Relationship of Tree Survival and Yield to Coal-Spoil Characteristics

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SUMMARY

A study was made of the relationships between 7- to 8-year survival and yield of two broadleaved and five coniferous species and a number of selected chemical characteristics of Iowa coal-spoil materials.

The objectives were: (1) to determine if survival and yield of these tree species are related to the chemical characteristics of the spoils, (2) to identify those spoil chemicals most closely related to survival and yield of each of the tree species tested and (3) to provide this information to permit formulation of hypotheses for future controlled experiments.

Species investigated were green ash, cottonwood, eastern redcedar, pitch pine, jack pine, red pine and Virginia pine. Surface samples of spoil material were analyzed for pH, exchangeable Al, exchangeable and soluble bases. nitrifiable N, cation exchange capacity, soluble salt concentration, available P and available K. Slope position was included as an indirect measure of available moisture and nutrients. Linear multiple regression and simple and multiple correlation were used.

Tree survival and yield were related to the chemical characteristics of the spoils. Variables seemingly related to tree survival were pH, soluble salt concentration, exchangeable Al, cation exchange capacity and nitrifiable N. Linear multiple regression accounted for as much as 82 percent (pitch pine) and as little as 58 percent (jack pine) of the variation in tree survival.

Regressions for tree yields accounted for 90, 78 and 76 percent of the variation with cottonwood, eastern redcedar and pitch pine. Cottonwood yield was best related to exchangeable Al and soluble salt concentration; eastern redcedar yield was related to slope position, nitrifiable N and soluble salt concentration; and pitch pine yield was related to cation exchange capacity and exchangeable and soluble bases.

Relationship of Tree Survival and Yield to Coal-Spoil Characteristics[1]

by P. L. Lorio, Jr.,[2] and G. E. Gatherum[3]

The complexity of environmental factors affecting tree growth is generally appreciated (Billings 1952, Heiberg and White 1956, Thomson and McComb 1962 and Zahner 1958). On specific sites and soil types, however, certain factors are more limiting than others. On Iowa coal-spoil materials, low levels of some nutrients and toxic levels of others appear to markedly limit tree survival and yield (Einspahr 1955 and Lorio 1962).

Einspahr (1955) related poor survival and growth on some classes of spoils to nitrogen and phosphorus deficiencies. Aluminum and manganese levels toxic to trees have been found on certain classes of spoils (Einspahr 1955 and Knudsen and Struthers 1953). However, additional information on these and other nutritional relationships is needed before recommendations concerning reclamation of Iowa coal spoils can be improved. The chemical and physical properties of coal-spoil banks have been studied by a number of workers (Croxton 1928, Einspahr 1955 and Kohnke 1950), but few attempts have been made to relate tree survival and yield to specific characteristics of the materials.

The over-all objective of this study was to investigate the relationships between 7- to 8-year survival and yield of two broadleaved and five coniferous species and a number of selected chemical characteristics of Iowa coal-spoil materials. Thus, specific objectives were to: (1) determine if survival and yield of these tree species are related to the chemical characteristics of the spoils, (2) identify those spoil chemicals most closely related to survival and yield of each of the tree species tested and (3) provide this information to permit formulation of hypotheses for future controlled experiments designed to identify cause and effect relationships between chemical characteristics of the spoils and survival and yield of each of the tree species. Linear multiple regression and simple and multiple correlation were used. The relationships of survival and yield to the following measures of soil fertility were investigated:

X_1—acidity (pH)
X_2—exchangeable aluminum (me. per 100 g.)
X_3—exchangeable and soluble bases (me. per 100 g.)
X_4—nitrifiable nitrogen (pounds per acre)
X_5—cation exchange capacity (me. per 100 g.)
X_6—soluble salt concentration (parts per million)
X_7—available phosphorus (pounds per acre)
X_8—available potassium (pounds per acre)
X_9—slope position (upper or lower)
X_{10}—(X_1) (X_2)
X_{11}—(X_2) (X_6)
X_{12}—(X_2) (X_7)

In addition, the interaction of exchangeable aluminum with pH, soluble salt concentration and available phosphorus was tested. Slope position (upper or lower) was included as an indirect measure of available moisture and nutrients. Limited degrees of freedom precluded the use of interactions in the regression equations for yield. Instead, various combinations of the variables were used, and the effect of additions or deletions of any variable was tested. Seven- to 8-year survival and yield data for the seven species and laboratory analyses of chemical characteristics of the coal spoils have been reported by Lorio (1962) and by Lorio et al. (1964). Chemical data pertinent to this paper are included in table 1.

METHODS

The study was conducted on plots established in 1953 by Einspahr (1955). Originally, 3-row plots of each species were planted at random in each of the three blocks in each of the six coal-spoil areas at a 2x2-foot spacing. Each row contained 10 trees. In the present study, the

Table 1. Range in quantity of each chemical factor investigated.

Variables	Range in quantity		
X_1–acidity (pH)	2.7	to	8.0
X_2–exchangeable aluminum (me. per 100 g.)	0.0	to	9.1
X_3–exchangeable and soluble bases (me. per 100 g.)	1.0	to	55.4
X_4–nitrifiable nitrogen (lbs. per A.)	2	to	62
X_5–cation exchange capacity (me. per 100 g.)	8.3	to	19.3
X_6–soluble salt concentration (parts per million)	50	to	4380
X_7–available phosphorus (lbs. per A.)	0.5	to	9.5
X_8–available potassium (lbs. per A.)	42	to	354

[1]Project 1218 of the Iowa Agricultural and Home Economics Experiment Station. Funds for this project are provided by the Iowa Coal Research Association.
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20x60-foot replications were split into upper and lower slopes. The data were sorted arbitrarily into groups representing the upper 10 feet and the lower 10 feet of each replication.

The experimental areas, all within 10 miles of the Des Moines River, are located in Marion, Mahaska, Wapello, Davis and Van Buren counties. The topography consists of irregular rows of low cone-shaped hills from 10 to 50 feet in height and with slopes of 20 to 50 percent. Usually, the vegetation is sparse and includes such pioneer tree species as cottonwood, boxelder and American elm. Some banks are covered with yellow sweetclover, orchardgrass and timothy, all sown artificially some years previously. The coal-spoil materials have been described by Einspahr (1955).

Measurements and analyses

Laboratory analyses were made of composite samples of the surface 6 inches of coal-spoil material on the upper and lower portions of the replications at each location. A composite sample consisted of about 40 borings obtained with a tube auger. The samples were air-dried in the laboratory, then ground and sieved through a 2-mm wire mesh screen.

The following determinations were made for each sample: pH, cation exchange capacity, exchangeable and soluble bases, exchangeable aluminum, soluble salt concentration, nitrifiable nitrogen, available phosphorus and available potassium.

The pH was determined with a glass electrode in a 1:2.5 soil to water ratio as described by Jackson (1958). Cation exchange capacity and exchangeable and soluble bases were determined with the methods described by Black (1957) in which a neutral, 1*N* NH_4 OA_c extracting solution is used. Exchangeable aluminum was determined by titration of the acidity formed in neutral, normal KCl leachates with standard NaOH according to a procedure described by Lin (1959).

Soluble salt concentration was determined from a 1:2 soil to water extract with the method and the direct indicating bridge (solubridge) described by the U.S. Salinity Laboratory Staff (1954). Conductivity readings were converted to concentration in parts per million by use of a standard curve developed at the Iowa State University Soil Testing Laboratory. Nitrifiable nitrogen was determined with the method described by Stanford and Hanway (1955). Available phosphorus was determined by method number one of Bray and Kurtz (1945), and available potassium was determined with the flame photometer by the direct method.

Tree survival was determined by calculating the percentage of planted trees remaining, and yield per subplot was obtained by multiplying average tree height by the number of trees per subplot.

Simple correlation coefficients were calculated for all variables measured. Linear multiple regression analyses were computed, with survival percentages and yield as dependent variables, for the following species: red pine (*Pinus resinosa* Ait.), jack pine (*P. banksiana* Lamb.), pitch pine (*P. rigida* Mill.), Virginia pine (*P. virginiana* Mill.), eastern redcedar (*Juniperus virginiana* L.), green ash (*Fraxinus pennsylvanica* Marsh.), and cottonwood (*Populus deltoides* Bartr.). Cottonwood, eastern redcedar and pitch pine were selected for additional analyses in which the independent variables were used singly and in different combinations.

RESULTS AND DISCUSSION

Survival and coal-spoil characteristics

Simple correlation analyses indicated some relationships between the chemical factors measured and survival of trees. Correlations of variables with survival varied among species (fig. 1).

Linear multiple regressions were significant for all species, accounting for as much as 82 percent of the variation for pitch pine survival and for as little as 58 percent of the variation for jack pine survival. Some variables were significant in the regressions for all species except eastern redcedar and jack pine (table 2).

Variables which were correlated significantly with survival of a species in terms of simple correlation were not always significant in the regression equation. For example, five variables were correlated with eastern redcedar survival at the 1-percent probability level, yet none of the terms was significant in the regression equation. In addition, the signs of several regression coefficients differed from those of the correlation coefficients. The high amount of intercorrelation among the variables which were well correlated with survival of this species caused these changes in degree of significance and sign. When two or more variables, which are intercorrelated and are likewise correlated with the dependent variable, are included in the same regression equation, the amount of variation that can be accounted for by any one variable, after fitting the other(s), is limited.

Yield and coal-spoil characteristics

Simple correlation analyses indicated some relationships between tree yield and chemical characteristics of the coal-spoil materials. Correlation of variables with yield varied among species (table 3).

Linear multiple regressions for cottonwood, eastern redcedar and pitch pine were significant, and the variables accounted for 90, 78 and 76 percent of the variation in yield. Multiple regression statistics are shown for the significant variables for cottonwood and eastern redcedar (table 4). No single variable was significant for pitch pine. To facilitate interpretation of the relationships of the chemical variables to the growth of cottonwood, eastern redcedar and pitch pine, a number of regressions were calculated, based on combinations of two or more variables.

Eastern redcedar yield was related most closely to pH and available phosphorus among the combinations of two variables, $R^2 = 49$ percent. In combinations of three variables, available phosphorus, soluble salt concentration

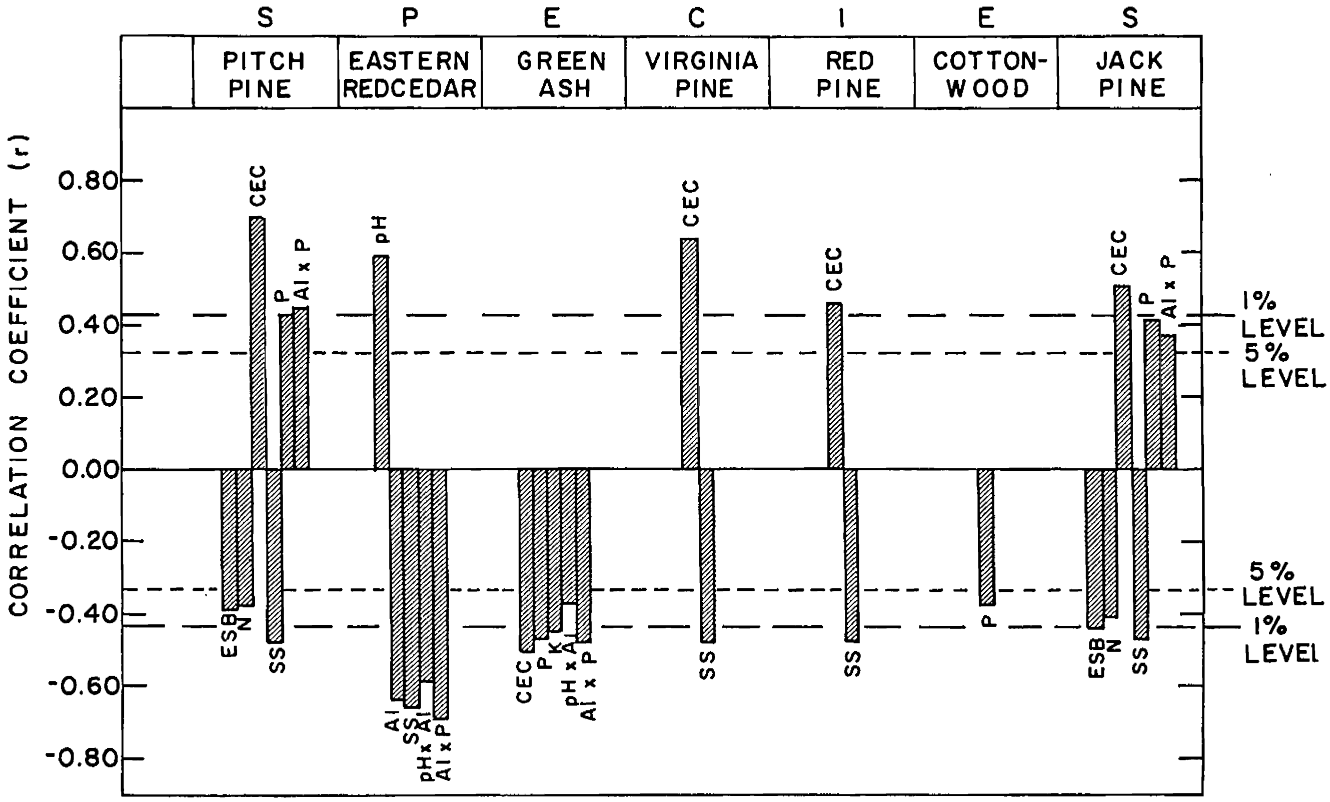


Fig. 1. Simple correlations of tree survival with chemical characteristics of coal spoils.

Table 2. Multiple regression statistics for variables significant in the survival regressions for five tree species, statistics adjusted for the nonsignificant variables.

Species	Y Survival (Sin^{-1} (percentage)$^{1/2}$)	Variables and statistics		
Green ash	$\bar{y}$ = 52.20 df = 35	X_2–Exchangeable Al b_i = 44.788* S_{b_i} = 20.351	X –Soluble salts –0.0153* 0.00732	X_{10}–(X_1) (X_2)[a] –15.965* 6.676
Pitch pine	$\bar{y}$ = 24.92 df = 35	X_4–Nitrifiable N b_i = –0.702** S_{b_i} = 0.238	X_5–Cation exchange capacity 4.155** 1.327	X_7–Available P – 4.937* 2.063
Cottonwood	$\bar{y}$ = 20.85 df = 35	X_5–Cation exchange capacity b_i = 4.659* S_{b_i} = 1.674		
Virginia pine	$\bar{y}$ = 18.55 df = 35	X_4–Nitrifiable N b_i = –0.630** S_{b_i} = 0.213	X_5–Cation exchange capacity 2.989* 1.185	
Red pine	$\bar{y}$ = 18.01 df = 35	X_4–Nitrifiable N b_i = –0.832** S_{b_i} = 0.282		

[a](X_1) (X_2) = pH x Exchangeable Al.
* Significant at 5 percent level.
**Significant at 1 percent level.

Table 3. Simple correlations of tree yield with chemical characteristics of coal spoils.

Species	df (n–2)	Variables and correlation coefficients (r)			
Cottonwood	16	X_3–Exchangeable and soluble bases 0.72**	X_4–Nitrifiable N 0.52*		
Eastern redcedar	33	X_1–pH 0.66**	X_2–Exchangeable Al –0.66**	X_3–Exchangeable and soluble bases 0.48**	X_4–Nitrifiable N 0.57**
Pitch pine	18	X_5–Cation exchange capacity 0.76**	X_7–Available P 0.50*	X_8–Available K 0.74**	
Green ash	27	X_3–Exchangeable and soluble bases 0.37*	X_5–Cation exchange capacity –0.38**		
Red pine	12	X_7–Soluble salts –0.54*			
Jack pine	17	X_8–Available K 0.47*			

* Significant at the 5 percent level.
**Significant at the 1 percent level.

Table 4. Multiple regression statistics for variables significant in the yield regression for cottonwood and eastern redcedar, statistics adjusted for nonsignificant variables.

Species	Y Yield (no. trees x ave. height per subplot)	Variables and statistics		
Cottonwood	$\bar{y}$ = 54.80	X_2–Exchangeable Al	X_6–Soluble salts	X_7–Available P
	df = 17	b_i = –19.898*	0.0216*	–13.860**
		S_{b-i} = 6.455	0.0088	4.073
E. redcedar	$\bar{y}$ = 46.09	X_4–Nitrifiable N	X_6–Soluble salts	X_9–Slope position
	df = 34	b_i = 0.581*	–0.013**	11.735**
		S_{b-i} = 0.263	0.00385	3.327

* Significant at 5 percent level.
**Significant at 1 percent level.

and exchangeable and soluble bases accounted for 59 percent of the variation, whereas all variables explained 78 percent of yield variation.

Pitch pine yield was related most closely to cation exchange capacity and to exchangeable and soluble bases among the combinations of two variables, $R^2 = 70$ percent (table 5). After both variables were fitted, the regression on the seven deleted variables was not significant (table 6). All nine variables accounted for 76 percent of the variation in yield.

Exchangeable aluminum and soluble salt concentration occurred in all variable combinations that accounted for a marked reduction in sum of squares for cottonwood yield. The two variables accounted for 65 percent of the variation, and the addition of any one other variable did not improve the regression significantly. The following five variables accounted for 85 percent of the variation in yield: exchangeable aluminum, soluble salt concentration, available phosphorus, available potassium and nitrifiable nitrogen. All nine variables accounted for 90 percent of the variation. Multiple regression statistics and analysis of variance of the regressions showed that the deleted variables did not improve the regression significantly (tables 7 and 8).

As stated in the section on survival and coal-spoil characteristics, simple correlation coefficients may not indicate the significance of variables in regression. Intercorrelation among independent variables, when used in the same regression equation, may cause nonsignificance

Table 5. Multiple regression statistics of two variables for pitch pine yield, seven variables deleted.

	X_3 Exchangeable and soluble bases	X_5 Cation exchange capacity
b_i =	–0.562*	4.999**
S_{b-i} =	0.224	0.794

* Significant at 5 percent level.
**Significant at 1 percent level.

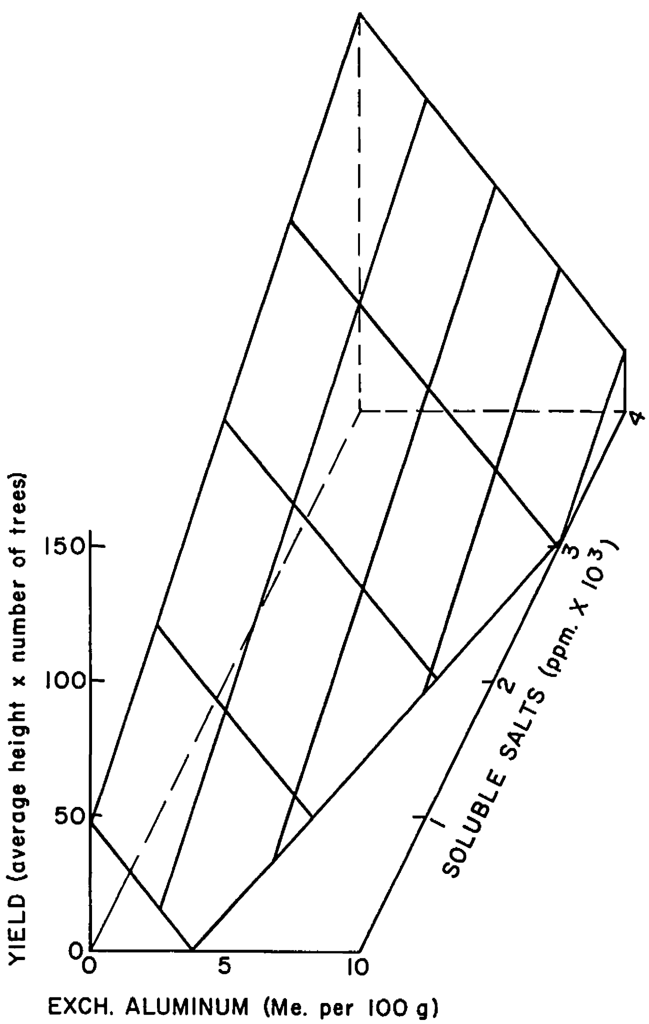
Table 6. Analysis of variance of regression on seven deleted and two remaining variables for pitch pine yield.

Variation due to:	df	Sum of squares	Mean square
Total	19	9,286.82	
Regression on X_3, X_5	2	6,501.43	3,250.72
Deviations	17	2,785.39	163.85
Regression on X_1, X_2, X_4, X_6, X_7, X_8, X_9, after fitting X_3, X_5	7	599.54	85.65
Regression on X_1, X_2, ... , X_9	9	7,100.97	
Deviations	10	2,185.85	218.58

$F^2_{17} = 3,250.72/163.85 = 19.840^{**}$

$F^7_{10} = 85.65/218.58 = 0.392$

**Significant at 1 percent level.



$y = 46.9 - 12.6$ (Me. of Al^{+3}) $+ 0.0253$ (p.p.m. of Salts)

Fig. 2. Block diagram of the regression of cottonwood yield on exchangeable aluminum and soluble salt concentration.

Table 7. Multiple regression statistics of five variables[a] for cottonwood yield, four variables deleted.

	X_2	X_4	X_6	X_7	X_8
b_i =	−11.164**	−1.135*	0.0257**	−11.065**	0.364**
S_{b_i} =	2.876	0.466	0.00502	3.156	0.113

[a]X_2 = exch. Al; X_4 = nitrif. N; X_6 = soluble salts; X_7 = avail. P; X_8 = avail. K.

**Significant at 1 percent level.

* Significant at 5 percent level.

Table 8. Analysis of variance of regression on four deleted and five remaining variables for cottonwood yield.

Variation due to:	df	Sum of squares	Mean square
Total	17	22,655.76	
Regression on X_2, X_4, X_6, X_7, X_8	5	19,237.21	3,847.44
Deviations	12	3,418.55	284.88
Regression on X_1, X_3, X_5, X_9, after fitting X_2, X_4, X_6, X_7, X_8	4	1,227.23	306.81
Regression on X_1, X_2, ... , X_9	9	20,464.44	
Deviations	8	2,191.32	273.92

$F^5_{12} = 3,847.44/284.88 = 13.505^{**}$

$F^4_8 = 306.81/273.92 = 1.120$

**Significant at 1 percent level.

of one or more variables. Moreover, intercorrelation may cause coefficients to change sign when variables are added or deleted in multiple regression.

The variability of the correlation between the independent variables and yield of cottonwood, when corrected for the effect of the relationship of other variables in yield (Ezekial and Fox 1959, p. 192), is shown in figs. 2 through 6. Exchangeable aluminum was not correlated significantly with cottonwood yield, but whenever correction was made for soluble salt concentration, the correlation of aluminum with yield was highly significant (fig. 3). Correction for phosphorus increased the partial correlation, but correction for nitrifiable nitrogen reduced the correlation almost to zero. A possible explanation for some of the change in the partial correlation coefficients is that high soluble salt concentration occurred with high and low exchangeable aluminum and with high and low yield. When the variation associated with soluble salt concentration was removed, the relation between yield and exchangeable aluminum was improved greatly. This is best illustrated in fig. 2 which shows the regression surface described by the two variables. Similarly, nitrifiable nitrogen was sufficiently well correlated with yield and with exchangeable aluminum that little variation

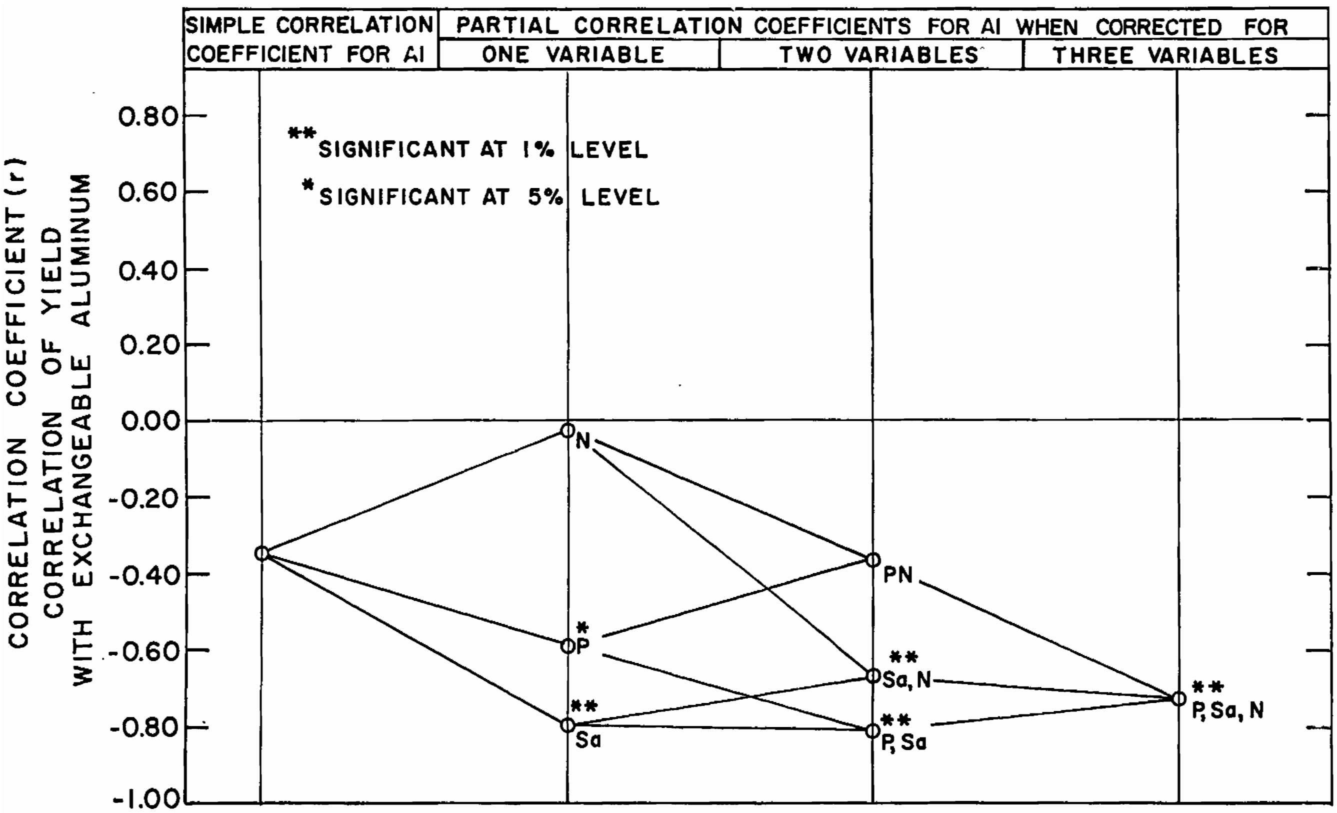


Fig. 3. Simple and partial correlation coefficients for correlation of cottonwood yield with EXCHANGEABLE ALUMINUM; N = nitrifiable nitrogen, P = available phosphorus, Sa = soluble salt concentration.

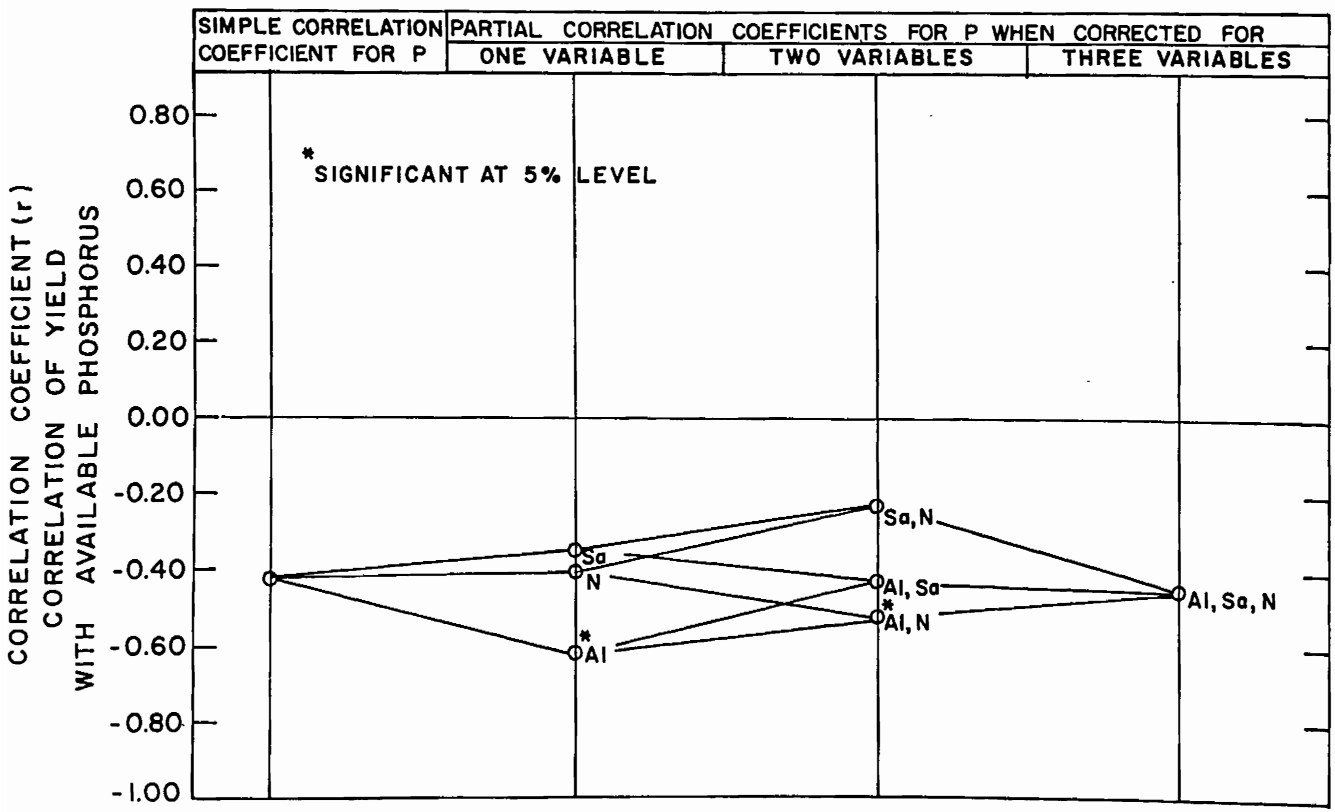


Fig. 4. Simple and partial correlation coefficients for correlation of cottonwood yield with AVAILABLE PHOSPHORUS; N = nitrifiable nitrogen, Sa = soluble salt concentration, Al = exchangeable aluminum.

could be associated with exchangeable aluminum after regression was made on nitrifiable nitrogen. Available phosphorus was neither correlated significantly with yield nor with exchangeable aluminum; therefore, in combination with exchangeable aluminum in a regression equation, phosphorus accounted for a small amount of variation not associated with exchangeable aluminum. The remaining variation was better related to the levels of exchangeable aluminum; therefore, the partial correlation was increased.

Except where correction was made for exchangeable aluminum, the partial correlation coefficient of available phosphorus with yield did not vary greatly (fig. 4). The explanation for the better correlation where correction was made for exchangeable aluminum is similar to that given in the preceding paragraph.

The partial correlation of soluble salt concentration with yield varied when corrections were made for exchangeable aluminum, nitrifiable nitrogen and available phosphorus (fig. 5). Explanation for the great increase in correlation when correction was made for exchangeable aluminum is the converse of that given for the change in the correlation of exchangeable aluminum with yield when correction was made for soluble salt concentration.

The correlation of nitrifiable nitrogen with yield changed from a significant positive to a negative, though nonsignificant, relation when the variation associated with exchangeable aluminum, available phosphorus and soluble salt concentration was removed (fig. 6). The negative correlation of nitrifiable nitrogen with exchangeable aluminum appeared to account for most of the change. The variation in yield, after correction for exchangeable aluminum and soluble salt concentration, was not correlated with nitrifiable nitrogen.

CONCLUSIONS

In reference to the objectives of this study, the following was determined: (1) Survival and yield of the tree species studied are related to the chemical characteristics of Iowa coal-spoil materials. (2) Tree species studied vary in their response to coal-spoil chemicals. (3) Data obtained can be used to formulate hypotheses for future controlled experiments designed to identify cause and effect relationships between chemical characteristics of the coal spoils and survival and yield of each of the tree species studied.

Survival

Cottonwood survival was not clearly related to any one variable. Seemingly, this species will survive at rather high levels of exchangeable aluminum and soluble salt concentration and under strongly acid conditions. Green ash was somewhat more sensitive to nutrient conditions, and survival was partly related to exchangeable alum-

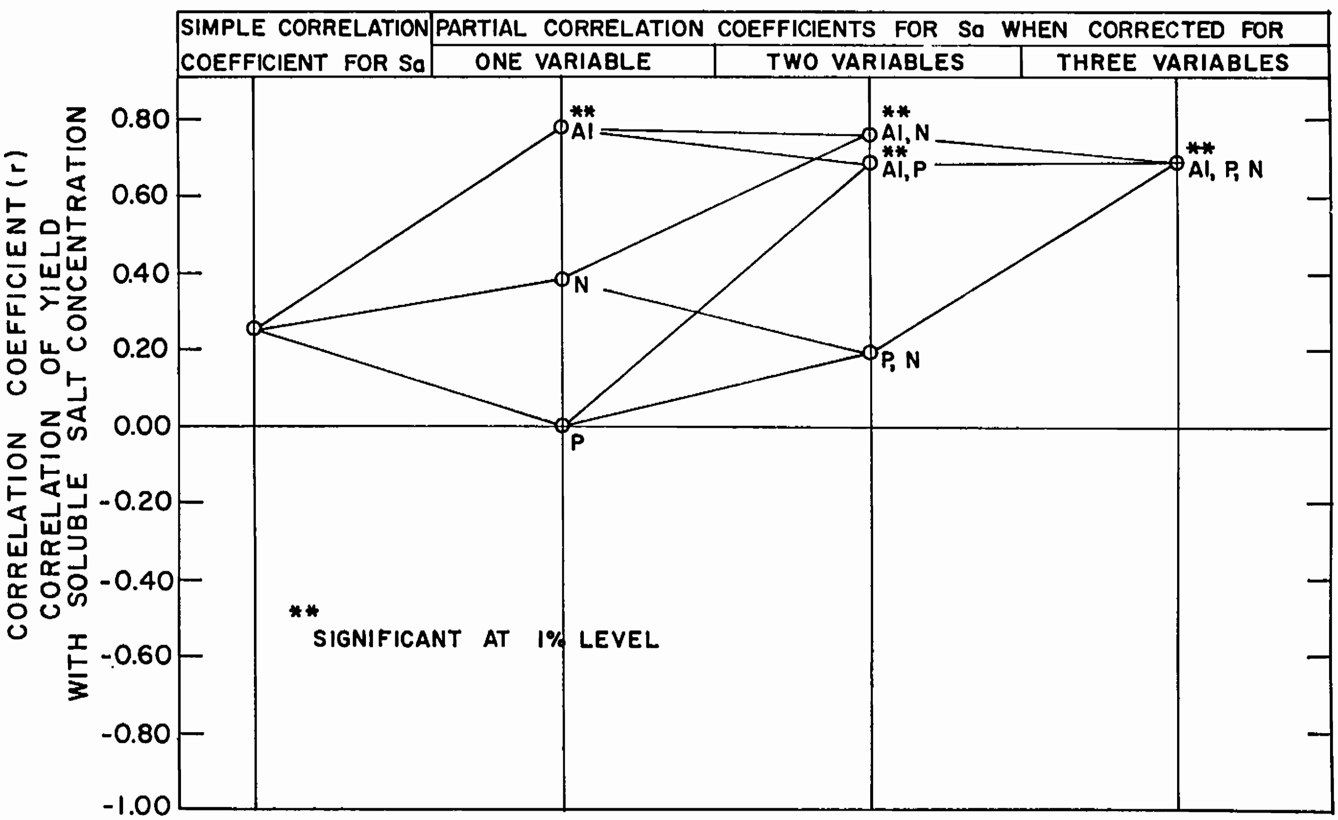


Fig. 5. Simple and partial correlation coefficients for correlation of cottonwood yield with SOLUBLE SALT CONCENTRATION; N = nitrifiable nitrogen, P = available phosphorus, Al = exchangeable aluminum.

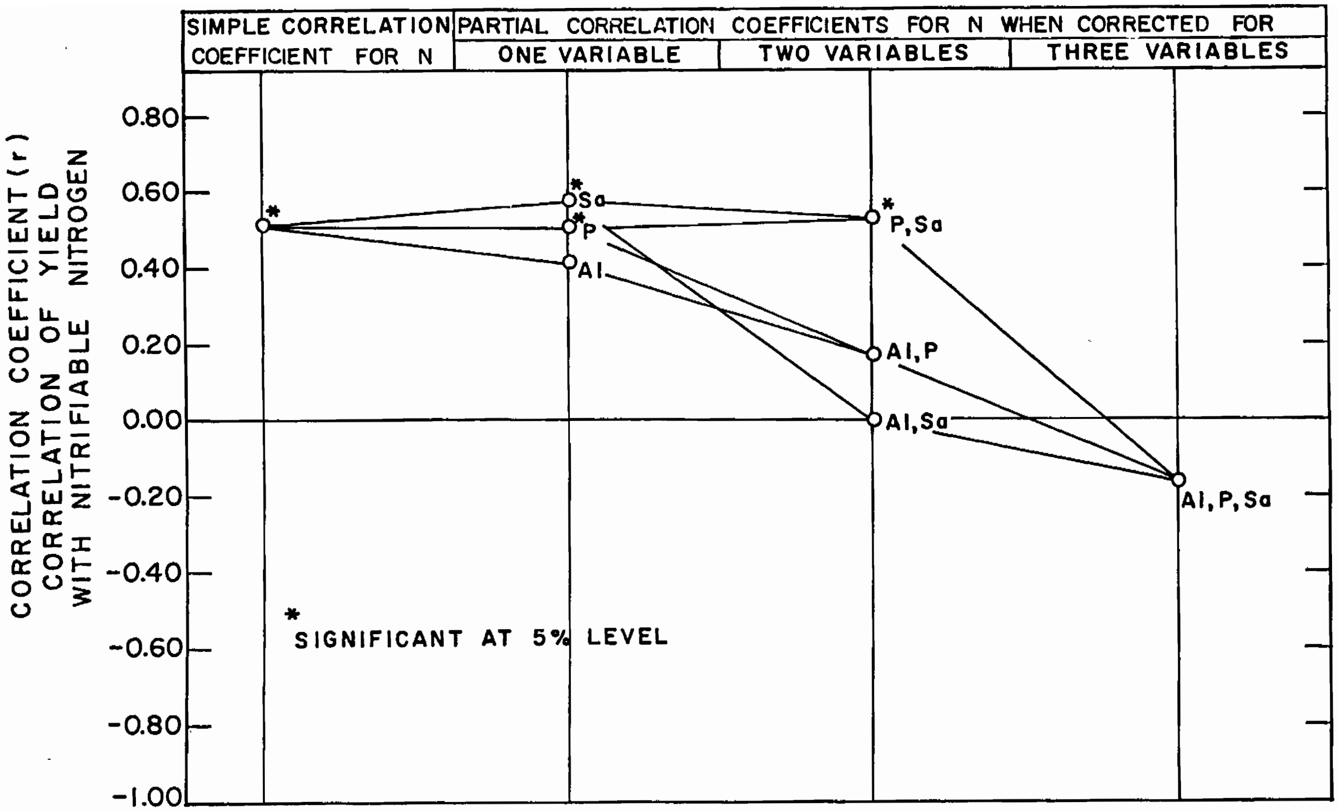


Fig. 6. Simple and partial correlation coefficients for correlation of cottonwood yield with NITRIFIABLE NITROGEN; P = available phosphorus, Sa = soluble salt concentration, Al = exchangeable aluminum.

inum, soluble salt concentration and the pH-exchangeable aluminum interaction.

Although no single variable was significant in regression, eastern redcedar survival was correlated positively with pH and negatively with exchangeable aluminum and soluble salt concentration. Pine survival seemingly is related to cation exchange capacity, nitrifiable nitrogen and soluble salt concentration. Survival of pitch and Virginia pine was related to cation exchange capacity in simple correlation and in regression when the variation accounted for by other variables was removed. Cation exchange capacity is associated with the amount and kind of clay and with the amount of organic matter in the soil. The exchange capacity of the soil increases with an increase in clay content, organic matter and montmorillonitic clay. These variables are related to fertility levels and the moisture-holding capacity of the soil, factors which influence survival of trees. In the range of observations of this study, cation exchange capacity was correlated positively with available phosphorus and available potassium and was correlated negatively with soluble salt concentration. Each of these variables could have a direct effect on the survival of pine species, and their net effect is reflected in the relation of cation exchange capacity to survival.

Yield

Because survival was low on many plots, fewer data were available for the investigation of yield and coal-spoil characteristics than for the investigation of survival. Results of statistical tests reflect this in terms of significant relationships obtained. Only regressions for cottonwood, eastern redcedar and pitch pine accounted for significant amounts of variation in yield. The importance of some of the chemical characteristics was shown by the high percentage of variation accounted for by as few as two variables.

The two variables best related to cottonwood yield were exchangeable aluminum and soluble salt concentration. High soluble salt concentration occurred under both acid and calcareous conditions. Seemingly, the high soluble salt concentrations are not detrimental to cottonwood growth on the calcareous materials, but where soluble salt concentrations were high, pH low and exchangeable aluminum high, yield was reduced greatly. These results suggest the possibility of aluminum toxicity to trees on acid coal-spoil materials. Cottonwood trees can survive and grow to some extent at relatively high levels of exchangeable aluminum, but controlled laboratory and greenhouse studies are required to define clearly the limits of cottonwood tolerance to aluminum activity.

A significant amount of variation in yield of eastern redcedar was accounted for by slope position after regression on eight other variables. The relationship is probably a reflection of better moisture conditions, greater accumulation of soil-size spoil material and better nutrient supply and balance for root growth on the lower slopes, although slope position was not correlated with any one variable. In addition, the significance of coefficients for soluble salt concentration and nitrifiable nitrogen in regression indicates that these variables were related to the growth of eastern redcedar.

Much of the variation in pitch pine yield was explained by cation exchange capacity and exchangeable and soluble bases. Intercorrelation among independent variables obscured these relationships in the general regression, but the regression of yield on these two variables alone indicated their possible importance to growth of pitch pine on spoil banks. Cation exchange capacity is related to some factors of fertility and water-holding capacity that affect plant survival and growth, and, in general, pine species do not grow well on calcareous soils in which the exchangeable and soluble base content is high. Mycorrhizae, so important in the nutrition of pine species, usually are not present in calcareous soils (Kramer and Kozlowski 1960), and this deficiency may be the more direct factor associated with poor pine growth on spoil materials high in bases.

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