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Predicting Forage Yields Using Properties of Illinois Soils, USA

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Abstract: An evaluation of 16 selected soil properties in relation to the established 1970s forage yields was performed by principal component analysis and multiple regression analysis. The predictive values of 16 selected physical and chemical soil properties were tested across 595 soils placed into two drainage groups. Properties reflecting the subsurface density and rooting ability of alfalfa (*Medicago sativa* L.) provided the greatest explanation of alfalfa yield variation on the well drained soils. Depth of the surface horizons and wetness factors had the highest correlation with grass-legume mixture yields on the poorly drained soils. The models explained approximately 50% of the 1970s yield variation in alfalfa yields and approximately 50% of the 1970s yield variation in grass-legume mixture yields. The forage yield trend calculated from farmer yields of 0.99Mg ha^{-1} was added to the 1970s predicted and established yields to obtain the 1990s predicted and established yields. Current 1990s yields were estimated using the equation produced by the regression of 1970s basic management level productivity index (PI) and Farm Business Farm Management (FBFM) farmer-reported forage yields. This provided another method to check the model's predicted yields against farmer-reported (FBFM) yields. Composite forage estimates were obtained from the mean of the 1990s predicted yields, 1990s established yields, and the farmer reported (FBFM) yields.

Key words: Forage yield, alfaalfa, grass-legume, rooting ability, FBFM

Introduction

Illinois is one of the leading states in terms of agricultural productivity in USA. Illinois has deep, nutrient-rich soils, a favorable climate, and suitable topography for crop and forage production. The 1997 National Resources Inventory (NRI) reported Illinois with 8,458,700 hectares of prime farmland. These acres account for 66% of the total non-federal rural land. Illinois also reported to have 994,100 hectares of hay and pastureland (7% of the total non-federal rural land).

Even within such an agriculturally rich state, there are considerable variations in climate and formation of soils used in forage production. Northern Illinois experienced four glacial events, which rejuvenated the soils and created the level topography. Southern Illinois soils have been exposed to more weathering and the original rolling topography remains. Climate varies from north to south. Differences in soil productivity are functions of climate variability, differing parent materials, and soil management.

Crop and forage yields are the result of climate, soil properties, and management. Climatic conditions can rarely be controlled. However, management practices are constantly changing. Lindstrom *et al.* (1992) found management practices which change available water capacity, bulk density, or pH of the surface horizons also tend to affect productivity index (PI) values. Climate, soil properties, and management are highly correlated and the actual relationships are the subjects of many scientific studies. Soil conditions, including physical and chemical properties, are important for crop and forage yield prediction (Olson, 1981).

As the surface layers of the soil are removed through erosion, productivity of the soil declines if the subsoil is not favorable to crop growth (Pierce *et al.*, 1983). Profile erosion results in crop and forage yield being the function of subsoil properties in addition to management (Craft *et al.*, 1992). When the thickness of the topsoil is diminished, yields are more associated with subsoil characteristics (Shrader *et al.*, 1960).

Accurate and reliable forage yield information is needed for each soil type found in Illinois for accurate land appraisal, tax assessment, chemical and fertilizer inputs, farm management decisions, government regulations and incentive programs, land investment, mining, and farmland preservation. Most of the forage productivity information currently used in Illinois is from Cooperative Extension Circular 1016 "Productivity of Illinois Soils" (Odell and Oschwald, 1970). Much of the data used to create Circular 1016 was collected during 1933 through 1950 from county farm records and research plots from Agronomy Research Centers. Circular 1156 "Soil Productivity in Illinois" (Fehrenbacher *et al.*, 1978) adjusted the previous data for improvements in technology. A supplement to Circular 1156 contained crop yields under 1970s management for soils established from 1978 through 1994 (Olson and Lang, 1994). There is a need for accurate and current forage yield estimates for alfalfa and grass-legume mixtures for all Illinois soils. It is anticipated that 1990s forage yields and soil productivity data will be provided for wise land-use planning, sustainable farm management, tax assessment, input rates, and land appraisal.

The primary objectives of this study were to: (I) establish the relationships between soil properties and 1970s forage yields, (ii) determine the effect of technology and crop management on forage yield trends since the 1970s and (iii) to develop and test a method to predict the 1990s forage yield estimates for all Illinois soils.

Materials and Methods

The following procedures were used to achieve the study objectives: (I) to place all Illinois soils into two drainage groups (well drained soils for alfalfa (*Medicago sativa* L.) and poorly drained soils for grass-legume mixtures), (ii) to develop a model using various soil properties to predict 1970s hay yields for all soil types and complexes in Illinois, (iii) to assess the accuracy of the model predicted results by comparing with 1970s established yields published in Circular 1156, (iv) to determine the projected magnitude of hay yield change from 1976 to 1998 for both drainage groups, (v) to obtain the 1990s forage yields by increasing the predicted and established 1970s yields by the projected magnitude of 22-years of yield change, (vi) to determine the relationship between 1970s basic management level productivity index (PI) and 1990s farmer reported (Farm Business Farm Management) forage yields, and (vii) to average the forage yields from three sources to predict the 1990s forage yields for all Illinois soil types.

Drainage group selection: Since alfalfa does not perform well in poorly drained soil situations, all soil types in Illinois were placed into one of two drainage groups. It is assumed that a better-adapted legume and grass will be grown in the poorly drained sites. The poorly drained group was used to develop the grass-legume mixture model. The well drained group was used to develop the alfalfa model. Redoximorphic (wetness) features, such as gray (low chroma mottles or accumulations of Fe-Mn oxides) are a fairly accurate field indicator of drainage. Therefore, soils were placed into groups based on the depth to redoximorphic features. Poorly drained soils were those with redoximoprhic features above 56 cm in the soil profile. Well drained soils contained redoximorphic features at or below a 56 cm depth. Some soils were also placed in the poorly drained group on the basis of the drainage classification of the official soil series. Soils with drainage classifications of somewhat poor or wetter were moved into the poorly drained group even if evidence of redoximorphic features was not evident until deeper in the soil profile. Complexes that contained both well drained and poorly drained soils were placed into the poorly drained group on the basis that any amount of poorly drained soil would affect the yield of alfalfa and would accordingly be planted to a different forage crop.

Soil property selection: The great multitude of soil parameters and combinations thereof would result in an incomprehensible list of variables to use in yield prediction equations. Variables were chosen on their relevance to hay yields to climatic and morphological (edaphic) conditions of Illinois. A long list of soil properties was reduced to 16 soil properties that had previoulsy been shown in the agronomic literature (including previously cited references) to affect forage yields. These sixteen physical and chemical soil properties, which may significantly affect forage yield data were identified in Table 1. Property values for each soil type were obtained from United States Department of Agriculture, Natural Resource Conservation Service (USDA, NRCS), Soil Interpretation Records (Form 5) for all Illinois soils series. Most of the data were compiled from soil surveys over several locations and laboratory analyses of many samples (including the Illinois soil characterization database of 2160 pedons). Hence, each soil characteristic has a range of values. A mean was estimated from such a range.

Table 1: Soil properties used to predict forage yield prediction models

Soil properties	Symbol
Thickness of the A and E horizons (cm)	Thick AE
Silt in the A and E horizons (%)	Silt AE
Organic matter in the A and E horizons (%)	OM AE
Cation exchange capacity (CEC) of the A and E horizons (cmole/Kg)	CEC
Depth to redoximorphic features (cm)	Redox
Thickness of the B horizon (cm)	Thick B
Plant available water holding capacity (cm) to a depth of 150 cm	H_2O
Rooting depth (cm)	Root Depth
Depth to second parent material (cm)	2PM
Permeability (cm/hr)	Perm
pH of the A and E horizons	AEpH
pH of the B horizons	BpH
Bulk density of the A and E horizons (g/cc)	DbAE
Bulk density of the B horizon (g/cc)	DbB
Exchangeable sodium	Na
Percent clay in the B horizon	Clay

Principal component analysis (PCA) was used to reduce the number of variables by creating artificial variables, or principal components, that accounted for a great amount of the variance. The principal components evaluate the correlation between variables and eliminate redundancy. For example, CEC is related to the organic matter present. High CEC and a high organic matter percent are both favorable for high forage yields. Therefore, these two variables would be placed in the same principal component. A principal component is "a linear combination of optimally-weighted observed variables" (Hatcher and Stepanski, 1994). In each forage yield model, the soil series received scores for each component. The series score for each individual variable was optimally weighted and then summed to result in the component score. The component scores are only a scale-number of the variables used in the component; they are not the actual values of forage yield.

Below is the equation to determine the scores for the first component created in a principal component analysis:

$C_1 = b_{11}(X_1) + b_{12}(X_2) + \ldots b_{1p}(X_p)$ ------------ (Equation 1)

Where:

C_1 = the series' score on principal component 1 (the first component extracted)

b_{1p} = the regression coefficient for observed variable p, as used in creating principal component 1

X_p = the series' score on observed variable p

The regression weights were determined through the Statistical Analysis System (SAS) PROC FACTOR procedure (SAS, 1994). An eigen equation produced the weights which for this set of data no other set of weighted values could create the components that accounted for the greatest amount of variance in the observed variables.

The first component extracted accounts for the greatest amount of total variance in the observed variables. In a highly correlated data set, the first component contains several correlated variables. The second component will account for the maximal amount of variance that is not already accounted for by the first component. The second component will contain observed variables that do not exhibit a strong correlation with the variables of the first component. The remaining components also account for the maximal amount of variance not already accounted for by the preceding components. Subsequent components are also not correlated with any of the preceding components.

Variables that account for the greatest amount of variance in the component are called loading variables. Variables loading on more than one component are dropped from the final component interpretation because that variable is not a pure measure of one construct.

Multiple regression analysis: Multiple regression analysis was used to provide estimates between the artificial variables created by principal component analysis and forage yields. Multiple regression is a method of relating two or more independent variables to the dependent variable. All computations were performed using the following model:

$Y_1 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i + \epsilon_j$ -------- (Equation 2)

Where:

Y_1 = dependent variable

$X_1, X_2 \ldots X_i$ = independent variables

$\beta_0, \beta_1 \ldots \beta_i$ = regression coefficients

ϵ_j = error

In this particular model, Y is the predicted forage yield. β represents the regression coefficients of the independent variables, in this case, the principal components. ϵ_j is the error term due to the fact that the independent variables do not completely account for all the variation in Y.

Multicollinearity is a high degree of correlation among several "independent" variables. Multicollinearity is one of the main problems associated with multiple regression analysis. However, principal component analysis, particularly PCA with oblique rotations, drastically reduces the possibility of correlations between the principal components, which are the independent variables in the multiple regression models.

Variable selection: Several methods are available for variable selection in the SELECTION = option in the MODEL statement of PROC REG in SAS (SAS, 1994). MAXR selection was chosen so as to include all the principal components. MAXR finds the one-variable regression with highest R^2, then the two-variable regression with the highest R^2, and so on until all the variables are included in the regression equation.

Hay yield trends in Illinois: Regression techniques were used to evaluate the relationship between years and yields of alfalfa and grass-legume mixtures as reported in the Illinois Agricultural Statistics Service (Illinois Agricultural Staff, 1945 to 1999). Data from the years 1976 to 1999 were analyzed. Yield trends were measured through the least squares method that used the following yield trend equation:

$Y = a + bx$ ------------------ (Equation 3)

Where:
Y = predicted value of Y based on the selected year
a = estimated value of Y where $x = 0$
b = average change in Y for each change in year

The direct method, where the point of origin is the initial year, was used to compute the equation for the linear trend line (Pachett, 1982). The trend will give the annual yield increase accounting for the effects of weather and technology.

Analysis of farm records: Approximately 5,000 farms from every county in Illinois participate in the Farm Business Farm Management (FBFM) association of Illinois (Rejesus and Hornbaker, 1999). FBFM is designed to assist producers with management decisions and provides help with farm record- keeping and analysis. The Farm and Resource Management Laboratory (FaRM Lab) developed an alternative analysis of yield trends and productivity based on the data in FBFM records. This analysis provided a method of checking the model yields against actual recorded data. The linear relationship between basic PI (Fehrenbacher *et al.*, 1978) and forage yield provided a method of obtaining current forage yields.

The FaRM Lab analysis used farm records from approximately 5,000 of the farms in state during the period 1976 to 1995. Approximately 1,300 of those farms reported forage yield data. During the given time period, not all farms reported production information every year. However, the intent was to analyze the regional and county trends, not individual farm trends.

A linear relationship was determined between basic management level productivity indices (PIs) and FBFM reported hay yields (1988-1997). This regression was run to determine if the highest forage yields were obtained from the soils with the highest PIs. This regression was run on both drainage classes, and a significant relationship was found in both classes. A current forage yield was generated through these linear regression yield equations.

The yield equation generated from FBFM records resulted in negative alfalfa yields for soils with basic PIs of 50 or lower. It is assumed that alfalfa is generally not grown on soils with low PIs. All soils, regardless of drainage group, with PIs lower than 55 were rated for grass-legume mixtures. Complexes that contained a soil rated for a grass-legume mixture were also rated for grass-legume mixtures.

Estimation of final 1990s hay yields: The 1970s model predicted and established (Circular 1156) yields were increased by the appropriate 22-year yield trend in order to obtain the 1990s estimated yields. The linear relationship between basic management level PIs and FBFM reported hay yields (1988-1997) was used to estimate the 1990s yields for all soil types. PROC ANOVA was then used to compare the predicted, established, and reported yields.

A Pearson correlation analysis was used to determine the relations between the soil properties and forage yield.

An observation outside the range of the rest of observations of a data set is known as an outlier. A quantitative value for detecting outliers is the studentized residual that was obtained by dividing the residual by their standard error. The residual were estimated from the following equation (SAS Institute, Inc., 1994):

Studentized residual = $(y_i - \mu\, {}^{Y}/_{x})/\sqrt{\ }\ \mathrm{MSE}\ (1 - h_i)$ ----- (Equation 4)

Where: h_i is the ith diagonal element of the matrix $[X(X'X)^{-1}X']$

Trends were determined from the 10-year moving average from 1978 to 1999.

A high correlation between basic management level productivity index (PI) and Farm Business Farm Management (FBFM) reported yields was established. The FBFM database contains the records of approximately 5,000 farms (Rejesus and Hornbaker, 1999). Forage yield data was collected from approximately 1,300 farms across the state of Illinois.

Results and Discussion

The mean and standard deviation (SD) for soil properties and forage yields at an average level of management on the well drained soils are provided in Table 2. Table 3 contains the simple statistics of the poorly drained soils. The mean and SD for soil properties and forage yields at an average level of management on the poorly drained soils are shown in Table 3. As one would expect the depth to redoximorphic features was much greater for the well drained soils. The organic matter and clay content were higher for the poorly drained soils. The average hay yield was slightly higher for the poorly drained soils.

Simple correlation coefficients between the paired soil factors and forage yield are presented in Tables 4 (well drained soils) and 5 (poorly drained soils). In correlation analysis, the ideal situation is for each predictor variable to be significantly correlated with dependent variable and for the predictor variables not to be correlated with each other. In this study, nearly all variables were correlated to some degree. The correlation analysis assists in determining the accuracy of the component groupings. Correlation coefficients between each principal components and forage yield for both well drained soils and poorly drained soils are shown in Tables 6 and 7, respectively.

Five components were selected for the well drained soils (Hadley, 2000). Factor 1, the soil texture component, was explained by silt percentage in the A and E horizons, permeability of the B horizon, bulk density of the A and E horizons, and percentage clay in the B horizon. Factor 2, the B horizon density and rooting component, was explained by the rooting depth, depth to second parent material, and bulk density of the B horizon. Factor 3, soil pH, was best explained by the A and E horizon pH and the B horizon pH. Factor 4, the surface thickness and organic matter component, was explained through the thickness of the A and E horizons and the percent organic matter found in the A and E horizons. Factor 5, exchangeable sodium, was only explained by the exchangeable sodium soil variable.

Six components were selected for the poorly drained soils (Hadley, 2000). Factor 1, the surface fertility and exchange component, was best described by organic matter, cation exchange capacity, and pH of the A and E horizons. Factor 2, the B horizon density and rooting component, was explained through depth to second parent material and bulk density of the B horizon. Factor 3, surface texture and density, was explained by the A and E horizons silt content and bulk density. Factor 4, B horizon thickness, was the only variable loading on the B horizon thickness component. Factor 5, the surface depth and redoximorphic features component, was explained though the thickness of the A and E horizons and the depth to redoximorphic features. Factor 6, exchangeable sodium, was explained only through exchangeable sodium.

Variables that loaded on more than one component for the well drained soils were: CEC, thickness of the B horizon, and plant available water. Variables loading on more than one component for the poorly drained soils were: plant available water, rooting depth, permeability of the B horizon, pH of the B horizon, and percent clay in the B horizon.

The eigenvectors, or regression coefficients, used to derive each principal component of the well drained soils are found in Table 8. Table 9 contains the eigenvectors used to derive the principal components of the poorly drained soils. Loading variables are those with eigenvectors greater than 0.40.

Table 2: Simple statistics for response and predictor variables for 328 well drained soils.

Variables	Mean	Std. Dev.	Range	CV (%)
Thickness of the A & E horizons (cm)	30.0	17.0	0-132	56
Silt in the A & E horizons (%)	54.0	20.0	2-89	37
Organic matter in the A & E horizons (%)	2.4	1.0	0.5-6.0	10
Cation exchange capacity (cmole/kg)	16.5	6.7	2-75	41
Depth to redoximorphic features (cm)	125.0	36.0	56-150	29
Thickness of the B horizon (cm)	79.0	36.0	0-150	45
Available water to 60 inches (cm)	22.0	7.0	2-34	32
Rooting depth (cm)	106.0	36.0	15-150	34
Depth to second parent material (cm)	108.0	44.0	13-150	41
Permeability of the B horizon (cm/hr)	5.6	8.6	0.1-51	154
pH of the A & E horizons	6.4	0.5	4.6-8.2	8
pH of the B horizon	6.3	0.9	0-8.2	14
Bulk density of the A & E horizons (g/cc)	1.4	0.1	1.15-1.68	8
Bulk density of the B horizons (g/cc)	1.6	0.2	1.2-2.6	14
Exchangeable sodium (%)	0.1	1.2	0-14.5	1046
Clay of B horizon (%)	27.0	11.0	0-63	39
Average hay yield (mt ha^{-1})	7.6	2.1	2.8-11.2	26

Table 3: Simple statistics for response and predictor variables for 265 poorly drained soils.

Variables	Mean	Std. Dev.	Range	CV (%)
Thickness of the A & E horizons (cm)	35.0	14.0	0-97	40
Silt in the A & E horizons (%)	56.0	16.0	8-84	28
Organic matter in the A & E horizons (%)	3.4	1.6	0.8-10	46
Cation exchange capacity (cmole/kg)	21.0	8.0	4-60	35
Depth to redoximorphic features (cm)	30.0	17.0	0-109	56
Thickness of the B horizon (cm)	78.0	30.0	0-142	39
Available water to 60 inches (cm)	25.0	5.0	5-34	22
Rooting depth (cm)	112.0	28.0	20-150	25
Depth to second parent material (cm)	117.0	40.0	20-150	34
Permeability of the B horizon (cm/hr)	3.3	6.1	0.1-51	181
pH of the A & E horizons	6.5	0.5	5.0-7.9	7
pH of the B horizon	6.5	0.9	0-8.2	14
Bulk density of the A & E horizons (g/cc)	1.3	0.1	1.15-1.60	7
Bulk density of the B horizons (g/cc)	1.5	0.2	1.20-2.65	10
Exchangeable sodium (%)	0.3	1.9	0-22	666
Clay of B horizon (%)	32	11.0	0-68	35
Average hay yield (mt ha^{-1})	8.3	1.8	2.0-11.4	21

Table 4: Simple correlation coefficients among hay yield and soil variables for well drained soils in Illinois

	Thick AE	Silt AE	OMAE	CEC	Redox	Thick	H_2O	Root kB	2PM	Perm	AEpH	BpH	DbAE	DbB	Na	Clay
Thick AE#	1.00*															
SiltAE	-0.12	1.00														
OMAC	0.32	0.16	1.00													
CEC	0.07	0.30	0.45	1.00												
Redox	-0.05	-0.19	-0.05	-0.24	1.00											
ThickB	-0.15	0.30	-0.02	0.01	-0.01	1.00										
H_2O	0.17	0.55	0.18	0.18	-0.16	0.41	1.00									
Root Depth	0.32	0.16	0.01	0.01	-0.05	0.55	0.50	1.00								
2Pm	0.22	-0.01	-0.06	-0.06	-0.01	0.07	0.37	0.30	1.00							
Perm	0.20	-0.57	-0.15	-0.32	0.21	-0.14	-0.36	0.01	0.11	1.00						
AepH	0.01	-0.05	0.09	0.06	0.05	-0.36	0.09	-0.21	0.10	0.04	1.00					
BpH	0.03	-0.09	0.16	0.06	-0.02	-0.27	0.08	-0.13	0.09	-0.01	0.57	1.00				
DbAE	0.02	-0.52	-0.33	-0.31	0.21	-0.16	-0.35	-0.12	0.03	0.36	-0.05	-0.08	1.00			
DbB	-0.16	-0.19	-0.05	-0.02	0.04	-0.26	-0.62	-0.41	-0.46	0.04	-0.05	-0.02	0.28	1.00		
Na	-0.04	0.03	-0.04	0.00	-0.05	0.04	-0.07	0.03	0.05	-0.06	-0.04	0.13	0.05	0.03	1.00	
Clay	-0.17	0.43	0.18	0.39	-0.22	0.21	0.07	0.05	-0.28	-0.58	-0.19	0.00	-0.31	0.21	0.05	1.00
Hay	0.22	0.38	0.46	0.24	-0.07	0.25	0.72	0.41	0.12	-0.25	0.13	0.19	-0.34	-0.40	-0.13	0.10

* p-values > 0.11 and .13 significant at 5% and 1% levels, respectively   # Symbols are defined in Table 1

Regression analysis of Circular 1156 forage yields: Regression models of the principal components were used to determine the predicted forage yields. The MAXR selection was used to obtain the minimum error sum of squares, or the maximum R^2. The equation that produced the best fit for each drainage group is presented in Table 10. The thickness of the B horizon component in the poorly drained equation had a regression coefficient of 0.00006, and was therefore dropped from the poorly drained soils equation. Both equations explained approximately 50 % of the yield variation.

The B horizon density and rooting component contributed the greatest partial R^2 (0.26) to the equation for the well drained soils. The surface depth and redox factors contributed 31 % of the variation in the poorly drained model.

Estimated forage yields using soil property models produced high R^2 values when compared to yield estimated found in Circular

Table 5: Simple correlation coefficients among hay yield and soil variables for poorly drained soils in Illinois.

	Thck AE	Silt AE	OMAE	CEC	Redox	Thc kB	H_2O	Root	2PM	Perm	AEpH	BpH	DbAE	DbB	Na	Clay
ThickAE#	1.00*															
SiltAE	0.08	1.00														
OMAE	0.39	-0.27	1.00													
CEC	0.24	-0.08	0.68	1.00												
Redox	0.34	0.11	0.13	-0.02	1.00											
ThickB	-0.14	0.26	-0.18	-0.03	0.10	1.00										
H_2O	0.19	0.49	-0.03	-0.06	0.18	0.11	1.00									
Root depth	0.23	0.15	0.01	0.06	0.17	0.41	0.35	1.00								
2PM	0.17	0.00	0.00	0.01	0.01	-0.04	0.28	0.26	1.00							
Perm	-0.02	-0.40	0.06	-0.18	0.13	-0.07	-0.21	-0.02	-0.02	1.00						
AepH	0.13	-0.23	0.46	0.34	-0.01	-0.24	0.04	0.03	0.12	-0.01	1.00					
BpH	0.05	-0.17	0.42	0.30	0.05	-0.08	0.05	0.08	0.08	-0.03	0.57	1.00				
DbAE	-0.14	-0.40	-0.21	-0.28	-0.11	-0.03	-0.23	-0.05	0.07	0.18	-0.06	-0.07	1.00			
DbB	-0.13	-0.27	0.02	-0.04	-0.03	-0.06	-0.54	-0.29	-0.36	0.19	-0.07	-0.21	0.24	1.00		
Na	-0.10	0.06	-0.10	-0.05	-0.05	0.21	-0.12	0.00	0.02	-0.08	0.00	0.20	0.08	0.05	1.00	
Clay	-0.04	0.23	-0.05	0.37	-0.24	0.32	-0.10	0.17	-0.06	-0.46	-0.14	0.00	-0.12	-0.13	0.02	1.00
Hay	0.29	0.15	0.31	0.11	0.48	0.02	0.51	0.31	0.09	0.07	0.16	0.27	-0.22	-0.30	-0.25	-0.27

Symbols are defined in Table 1   * p-values $>$ 0.12 and 0.16 significant at the 5% and 1% levels, respectively

Table 6: Simple correlation coefficients among hay yield and soil property factors for well drained soils.

	Soil Texture	B horizon density & rooting	Soil pH	Surface thickness & OM	Exchangeablesodium
Soil Texture	1.00*				
B Horizon Density & Rooting	0.06	1.00			
Soil pH	-0.08	-0.09	1.00		
Surface Thickness & OM	0.07	0.09	0.02	1.00	
Exchangeable Sodium	-0.06	-0.03	-0.09	0.00	1.00
Alfalfa Hay Yield	0.38	0.50	0.05	0.36	-0.19

* p-values $>$ 0.09 significant at the 10% level

Table 7: Simple correlation coefficients among hay yield and soil property factors for poorly drained soils.

	Surface fertility & exchange	B horizon density & rooting	Surface texture & density	B horizon thickness	Surface depth & redox	Exchangeable sodium
Surface Fertility & Exchange	1.00*					
B Horizon Density & Rooting	0.15	1.00				
Surface Texture & Density	0.04	0.14	1.00			
B Horizon Thickness	-0.03	-0.02	0.31	1.00		
Surface Depth & Redox	-0.01	0.22	-0.03	-0.12	1.00	
Exchangeable Sodium	-0.05	0.11	-0.19	-0.22	-0.02	1.00
Grass-legume Hay Yield	0.25	0.43	0.24	-0.01	0.55	-0.05

* p-values $>$ 0.07 significant at the 10% level

Table 8: Eigenvectors of principal components of well drained soils in Illinois

	Soil texture	B horizon density & rooting	Soil pH	Surface thickness & OM	Exchangeable sodium
AEThck#	-0.38	0.20	-0.07	0.74	0.04
AE silt	0.78	0.26	-0.06	-0.09	-0.02
OM	0.26	-0.09	0.10	0.77	-0.12
CEC	0.54	-0.16	0.09	0.45	0.07
Redox	-0.35	0.02	0.00	0.00	-0.38
Bthck	0.25	0.43	-0.55	-0.12	0.04
H_2O	0.40	0.78	0.06	0.02	-0.06
Root	-0.03	0.63	-0.40	0.27	0.13
PM2	-0.25	0.71	0.18	-0.07	0.15
Perm	-0.81	0.01	-0.04	0.13	-0.10
AepH	0.02	0.12	0.86	-0.03	-0.07
BpH	0.08	0.10	0.82	0.08	0.24
AEDb	-0.64	-0.19	-0.13	-0.16	0.16
Bdb	-0.02	-0.82	-0.07	0.03	0.11
Na	0.04	0.04	0.11	-0.05	0.89
Clay	0.74	-0.30	-0.18	0.07	0.18

#Symbols are defined in Table 1

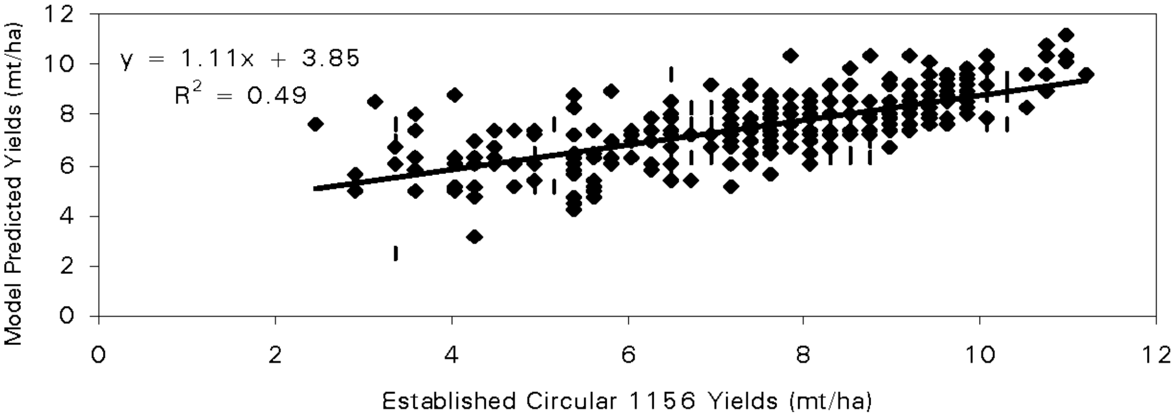

Fig. 1: Relationship between 1970s established Circular 1156 and model predicted hay yields of alfalfa on well drained soils of Illinois.

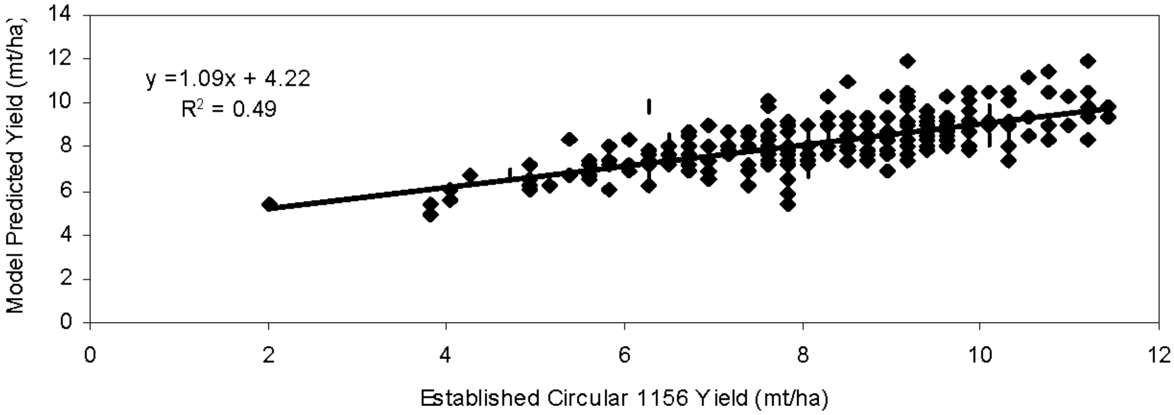

Fig. 2: Relationship between 1970s established Circular 1156 and model predicted hay yields of grass-legume mixtures on poorly drained soils of Illinois

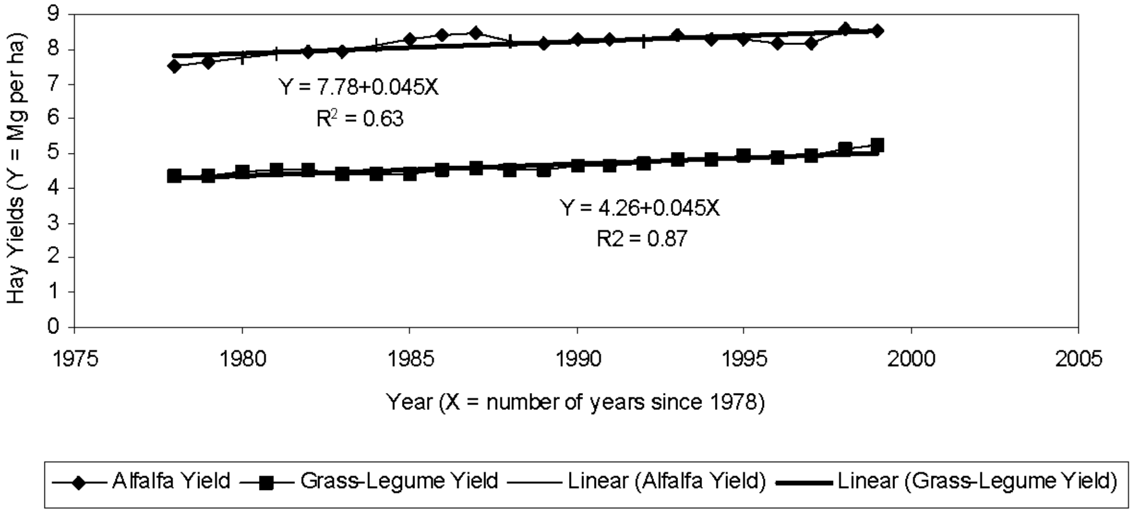

Fig. 3: The 10-years moving average yield trend of alfalfa and grass-legume mixtures on well and poorly drained soils in Illinois.

Table 9: Eigenvectors of principal components of poorly drained soils in Illinois.

	Surface fertility & exchange	B horizon & rooting	Density & density	Surface texture thickness	B horizon & redox	Surface depth sodium
AEThck#	0.37	0.15	0.11	0.03	0.51	-0.27
AE silt	-0.27	0.08	0.84	0.04	0.04	0.07
OM	0.88	-0.14	-0.04	-0.07	0.23	-0.03
CEC	0.86	-0.12	0.09	0.16	-0.10	-0.10
Redox	0.12	-0.05	0.17	0.19	0.80	0.03
Bthck	-0.14	-0.06	-0.01	0.88	0.07	0.31
H_2O	-0.15	0.63	0.45	-0.04	0.18	-0.04
Root	0.07	0.46	-0.20	0.74	0.21	0.01
PM2	-0.03	0.82	-0.26	0.08	-0.07	-0.12
Perm	-0.08	-0.15	-0.56	0.01	0.52	-0.02
AepH	0.62	0.20	-0.08	-0.27	-0.04	0.30
BpH	0.59	0.18	-0.02	-0.04	-0.04	0.59
AEDb	-0.26	0.14	-0.75	0.13	-0.17	-0.03
Bdb	0.01	-0.74	-0.27	-0.02	0.10	0.00
Na	-0.03	-0.12	0.10	0.28	0.01	0.85
Clay	0.22	-0.02	0.15	0.50	-0.57	-0.13

Symbols are defined in Table 1

Table 10: Regression model for forage yield in mt ha^{-1}.

Well Drained Soils:	Yw = 7.59 + 0.63 (soil texture) + 0.35 (B horizon density and rooting) + 0.20 (soil pH) + 0.22 (surface thickness & OM) - 0.2 9 (exchangeable sodium) #
Poorly Drained Soils:	Yp = *8.24 + 0.36 (surface fertility and exchange) + 0.18 (B horizon density and rooting) + 0.34 (surface texture and density) + 0.34 (surface depth and redox) – 0.045 (exchangeable sodium) #

= Yw equals the alfalfa yields in mt ha^{-1}, * Yp equals the grass-legume yields in mt ha^{-1}.

1156 (Figs. 1 and 2). The models explained approximately 50 percent of the yield variation in both the well drained and the poorly drained soils.

The residual and studentized residual values were obtained with PROC REG in SAS.

The forage yields obtained from the prediction models were evaluated with a student residual limit of 2.0 to identify outliers. Less than one percent (3 of 328) of the observations for well drained soils had values greater than the established limit. No outliers were observed in the poorly drained soils. Organic soils (composed of decomposed plant materials) were not included in model development because a previous study (Garcia-Paredes *et al.*, 2000) determined these soils to be outliers. In addition, these soils were eliminated from any model testing.

Forage yield trends in Illinois: Forage yields in Illinois have increased significantly from 1978 to 1999. Swanson *et al.* (1977), as cited by Garcia-Paredes *et al.* (2000), stated that the increased yields are probably a result of advanced technology. Technology is considered to include: (I) biological and chemical inputs such as improved cultivars, mineral fertilizers, and pesticides; (ii) mechanical resources; and (iii) such as management. The upward trend in yields is also accompanied by annual fluctuations due to weather conditions.

A relationship of forage yield versus time (years) was established using regression analysis. Yield response trends were determined for well drained soils and poorly drained soils (Fig. 3). Simple linear trends give the annual yield increase considering both the effects of technology used by farmers and weather they experienced. Alfalfa yields were more significantly impacted by weather and management than the grass-legume yields which is reflected in the lower standard deviation of the grass-legume yield trend line (Fig. 3). This is believed to be the result of compensation/complementarily relationship between a grass and legume in a mixed stand. If weather conditions are poor for one of the species in the mix, then the other species can take advantage of an open niche and perform well; therefore, the yields fluctuations were buffered. Also, legumes other than alfalfa were used.

Comparison of the 1990s forage yields: The yield trend equations, generated from a 22-year time period from 1978 to 1999, were used to estimate the yield data for the 1990s for each soil type. The hay yields for both alfalfa and grass-legume mixtures increased at a rate of 0.045 Mg per ha per year. Therefore, the hay yields have increased 0.99 Mg per ha per year since 1978. The 1990s yield was obtained by adding the yield trend to the 1970s yields. A comparison was then made between the 10-year rolling averages for the 1990s as reported by FBFM and the 1990s established and 1990s predicted yields.

Determining relationships between PI and yield: The linear relationship between yields and basic PIs is expressed for alfalfa and grass legume mixtures by the following equations: Y = 0.325 X - 16.29 (R^2 = 0.97) and Y = 0.25 X - 5.99 (R^2 = 0.70), respectively. Another set of 1990s yields was obtained using the equations generated in the FBFM regression. This set of yields was used with the 1990s predicted and established yields in determining the final mean forage yield.

The 1990s predicted and established yields were statistically similar, while the FBFM yield was much lower in the well drained group. The mean predicted yield was 9.0 Mg per ha, the mean established yield was 9.4 Mg per ha, and the mean FBFM yield was 6.9 Mg per ha. The mean yields in the poorly drained group were all statistically different. However, FBFM yields were much lower than the 1990s predicted and established yields in the well drained group. The mean of the model predicted yields was 8.5, the mean of the established yields was 8.1, and the FBFM mean yield was 7.4.

FBFM yields were lower in both drainage groups. The reported forage yields are for the farm's calculated basic PI. Forages tend to be grown on the lowest PI soils on the farm, but the recorded PI is the average basic PI of the farm. Therefore, the forage yields actually reflect the lowest PI soils of the farm.

Determining mean 1990s forage yields: Mean 1990s forage yields were determined from the average of the 1990s predicted yields, the 1990s established yields, and the FBFM yields. Standard deviations of yield ranged from 0.38 to 4.57 Mg per ha in the soils rated for alfalfa. Forty percent (109 soils out of 269 soils) had standard deviations equal to or greater than 2.2 Mg per ha. One soil had a standard deviation equal to or greater than 4.5 Mg per ha. The standard deviations in the soils rated for the grass-legume mixtures ranged from 0.00 to 3.49. Two percent (11 soils out of 481 soils) had standard deviations equal to or greater than 2.2 Mg per ha.

The standard deviations of the grass-legume mixture were less severe than the standard deviations of alfalfa. There was much less alfalfa data available through FBFM from which to develop the basic PI forage yield equation. The three yield sources showed more variation in alfalfa yields than in the grass-legume mixture yields. The 1990s model predicted yields, 1990s established yields, and the FBFM yields were averaged for each soil to obtain the final hay yield estimates. Farmer reported hay yields were consistently lower than what the model and the established yields. Properties reflecting the subsurface density and rooting ability of alfalfa (well drained soils) had the highest correlation with yields on the well drained soils. Depth of the surface horizons and wetness factors provided the greatest explanation of yield variation on the poorly drained soils where yields were predicted for grass-legume mixtures. The models explained approximately 50 % of the 1970s yield variation in alfalfa on well drained mineral soils and approximately 50 % of the 1970s yield variation in grass-legume mixtures on poorly drained mineral soils. The yield trend of 0.99 Mg per ha per year was added to the 1970s predicted and established yields to obtain the 1990s established and predicted yields. Current 1990s yields were also obtained through the equation produced by the regression of the established 1970s basic management level productivity index (PI) and FBFM farmer-reported forage yield. Composite forage estimates were obtained from the average of the 1990s predicted, established, and farmer reported (FBFM) yields.

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