THE USE OF NITROGEN-FIXING TREES AS INDICATORS OF SITE QUALITY

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SUMMARY

This paper sets out to show how the results of the performance of Nitrogen-fixing trees in a network of three tropical soil families (located in the Philippines, Indonesia and Hawaii) could be used to test the Benchmark hypothesis that soil with similar soil family classification should exhibit similar crop performance irrespective of location. It also shows which of five nitrogen-fixing trees so tested did in fact support that hypothesis.

The paper also considers that the Benchmark hypothesis should, in order to be a suitable basis for agrotechnology transfer, be broadened to include the other non-soil factors (eg. climate and relief) which have a tremendous effect on the site and thus influence plant growth enormously.

Furthermore the paper contends that nitrogen-fixing trees are not, a priori, the best tree species for use as indicators of site quality and therefore of soil family classification.

Finally the paper draws attention to the fact that an essential pre-requisite for the global application of results obtained by testing the Benchmark hypothesis is the establishment - by an ad hoc team of Soil Science experts - of a correspondence

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between the U.S. System of soil classification and the other (FAO, French) soil classification systems practised in different countries. It notes also that such a correspondence should be the spring board from which to leap into the new project which has followed the Benchmark Soils Project (BSP) and which has been called IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer)

INTRODUCATION

This paper has been developed from observations which the author made in response to a memorandum (1) addressed in August 1982 to all their international cooperators by the researchers of the Benchmark Soils Project, University of Hawaii. That memorandum presented the initial findings on the growth of nitrogen-fixing trees planted in their network of three tropical soil families and sought to establish from those cooperators, inter alia, if the findings presented do support the Benchmark hypothesis being tested by the Benchmark Soils Project ie. the hypothesis that soil with similar soil family classification should exhibit similar crop performance irrespective of location (1). The growth measurements are shown on a table hereinafter.

The impetus to develop those observations into the present paper has come from the fact that a Workshop on Nitrogen-fixing trees has been organised by the International Development Research Center to take place in Dakar (2), Senegal from 17 - 21 March, 1986 - a Workshop to which I have had the honour of being invited (2) - and the programme of the workshop indicates that one of the sessions will address the role of Nitrogen-fixing trees as producers of furniture wood, firewood, forage and as components of Agroforestry. Since the test which was carried out by the Benchmark Soils Project in relation to the Benchmark hypothesis carries in effect an assumption that Nitrogen-fixing trees could satisfactorily play the role of site-quality indicators, it occurred to the author that it might be instructive to examine that role a little more closely.

Another factor that has prompted the development of those observations into the present paper is that Cameroon is one of the cooperators of the Benchmark Soils Project [3] and the author would like to share his reflections on this matter with other scientists during an international forum.

<u>OBJECTIVE</u> The objective of the paper is five-fold :

(i) To present the Seminar participants and other interested scientists the author's observations on how the results of the performance of Nitrogen-fixing trees could be used to test the Benchmark hypothesis ;

(ii) To show which of five Nitrogen-fixing trees so tested did in fact support the hypothesis ;

(iii) To suggest the need for broadening the Benchmark hypothesis to include non-soil factors, if that hypothesis is to be a suitable basis for agrotechnology transfer ,

(iv) To examine the suitability of Nitrogen-fixing trees as indicators of site quality and therefore of soil family classification and

(v) To draw attention to the need for harmonising soil classification so as to facilitate a global application of results obtained by testing the Benchmark hypothesis.

INITIAL FINDINGS ON THE GROWTH PERFORMANCE OF NITROGEN-FIXING TREES PLANTED IN THREE TROPICAL SOIL FAMILIES

The initial findings are set out as average height in meters of five replicated nitrogen-fixing tree species at 6 months after planting in three soil families. They are as follows :

NFT Species (1)	Davao (2)	Nakau (3)	Waipio (4)	Iole (5)
1. Leucaena diversifolia	4.24	2.49	2.06	0.50
2. Leucaena leucocephala	4.22	2.39	1.18	0.20
3. Sesbania grandiflora	3.81	2.14	1.06	0.45
4. Calliandra calothyrsus	2.75	2.03	0.75	0.40
5. Acacia auriculiformis	1.95	1.60	0.70	0.30
Tallest species at each site	Leucaena diversifolia & leucaena Leucocephala	Albizia falcataria 2.73 & Leucaena diversifolia 1.58 m	Leucaena diversifolia & Albizia falcataria	Acacia mearnsii 1.29 m & Euclyptus Saligna 0.72 m

Site	Soil Family Classification
Davao, Philippines	clayey, kaolinitic, isohyperthermic, Typic Paleudults
Nakau, Sumatra	clayey, kaolinitic, isohyperthermic, Typic Paleudults
Waipio, Hawaii	clayey, kaolinitic, isohyperthermic, Tropeptic Eutrustox
Iole, Hawaii	thixotropic, isothermic, Hydric Dystrandepts

Examination of initial findings to discover if they do support the Benchmark Soils Project Hypothesis

(i) The Hypothesis to be tested

The Benchmark Soils Project hypothesis to be tested is that "Soil with similar soil family classification exhibits similar crop performance irrespective of location".

(ii) Definition of terms

In order to assist - indeed to render possible - the use of data given above for testing the validity of the Benchmark hypothesis, it is necessary to eliminate all ambiguity of meaning by clarifying or redefining certain terms used in the formulation of the hypothesis as well as by clarifying the real objectives of the experiment as summarised by the Benchmark hypothesis.

These terms are :

- <u>Similar soil family classification</u>

  Similar soil family classification may mean :

  (a) <u>Identical</u> soil family classification.

  Given this meaning, we can identify 2 and only 2 soil family classifications in the findings given above that are "similar". These are the soil family classifications at Davao (Philippines) and at Nakau (Sumatra). The soil family classifications at these two sites are indentical and represented by : clayey, kaolinitic, isohyperthermic, Typic, Paleudults.

  (b) Soil family classification which is "<u>not too different even if different</u>". Given this meaning we can indentify 3 soil family classifications that are similar. These are the soil family classifications for Davao, Nakau and Waipio (Hawaii).

  (c) <u>Similar soils</u> may also mean [4] "soils in similar climates, despite differences in parental or source rocks". This definition has not been adopted here since it does not involve any soil measurement; it involves only measurements of climatic data.

- <u>Similar crop performance</u>

  This will be taken to mean crop performance that is the same or that shows differences that are not significant.

  <u>The real objectives of the experiment</u>

  The principal objective of the experiment is, we believe, to find out whether, <u>for a selected nitrogen-fixing tree</u> (eg. <u>Leucaena diversifolia</u>) there is any significant differences in crop performance in the 3 similar sites mentioned in the above definition ie. the sites at Davao, Nakau and Waipio. In this connection, the principal objective is <u>not</u> to find out from among the 5 nitrogen-fixing trees mentioned in column (1) of the findings, which is the winner for planting programmes in the sites considered. The secondary objective of the experiment might be to obtain some clue about the relative performance of the 5 nitrogen-fixing trees mentioned above in the 3 sites said to be similar.

(iii) Experimental Design

Though this has not been expressely stated, we believe the Experimental Design employed has been Complete Blocks, Randomised; with 4 Blocks (hence 4 Replications) and 5 Treatments.

Given the concern of the Benchmark hypothesis (crop performance in similar soil sites) and the amplification of this concern as given in the statement of the principal and secondary objectives above, it may be asked whether the experiment should have involved 3 sites only (Davao, Nakau, Waipio) or it should also have included a 4th site, Iole, which is certainly dissimilar from the other sites. This is a question of whether the data in column (5) - Iole site - is superfluous (and should be excluded from the comutations to be made) or whether it is necessary and should be treated as the "control". On this question, it seems that the Benchmark hypothesis makes no affirmation about dissimilar soils (though it is curious to note that the Benchmark Soils News [(5)] in discussing in the second quarter of 1982 these same findings of the Benchmark hypothesis made the topic theme "Nitrogen Fixing Trees Reflect Soil Family Differences"); the data for Davao, Nakau and Waipio were all that concerned that hypothesis; we shall therefore make separate computations (statistical analysis) based on data from these 3 sites only ie. adopt a design of 5 Treatments and 3 Replications. However, since figures for a 4th site have been included in the experiment and since we can also incorporate those figures into the computations with a view to :

(a) determining the relative performance of any of the nitrogen-fixing trees in the site at Iole, as compared with the performance in the sites at Davao, Nakau and Waipio ;

and (b) comparing the relative precision of the two designs, we shall make a second, separate, set of computations (statistical analysis) based on data from all the 4 sites (ie. a design of 5 Treatments and 4 Replications).

The Treatments

These are the 5 legume species planted in the sites selected ie. the nitrogen-fixing trees (NFT) listed in column (i) of the findings. Here it may be noted that some of the species (Albizia falcataria, Acacia mearnsii and Eucalyptus saligna) stated (at the bottom of the findings) as being the tallest species at each site are absent from the list of 5 species recorded in column (1). These "tallest species" will therefore not be considered in determining whether or not crop performance in similar soil families is similar.

Treatment Effects

These are the crop performances (in meters of mean height after 6 months) given in the findings for each of the species used ie. the figures in columns (2), (3), (4) and (5) of the findings. As a corollary to the remark made above about the tallest species, it may here be further noted that the mean heights for the tallest species given in the findings (2.73m, 1.58m, 1.29m and 0.72m) will not be used as they provide data from which no inference-relevant to the hypothesis to be tested-can be made.

(iv) Verification of the Treatment comparisons that are relevant to each of the stated objectives of the experiment

For the principal objective defined above, the treatment comparisons that are relevant are comparisons, in the first place of the mean heights in columns (2), (3) where sites are identical and, in the second place of the mean heights in column (3) as well for selected species. For example for Leucaena diversifolia, comparisons of 4.24, 2.49 and 2.06 are involved.

For the secondary objective, the treatment comparisons are the comparisons, for a given site (Block), of the figures for that site. For the site at Davao, this involves comparisons of the figures in column (2) ie. 4.24, 4.22, 3.81, 2.75, 1.95 to see if they are significantly different one from another.

(v) <u>The standard method of determining or testing significance</u>

A standard method of testing significance in field experiments is to proceed by drawing up an "<u>Analysis of Variance Table</u>" which gives for the different sources of variation that are concerned (Total, Treatment, Block and Error) the appropriate Degrees of freedom (df), the sum of squares of means for total (SS), the sum of squares for Treatment's (SST), the sum of squares for Block (SSB) and the sum of squares for Error (SSE). These statistics, combined with a knowledge of the Correction Factor (CF) lead to the calculation of the Mean Square Variance for Treatments (MST), for Blocks (MSB) and for Error (MSE). From these Mean Square Variance values, the F value for Treatments (MST/MSE) and the F value for Blocks (MSB/MSE) are calculated. These calculated or observed F values can then be compared with the Tabulated F values for Treatments and Blocks at the 5 % probability level to see if they are significant or not. (If the tabulated F values are smaller than the calculated or observed values, it is legitimate to reject the Null Hypothesis and to conclude that the differences in the Treatments and Blocks are significant at the 5 % level).

Using the above overview and bearing in mind the mathematical definition of the concepts referred to above as given by standard statistical theory, we have established as hinted earlier, 2 Analysis of Variance Tables, one involving the first Design (3 Replications) and the other the second Design (4 Replications). The details of these analysis are given hereunder (see vi (a) - (vi) (d).

(vi)(a) **Statistical Analysis of the Growth Performance Nitrogen-fixing Trees (1st Design - 3 sites).**

BLOCKS > TREATMENTS	DAVAO		NAKAU		WAIPIO		SUM OF MEANS (TREATMENTS)	SQAURE OF SUM OF MEANS (TREATMENTS)
1.	4.24	17.98	2.49	6.20	2.06	4.24	8.79	77.26
2.	4.22	17.81	2.39	5.71	1.18	1.39	7.79	60.68
3.	3.81	14.52	2.14	4.58	1.06	1.12	7.01	49.14
4.	4.75	7.56	2.03	4.12	0.75	0.56	5.53	30.58
5.	1.95	3.80	1.60	2.56	0.70	0.49	4.25	18.06
SUM OF MEANS BLOCKS	16.67		10.65		5.75		33.37	235.72
SUM OF SQUARES MEANS		61.67		23.17		7.80		92.64
SQUARE OF SUM OF MEANS	287.98		113.17		33.06			434.21

$$CF = \frac{(33.37)^2}{3 \times 5} = \frac{111\ 3.56}{15} = 74.18$$

$$SST = \frac{235.72}{3} = 78.57$$

$$SSB = \frac{434.46}{5} = 86.84$$

VI (b) Analysis of Variance Table

(1st Design - 3 Sites)

SOURCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE VARIANCE	F VALUE (Observed)
Total	14	SS-CF = 92.64-74.18 = 18.46		
Treatment	4	SST-CF = 78.58-74.18 = 4.39	$\frac{4.39}{4} = 1.10$	$\frac{1.10}{0.18} = 6.11$
Blocks	2	SSB-CF = 86.84-78.18 =12.66	$\frac{12.66}{2} = 6.33$	$\frac{6.33}{0.18} = 35.17$
Error	8	SS-SST-SSB = 18.46-4.39-12.66 = 1.41	$\frac{1.41}{8} = 0.18$	

Tabulated F Value

For Treatments : 5 %
3.84

For Blocks 5 %
4.46

VI (c) **STATISTICAL ANALYSIS OF THEGROWYH PERFORMANCE OF NITROGEN FIXING TREES (2nd Design - 4 Sites)**

BLOCKS	DAVO		NAKAU		WAIPIO		TOLE			
TREATMENTS	Mean Ht (M)	(Mean Ht)2	Mean Ht (M)	(Mean Ht)2	Mean Ht (M)	(Mean Ht)2	Mean Ht (M)	(Mean Ht)2	Sum of Means	Squares of sum of mean (treatment)
1	4.24	17.98	2.49	6.20	2.06	4.24	0.50	0.25	9.29	86.30
2	4.22	17.81	2.39	5.71	1.18	1.39	0.20	0.04	7.99	63.84
3	3.81	14.52	2.14	4.58	1.06	1.12	0.45	0.20	7.46	55.65
4	2.75	7.56	2.03	4.12	0.75	0.56	0.40	0.16	5.93	35.16
5	1.95	3.80	1.60	2.56	0.70	0.49	0.30	0.09	4.55	20.70
Sum of mean (blocks)	16.97		10.65		5.75		1.85		35.22	261.65
Sum of squares of means		61.67		23.17		7.80		7.40		100.04
Squares of sum of means	287.98		113.42		33.06		3.42			437.88

$$C.F. = \frac{(35.22)^2}{4 \times 5} = \frac{1240.44}{20} = 62.02$$

$$S.S.T. = \frac{261.65}{4} = 65.41$$

$$S.S.B. = \frac{437.88}{5} = 87.58$$

VI (d) Analysis of Variance Table

(2nd Design - 4 Sites)

SOURCE	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE VARIANCE	F VALUE (Observed)
Total	19	SS-CF = 100.04-CF = 100.04-62.02=38.02		
Treatment	4	SST-CF = 65.41-62.02= 3.39	$\frac{3.39}{4}$ = 0.85	$\frac{0.85}{0.67}$ = 1.27
Block	3	SSB-CF = 87.58-62.02=25.56	$\frac{25.56}{3}$ = 8.52	$\frac{8.52}{0.67}$ = 12.72
Error	12	SS-SST-SSB=38.02-29.95=8.07	$\frac{8.07}{12}$ = 0.67	

Tabulated F value

	5%
For Treatments	3.26
For Blocks	3.49

(vii) <u>Interpretation of Results from the Analysis of Variance Tables</u>

(a) <u>1st Design (3 Sites)</u>

Since the observed F value for Treatments (6.11) is greater than the tabulated F value for Treatments (3.84) at the 5 % probability level, we can reject the null hypothesis for Treatments and say that the differences between treatment effects are significant at the 5 % probability level.

Furthermore since the observed F value for Blocks (35.17) is vastly greater than the tabulated F value for Blocks (4.46) at the 5 % probability level, we may safely conclude that Block (site) differences are significant at the 5 % probability level.

This finding is surprising and indicates that the similarity of site denoted by the soil family classification is a superficial similarity and that other non soil factors (eg. climatic and relief factors) that play a significant role in crop performance are operating.

Since Treatment differences are found by the F test to be significant, we may now embark on the operation of finding out which Treatment means are significantly different. This we can do by calculating the Least Significant Difference (L.S.D), using the t test :

$$L.S.D_{0.05} = t_{0.05}\sqrt{\frac{2S^2}{r}}$$

where $L.S.D._{0.05}$ = Least Significant Difference at the 5 % probability level

$t_{0.05}$ = tabular t value for the degree of freedom for Error at 5 % probability level ;

S^2 = Mean Square for Error = MSE

r = number of replications.

Substituting, we have

$$L.S.D._{0.05} = 2.306\sqrt{\frac{2. \times 0.18}{3}}$$

$$= 2.306 \times \sqrt{0.12} = 2.306 \times 0.34$$

$$= 0.78$$

Considering the L.S.D of 0.78 and considering the crop performances in the 4 locations, we might conclude that the Benchmark hypothesis appears to be true for :

(i) Leucaena diversifolia in respect of Nakau and Waipio (for 2.49m - 2.06m = 0.43m, which is less than the L.S.D of 0.78m).

(ii) Sesbania grandifolia in respect of Waipio and Iole (for 1.06m - 045m = 0.61m, which is less than the L.S.D of 0.78m).

(iii) Calliandra calothyrsus in respect of Davao and Nakau (for 2.75m - 2.03m = 0.72m which is less than the L.S.D of 0.78m).

(iv) Acacia auriculiformis in respect of Davao and Nakau (for 1.95m - 1.60m = 0.35m, which is less than the L.S.D of 0.78m).

This observation may be reformulated by stating that in this experiment the similarity of the sites at Davao and Nakau has been demonstrated by the performance of Calliandra calothyrsus and Acacia auriculiformis on these sites. On the other hand the performance of Leucaena diversifolia, Leucaena leucocephala and Sesbania grandifolia in Davao and Nakau has not shown that these sites are similar. From this one may conclude that all nitrogen-fixing trees are not equally efficient as indices of site quality and/or that soil family classification alone may be a necessary but not a sufficient condition for defining site quality.

(b) 2nd Design (4 sites)

Since the observed F value for Treatments (1.27) is smaller than the tabulated F value for Treatments (3.26) at the 5 % probability level, we can accept the null hypothesis for Treatments.

Furthermore since the observed F value for Blocks (12.72) is greater than the tabulated F value for Blocks at the 5 % probability level, we may conclude that Block (site) differences are significant at the 5 % probability level.

We may now find out which Block means are significantly different by calculating the L.S.D using the t test as before :

$$L.S.D._{0.05} = t_{0.05}\sqrt{\frac{2S^2}{r}}$$

Substituting, we have :

$$L.S.D._{0.05} = 2.176\sqrt{\frac{2 \times 0.67}{4}}$$

$$= 2.176\sqrt{0.335}$$

$$= 2.179 \times 0.58$$

$$= 1.26$$

Using the L.S.D of 1.26 and considering crop performances in the two identical (and therefore similar) sites, we find, as before, that the Benchmark hypothesis has been upheld by the data for *Calliandra calothyrsus* and *Acacia auriculiformis* in respect of Davao and Nakau (since 2.75 - 2.03 = 0.72, which is less than 1.26; and 1.95 - 1.60 = 0.35, which is less than 1.26) but not upheld by the data for any of the tree species *Leucaena diversifolia*, *Leucaena leucocephala* and *Sesbania grandifolia*.

(viii) Comparison of the relative precision of the two designs

This may be done by computing the Error variance of the difference between the means for the two designs using :

$$\text{Error Variance of difference} = \frac{2S^2}{r} \quad (6)$$

where S^2 = mean square for error = MSE

r = number of replications

Substituting for the 1st design, we have Error Variance of

$$\text{difference} = \frac{2 \times 0.18}{3} = \frac{0.36}{3} = 0.12$$

Substituting for the 2nd design, we have Error Variance of

$$\text{difference} = \frac{2 \times 0.67}{4}$$

$$= 0.335 = 0.33$$

The greater the value of $\frac{2S^2}{r}$, the smaller the efficiency of the design. In the two designs considered the 1st (with only 3 replications) was therefore more efficient than the 2nd. Furthermore, by definition, the inverse ratio per unit (design) of variances is sometimes called the <u>relative efficiency</u>[6]. Thus in our case, the relative efficiency of the first design (involving 3 replications) is 1/0.12 = 8.33; similarly the relative efficiency of the second design (involving 4 replications) is 1/0.33 = 3. The relative efficiency of the first design compared to that of the second is therefore 8.33/3 = <u>2.78 or 278 %</u>; otherwise stated, the relative gain in efficiency of the first design over the second design is 1.78 or <u>178 %</u>.

DISCUSSION

(i) The experimental design

In this section we offer comments about how the experimental design might have been organised so that the data obtained from it might better assist the statistician to determine whether the researchers' hypothesis was tenable or not.

Since the researchers' hypothesis is concerned with crop performance in similar soil family classification in different locations, the simplest approach in evolving a design that could be used to test the hypothesis consists in :

(a) selecting, unambiguously, a given soil family classification ;

(b) selecting different (three, four or more) locations each of which enjoys the soil family classification selected in a) above ;

(c) planting a selected crop on each of the locations referred to in (b) above using a design of Complete Blocks Randomised (Such planting may be made using other crop types if desired to see for what particular crops - or range of crops - the hypothesis is true);

and (d) comparing, for the crop selected, performance recorded in each of the locations to see if differences are significant. It may here be noted that, as we have already remarked elsewhere above, the researchers did not, in presenting their findings, make it quite clear which of the four family classifications they considered were in fact "similar". In consequence some ambiguity could arise in considering the locations that are relevant for the exercise of testing this hypothesis.

(ii) The Benchmark hypothesis

The Benchmark hypothesis states that "similar soil family classification exhibits similar crop performance, irrespective of location". We know for certain that such non-soil factors as rainfall and its distribution, air temperature, prevailing winds and altitude affect crop performance one way or the other. If the hypothesis seeks to suggest that the separate or combined effect of these other-factors is minimal in relation to the effect of soil, that would seem to be too large a claim. Perhaps this explains why, for the first three nitrogen-fixing trees used in the experiment, the performance (as measured by mean height) in the location Davao was significantly different from the performance in the location Nakau, notwithstanding that the two locations have identical soil family classification. Furthermore, if we consider cases where crop performance is measured by "fruit yield" (and not by height growth) and the fact that for some crops (eg. cocoa) the greatest handicap to production is due to pest (fungal) attack, the Benchmark hypothesis should be modified to take account of such cases. In deed the present IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) approach [7] which is concerned with reaching a concensus on, among other things, "the minimum soil-crop-weather-management data set to collect from each experiment" is to be lauded as it is already addressing this concern.

(iii) The suitability of Nitrogen-fixing trees as indicators of site quality

Since all living things require Nitrogen to live and grow and since plants can only use Nitrogen that is combined or fixed (with Hydrogen or Oxygen) in simple compounds (primarily Ammonium and Nitrate compounds) [8], plants to be used as site quality indicators should preferrably be those which lack the capacity to change the site by Nitrogen-fixing. In this connection, the growth performance of Nitrogen-fixing trees may be said to be due to two factors :

- the soil and other environmental factors existing at the site before planting ;
- the ability of these trees to fix the Nitrogen in the soil by means of the symbiotic bacteria contained in the root nodules of these legume plants (9).

These considerations suggest that Nitrogen fixing trees are not, a priori, the best tree species for use as indicators of site quality and therefore of soil family classification.

(iv) The global application of results obtained by testing the Benchmark hypothesis

Since different countries use different systems of soil classification it is recommended that an ad hoc team of soil science experts should work to establish a correspondence between these systems (the United States, FAO and French) so as to facilitate a global application of results obtained by testing the Benchmark hypothesis. Such a correspondence would also be an invaluable tool to researchers of the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT).

C O N C L U S I O N

The thought - provoking views contained in this paper have been expressed in the hope that they may make some contribution to the cause of international cooperation in the domain of scientific development. The author will be grateful for any positive criticism that these views may provoke./-