ANALYSIS: ORGANIC MATTER & ELECTRICAL CONDUCTIVITY ALTERNATIVE

Vary electrical conductivity and organic matter; BD and HC will vary also; SL=3 and FR=0.

$N := 35 \qquad i := 0 .. N$

$$HCZ_i := \frac{9 + (i \cdot .1) - 3.9296}{4.0030}$$

$$SLZ_i := \frac{3 - 3.000}{4.6810}$$

$$FRZ_i := \frac{0.0 - 0.9075}{3.4929}$$

$$ECZ_i := \frac{2 + (i \cdot 0.06) - 2.526}{1.0947}$$

$$BDZ_i := \frac{1.5 + (i \cdot -.01) + -1.3584}{0.2644}$$

$$OMZ_i := \frac{0.2 + (i \cdot 0.2) - 3.9512}{0.6638}$$

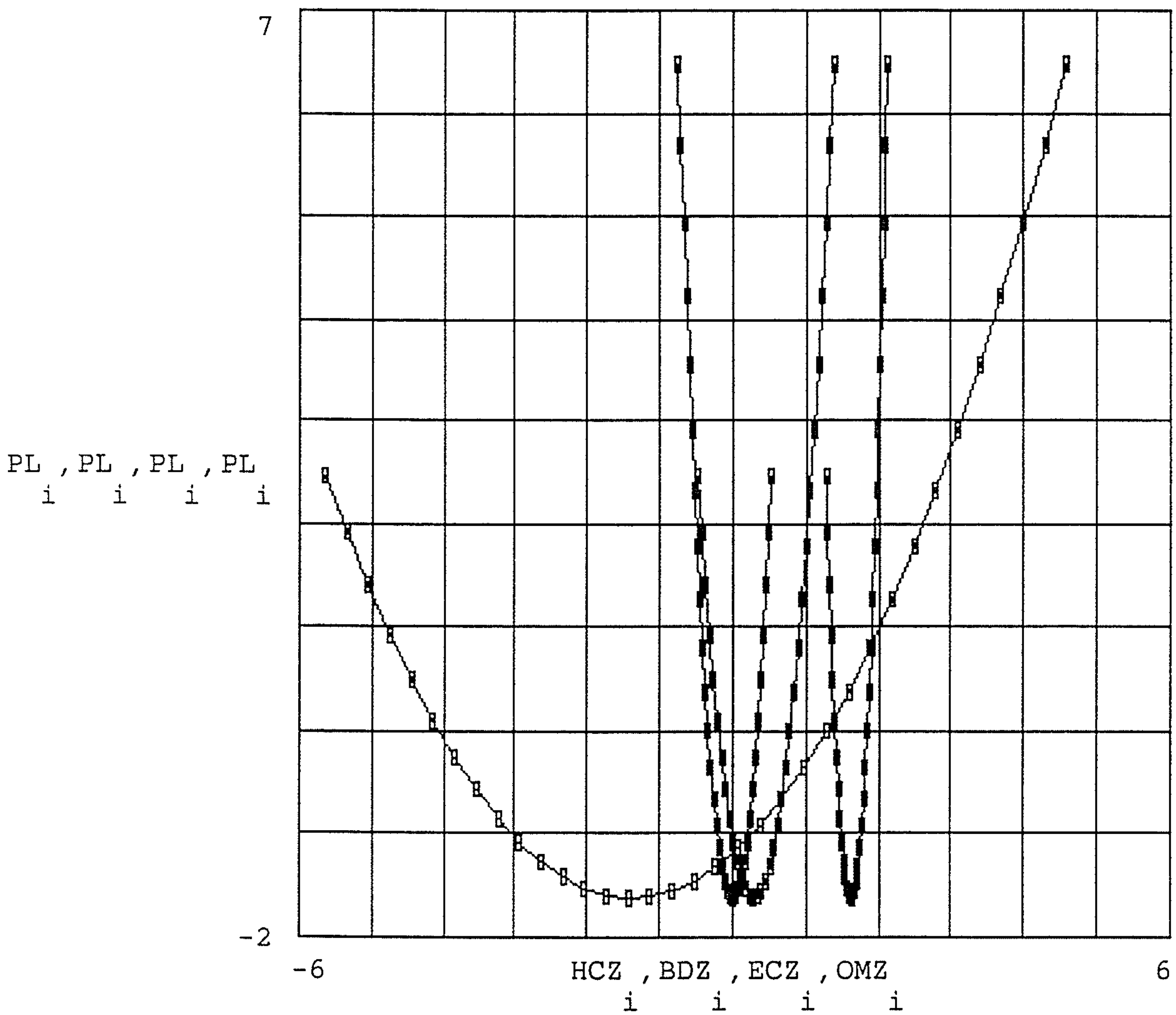
$$PLANTA_i := .6206 + \left[-1.1805 \cdot HCZ_i\right] + \left[-0.3575 \cdot SLZ_i^{\,2}\right] + \left[-1.9375 \cdot BDZ_i \cdot FRZ_i\right]$$

$$PLANTB_i := \left[-2.3420 \cdot ECZ_i \cdot FRZ_i\right] + \left[1.2424 \cdot OMZ_i \cdot ECZ_i\right]$$

$PLANTS_i := PLANTA_i + PLANTB_i \qquad PL_i := PLANTS_i$

Table and graph of design analysis with electrical conductivity and percent organic matter varied; BD and HC will also vary; FR=0, SL=3.

HCZ i	SLZ i	BDZ i	FRZ i	ECZ i	OMZ i	PLANTS i
1.267	0	0.536	-0.26	-0.48	-5.651	2.476
1.292	0	0.498	-0.26	-0.426	-5.35	1.917
1.317	0	0.46	-0.26	-0.371	-5.049	1.398
1.342	0	0.422	-0.26	-0.316	-4.747	0.921
1.367	0	0.384	-0.26	-0.261	-4.446	0.485
1.392	0	0.346	-0.26	-0.206	-4.145	0.09
1.417	0	0.309	-0.26	-0.152	-3.843	-0.264
1.442	0	0.271	-0.26	-0.097	-3.542	-0.578
1.467	0	0.233	-0.26	-0.042	-3.241	-0.85
1.491	0	0.195	-0.26	0.013	-2.939	-1.081
1.516	0	0.157	-0.26	0.068	-2.638	-1.271
1.541	0	0.12	-0.26	0.122	-2.337	-1.42
1.566	0	0.082	-0.26	0.177	-2.036	-1.528
1.591	0	0.044	-0.26	0.232	-1.734	-1.595
1.616	0	0.006	-0.26	0.287	-1.433	-1.621
1.641	0	-0.032	-0.26	0.342	-1.132	-1.605
1.666	0	-0.07	-0.26	0.396	-0.83	-1.549
1.691	0	-0.107	-0.26	0.451	-0.529	-1.452
1.716	0	-0.145	-0.26	0.506	-0.228	-1.314
1.741	0	-0.183	-0.26	0.561	0.074	-1.135
1.766	0	-0.221	-0.26	0.616	0.375	-0.914
1.791	0	-0.259	-0.26	0.671	0.676	-0.653
1.816	0	-0.297	-0.26	0.725	0.977	-0.351
1.841	0	-0.334	-0.26	0.78	1.279	-0.007
1.866	0	-0.372	-0.26	0.835	1.58	0.377
1.891	0	-0.41	-0.26	0.89	1.881	0.803
1.916	0	-0.448	-0.26	0.945	2.183	1.269
1.941	0	-0.486	-0.26	0.999	2.484	1.777
1.966	0	-0.523	-0.26	1.054	2.785	2.325
1.991	0	-0.561	-0.26	1.109	3.086	2.915
2.016	0	-0.599	-0.26	1.164	3.388	3.546
2.041	0	-0.637	-0.26	1.219	3.689	4.217
2.066	0	-0.675	-0.26	1.273	3.99	4.93
2.091	0	-0.713	-0.26	1.328	4.292	5.684
2.116	0	-0.75	-0.26	1.383	4.593	6.478
2.141	0	-0.788	-0.26	1.438	4.894	7.314


7
-2
-6
6
PL , PL , PL , PL
i i i i
HCZ , BDZ , ECZ , OMZ
i i i i

BIBLIOGRAPHY

Arndt, B.M. and S.R. Moran. 1974. Physical Data for Land-use Planning Cass County, North Dakota and Clay County, Minnesota. North Dakota Geological Survey, Report of Investigation 54.

Banks, C.H. 1954. The factorial analysis of crop productivity. J. Roy. Statist. Soc., Series B, 16,(1): 100-111.

Bauer, A.M. 1982. Manipulating mining operations to create wildlife habitats: a pre-mining planning process. Svedarsky, W.D. and R.D. Crawford eds. In: Wildlife Values of Gravel Pits. Agricultural Experiment Station, University of Minnesota, miscellaneous publication 17, p 41-43.

Baxter, J.G. 1969. Site Planning for Sand and Gravel Operations. National Sand and Gravel Association, Silver Springs, MD.

Brady, N.C. 1974. The Nature and Properties of Soils. Macmillian Publishing, Co., 8th edition.

Cardwell, S.P. 1985. The history of reclamation: The times- they are a changin'. 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. University of Kentucky, p 279-289.

Chichester, F.W. 1983. Premining evaluation of forage grass growth on mine soil materials from an East-Central Texas lignite site: 2. soil profile horizons. Soil Science 135(6):236-244.

Clay County. 1968. Lease agreement between Kost Brothers, Inc. and Marvin and Pearl Spillum.

Crum, J.R. and R.H. Rust. 1986. Characterization and stratigraphy of soil parent materials of West-central Minnesota. Soil Sci. Soc. Am. J., 50:1509-1515.

Daniel, W.W. 1978. Applied Nonparametric Statistics. Houghton Mifflin Company.

Doll, E.C., N.C. Wollenhaupt, G.A. Halvorson and S.A. Schroeder. 1984a. Planning and evaluating cropland reclamation after stripmining in North Dakota. Minerals and the Environment. 6:121-126.

Doll, E.C., S.D. Merrill and G.A. Halvorson. 1984b. Soil Replacement for Reclamation of Stripmined Land in North Dakota. North Dakota Agric. Exp. Sta., Bull. 514.

Doll, E.C. 1985. Use of soil parameters in evaluation of reclamation success. 1985 Mine-Land Reclamation Research Review. Land Reclamation Research Center North Dakota State University and the Northern Great Plains Research Center USDA, p 26-32.

Doll, E.C. and N.C. Wollenhaupt. 1985. Use of soil parameters in the evaluation of reclamation success in North Dakota. Bridging the Gap Between Science, Regulation, and the Surface Mining Operation. ASSMR Second Annual Meeting, Denver, CO, p 91-94.

Dziadyk, B. 1981. Structure and Function of Plant Communities in a Western Minnesota Tallgrass Prairie. Ph.D. Dissertation, North Dakota State University.

Dunham, D.M. 1981. Prairie-Forest Ecotone of Northwestern Minnesota. M.S. Paper, North Dakota State University.

Espenshade, E.B., Jr. (ed.). 1974. Goode's World Atlas. Rand McNally and Company, 14th edition.

Freund, R.J. and P.D. Minton. 1979. Regression Methods: A Tool for Data Analysis. Marcel Dekker, Inc., N.Y., N.Y.

Graham, J.P., P.S. Blackwell, J.V. Armstrong, D.G. Christian, K.R. Howse, C.J. Dawson and A.R. Butler. 1986. Compaction of a silt loam by wheeled agricultural vehicles. II. effects on growth and yield of direct-drilled winter wheat. Soil & Tillage Research 7:189-203.

Grandt, A.F. 1984. History of reclamation research. Symposium on the Reclamation of Lands Disturbed by Surface Mining a Cornerstone for Communication and Understanding. 1984 National Meeting ASSMR, Owensboro, KY, p 164-187.

Green, J.C. and R.B. Janssen. 1975. Minnesota Birds Where, When and How Many. University of Minnesota Press.

Hall, D.L. 1987. Reclamation planning for coal strip-mined lands in Montana. Landscape and Urban Planning 14:45-55.

Hanson, J.D. 1976. The Oak Savanna in Southeastern North Dakota. M.S. Thesis, North Dakota State University.

Hargis, N.E. 1984. Soil handling for surface mine reclamation. J. Soil and Water Cons. 39:300-305.

Hazard, E.B. 1982. The Mammals of Minnesota. University of Minnesota Press.

Jacobson, M.N. 1982. Soil Survey of Clay County, Minnesota. USDA, SCS and Minnesota Agricultural Experiment Station.

Jacobson, M.N. 1986. Personal correspondence.

Jenson, D.R. 1967. Selecting Land Use For Sand and Gravel Sites. National Sand and Gravel Association, Silver Springs, MD.

Jurinak, J.J., J. Bowden, F. Samson, T. Portal 1987. Electrical conductivity. In: Williams, R.D. and G.E. Schuman, (eds.) Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures. Soil Conservation Society of America, Ankeny, IA, p 27-34.

Kendall, M. 1939. The geographical distribution of crop productivity in England. J. Roy. Statist. Soc., 102, 21.

Kendall, M. 1980. Multivariate Analysis. Macmillan Publishing Co., Inc.

Kerr, K.W, F.K. Kerr, C.G. Hanson and B.C. Camenga. 1986. Cost Data for Landscape Construction. Kerr Associates, Minneapolis, MN, 7th edition.

Kline, L.G. 1985. Recent concerns in assessing revegetation success and releasing bond liability. In: Bridging the Gap Between Science, Regulation, and the Surface Mining Operation. ASSMR Second Annual Meeting, Denver, CO.

Lohse, J.S., P. Giordano, M.C. Williams, and F.A. Vogel. 1985 Illinois agricultural land productivity formula. In: Bridging the Gap Between Science, Regulation, and the Surface Mining Operation. ASSMR Second Annual Meeting, Denver, CO, p 24-39.

Lyle, E.S. Jr. 1987. Surface Mine Reclamation Manual. Elsevier.

Maclay, R.W., L.E. Bidwell and T.C. Winter. 1969. Water Resource of the Buffalo River Watershed West-central Minnesota. U.S. Geological Survey.

Marschner, F.J. 1974. The original vegetation of Minnesota. North Central Experiment Station, USDA, St. Paul, MN.

MathSoft. 1987. MathCAD: The Engineer's Scratch Pad. Version 1.1 MathSoft, Inc.

McAllister, D.M. 1982. Evaluation in Environmental Planning. MIT Press.

McCuen, R.H. 1985. Statistical Methods for Engineers. Prentice-Hall, Inc. Englewood Cliffs, N.J.

McLellan, A.G. 1985. Government regulatory control of surface mining operations--new performance guideline models for progressive rehabilitation. Landscape Planning 12:15-28.

McSweeney, K., I.J. Jansen, C.W. Boast and R.E. Dunker. 1987. Row crop productivity of eight constructed minesoils. Reclamation and Revegetation Research 6:137-144.

Medhaug, C.L. 1985. Deciduous Forest Communities, Otter Tail County, Minnesota. M.S. Thesis, North Dakota State University.

Micro Control Systems. 1986. Cadkey. Micro Control Systems, Version 1.4E.

Montgomery, D.C. and E.A. Peck. 1982. Introduction to Linear Regression. John Wiley and Sons.

Munn, L., N. Harrington and D.R. McGirr. 1987. Rock fragments. In: Williams, R.D. and G.E. Schuman, eds., Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures. Soil Conservation Society of America, Ankeny, IA.

National Soils Handbook. 1983. United States Department of the Interior.

Neill, L.L. 1979. An evaluation of soil productivity based on root growth and water depletion. M.S. Thesis, Univ. of Missouri, Columbia.

North Dakota Public Service Commission. 1983a. Laws Governing the Surface Mining and Reclamation Operations. NDPSC, Bismarck, ND.

North Dakota Public Service Commission. 1983b. State of North Dakota Rules Governing the Reclamation of Surface-mined Land. NDPSC, Bismarck, ND.

Omodt, H.W., F.W. Schroer and D.D. Patterson. 1975. The properties of important agricultural soils as criteria for mined land reclamation. N.D.S.U. Agric. Exp. Stn. Bull. 492.

Phillips, G.L., W.D. Schmid and J.C. Underhill. 1982. Fishes of the Minnesota Region. University of Minnesota Press.

Pierce, F.J., W.E. Larson, R.H. Dowdy and W.A.P. Graham. 1983. Productivity of soils: Assessing long-term changes due to erosion. J. Soil and Water Cons. 38:39-44.

Plotkin, S.E. 1986. Overseeing reclamation: From surface mine to cropland. Environment 28(1):16-20, 40-44.

Power, J.F., F.M. Sandoval and R. Ries. 1978. Restoration of productivity to disturbed land in the Northern Great Plains. In: R.A. Wright (ed.) The Reclamation of Disturbed Arid Lands. University of Mexico Press.

Ramalingam, P. 1976. Systems Analysis for Managerial Decisions: A Computer Approach. John Wiley & Sons.

SAS Institute. 1983. SAS User's guide: Statistics, 1982 Edition. SAS Institute Inc., Cary, N.C.

Schafer, W.M. 1979. Guidelines for estimating cover soil quality and mine soil capability for use in coal strip mine reclamation in the western U.S. Reclamation Review 2:67-74.

Schafer, W.M. 1984a. Mine-soil restoration and maturity: A guide for managing mine-soil development. Symposium on surface coal mining and reclamation on the Great Plains, p 172-185.

Schafer, W.M. 1984b. Agricultural capability classification of pre- and post-mined landscapes in the Northern Great Plains. J.Soil and Water Cons. 39:270-273.

Schellie, K.L. and D.A. Rogier. 1963. Site Utilization and Rehabilitation Practices for Sand and Gravel Operations. National Sand and Gravel Association, Silver Springs, MD.

Shelford, V.E. 1978. The Ecology of North America. University of Illinois Press, paperback.

Simpson, J.W.. 1985. The emotional landscape and public law 95-97. Landscape Architecture 75(3):60-63, 108-109, 112-113.

Sindelar, B.W. and S. Murdock. 1985. The utilitarian concept for determining mined land reclamation success. In: Bridging the Gap Between Science, Regulation, and the Surface Mining Operation. ASSMR Second Annual Meeting, Denver, CO, p 84-86.

Smith, P.L., E.F. Redente and E. Hoper. 1987. Soil organic matter. In: Williams, R.D. and G.E. Schuman, (eds.) Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures. Soil Conservation Society of America, Ankeny, IA, p 185-214.

Snarski, R.R., J.B. Fehrenbacher and I.J. Jansen. 1981. Physical and chemical characteristics of pre-mine soils and post-mine soil mixtures in Illinois. Soil Sci. Soc. Am. J., 45:806-812.

Spindler, D. and D. Downing. 1986. Restoration of agricultural productivity on mined land. American Society of Agricultural Engineers, paper no. 86-2614.

Soil Survey Staff. 1983. National Soils Handbook. Part 603: Applications of Soil Information. Working Draft 430-VI-NSH. Soil Conservation Service, USDA.

Tabachnick, B.G. and L.S. Fidel. 1983. Using Multivariate Statistics. Harper and Row Publishers.

Teller, J.T. and L. Clayton, eds. 1983. Glacial Lake Agassiz. Geological Association of Canada Special Paper 26.

Tomlin, C.D. 1986. The IBM Personal Computer Version of the MAP Analysis Package. Laboratory for Computer Graphics and Spatial Analysis, Harvard Graduate School of Design.

Toy, T.J. and D. Shay. 1987. Comparison of some soil properties on natural and reclaimed hillslopes. Soil Science 143(4):264-277.

Toy, T.J. and R.F. Hadley. 1987. Geomorphology and Reclamation of Disturbed Lands. Academic Press.

Vories, K.C. 1985. Proof of vegetative productivity: Research needs. 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. University of Kentucky, p 145-149.

Walsh, J.P. 1985. Soil and overburden management in western surface coal mines reclamation - findings of a study conducted for the congress of the United States - Office of Technology Assessment. In: Bridging the Gap Between Science, Regulation, and the Surface Mining Operation. ASSMR Second Annual Meeting, Denver, CO, p 257-264.

Wanek, W.J. 1967. The Gallery Forest Vegetation of the Red River of the North. Ph.D. Dissertation, North Dakota State University.

Western Minnesota Steam Threshers Reunion. 1987. Memories of Bygone Years. Western Minnesota Steam Threshers Reunion, Inc. 31st edition.

Westman, W.E. 1985. Ecology, Impact Assessment and Environmental Planning. John Wiley & Sons.

Williams, R.D. and G.E. Schuman, eds. 1987. Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures. Soil Conservation Society of America, Ankeny, IA.

Winter, T.C., L.E. Bidwell and R.W. Maclay. 1969. Water Resources of the Otter Tail River Watershed West-central Minnesota. U.S. Geological Survey.

Wonnacott, T.H. and R.J. Wonnacott. 1981. Regression: A Second Course in Statistics. John Wiley and Sons.

Younger, M.S. 1979. Handbook for Linear Regression. Duxbury Press, Wadsworth, Inc.