Sugarbeet Productivity Model for Clay County Minnesota

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ABSTRACT

An equation to predict soil productivity for sugarbeet (*Beta vulgaris* L.) is described for Clay County, Minnesota. The equation contains percent clay and pH as the main effect regressors, plus percent clay squared, available water holding capacity times percent clay, and pH times electrical conductivity as the other significant regressors. The model is significant at $P<0.0001$ with a multiple coefficient of determination (R^2) equal to 0.63. Each regressor is significant for Type II sums of squares at $P<0.0035$. The model is useful for reclamation and restoration of agricultural lands suitable for the production of sugarbeets.

Additional Key words: Reclamation, farmland preservation, soil conservation, cropland planning

Agricultural soils often are disturbed by human activities such as surface mining, road construction, pipeline construction and related operations. There is great concern about restoring the agricultural productivity of disturbed soils and preserving the integrity of agricultural lands. Until recently, reliable quantitative methods to predict restoration effectiveness were unavailable. However, reclamation/restoration technology now has advanced so that it is possible to predict the suitability of soil profiles for various crops and woody plants.

Burley (1988) reviewed the historical development leading to the formulation of reclamation productivity models. In addition, Burley and Thomsen (1987) reported a methodology using U.S. Soil Conservation Service (SCS) soil data and SCS crop production data published in county soil surveys to develop an equation to predict soil productivity. The procedure employs a soil depth weighting factor described by Doll et al. (1984), multivariate techniques first described by Kendall (1939) to obtain a single vegetation growth score from more than one type of crop, and multiple regression to select the soil factors that best predict vegetation growth.

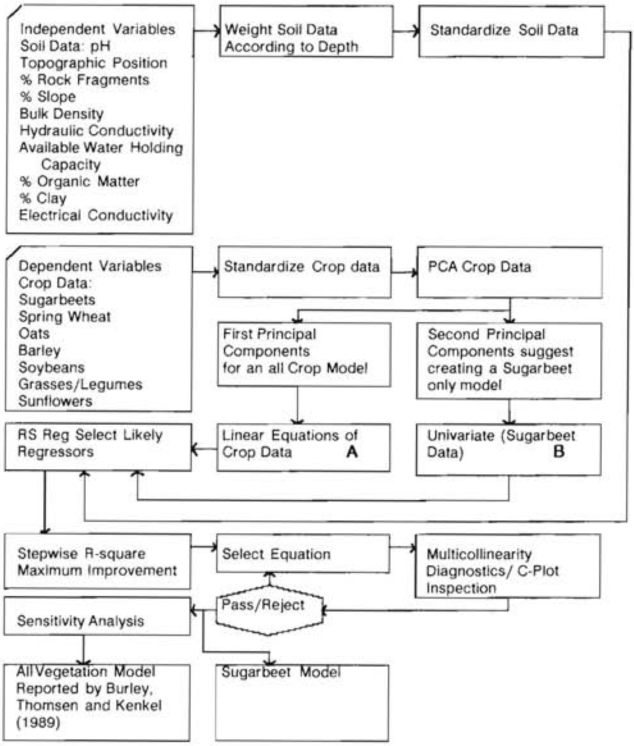
These soil productivity models are different from the growth models described by Lee (1983). Whereas growth models attempt to simulate plant biomass development, soil productivity models predict the suitability of the soil to support plant growth. Soil productivity models can predict the mean expected vegetation biomass for a particular soil, but do not predict plant growth for a year specific set of climatological data, real or simulated.

Burley, Thomsen and Kenkel (1989) developed an agricultural productivity model to reclaim Clay County, Minnesota soils for seven crops, and Burley (1991) reported a similar model that used the same seven crops plus woody trees and shrubs. One of the crops in both models was sugarbeet (*Beta vulgaris* L.) which responded in a highly predictable manner, similar to the other six crops and woody plants. However, the model described by Burley, Thomsen and Kenkel (1989) was based upon a principal component linear combination in which sugarbeet productivity appeared to be weighted less than the other crops (Table 1). The second principal component scores contained eigenvectors (all negative values except for sugarbeet) and an eigenvalue (proportion * 7=0.73) suggesting a strictly sugarbeet model could explain further variance in the data. Sugarbeet did not covary with the other crops as much as the other six crops (wheat, barley, oats, soybeans, sunflowers and grasses/legumes) covaried with each other. In other words, if a grower were interested strictly in sugarbeet production, the general models reported by Burley, Thomsen, and Kenkel (1989) or Burley (1991) might not be as useful as a model constructed only for predicting sugarbeet productivity. This paper describes the development of a sugarbeet productivity model.

Table 1. Principal Component Eigenvectors and Eigenvalues for a sugarbeet model.

	EIGENVALUE 1 PROPORTION	EIGENVALUE 2 PROPORTION
	0.814	0.104
CROP	PRIN1	PRIN2
Wheat	0.410	-.024
Barley	0.412	-.094
Oats	0.410	-.138
Sunflowers	0.377	-.159
Sugarbeets	0.238	0.965
Soybeans	0.394	-.100
Grasses/Legumes	0.374	-.068

Figure 1. A flowchart of the procedure used to generate a reclamation productivity model. Box A indicates the position where a PCA linear combination was used by Burley, Thomsen and Kenkel (1989). Box B indicates the point at which a single variable was used for a sugarbeet productivity model, in contrast to Box A.



METHOD

The approach to developing a sugarbeet productivity model was identical to that of Burley and Thomsen (1987) (Figure 1). Johnson and Wichern (1988) and Pielou (1984) describe in depth the multivariate procedures employed. Eighty soil units were employed in the study. Sugarbeet yields for each soil were gathered from approximately 10 years of trials (normal years, drought and seasonally wet years) conducted by the SCS [see Jacobson (1982) for a description of the climatological characteristics for the county]. These yields were combined to form an average expected yield.

The method attempts to find soil properties that significantly predict plant growth, in this case, the growth of sugarbeets. If a model is found, it generates a unitless value that indicates relative soil productivity. For this study, the relative sugarbeet productivity value is abbreviated as "SBP."

For each significant regressor in the SBP model, there will be a number of coefficients associated with the regressor. First, since all soil variables are standardized with a mean of 0 and a variance of one before entering the multiple regression process, each significant regressor has a set of values associated with it (equation 1).

Example Regressor = (0.339*(CL-22.84)/14.31) **EQUATION 1**
Where

0.339 = Slope coefficient selected by computer in multiple regression analysis
CL = Regressor variable, in this case % Clay
22.84 = Mean of % Clay for all 80 soils
14.31 = Variance of % Clay for all 80 soils

In other words, CLZ (the standardized value for % clay for a soil from the study area) is given by:

CLZ = (CL-22.84)/14.31 **EQUATION 2**

Therefore, each main effect regressor selected in the modeling process will have a coefficient for slope, mean and variance.

RESULTS AND DISCUSSION

Equation 3 and Table 2 illustrate the results of the regression analysis and the selection of the best model.

Table 2. Sugarbeet regression equation.

R-SQUARE=0.63 C(P)6.96

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	5	49.59	9.918	24.95	0.0001
ERROR	74	29.41	0.397		
TOTAL	79	79.00			

	B-VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-.432				
CLZ	0.339	0.0937	5.215	13.12	0.0005
PHZ	0.425	0.0769	12.160	30.60	0.0001
CLZCLZ	0.182	0.0604	3.611	9.09	0.0035
AWZCLZ	-.816	0.2333	4.904	12.34	0.0008
PHZECZ	0.363	0.0769	8.834	22.23	0.0001

Where:

CLZ = (CL-22.84)/14.31
PHZ = (PH-7.50)/0.43
CLZCLZ = (CL-22.84)*(CL-22.84)/14.31
AWZCLZ = ((AW-.0259)/0.69)*((CL-22.84)/14.31)
PHZECZ = (PH-7.50)/0.43)*((EC-2.53)/1.09)

$$\begin{aligned} SBP=&-0.342+(0.339*(CL-22.84)/14.31)\\ &+(0.425*(pH-7.50)/0.43)\\ &+(0.182*((CL-22.84)*(CL-22.84)/14.31)\\ &+(-0.816*((AW-.0259)/0.69)*((CL-22.84)/14.31))\\ &+(0.363*((pH-7.50)/0.43)*((EC-2.53)/1.09) \end{aligned}$$

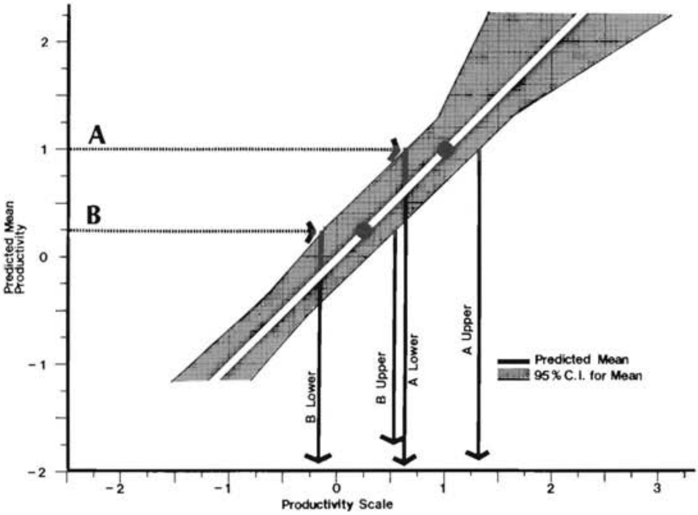
EQUATION 3

Where:
SBP=Sugarbeet Productivity (unitless)
CL=Percent Clay, by weight
pH=pH
AW=Available Water Holding Capacity, cm cm^{-1}
Ec=Electrical Conductivity, Mmhos cm^{-1}

The regressors identified in the model are substantiated by the traditional agronomic literature concerning the production of sugarbeets (Sugar Beet Research and Education Committee,1980; Vukov, 1977; McGinnis, 1971; Loomis, Ulrich and Terry, 1969; Great Western Sugar Company, 1951). This literature suggests that sugarbeets require ample moisture yet good aeration, can tolerate or even prefer higher pH values (6.7-7.5) than other crops, prefer abundant nutrients, and do not tolerate soil compaction. This means that sugarbeets can grow well upon clayey to clay/loam soils of the Red River Valley in Minnesota, provided that the soil is not excessively wet which prevents aeration.

The regression model suggests that the main effects of percent clay and pH are positively associated with increases in sugarbeet production. The squared term "percent clay times percent clay" also is positively associated with increases in sugarbeet production. In addition, the interaction term "pH times electrical conductivity" is positively associated with increases in sugarbeet productivity. However, the interaction term "available water holding capacity times percent clay" is negatively associated with increases in sugarbeet productivity. This means that as clay content increases, the water holding capacity of the soil must be reduced. However, tested methods to accomplish changes in the water holding capacity of the soil have not been described in the literature. Therefore, although the equation may suggest that such a meaningful relationship exists, the tools and techniques necessary to achieve a soil management objective may not yet exist. Nonetheless, most of the findings in the regression model and past literature are in fundamental agreement concerning the production of sugarbeets.

Figure 2. The 95% confidence limits surrounding the predicted sugarbeet productivity means and how to compare the productivity of two soil types at a 90% confidence level.



All other terms examined in the study (hydraulic conductivity, bulk density, topographic position, percent slope, percent rock fragments, percent organic matter, other squared terms and interaction terms) do not contribute to the predictive quality of the model, meaning that they are either ineffective or redundant.

Figure 2 illustrates the 95 percent confidence limits associated with the predicted mean (SBP) in the model. This figure can be used to generate visual multiple comparisons between predicted sugarbeet productivity means. The predicted means for each soil to be examined are generated by computing the productivity score given in Equation 3. Equation 4 illustrates the mathematical procedure to convert predicted productivity scores into average crop yield (tons/acre). Any negative score in equation 4 should be considered equal to zero productivity.

$$SB=5.52+(SBP*8.02) \qquad \textbf{EQUATION 4}$$

Where:

SBP=Sugarbeet productivity from Equation 1
SB=Predicted Sugarbeet productivity (tons/acre)
8.02=Variance of sugarbeet production on all 80 soils
5.52=Mean sugarbeet production on all 80 soils

Quantitative Soil Productivity Prediction

In Soil Surveys prepared by the Soil Conservation Service, soils within a series vary considerably. This SBP model provides an example of a quantitative soil productivity equation concerning the agronomic production of sugarbeets where actual measured site parameters can be used to predict sugarbeet production. This quantitative predictability can increase and focus the efforts to maximize average sugarbeet productivity, while minimizing the acreage planted to sugarbeets.

In addition, the model assists in the identification of prime sugarbeet production soils. These soils can be incorporated into county land-use plans to preserve prime sugarbeet soils and ensure an efficient and effective sugarbeet productivity future.

In landscapes where the soil has been highly disturbed, this model can be applied to assess quantitatively the productivity of the reclaimed soil for sugarbeets. The model can prescribe clay content and pH levels necessary for relative sugarbeet production. Even though the model is significant, only 63 per cent of the variance is explained by the model. Other potential regressors (such as soil nutrient levels and soil organisms) may require testing to improve the model.

This model is limited to producing sugarbeets under the present climatological regime and parent soil material found in Clay County, Minnesota; however, the procedures employed to develop the model can be used to develop sugarbeet productivity models for other producing regions of the United States and Canada.

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