

*T H E A P P L I C A T I O N O F S O I L T E S T I N G
M E T H O D S T O S I T E A S S E S S M E N T A N D
T R E E G R O W T H*

by

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I N T R O D U C T I O N

Trees growing in the forest are part of a complex dynamic system which is often subdivided into component parts such as soil properties, atmosphere, management practices and biological factors. The growth of a plant will be affected by all these factors to a greater or lesser extent and for accurate predictions to be made, each variable must be calibrated concurrently with the others. In order to make the calibration for a particular factor, it is necessary to have a valid method of assessment for the properties and a series of experimental sites which covers the complete range of the property.

Uptake of nutrients by a plant depends not only upon the nutrients available in the soil, but also on the soil moisture, competition between plants and many other factors. Major nutrient deficiencies in the establishment phase of a tree crop (up to 10 years) have been investigated successfully by empirical experimentation using foliar analysis as the indicator. This technique has serious draw-backs as the plantation grows and in the case of marginal deficiencies it is not possible to predict the response or make an accurate economic assessment of a fertilizer application. As a consequence, a fixed amount is applied if a deficiency is suspected.

Relating tree growth to site factors, including soil nutrients, is an obvious way of overcoming the problems associated with plant analysis. Soil testing is used extensively in agriculture to provide a quantitative index of nutrient availability and has reached a reasonable level of sophistication. Compared to the intensive fertilizer regimes and site amelioration in agriculture, upland afforestation is quite different. The plants are perennial and the chemical and hydrological properties of the soil undergo large changes due to the formation of a litter layer and increased water use. Sampling problems could also arise due to the changing rooting volume of the plants.

If useful relationships between tree growth and site measurement are to be obtained, it is necessary to calibrate the analytical methods. Because of lack of knowledge, assumptions have to be made about the

characteristics of the site properties to be assessed so that analytical procedures can be established. It is important that these methods should go a long way towards assessing the intended parameter and are not compromised by ease of analytical technique or data acquisition. It is necessary to understand what the soil test value (STV) for a chemical property actually represents. The mechanism of soil test measurements gives an insight into how individual chemical properties behave in forest soils and indicates suitable analytical conditions for the determination of soil test values.

S O I L T E S T M E T H O D S

Agronomists make an assessment of the nutrient available to plants using solutions of various salts and acids ("extractants"). Soil nutrients are loosely classified as 'available' or 'non-available' whether they can be assessed by these methods or not, and any fertilizer is expected to distribute itself between these forms and the plants growing on the site. These soil test techniques had most success in those regions where high inputs of fertilizer have been made for some time. In contrast, only small amounts are added to forest soils and the distribution of nutrient between the different forms in a forest soil might be expected to be different to that in an agricultural soil. The uptake of nutrient by a plant will be through the liquid phase, however, and it seems reasonable initially to make an attempt to estimate the more soluble nutrient using these methods.

The soil test value (STV) for a soil property is affected by variations in pH, solution to soil ratio (s) and extraction time (t). Even the type of shaking machine can be important in determining the value. For a particular soil property, the values obtained using different extractions are usually highly correlated with one another and with other soil properties, but do not prove useful for predicting tree growth (Ballard & Pritchett, 1975).

In view of the conflicting evidence, the usefulness of extraction procedures was assessed by studying various fertilizer trials which were located on sites deficient in phosphate. The species chosen was Sitka spruce (*Picea sitchensis* (Borg) Carr) and the experiments covered a range of age (4 - 38 years), soil type, form of fertilizer and time of sampling after fertilizer addition. Other chemical properties were measured to see if they had an indirect influence on the nutrient supply or uptake. The soil test methods used were:

- (a) total N - Kjeldahl digestion then colourimetrically by the indo-phenol blue method.
- (b) P - Bray 2 (0.03M NH_4F + 0.05M HCl) then colourimetrically by phosphomolybdenum blue method ($s = 10$, $t = 2$ min).
- (c) K, Ca, Mg - extraction with 1M ammonium acetate (pH 7 & 4.8) and measured by atomic absorption or emission. ($s = 25$, $t = 1$ h).

TABLE 1

Matrix of correlation coefficient between soil test values and tree growth measured as standing basal area, (BA) and incremental growth, (I) over 6 years for a plantation of pole stage Sitka spruce.

Variables	Correlation coefficients (r)									
	BA71	BA73	BA75	BA77	N	P	K	Ca	Fe	Al
BA 71	1.000									
BA 73	0.982***	1.000								
BA 75	0.977***	0.944***	1.000							
BA 77	0.878**	0.935***	0.917**	1.000						
N	-0.026	0.109	0.074	0.259	1.000					
P	0.317	0.413	0.390	0.436	0.887**	1.000				
K	0.222	0.138	0.086	-0.174	-0.004	0.253	1.000			
Ca	0.303	0.414	0.387	0.548	0.910**	0.926***	0.016	1.000		
Fe	0.057	-0.049	-0.029	-0.081	-0.873**	0.845**	0.115	-0.739*	1.000	
Al	0.162	0.068	0.103	0.024	-0.840**	-0.763*	-0.169	-0.661	0.978***	1.000
I 71-73	-0.217	-0.031	-0.031	0.194	0.721*	0.471	-0.472	0.552	-0.572	-0.515
I 71-75	0.103	0.259	0.311	0.369	0.465	0.409	-0.590	0.456	-0.397	-0.243
I 71-77	-0.456	-0.313	-0.335	0.024	0.538	0.148	-0.603	0.386	-0.272	-0.293
r > 0.92	significant at 0.1% level (***)									
r > 0.83	1% level (**)									
r > 0.71	5% level (*)									

- (d) Fe & Al - extraction with sodium dithiomite ($s = 100$, $t = 1h$) or 1M ammonium acetate (pH 7 & 4.8) ($s = 25$, $t = 1h$) and measured by atomic absorption.

None of the properties, either alone or combined with others, could be related to tree growth. In the age range 25 - 40 years the factor which affected tree growth most was the basal area of the trees in each of the plots even though large amounts of phosphate had been applied. This could be attributable to a physiological factor since Sitka spruce at this age has been shown on some sites to respond to an application of both phosphate and potassium but not when either is added alone (Miller 1978). Table 1 shows that many of the soil properties are correlated with one another but not with the incremental growth or the actual size of the trees. The relationships between the individual soil properties are hard to define and there is insufficient information to reach any conclusions. Since a response to the fertilizers was observed on most of the sites, this suggests that either the soil tests are not measuring a suitable form of nutrient, the sampling scheme is inefficient or that some other factor is confounding the results.

Changes in analytical conditions.

The observed level of the *STV*, for most of the properties measured, changed with the analytical conditions and these effects are summarised in table 2. The estimation of an *STV* can be considered as a series of chemical reactions and table 3 gives details of a possible mechanism which can be applied to any of the extraction procedures and permits the interpretation of the dependence of the *STV* on s and t . The relative magnitude of the different terms in equations 3 and 4 will determine which reactions affect the concentrations of the different chemical

TABLE 2

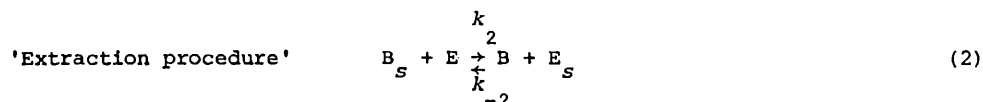
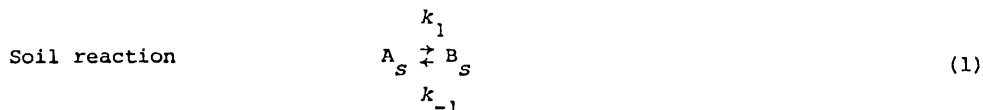
Effect of analytical conditions on the observed soil test value

	Soil test			
	P	K	Ca	Al
Air drying before analysis	+	+	0	
Decreasing pH (NH_4OAc extraction)	0	0	0	+
Increasing solution: soil ratio	0	0	+	+
Increasing time	+	0	+	+

+ = increase = decrease 0 = unchanged.

TABLE 3

Simple mechanism for interpreting soil transformations and extraction procedures



Providing $(E) \gg (B_s)$ it is not relevant whether reaction (2) represents exchange or dissolution. E represents the extractant and X_s the concentration of X in the soil.

The rates of reaction are given by:

$$d(B_s)/dt = \rho \left[k_1(A_s) - k_{-1}(B_s) + sk_{-2}(E_s)(B) - sk_2(B_s)(E) \right] \quad (3)$$

$$d(B)/dt = \rho \left[sk_2(B_s)(E) - sk_{-2}(B)(E_s) \right] \quad (4)$$

where ρ = the bulk density of the soil and (X) = concentration of X

Case 1 $k_2 \gg k_1$

$t \gg 1/k_2(E)$, $d(B)/dt \rightarrow 0$ and (B) shows no dependence on s or t

$t \approx 1/k_2(E)$, (B) increases with s and t

Case 2 $k_2 > k_1$

$t < 1/k_2(E)$, (B) increases with s and t

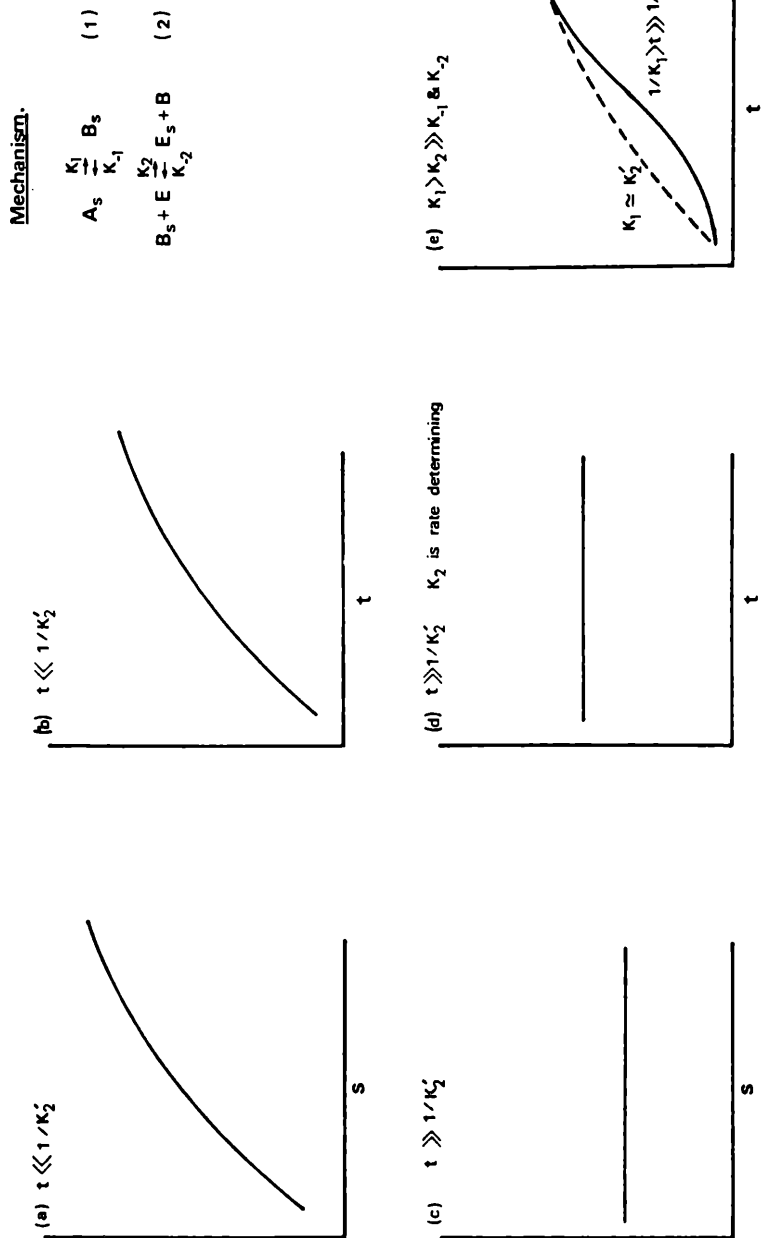
$1/k_2(E) < t < 1/k_1$, (B) increases with s

$t \rightarrow 1/k_1$ (B) increases with t

Case 3 $k_2 \approx k_1$

Increases with s and t until $t \gg 1/k_2(E)$ and $1/k_1$

Fig 1



Predicted dependence of the soil test value on solution:soil ratio (s) and time (t), assuming a series of consecutive reversible reactions.

forms. The most important factors in these equations are the relative sizes of the reaction rate constants, k_i , which dictate the distribution between the different forms, and the time at which the measurements are made. By making assumptions about the relative sizes of these variables, it is possible to predict the dependency of the *STV* (represented as in B in this mechanism) on s and t . By comparing these curves (fig 1) to those observed for the individual properties, it is possible to infer the relative sizes of the rate constants for some of the soil properties. This suggests the extent to which each form of the property is contributing to the *STV* at particular analytical conditions.

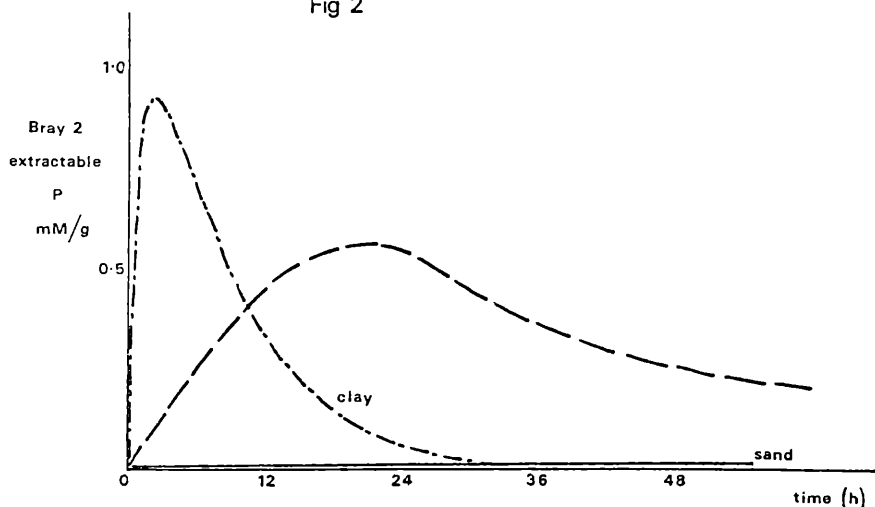
For the solution concentration to be independent of s , the rate of reaction 2 has to be much faster than reaction 1 and t has to be long enough so that reaction 2 is approaching equilibrium. Under these conditions the dependence upon t will also disappear until the solution concentration is affected by equation 1. At short times both phosphate and potassium have little or no dependence upon s or t suggesting that reaction 2 is comparatively fast. On increasing t , the *STV* for potassium does not change whereas that for phosphate begins to increase at $t > 1$ hour.

If the values of the rate constants for the forward reactions are similar, then a continuous rise in the *STV* with time would be observed. Under these circumstances it would not be possible to distinguish whether reaction 1 is occurring or not. Within the time limits of this experiment, potassium does not seem to undergo a reaction within the soil matrix whereas phosphate does. In some cases, the increase of the phosphate *STV*, at times greater than 1 hour, is not a smooth curve suggesting that the mechanism is more complex than that shown in table 3 and might involve either parallel or further consecutive reactions. Mechanisms of this type have been proposed for phosphate interactions with soils (Mansell, Selim and Fiskell 1977) but the evidence for more complex mechanisms is not clear.

To verify whether a reaction is occurring to any extent within the soil, a quantity of the element in question can be added in solution to a soil and the concentration in solution and the *STV* monitored. Fig 2 shows typical results obtained after an addition of phosphate and indicates that the *STV* is dependent upon the particle size distribution of the sample. As predicted by the presence of the soil bulk density, ρ , in the rate equations, the proportion of phosphate which remains detectable as the *STV* decreases as the clay fraction increases. It is estimated that for phosphate, the values of the rate constants are such that $k_1 > 10.k_{-1}$; $k_2 > 10.k_{-2}$ and $k_2 > 100.k_1$. The form of soil phosphate measured by the normal extraction conditions for the Bray 2 method is produced directly from the solution phosphate and its transient nature suggests that the mechanism is as depicted in table 3 rather than a series of parallel reactions where the extractant attacks increasingly insoluble forms. The *STV* estimated by the Bray 2 method represents only a small proportion of the phosphate in forest soils and it is apparent that the major source of soluble phosphate is not assessed using the normal analytical conditions.

No data is available at present concerning soil properties other than phosphate and potassium and this must be obtained if the *STV*'s are to be meaningful. By choosing suitable values of s and t for the estimations,

Fig 2



Dynamics of soil phosphate time dependence of extractable P after addition of 1 mM P/g soil

it might be possible to determine the concentrations of the different forms of a property in a soil with reasonable accuracy. This can only be done if a knowledge of the mechanism exists. An arbitrary choice of a single value of s and t will give an *STV* which is composed of unknown proportions of different chemical entities. The analysis of samples at several different combinations of s and t would seem to offer a better alternative.

Field variation of soil properties

Although a knowledge of the variation of different parameters is necessary for accurate interpretation, the variation of *STV's* is only rarely known when these are being related to other factors. This type of work is unglamorous and only a few detailed studies have been made considering the number and type of experiments which monitor *STV's*. Most sampling schemes are systematic since they are easy to operate in the field and give an estimate over the whole area sampled. The pattern and depth of sampling might be important when considering the early stages of a plantation and the associated management practices that can change the rooting volume.

The variation of *STV's* measured under a 38 years old plantation of Sitka spruce (table 4) are similar to those previously reported for forest soils (Alban 1974; Blyth & Macleod, 1978). The differences in the variation of individual properties between a series of adjacent plots is so large that no two plots could be considered to be alike. True replication of soil properties does not seem to exist suggesting that plots must be considered only as individuals and the variation in each estimated separately. Even with this level of variation, the lack of correlation between *STV's* and tree growth could not be attributed to soil test variability.

TABLE 4

Estimates of (a) the mean and (b) the number of samples¹ needed to estimate the mean of soil parameters under a plantation of Sitka spruce.

Soil test		With F + H layers		Without F + H layers.	
		a	b	a	b
Total	N	0.81	13	0.77	11
Bray 2	P	21	58	18	50
Ammonium acetate extractable (pH 4.8)					
	k	84	12	65	17
	Ca	228	43	186	47
	Mg	70	13	66	12
Dithianite extractable					
	Fe	245	29	247	22
	Al	19	24	20	13

¹ estimated to $\pm 10\%$ with 95% confidence limits.

Other factors affecting the validity of soil test values

The commonly used soil test methods would not be expected to make an estimate of the organic forms in the soil. In the case of phosphate, the litter layer which is predominantly organic is considered to supply approximately half of the annual requirement of a tree crop (Miller et al, 1979). As the canopy closes and a litter layer becomes established, different methods will have to be used to estimate the properties of interest. This assumes that there is a distinct litter layer which can be treated separately. Except in rare cases when the litter decomposes within one year, site assessment techniques would have to take into account the changing dependence upon the litter layer as a source of nutrient. The build up of a litter layer represents an accumulating nutrient drain on the site and the proportion of nutrient which remains unavailable to a tree crop is an important factor. Since litter accumulates on most sites, measuring only the total nutrient contents does not seem to be a worthwhile exercise.

There is evidence that physiological factors can affect nutrient uptake and the growth of the tree crop. This can take the form of nutrient balance or directly in the growth and development of the roots. If more than one nutrient has to be assessed in order to predict the response of a tree crop to added fertilizer as suggested by Miller (1978), it will be necessary to understand the inter-relationship between site factors and nutrient interactions before useful relationships will be obtained. The growth of the root system is as important as the bole of the tree since this affects both the stability of the tree and the ability to take up nutrients. Responses of the root system to environment are very difficult to observe and quantify (Sutton, 1978).

The mobility of nutrients within the tree and the input through rainfall could confound a relationship when these make a significant contribution to the nutrient requirements. In the establishment phase it is necessary to consider the ground flora on the site. Different species can either supply nutrients to the tree crop or can compete so effectively that the trees take a long time to reach canopy closure. For example, leguminous plants can supply nitrogen whereas *Calluna vulgaris* suppresses the growth of Sitka spruce. Soil test methods are not developed to the stage where such factors can be accounted for and there is a need for these aspects to be quantified.

D I S C U S S I O N A N D C O N C L U S I O N S

The poor correlation between tree growth and *STV*'s, measured using the normal analytical conditions, could be attributable to a number of factors. The problem might be physiological due to nutrient interactions, for example, in which case this problem will only be solved when the relevant research is done. Another possibility lies in the method of assessing *STV*'s. With the exception of potassium, there is clear evidence that the forms of the other properties, estimated using extractant solutions, are transients in a complex chemical mechanism. For phosphate, the Bray 2 method estimates a form which is in equilibrium with another form whose concentration is greater by a factor of 10. This other form could be the major source of phosphate to the tree crop and this possibility has to be evaluated.

The appearance of the bulk density in the rate equations could also be a contributory factor. This influences the rate at which nutrient passes into solution, but the movement of water over the root surfaces will affect the probability of nutrient uptake by the tree. It might be expected, therefore, that the tree growth/*STV* relationships will be dependent upon soil type which affects both the hydrological properties and the rooting pattern.

The rate of reaction is dependent upon the size of the rate constant and the concentrations of the different forms. Close to equilibrium, ie prior to afforestation, the concentrations of the different forms is established by the relative sizes of the rate constants. If a large

nutrient drain such as a tree crop now affects the system, the near-equilibrium conditions are disturbed. If the nutrient uptake by the tree crop is slow compared to reactions within the soil and between the soil and soil solution, then the concentrations in the soil *STV* will reflect the availability of the nutrient. If they are comparable in size, then the rate constants have to be determined which is a difficult proposition and could not be considered feasible for a large number of samples. All the evidence suggests that the rate of nutrient uptake is slower than the transformations in the soil although this is based on only a relatively small number of sites. The immediate need therefore lies in finding the analytical criteria to estimate the different forms of the soil properties and establish the major sources of soil nutrients to the tree crop.

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A B S T R A C T

The ability of soil testing techniques to assess site characteristics, or estimate available nutrients, depends upon the validity of the analytical techniques and a knowledge of the soil test variation in the field. The observed results obtained from using extractant solutions are dependent upon the preparation of the sample and the analytical conditions. No relationship between extractable nutrients and tree growth could be established even when gross nutrient deficiencies were known to exist. An intensive systematic sampling scheme indicated that the variability of soil parameters could not account for the poor relationship. It appears, from time-concentration studies, that the properties estimated by extraction techniques do not represent the major source of nutrient in the forest system but are part of a complex series of consecutive reversible reactions. Establishing the characteristics, and means of assessment, of the primary nutrient sources should be of the highest priority.

Other key words: *Picea sitchensis*; variation.

Z U S A M M E N F A S S U N G

Die Möglichkeit, durch Bodenanalysen die Eigenschaften eines Bodens zu charakterisieren oder die verfügbaren Nährstoffe zu schätzen, hängt von der Eignung der analytischen Methoden ab und erfordert ausserdem eine Kenntnis der Bodenvariationen des Standorts ab. Die Analysenergebnisse, die mit Hilfe von Lösungsmitteln erhalten werden, sind überdies abhängig von der Vorbehandlung der Bodenproben und den Analysebedingungen. Zwischen dem Gehalt an löslichen Nährstoffen und dem Zuwachs der Bäume konnte kein Zusammenhang festgestellt werden, selbst dort nicht, wo das Bestehen grossen Nährstoffmangels nachgewiesen war. Durch intensive systematische Probenahmen konnte festgestellt werden, dass Schwankungen der Bodenparameter nicht für diese mangelnde Korrelation verantwortlich sein können. Untersuchungen von Konzentrationsänderungen über kurze Zeiträume deuten darauf hin, dass die Bodeneigenschaften, die durch Extraktionsmethoden geschätzt werden können, nicht die Hauptnährstoffquellen im System des Waldes repräsentieren, sondern dass sie viel mehr nur einen Teil sehr komplizierter Aufeinanderfolgen reversibler chemischer Reaktionen darstellen. Es erscheint äusserst dringend, über die Natur der wichtigsten Nährstoffquellen Untersuchungen anzustellen und Mittel zu ihrer Feststellung zu erarbeiten.

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