QUANTITATIVE EVALUATION OF AGROTECHNOLOGY TRANSFER

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Abstract

Transferability of agrotechnology has long been implicitly assumed in making management recommendations. The Benchmark Soils Project was designed to experimentally evaluate the feasibility of transferring management practices in the tropics on the basis of the soil family. Two transfer models, based on the prediction of yields not used in estimating the transfer function, are proposed, and data analysis methodology developed for the evaluation of transferability within a soil family. The methodology includes calculation of the significance level of a prediction statistic and graphic comparison of the estimated transfer functions. Application of the evaluation methodology is made to maize experiments on *Hydric dsystrandepts*.

A. General

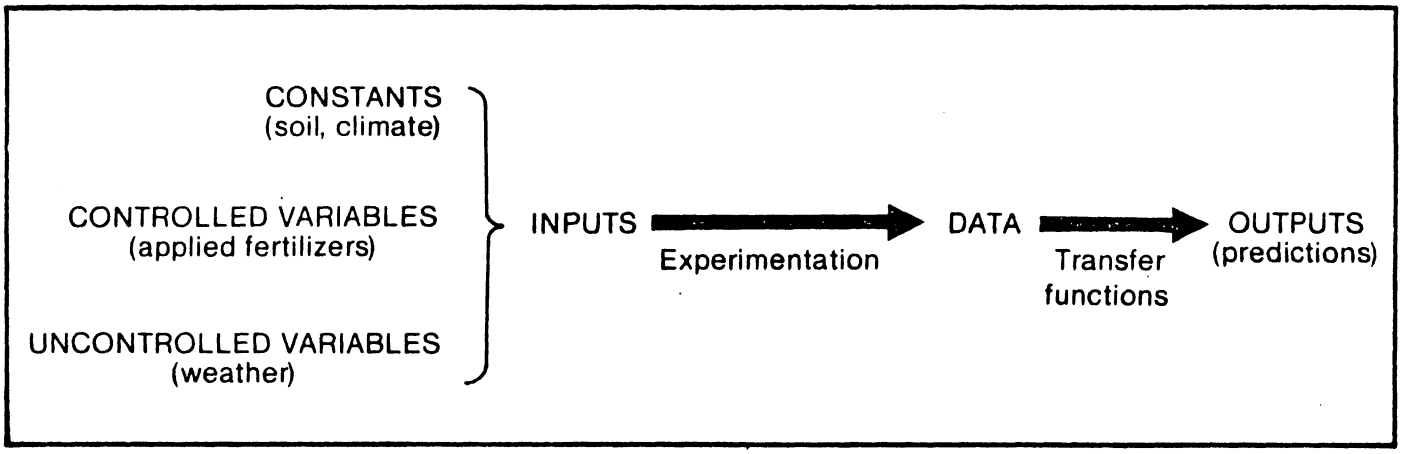
Agrotechnology transfer is the extrapolation of a response-input relationship, estimated from known experimental situations, to other similar conditions. Agronomists have long been concerned with the analogous problem of making inferences to farmers' fields. The target population for transfer can be defined as a geographical area or defined by other criteria such as soil and past management information (Cady 1974). Recommendations based on a relatively large number of site specific experiments, coupled with long-term experience of agronomists, has been the *modus operandi* for transferring agrotechnology. In less developed countries, however, a need presently exists to shorten the time and effort required for extensive site specific experimentation.

A major objective of the Benchmark Soil Project, established by U.S.A.I.D. (Agency for International Development) in cooperation with the Universities of Hawaii and Puerto Rico, is to evaluate the hypothesis that crop production technology is transferable on the basis of similarity of soils as indicated by the soil family in the Soil Taxonomy Classification System (Soil Survey Staff 1975). The soil family was selected for the hypothesis since the family classification integrates soil factors with the long-term environmental factors that influence crop yield. The theory is that experimental results, specifically the response of maize to applications of phosphorus and nitrogen, obtained from one series of experiments can be applied to other sites on the same soil family.

Transferability of management practices may be accepted when the weight of evidence is sufficiently convincing. Based on data from a series of experiments conducted by the Benchmark Soils Project, where the management factors are the same for each experiment, the feasibility of transferring crop response was evaluated. Developed here are the criteria and the data analysis methodology needed for the evaluation of transferability within a soil family.

A quantitative evaluation starts with formulation of a general transfer model for the relationship between response data and various inputs, as is schematically shown in Figure 1. Two determinants of yield, soil and the covariant of long-term climate, are important inputs and assumed to be constant within a soil family. Designed as variable inputs are management factors which are intentionally controlled at several levels. Other controllable factors not part of the treatment design are experimentally maintained at a constant level so that the response to the treatment design factors is the only information to be transferred. Actual soil levels of the treatment design factors are not constant

Figure 1



CONSTANTS
(soil, climate)
CONTROLLED VARIABLES
(applied fertilizers)
UNCONTROLLED VARIABLES
(weather)
INPUTS
Experimentation
DATA
Transfer
functions
OUTPUTS
(predictions)

across the experimental sites within a soil family, however, due to natural and past management variabilities. These and other variable inputs, including weather factors such as temperature and solar radiation, cannot be controlled at a constant level but they can be measured at each site.

B. The Transfer Model

For developing a measure of the weight of evidence in order to evaluate transferability, the relationship between the response data and the known levels of controlled and uncontrolled variables is characterized by parameters of a transfer function equation. Neglecting the uncontrolled variables for now, we can express the observed plot data (Y), which depend on the controlled variables, for example, applied phosphorus (P) and applied nitrogen (N), as

$$Y = f(P,N) + E \tag{1}$$

where the error component, E, the difference between the response data, Y, and the transfer function, $f(P,N)$, is attributable to unknown sources and assumed to be random variation. Different mathematical forms for $f(P,N)$, including polynomials and exponentials, have been used by soil fertility specialists. Historically, the parameters of the response-input relationship, $f(P,N)$, are estimated from the data for each site and the estimated function, $\hat{f}(P,N)$, is constructed by substituting the calculated statistics for the parameters. The resulting prediction equation for each site is expressed as $\hat{Y} = \hat{f}(P,N)$ where the $\hat{Y}$'s are the predicted data for each plot. The differences between the observed plot data and the predicted data, $Y - \hat{Y}$, are called the ordinary residuals.

A straightforward statistical procedure for evaluating the transfer hypothesis is to test the homogeneity of the regression coefficients in the k transfer functions relating response to the controlled variables at each of the k experimental sites. If the transfer function model is the same for all the selected sites, then agrotechnology can be transferred from one site to another through a common transfer function. Specifically, if the homogeneity hypothesis is not rejected, there is not sufficient evidence to indicate that a different model holds for each site. Then a common transfer function can be estimated and in this sense, the agrotechnology can be transferred.

However, agrotechnology transfer is interpreted here as the extrapolation of a response-input relationship, estimated from a series of experiments, to new sites. Practically, we would like to evaluate transferability with only one series of experiments; consequently, the evaluation needs to simulate the transfer to nonexperimental sites. As developed by Wood and Cady (1980), the general approach incorporates into the data analysis the prediction of yields not used in the estimation of the prediction equation. Specifically, the approach is to predict yields, denoted as $\hat{Y}_{(-i)}$, for one of k experimental sites using a transfer function estimated from the other $(k-1)$ sites. The subscript i is an index for sites, $i = 1, 2, \cdots, k$. This is then repeated for each of the k sites, that is, we predict yields for each site based on a transfer function estimated from the other $(k-1)$ sites. If the <u>transfer</u> residuals, $Y_i - \hat{Y}_{(-i)}$, are approximately the same magnitude as the <u>ordinary</u> residuals, $Y_i - \hat{Y}_i$, calculated by fitting a response function individually to each of the k sites, we have evidence for agrotechnology transfer. A specific criterion for the evaluation is the prediction statistic, P, defined as the ratio of the pooled sum of squared transfer residuals to the pooled sum of squared within-site ordinary residuals. Thus,

$$P = \sum_{i=1}^{k} [Y_i - \hat{Y}_{(-i)}]^2 \Big/ \sum_{i=1}^{k} (Y_i - \hat{Y}_i)^2 \quad . \qquad (2)$$

Two transfer function models will be considered.

1. **Transfer Model 1.** Assuming the data can be adequately fitted by a quadratic polynomial in the design variables, a simple transfer model (transfer model 1) is a second-order polynomial response surface that is common to all sites but that allows a different intercept for each site. For this model, the test statistic P - 1, multiplied by a known constant, follows the F distribution with 5(k - 1) and the pooled residual degrees of freedom (df). The prediction statistic, P, is evaluating the adequacy of a model with design variables only for use as a transfer model. The prediction equation is based on the shape of the response surface estimated from the other sites coupled with the site mean. Algebraically,

$$\hat{Y} = b_{0i} + b_1 P + b_2 N + b_3 P^2 + b_4 N^2 + b_5 PN \qquad \text{(Model 1)} \quad . \qquad (3)$$

If the P and N variables are coded around zero, then the site intercepts are the predicted yields in the middle of the design. The i subscript on b_{0i} indicates that the intercepts can vary from site to site, while the b_1, b_2, $\cdots$, b_5 terms determine the common shape of the response surfaces. For determining the economically optimal combination of P and N, only the shape, not the height, of the response surface is important. Consequently, differences in the average heights of the individual site response surfaces are allowed in the transfer model by centering the observed yields about the mean for each site.

2. **Transfer Model** 2. A second transfer model (transfer model 2) is model 1 augmented by additional variables for the uncontrolled but measured site variables. These additional variables account for differences in the shape of individual site response surfaces due to interactions between the response surface variables and the site variables, for example, between the P and N linear terms and site variables. For one site variable, denoted by p, the estimated transfer function is written as

$$\hat{Y} = b_{0i} + b_1 P + b_2 N + b_3 P^2 + b_4 N^2 + b_5 PN + b_6 pP + b_7 pN \quad . \tag{4a}$$

An alternative expression is

$$\hat{Y} = b_{0i} + (b_1 + b_6 p)P + (b_2 + b_7 p)N + b_3 P^2 + b_4 N^2 + b_5 PN \quad . \tag{4b}$$

This last equation emphasizes that the interaction variables allow different shapes of the response surface for each site since the estimated coefficients for P and N now depend on p . For transfer model 2, the test statistic, P - 1, is no longer proportional to an F statistic, but the distribution and subsequent significance level can be evaluated by procedures given in Wood and Cady (1980).

C. Application of Transfer Evaluation Methodology

Data from eight maize experiments on the thixotropic, isothermic family of Hydric dystrandepts were used as a numerical example for testing the transfer of yield response to applied P and N . Included are four sites (IOLE-E, KUK-A, KUK-C, and KUK-D) in Hawaii, two (PUC-K and BUR-B) in the Philippines, and two (PLP-G and LPH-E) in Indonesia. A general description of the experimental and treatment designs is given in Wood and Cady (1980).

A quadratic polynomial in the two treatment variables

$$\hat{f}(P,N) = \hat{Y}_i = b_{0i} + b_{1i}P + b_{2i}N + b_{3i}P^2 + b_{4i}N^2 + b_{5i}PN \tag{5}$$

is the assumed f(P,N) and is calculated for each site. The i subscript is an index for site identification, $i = 1$(IOLE-E), 2(KUK-A), ⋯, 8(LPH-E); $\hat{Y}_i$ are the predicted yields for the ith site, and the b's are the estimated quadratic polynomial response surface parameters. The six-parameter quadratic polynomial function is fitted well by the data (three replications of 13 treatment combinations of P and N). Lack-of-fit terms for each site with seven (13 - 6) df are not important and have been pooled with the experimental error sums of squares.

As shown in the previous section, the adequacy of transfer model 1 can be tested by the prediction statistic, which follows the F distribution with 35 and 264 df. The calculated F is 2.99, and the probability of a value of this magnitude, on chance alone, is less than 0.01 . Based on the weight of evidence of transfer model 1, a model with only design variables will not be sufficient. Stated differently, interactions between sites and the quadratic polynomial variables exist. Additional data analysis shows that the P, N, and P^2 terms of transfer model 1 interact with sites — that is, the eight b_1 coefficients for P, the eight b_2 coefficients for N, and the eight b_3 coefficients for P^2 have a systematic trend over the sites rather than the random pattern expected with no interaction. Consequently, the uncontrolled but measured site variables are introduced to quantitatively describe the sites.

Insight on interactions between treatment design variables and site variables can be gained from plotting the estimated coefficients for P, N, and P^2 against selected site variables as shown in Figure 2: block A shows b_1 vs. soil phosphorus as measured by the modified Truog method, Truog p; block B shows b_2 vs. soil nitrogen extracted by 2N KCℓ, Extr. n; block C shows b_2 vs. the average daily minimum temperature during an 8-week period around 50% tasseling, Min. Temp.; and block D shows b_3 vs. Min. Temp.

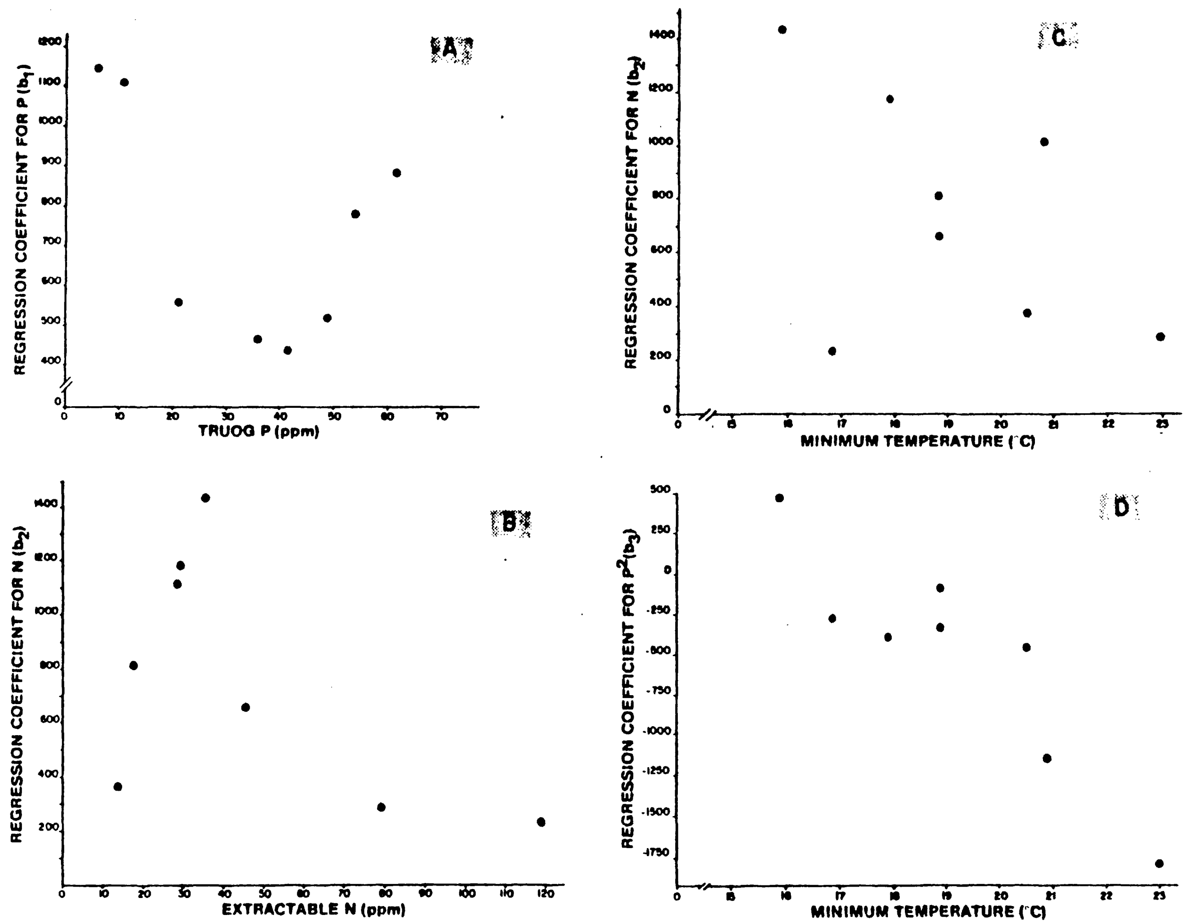
The systematic trends in the four plots of Figure 2 reflect the presence of interactions. Estimated regression coefficients calculated by fitting a quadratic polynomial to the data in Figure 2A are identical to the coefficients obtained by adding two interaction variables to the transfer model

$$\hat{Y} = b_{0i} + b_1P + b_2N + b_3P^2 + b_4N^2 + b_5NP + b_6pP + b_7p^2P \qquad (6a)$$

or, alternatively,

$$\hat{Y} = b_{0i} + (b_1 + b_6p + b_7p^2)P + b_2N + b_3P^2 + b_4N^2 + b_5NP \quad . \qquad (6b)$$

Figure 2


A
REGRESSION COEFFICIENT FOR P (b_1)
TRUOG P (ppm)
C
REGRESSION COEFFICIENT FOR N (b_2)
MINIMUM TEMPERATURE (°C)
B
REGRESSION COEFFICIENT FOR N (b_2)
EXTRACTABLE N (ppm)
D
REGRESSION COEFFICIENT FOR P^2 (b_3)
MINIMUM TEMPERATURE (°C)

The latter equation shows the effect of Truog phosphorus (p) on the shape of the response surface and, in particular, the effect of a site's level of soil phosphorus on the linear response to applied phosphorus (P) for that site. Table I compares the P response coefficients, estimated by $b_1 + b_6 p + b_7 p^2$ of the augmented transfer model (first column), with the P response coefficients, b_{1i}, estimated from the individual site analyses (second column) and from transfer model 1 (third column). The closeness of the first two columns, compared with the third column, indicates the need for site variable data to explain the differences in the P response data.

Based on Figures 2A, B, C, and D and on other analyses, four additional interaction variables were added to transfer model 2: namely Extr. n by N, Min. Temp. by N, $(\text{Min. Temp.})^2$ by N, and Min. Temp. by P^2. Inclusion of these interactions allows the N and P^2 coefficients of transfer model 1 to vary from site to site. With the six interactions incorporated in the transfer model, the transfer sums of squares were calculated and are shown in Table II along with the ordinary residual sums of squares and the site variable data. For example, when transfer model 2 is estimated from the last seven sites and used to predict the yields for IOLE-E, the transfer sum of squares, $\Sigma[Y_i - \hat{Y}_{(-i)}]^2$ is equal to 10,650,460, a 25% increase over the IOLE-E residual sum of squares. Summed over the eight sites, the prediction statistic is

$$P = 203,685,190/152,164,299 = 1.34 \quad . \tag{7}$$

This value of P is associated with a significance level of 0.32, giving evidence that the response surface for applied P and applied N can be transferred with an estimated transfer model including different intercepts and interactions between the site variables and the treatment design variables.

The P statistic, a ratio of sums of squares, is a summary statistic for comparing the transfer $[Y_i - \hat{Y}_{(-i)}]$ and ordinary $(Y_i - \hat{Y}_i)$ residuals. The actual

TABLE I

Comparison of Regression Coefficients for P Response, with and without Site Variables

	P response, site variables added ($b_1 + b_6p + b_7p^2$)	P response, no site variables (b_1)	
Site	Transfer model 2	Individual site model	Transfer model 1
Hawaii			
IOLE-E	447	443	822
KUK-A	634	779	780
KUK-C	546	535	814
KUK-D	1110	890	762
Philippines			
PUC-K	1068	1107	732
BUR-B	1336	1430	685
Indonesia			
PLP-G	418	462	824
LPH-E	691	554	811

TABLE II

Comparison of Residual and Transfer Sums of Squares after Adding Site Variables (Transfer Model 2)

Site	Residual sums of squares	Transfer sums of squares	Site variables: Modified Truog p (ppm)	Site variables: Extr. n (ppm)	Site variables: Min. temp. (^{o}C)
Hawaii					
IOLE-E	8,550,008	10,650,460	42	17	18.9
KUK-A	25,714,266	34,309,230	54	13	20.5
KUK-C	13,602,424	15,412,100	49	46	18.9
KUK-D	25,599,726	30,825,610	62	29	17.9
Philippines					
PUC-K	5,869,074	9,035,600	11	79	23.0
BUR-B	25,055,225	32,219,560	5	29	21.5
Indonesia					
PLP-G	29,893,412	40,316,440	36	35	15.9
LPH-E	17,880,236	30,916,190	22	119	16.8
Total	152,164,299	203,685,190			

magnitudes of the differences between the ordinary $\hat{Y}_i$, based on the individual site data, and the transfer $\hat{Y}_{(-i)}$, based on data from the other sites, are given in Table III. The tabular values are absolute differences, $|\hat{Y}_i - \hat{Y}_{(-i)}|$, for five treatment combinations with increasing levels of both P and N, and are averaged over the three replications for each site. The differences display variability but are sufficiently small, especially at the middle levels, so that the transfer predictions, $\hat{Y}_{(-i)}$, could be used for practical purposes to predict response to P and N application for sites where an experiment had not been carried out.

The predicted yields for each site, plotted three dimensionally with P and N as the horizontal axes, form an estimated response surface showing the predicted yield response for any combination of P and N within the experimental ranges of the factors. The response surface plots in Figure 3 summarize the results of the transfer analysis. Specifically, both transfer models can be graphically compared with the individual site predictions. In the middle row, the predicted yields (the vertical axis) from fitting a quadratic polynomial in applied P (the right horizontal axis) and applied N (the left horizontal axis) to each site individually are plotted. The best-fitting response surface is formed from the predicted yields and is represented by the 9 X 9 grid for each site.

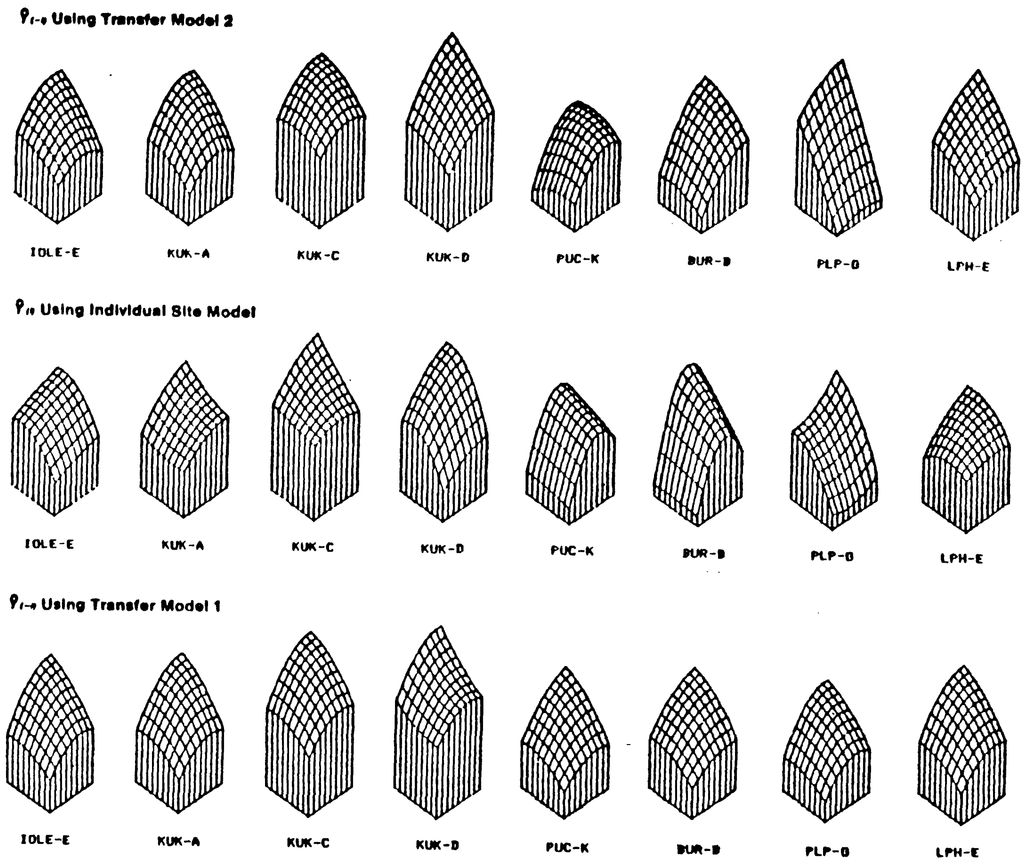
To simulate the transfer of technology, consider for a moment that an experiment was not done at the PUC-K site and one wanted to predict the nature of the response surface from the other seven sites. Using transfer model 1, the predicted response surface would be the PUC-K plot in the bottom row, while the plot in the top row results from estimating transfer model 2 from the other seven sites. The top response surface is a closer approximation to the middle response surface than the bottom one for PUC-K and is generally true for all sites.

TABLE III

Absolute Differences (kg/ha) between $\hat{Y}_i$ and $\hat{Y}_{(-i)}$ Using Transfer Model 2 for Five Treatment Combinations of Applied Phosphorus (P) and Nitrogen (N)

	Coded P and N treatment				
Site	-.85 P/ -.85 N	-.40 P/ -.40 N	0/ 0	+.40 P/ +.40 N	+.85 P/ +.85 N
Hawaii					
IOLE-E	164	78	59	94	195
KUK-A	684	193	538	469	99
KUK-C	246	183	267	71	481
KUK-D	471	139	350	249	238
Philippines					
PUC-K	160	279	120	78	344
BUR-B	125	225	359	327	93
Indonesia					
PLP-G	561	340	92	276	748
LPH-E	703	582	277	213	985

Figure 3


Using Transfer Model 2
IOLE-E
KUK-A
KUK-C
KUK-D
PUC-K
BUR-B
PLP-O
LPH-E
Using Individual Site Model
IOLE-E
KUK-A
KUK-C
KUK-D
PUC-K
BUR-B
PLP-O
LPH-E
Using Transfer Model 1
IOLE-E
KUK-A
KUK-C
KUK-D
PUC-K
BUR-B
PLP-O
LPH-E

The $\hat{Y}_i - \hat{Y}_{(-i)}$ differences in Table III are the differences between the transfer model 2 response surface in the top row and the response surface below in the middle row for five P and N combinations. The P and N combination of -0.85 and -0.85 is the front corner of each plot, the combination of +0.85 and +0.85 is in the back corner, and the other three points are on the diagonal line between the two corners.

If one views across the eight response surfaces in the bottom row, the similarity of P and N response can be noticed, but the resulting transfer equations do not predict as well as the transfer equations from transfer model 2 as represented by the top row. Some of the commonality of the P and N responses is retained, but the introduction of site-variable information into transfer model 2 allows each response surface in the top row to have a uniqueness that is associated with the particular site to be predicted. For the P response, the closeness of transfer model 2 to the actual response is also shown in Table I. For both the P and N responses, (1) the resemblance between the response surfaces for the top and middle rows of Figure 3 and (2) the P statistic value of 1.34 with the associated significance level of 0.32 for transfer model 2 are weights of evidence that the P and N responses can be transferred.

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