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GENOTYPE-ENVIRONMENT INTERACTION IN FLUE-CURED TOBACCO (*NICOTIANA TABACUM* L.)

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ABSTRACT

Eight randomly chosen tobacco cultivars were grown in three locations for two seasons. Significant differences were found among cultivars for all characters. Genotype x location and genotype x year interactions were small and nonsignificant for most traits. Genotype x location x year interactions were highly significant for three traits and usually greater than the first order genotype x environment interaction. However, the magnitude of genotype x environment interactions were only a small fraction of varietal differences.

Comparison of theoretical variances of treatment means with varying plot allocations revealed that increasing the number of years is more effective than increasing locations or replications in reducing the standard error. But adding more years costs more in time than adding locations. The acceptable optimum plot allocation for tobacco testing was found to be 3 replications, 6 locations in 2 years.

Another six selected cultivars were grown in six locations for two seasons. Significant genotype x environment interaction were found for the five characters. All the varieties except one were found adapted to wide range of environments based on b-value. Cultivars differed in stability based on b-value and s_d^2. NCBY was found to have high yield potential, adaptable and stable, hence an ideal check genotype for varietal testing.

Introduction

Genotype-environment (GE) interactions are of major importance to be considered in testing and evaluating varieties. Comstock and Moll (1963) have shown statistically the effect of large genotype-environment interactions in reducing progress from selection. Because of GE interactions, evaluation requires repeated testing in both time and space. A major emphasis has been to maximize the effects of such interactions and still adequately measure the genetic worth of the cultivar.

In the process of evaluating varieties, the breeder must ascertain performance of a variety in comparison with other varieties in a) yield level, e.g., the overall average yield compared to the overall yields of the others, b) adaptation, e.g., whether the variety is better adapted to one type of environment than to another,

and c) stability, e.g., the consistency of the performance relative to the yield performance of the other cultivars.

Different methods have been proposed to solve the problems created by genotype-environment interactions. An analysis of variance that combines years and locations was amply demonstrated by several workers (Sprague and Federer, 1951; Comstock and Robinson, 1952; Hanson *et al.*, 1956; and Comstock and 1963). This technique, however, could provide information only on the existence and magnitude of GE interaction but unable to give any measure of the contribution of individual genotypes to components of interaction.

Interest has been centered on regression techniques as an alternative method of analyzing GE interaction as proposed by Yates and Cochran (1938), developed by Finlay and Wilkinson (1963) and refined by Eberhart and Rusell (1966). Bilbro and Ray (1976) used *b* values as a measure of adaptation and proposed coefficient of determination (R^2) as a more logical parameter for stability. In this study, the method of Eberhart and Russell (1966) was adopted in determining stable genotypes because it considers two derived quantities, b and s_d^2, as measures of stability.

Trials to obtain the necessary information for proper evaluation of tobacco varieties and advanced breeding lines are both costly and time consuming. The question as to optimum allocation of replications, locations and years of testing necessary to obtain an estimate of a variety's potential in tobacco in the Philippines has received only limited attention.

The present study has the following objectives: 1) Ascertain the magnitude of GE interaction and its components and the relevance of each in testing procedures, 2) Determine optimum allocation of resources in conducting yield tests for flue-cured tobacco, 3) Estimate adaptation (b value) and stability (b and s_d^2) parameters for each of the different breeding lines used.

Materials and Methods

Cultivars and test locations

There were two sets of cultivars used in this study. The first set (Set I) was used to ascertain the magnitude of GE interaction through the variance component analysis, and in determining the optimum allocation of resources. It was composed of eight randomly selected cultivars representing high (Balikbayan, NCBY and Coker 254), medium (Buyer's Choice, WR-5 and Yellow Special), and low (Bissetes Special and Coker 298) yielding groups. It was grown in Batac, Ilocos Norte; Sta. Maria, Ilocos Sur; and Balaoan, La Union for two consecutive years (crop season 1982-1983 and 1983-1984).

The second set (Set II) was composed of selected cultivars entered in the advanced test for untopped flue-cured tobacco trials. It was composed of Balik-

bayan, NCBY, Coker 86, Coker 254, Coker 258 and Reams 266. The adaptability and stability of each variety were estimated. It was grown in Batac and Marcos, Ilocos Norte; San Juan and Sta. Maria, Ilocos Sur; Pidigan, Abra; and Balaoan, La Union for the same years as in set I.

Field experiment and data collection

All experiments were laid out in a randomized complete block design with four replications. A plot was composed of five rows 0.8 m apart. Plants were 0.5 m apart within rows. The following data were collected: cured yield, grade index, leaf width and length, number of days to flower, plant height and number of harvestable leaves.

Statistical analysis

A combined analysis of variance over location-year combination was computed for each set. For parameters with heterogenous variances based on Barlett's tests, log transformation was used. In some cases, locations were deleted to achieve homogeneity of variances.

Set I: Random Model

The statistical model is as follows:

$$x_{ijkr} = \mu + g_i + \ell_j + y_k + (\ell y)_{jk} + b_{rjk} + (g\ell)_{ij} \quad (gy)_{ik} + (g\ell y)_{ijk} + e_{ijkr} \qquad \text{(Eq. 1)}$$

where:

x_{ijkr}, is the observed value of the ith genotype in the rth replicate in the jth location in the kth year;

μ, the over all mean;

g_i, the ith genotypic effect;

ℓ_j, the jth location effect;

y_k, the kth year effect;

$(\ell y)_{jk}$, the interaction effect of the jth location with the kth year;

b_{rjk}, the block effect of the rth replication in the jth location in the kth year;

$(g\ell)_{ij}$, the interaction effect of the ith genotype with the kth year;

$(gy)_{ik}$, the interaction effect of the ith genotype with the kth year;

$(g\ell y)_{ijk}$, the interaction effect of the ith genotype with the jth location in the kth year;

e_{ijkr}, the experimental error.

Variance components. The variation components for the seven parameters were estimated based from the expected mean squares, derived considering Eq. 1.

Optimum allocation of resources. The theoretical variance of a variety mean was computed for characters with significance $\hat{\sigma}^2_{gy}$ or $\hat{\sigma}^2_{g\ell}$ or $\hat{\sigma}^2_{gy\ell}$ or their combination. The theoretical variance of the genotype mean (Jones, 1960) was computed using the following:

$$V_{\bar{x}} = \hat{\sigma}^2_{gy/y} + \hat{\sigma}^2_{g\ell/} + \hat{\sigma}^2_{gy\ell/y\ell} + \hat{\sigma}^2_{e/r\ell y} \qquad \text{(Eq. 2)}$$

where:

$V_{\bar{x}}$, the theoretical variance of genotype mean;

y, the number of years;

ℓ, the number of location;

r, the number of replications.

Estimates of the variance components obtained from set II materials were substituted into the formula with varying number of years, locations and replications, hence providing a basis for the comparison of the allocations with respect to the sizes of the resulting variances.

Three dimensional drawings were used to present the effects of various plot allocations. The joint effect of changing the number of years, location, and replication was visualized by the over-all slope of the surface. In all cases, the height arising from the base was the $V_{\bar{x}}$ as computed from the formula.

Actual variance of a variety mean of the Philippine Tobacco Research and Training Center's plot allocation was compared to the proposed plot allocations. Increase in percentage error and the number of plots reduced was simultaneously considered in recommending the optimum resource allocation.

Set II. Fixed Model

The statistical model is as follows:

$$x_{ijr} = \mu + \ell_i + g_j + b_{ri} + \ell g_{ij} + e_{ijr} \qquad \text{(Eq. 3)}$$

where:

x_{ijr}, is the observed value for the jth variety at the rth replication of the ith environment;

μ, the overall mean;

ℓ_i, the ith environment;

g_j, the jth genotypic effect;

b_{ri}, the rth block effect in the ith environment;

ℓg_{ij}, the genotype x environment interaction effect; and

e_{ijr}, the experimental error.

For character with significant GE interactions, adaptation and stability parameters were computed. A statistical technique developed by Finlay and Wilkinson (1963) then modified by Eberhart and Russell (1966) was used in this study. The model used was:

$$Y_{ij} = \mu_i + b_i I_j + \alpha_{ij}$$

where:

Y_{ij}, the mean of the ith variety at the jth environment;

μ_i, the mean of the ith variety over all environment;

b_i, the regression coefficient that measures the response of the ith variety to the jth environment;

I_j, the environmental index estimated as the difference between the mean of all the varieties at the jth environment and grand mean, with $I_j = 0$;

α_{ij}, the deviations from regression of the ith variety at the jth growing condition.

The environmental index was considered as an independent variable and the yield as the dependent variable. The analysis of variance form when adaptability and stability parameters were estimated is given in Table 1.

Adaptation analysis. The adaptation parameter (b), the regression coefficent, was estimated as follows:

$$b_i = \sum_i Y_{ij} I_j / \sum_i r_j^2 \qquad \text{(Eq. 4)}$$

When $b<1.0$ a variety is adapted to unfavorable environment, $b>1.0$, variety is adapted to favorable environments; and $b = 1.0$, a variety is either poorly or well adapted to all environments, depending upon the variety mean yield.

Stability analysis. The stability parameter considered was the combination of b-value and mean square deviation from regression (s_d^2) as proposed by Eberhart and Russell (1966). s_d^2 was computed using the following formula:

$$s_d^2 = [\sum_j \alpha_{ij}/(e-2)] - \frac{s_e^2}{r} \qquad \text{(Eq. 5)}$$

where:

s_d^2, the deviation from linear regression of the ith variety;

α_{ij}, the variance due to deviation from regression of the ith variety at the jth growing conditions;

s_e^2, mean square for pooled error;

e, the number of growing conditions.

A variety is stable when b = 1 and $s_d^2 = 0$.

Results and Discussion

Set I: Random Model

Variance components

The estimates of variance component for set I is presented in Table 1. The $\hat{\sigma}_y^2$ and $\hat{\sigma}_\varrho^2$ were not significant for all tobacco traits studied except for $\hat{\sigma}_y^2$ of cured yield. However, highly significant $\hat{\sigma}_{y\varrho}^2$ was observed for all characters. This implies that the ranking of the different locations based on the mean performance of the genotypes used, differed from year to year.

Large varietal differences ($\hat{\sigma}_g^2$) were present for all the traits. The $\hat{\sigma}_{gy}^2$ was significant for grade index and leaf width while $\hat{\sigma}_{g\varrho}^2$ was significant only for grade index. Significant estimates of $\hat{\sigma}_{gy\varrho}^2$ were obtained for days to flower, plant height and number of harvestable leaves. Similar results were obtained by Jones *et al.* (1960) for flue-cured tobacco at North Carolina.

Significant $\hat{\sigma}_{g\varrho}^2$ and $\hat{\sigma}_{gy}^2$ and nonsignificant $\hat{\sigma}_{gy\varrho}^2$ were found for grade index. This indicates that the eight varieties performed differently from year to year when averaged over locations and likewise from location to location when averaged over years. Presence of significant $\hat{\sigma}_{gy\varrho}^2$ and absence of significant $\hat{\sigma}_{gy}^2$ and $\hat{\sigma}_{g\varrho}^2$, as in days to flower, plant height and number of leaves, indicates that the interaction of varieties with environment arose from the distinct and exclusive conditions existing in a particular experiment (e.g. year-location combination). Results also suggest that years need not be consecutive and that locations in different years may not be in the same immediate area.

Estimates of $\hat{\sigma}_g^2$ were much greater than those of $\hat{\sigma}_{gy}^2$, $\hat{\sigma}_{g\varrho}^2$ and $\hat{\sigma}_{gy\varrho}^2$ for all characters except for grade index where $\hat{\sigma}_{g\varrho}^2$ was slightly greater than σ_g^2. Furthermore, $\hat{\sigma}_g^2$ was significant for yield but not for components of genotype x environment interactions. In tobacco, there are three phases of yield testing namely preliminary, general and advanced trials. The implication of small $\hat{\sigma}_{ge}^2$ components relative to $\hat{\sigma}_g^2$ is that, general trial can be deleted.

Optimum allocation of resources

Figure 1A illustrates the change in variance when year was fixed at 2 for grade index. Increasing the number of locations was evidently more effective than increasing the number of replications. Although actual variances cannot be determined from the surface figure, the illustration clearly shows the small increment in the decrease of variance when replication increases. This can be supported by the almost horizontal line depicted from replications 1-5 with location fixed at a particular number.

When number of years was increased as replication was fixed at 4 (Fig. 1B), a considerable decrease in variance was observed. Such decrease in variance was evident from 1-3 years though showing a decrease in increment with every additional year. It is more effective increasing the number of years than increasing the location or replication. However, more plots would be necessary through additional location or replication to attain the desired efficiency. Increasing the number of years would also mean delay in releasing new varieties. Results for leaf width, days to flower, plant height and number of harvestable leaves (Figs. 2, 3, 4 and 5, respectively) were similar with those for grade index. Another feature of the 5 graphs is that an optimum is reached as the surface starts to level off, this means that from that point an increase in the number of test will provide only a small gain in precision, and eventually, wasteful.

The Philippine Tobacco Research and Training Center uses 2 years, 7 locations, and 4 replications for their advance test. After the test, an outstanding variety is recommended to the Philippine Seed Board. Table 2 presents the actual standard error for 4 replications, 7 locations and 2 years (PTRTC procedure) as compared with the proposed number of replicates, locations and years for each of the tobacco trait with significant GE interactions. Relative efficiency was computed as the ratio of the theoretical variance of a variety mean over actual variance. A maximum increase in cv of 10% and the number of plots reduced was considered simultaneously in looking at the different plot allocation.

For grade index, the actual cv using the center's procedure was 5.75. The least number of resource allocation acceptable was 3 replications, 6 locations and 2 years with an increase of 6.16 (cv) or 7.13% with 20 plots reduction. The actual cv for leaf width was 0.0393 and using 3 replications, 5 locations and 3 years it was reduced by 2.04% with 11 plots reduced. Result for leaf width was also similar for plant height and indicates that increasing the number of years is more effective than increasing location. But the time constraint is much more important, hence 2 years of test is adequate and consideration was given to varying number of locations and replications relative to a testing period of two years.

Based on the above argument, the optimum plot allocation for leaf width, days to flower, plant height and number of harvestable leaves are (sequence of numbers represent replication, location, year), 4, 5, 2; 3, 6, 2; 4, 6, 2; and 4, 6, 2, respectively).

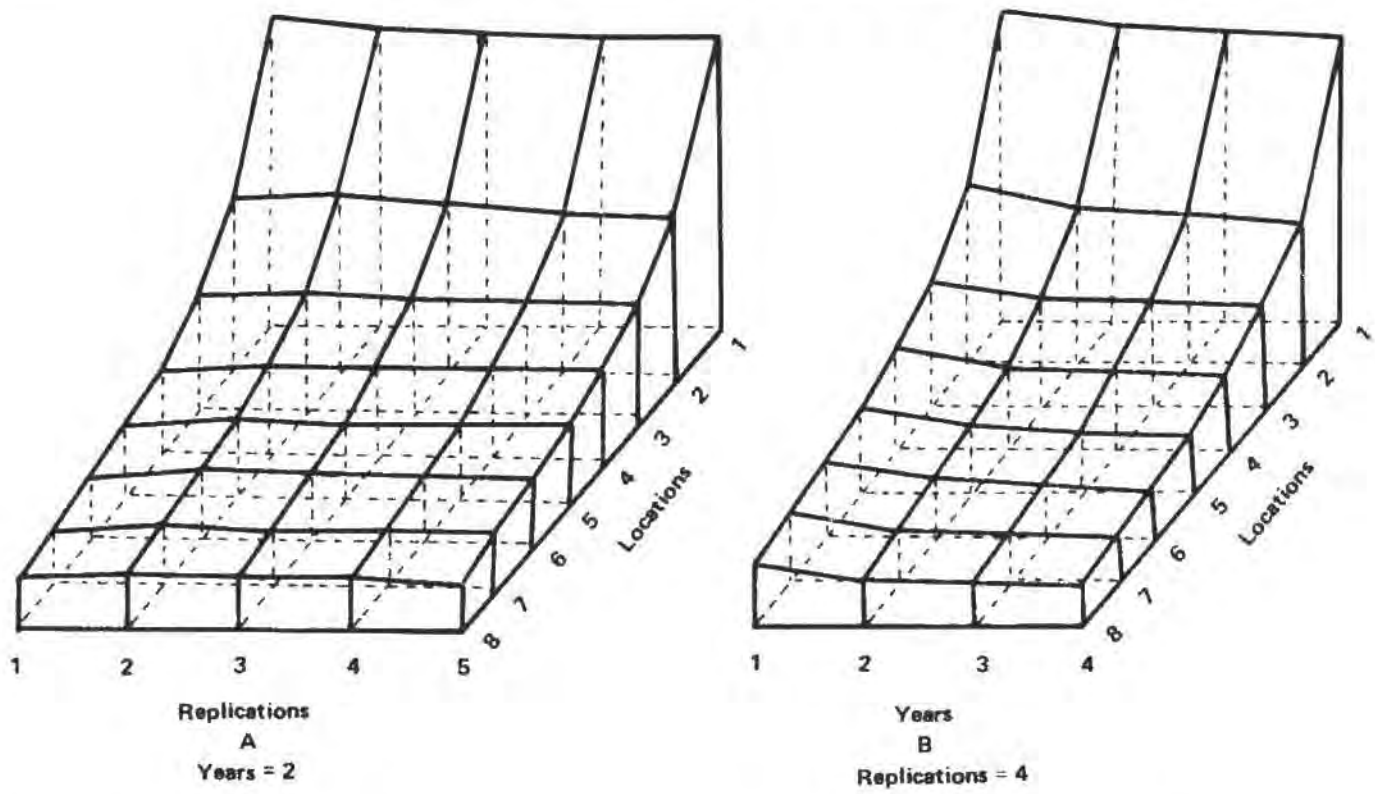

Fig. 1. Surface representing the theoretical variance of a variety mean resulting from various plot allocations for grade index. Variance is the height from the base.

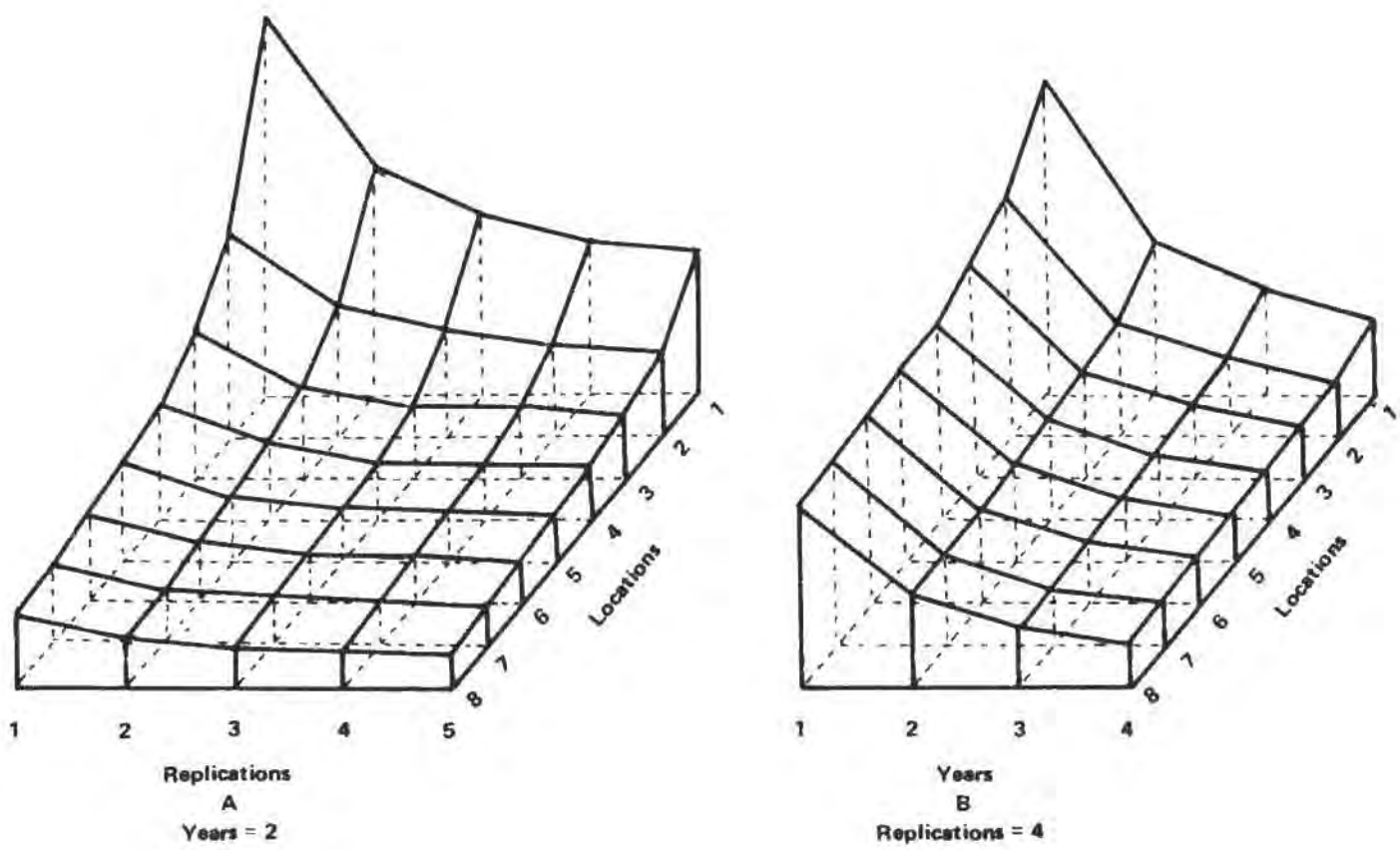

Fig. 2. Surface representing the theoretical variance of a variety mean resulting from various plot allocations for log leaf width. Variance is the height from the base.

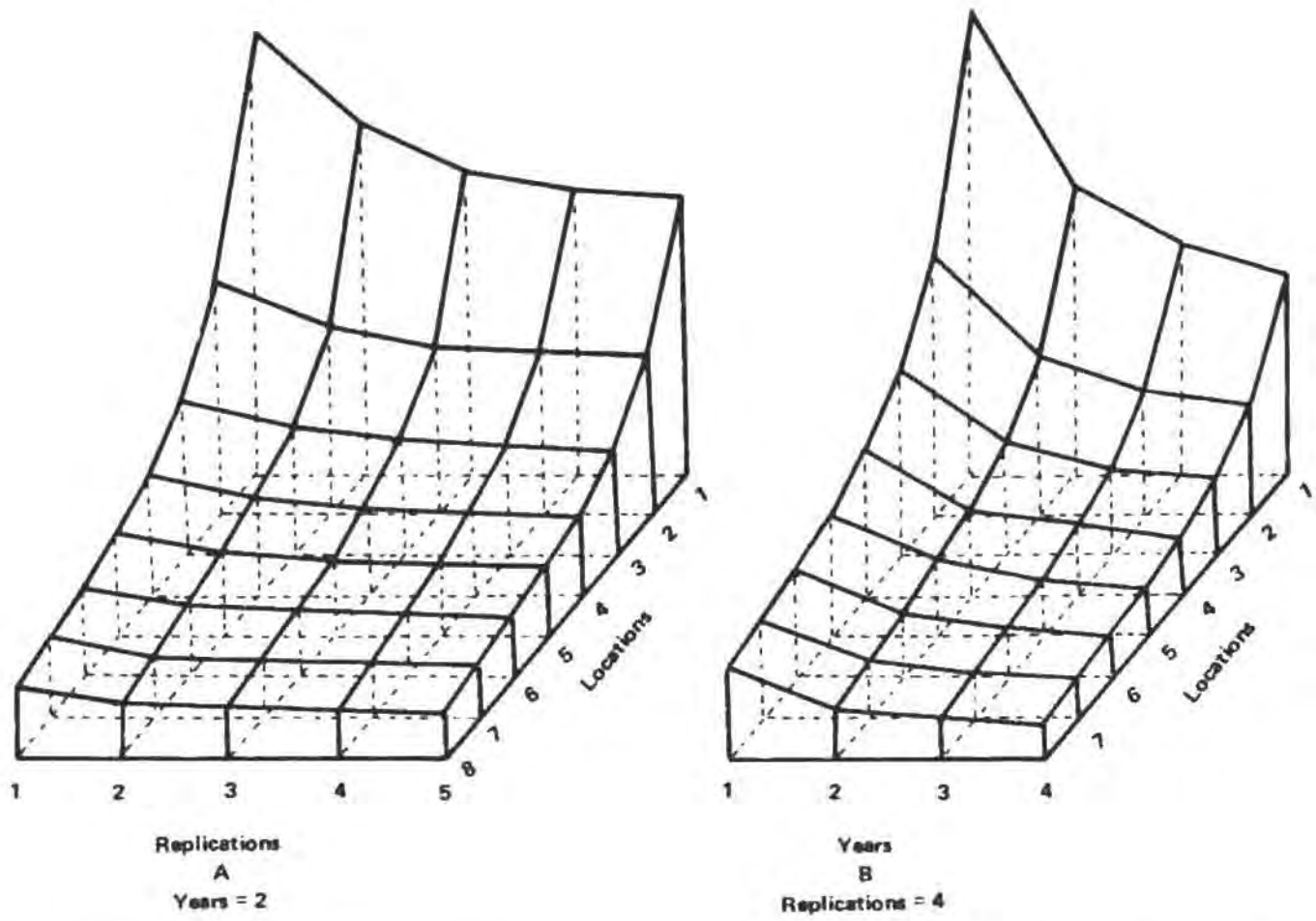

Fig. 3. Surface representing the theoretical variance of a variety mean resulting from various plot allocations for days to flower. Variance is the height from base.

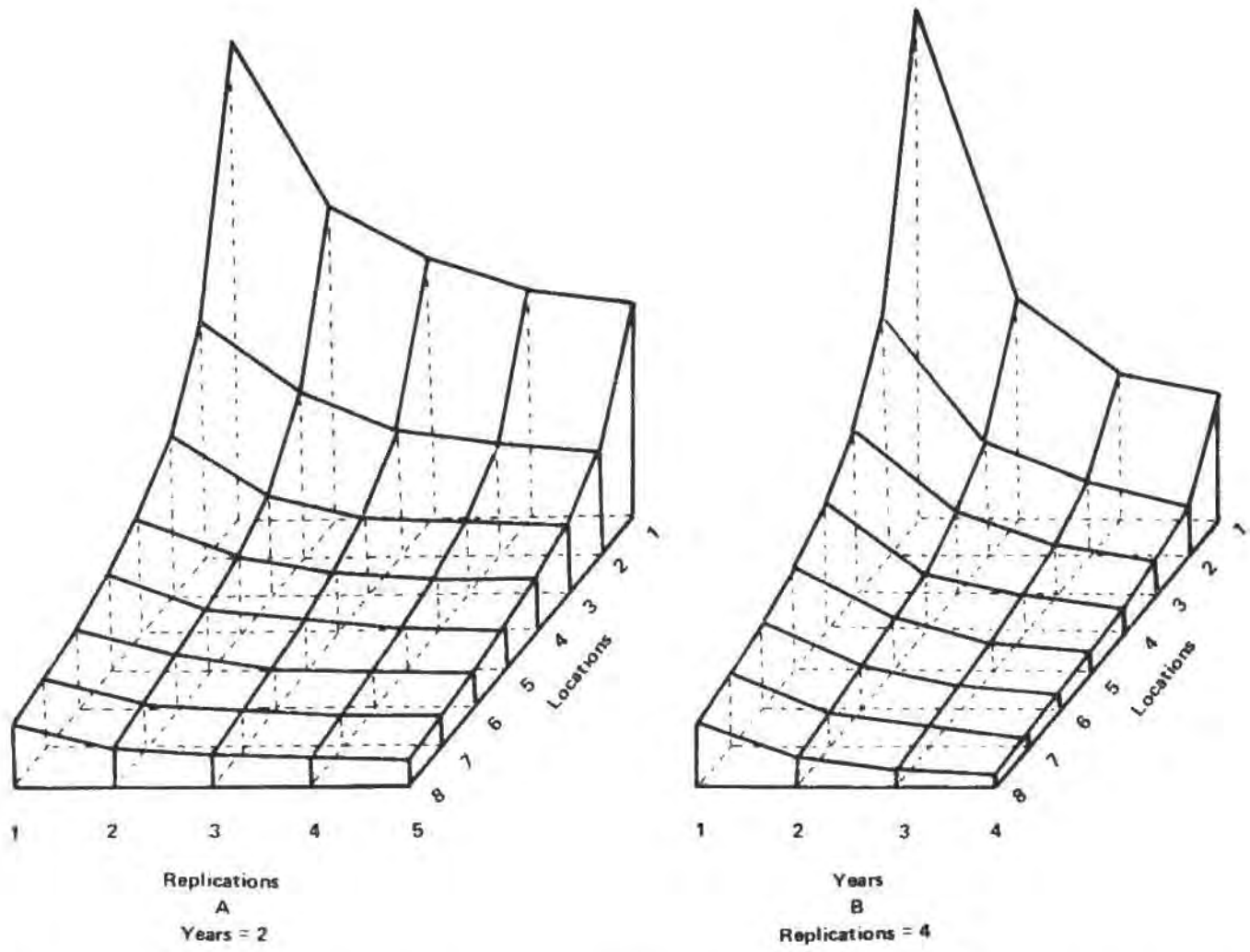

Fig. 4. Surface representing the theoretical variance of a variety mean resulting from various plot allocations for plant height. Variance is the height from the base.

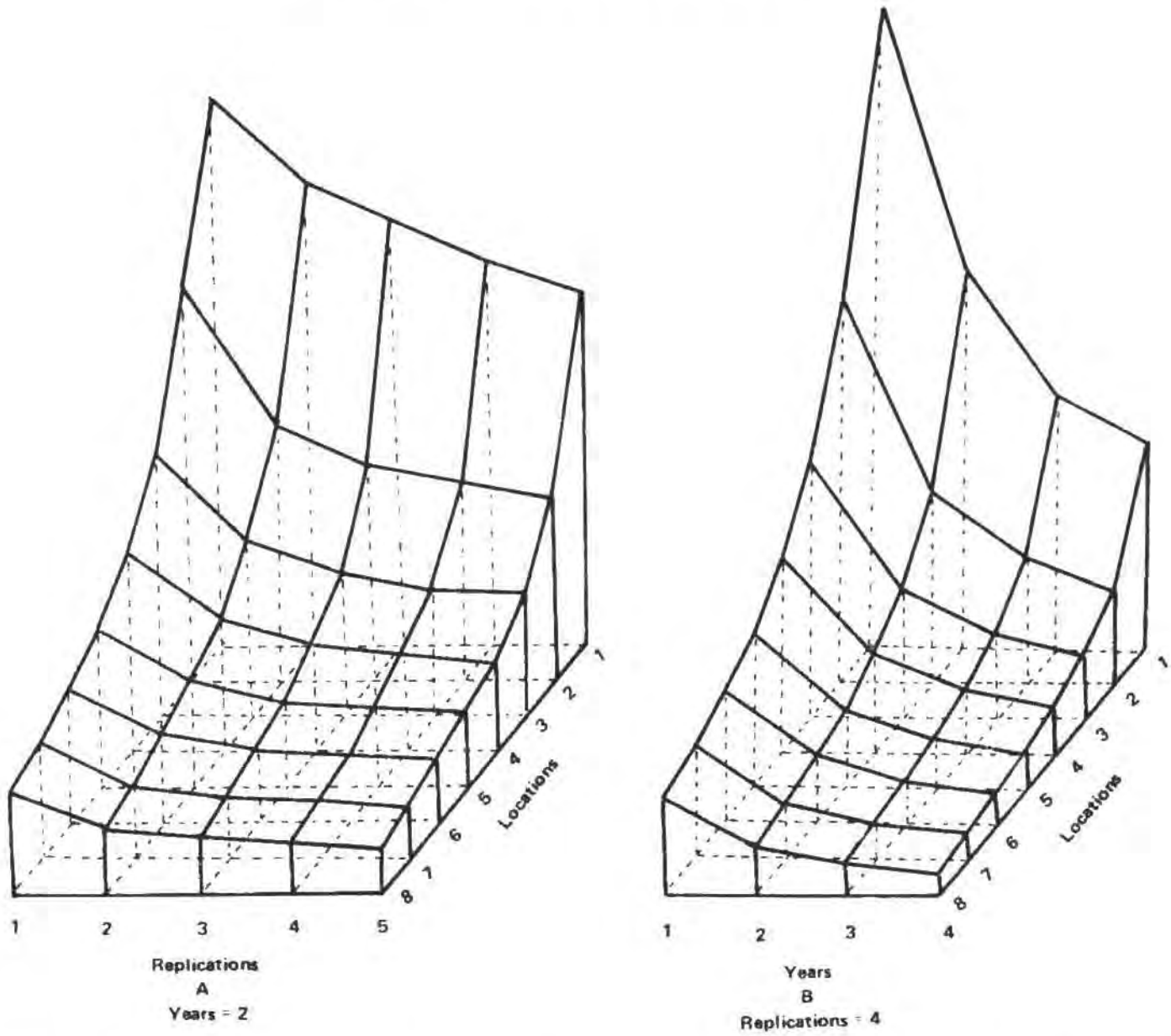

Fig. 5. Surface representing the theoretical variance of a variety mean resulting from various plot allocations for number of harvestable leaves. Variance is the height from the base.

Table 1. Estimates of variance components for 7 parameters of tobacco varieties (Set I)[1]

Variance Components	Parameters						
	Cured yield	*Grade index*	*Leaf width*	*Leaf length*	*Days to flower*	*Plant height*	*Number of harvestable leaves*
$\hat{\sigma}^2_y$	.24701**	.02208	−.00031	3.97857	21.3738	−168.68565	−.39168
$\hat{\sigma}^2_\ell$	.00287	−.01621	−.00060	9.06526	75.08249	−159.93801	1.60536
$\hat{\sigma}^2_{y\ell}$	.06981*	.4119**	.0428**	14.37088**	67.54576**	1,177.35835**	1.40106**
$\hat{\sigma}^2_g$	.06373**	.17102**	.0023**	21.6330**	49.71614**	192.16590**	8.95154**
$\hat{\sigma}^2_{gy}$	−.00032	.02199*	.00014*	.69762	.63095	0.31483	−.22372
$\hat{\sigma}^2_{g\ell}$	−.00755	.24232**	−.00009	.00784	2.09859	−3.19896	−.35742
$\hat{\sigma}^2_{gy\ell}$	.01442	−.00789	.00017	−.06568	4.79539**	33.97257**	1.0707**
$\hat{\sigma}^2_e$	.07779	.04008	.00110	9.63331	6.91294	68.14784	2.38105

[1]* and ** significantly different at 5% and 1% level, respectively.

Table 2. Standard errors for variety means under the PTRTC testing procedure (4 replications, 7 locations and 2 years) and with the several pertinent combinations of replications, locations and years

Combination*			No. of plots reduced	Grade index		Leaf width		Days to flower		Plant height		No. of harvestable leaves	
R	L	Y		CV	% Increase	CV	% Increase	CV	% Increase	CV	% Increase	CVCV	% Increase
PTRTC Procedure													
4	7	2	–	5.75	–	.0393	–	1.366	–	1.081	–	1.493	–
–													–
3	7	2	14	5.80	.87	.0416	5.85	1.398	2.34	1.145	5.92	1.579	5.76
4	6	2	8	6.12	6.43	.0403	2.54	1.451	6.22	1.164	7.68	1.614	8.10
3	6	2	20	6.16	7.13	.0418	6.36	1.479	8.27	1.233	14.06	1.705	14.20
4	5	2	16	6.58	14.43	.0417	6.11	1.554	13.76	1.270	17.48	1.7663	18.30
3	5	3	11	6.38	10.96	.0001	(2.04)	1.386	1.46	1.065	(1.48)	1.526	2.21

*R, L & Y denotes replications, locations and years, respectively.

Giving equal importance to the five traits, the percent increase in cv was averaged to compare the different plot allocations. Reducing the number of replications from 4 to 3 and maintaining 7 locations and 2 years gave an average of 4.15% increase in cv for all traits and a reduction from 56 to 42 plots. Given 4 replications and 2 years and reducing 7 locations to 6, there was an average increase of 6.19% and this supports the relatively large effect of reducing locations rather than replications. For the 5 parameters, the increase in the standard error of 3 replicates, 6 locations, 2 years had an average of 10.0% with plots reduced from 56 to 36 or 20 plots cheaper. The same result was found by Bonilla (1983) in a blank test where the optimum number of replications was 3 using Smith's index of soil heterogeneity (b) with 10% degree of precision.

The last combination is 3 replicates, 5 locations, and 3 years with an average increase of 2.22%, the smallest increase from the actual allocation and a reduction from 56 to 45 plots. Increasing the number of years at 3 replicates and reduction to 5 locations would mean a decrease in variance of variety mean for leaf width (2.04%) and plant height (1.48%).

The relative efficiencies discussed did not directly consider the cost because the total number of plots reflects the relative cost of gathering the necessary data. The 3 replications, 6 locations and 2 years gave a slight increase in the coefficient of variation or an average of 10% for the five characters and its recommendation can be justified because of a reduction of one-third in the total number of plots.

Set II: Fixed Model

Environment and genotype main effeets were highly significant for all characters. Significant GE interaction were found for all traits except for leaf width and length. Partitioning of the genotype x environment sum of squares based on Eberhart and Russell (1966) analysis to sum of squares due to regression and due to deviation from linearity of response from mean sum of squares for traits with significant GE interaction is presented in Table 4.

Adaptability analysis

Table 5 presents the mean value and b-value of the 6 varieties for cured yield. However, no b-value was significantly different from 1.0 (see Fig. 6) hence, all varieties were adapted to all environments with respect to their yield potential.

The mean grade index of the 6 tobacco varieties and their b-values are summarized in Table 6. Within this range of b-values, it can be detected that Coker 258 was adapted only to favorable environments (Fig. 7) and the rest of the varieties had adaptability to any kind of environment.

The varieties flowered at different times of the season. Balikbayan was a late flowering variety while Coker 86 was an early flowering one (Table 7). The regression lines of the 6 varieties is shown in Fig. 8.

Table 4. Analysis of variance and deviations from their regression of the 6 tobacco varieties based on mean sum of squares for the five traits with significant GE interaction (Set II)

		Mean Squares[1]		
Source of Variation	*D.F.*	*Log cured weight*	*Log grade index*	*Log days to flower*
Varieties	5	3.03×10^{-2}**	.1203**	3.40×10^{-3}**
Env. + (Varieties x Env.)	66(30)	2.78×10^{-2}**	1.3×10^{-2}**	2.12×10^{-3}**
Env. (Linear)	1	1.3528 **	.5404 **	.0578 **
Varieties x Env. (Linear)	5	9.5×10^{-3}**	.0130 **	4.0×10^{-5}**
Pooled deviation	60(24)	7.3×10^{-3}**	4.26×10^{-3}**	2.0×10^{-4}**
Balikbayan	10(4)	3.93×10^{-3}	4.14×10^{-3}*	6.25×10^{-4}**
NCBY	10(4)	2.22×10^{-3}	2.29×10^{-3}	1.5×10^{-4}
Reams 266	10(4)	5.25×10^{-3}	3.75×10^{-3}*	7.5×10^{-5}
Coker 86	10(4)	1.91×10^{-2}**	2.54×10^{-3}**	3.25×10^{-4}*
Coker 254	10(4)	9.15×10^{-3}**	5.03×10^{-3}**	7.5×10^{-5}
Coker 298	10(4)	3.83×10^{-3}	7.84×10^{-3}	2.25×10^{-4}
Pooled Error	216(108)	3.15×10^{-3}	1.82×10^{-3}	1.25×10^{-4}

[1]* and ** significant at 5% and 1% level, respectively.
( ) – degrees of freedom for days to flower and number of harvestable leaves.

Table 5. Summary of variety means, adaptation and stability parameters for log cured weight of 6 tobacco varieties grown at 12 environments (Set II)[1]

Variety	*Mean performance (tons/ha)*	*Adaptability (b-values)*[ns]	*Standard deviation from regression* (s^2_d)	*Classification*
Balikbayan	2.51a	0.8744	7.8×10^{-4}	stable
NCBY	2.37ab	0.7956	9.3×10^{-4}	stable
Reams 266	2.25b	0.9126	2.1×10^{-3}	stable
Coker 86	2.29b	1.3232	1.6×10^{-2}**	unstable
Coker 254	2.23b	0.9125	6.0×10^{-3}**	unstable
Coker 258	2.19c	1.1812	6.8×10^{-4}	stable

[1]Any two means having a common letter are not significantly different at the 5% level of significance.
**Significantly different from zero (0) at 1% level of significance.
ns – not significant

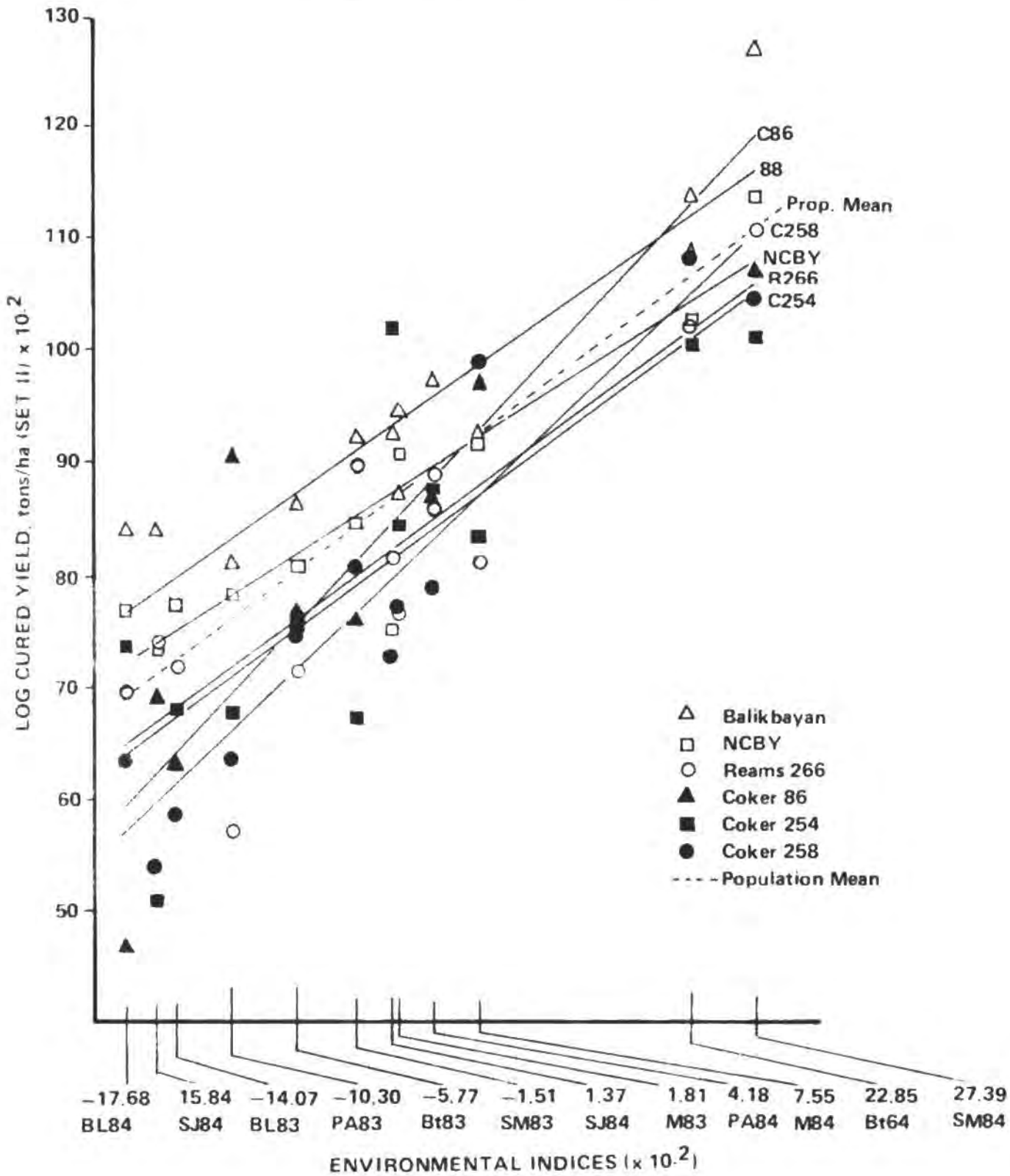

Fig. 6. Regression lines (SET II) showing the relationship of log cured yield of 6 tobacco varieties and population mean grown at different location and years – Bt., Batac, Ilocos Norte; M., Marcos, Ilocos Norte; S.J., San Juan, Ilocos Sur; Sm., Sta. Maria, Ilocos Sur; P.A., Pidigan, Abra; BL., Balaoan, La Union; 83 and 84 represent crop year 1982-83 and 1983-84, respectively.

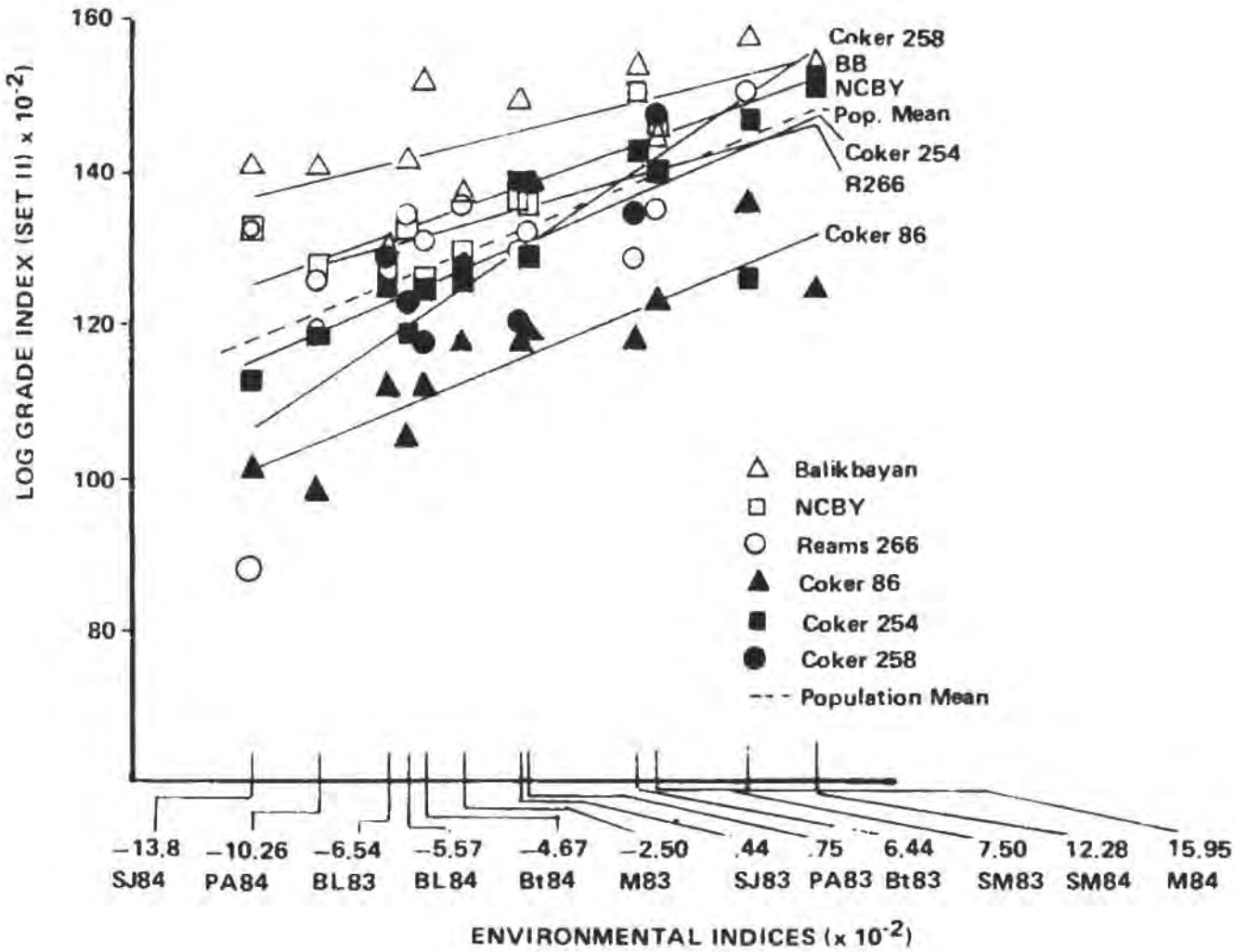

Fig. 7. Regression lines (SET II) showing the relationship of log grade index of 6 tobacco varieties and population mean grown at different location and years – Bt., Batac, Ilocos Norte; M., Marcos, Ilocos Norte; SJ., San Juan, Ilocos Sur; SM., Sta. Maria, Ilocos Sur; PA., Pidigan, Abra; BL., Balaoan, La Union; 83 and 84 represent crop year 1982-83 and 1983-84, respectively.

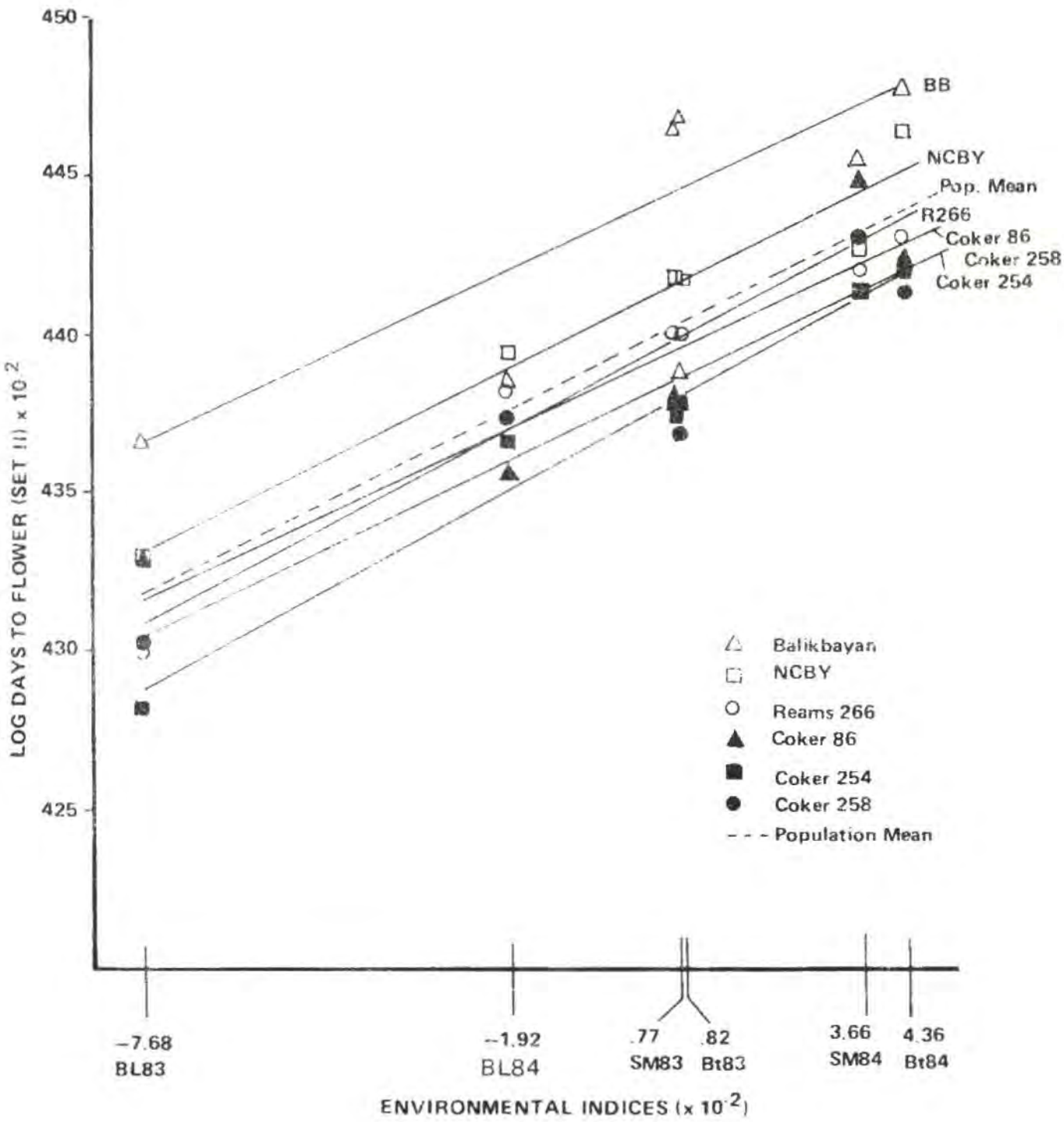

Fig. 8. Regression lines (SET II) showing the relationship of log days to flower of 6 tobacco varieties and population mean grown at different location and years – Bt., Batac, Ilocos Norte; SM., Sta. Maria, Ilocos Sur; BL., Balaoan, La Union; 83 and 84 represent crop year 1982-83 and 1983-84, respectively.

Table 6. Summary of variety means, adaptation and stability parameters for log grade index of 6 tobacco varieties grown at 12 environments (Set II)[1]

Variety	Mean *performance (tons/ha)*	*Adaptability (b-values)*^{ns}	*Standard deviation from regression* (s_d^2)	*Classification*
Balikbayan	4.28a	.6105	$2.32 \times 10^{-3*}$	unstable
NCBY	3.94b	.8981	4.6×10^{-4}	stable
Reams 266	3.86b	.6962	$1.92 \times 10^{-3*}$	unstable
Coker 86	3.17d	1.0378	7.2×10^{-4}	stable
Coker 254	3.66c	1.0746	$3.2 \times 10^{-3**}$	unstable
Coker 258	3.63c	1.6810@	$6.02 \times 10^{-3**}$	unstable

[1]Any two means having a common letter are not significantly different at the 5% level of significance.

@ – significantly different from 1.0 at 5% level.

* and ** – significantly different from zero (0 at 5% and 1% level, respectively).

With respect to plant height, the analysis showed that all tobacco varieties studied were considered to be adapted to all environments (Table 8). The environmental indices for plant height are shown in Fig. 9.

The analysis for number of harvestable leaves showed that all varieties were adapted to all environment except for Coker 258 which was adapted to favorable environment only (Table 9). The population mean and the regression lines for the 6 tobacco varieties are shown in Fig. 10.

For the five parameters with significant GE interaction, all the varieties were adaptable to any kind of environment or to a wide geographical area except for Coker 258 for grade index and number of harvestable leaves. Considering cured yield as a primary tobacco trait, the tobacco plant is adapted to any kind of environment. Such adaptation can be attributed to the fact that varieties used in this set were materials for advanced testing and passed adaptation requirements of preliminary and general tests.

Stability analysis

Table 5 shows that Balikbayan, NCBY, Reams 266 and Coker 258 were all stable based on yield. Coker 258 although stable in yield was found to be unstable for grade index (Table 6). NCBY and Coker 86 were found to be stable considering grade index.

For days to flower, NCBY, Reams 266, Coker 254 and Coker 258 were found to be stable while Balikbayan and Coker 86 were found to be unstable (Table 7).

In plant height, all varieties were stable except for Balikbayan which had significant s_d^2 (Table 8). For number of harvestable leaves, s_d^2 for all varieties were not significantly different from zero (Table 9). All varieties were stable except Coker 258 which had s_d^2 equal to 0 and b greater than 1.0.

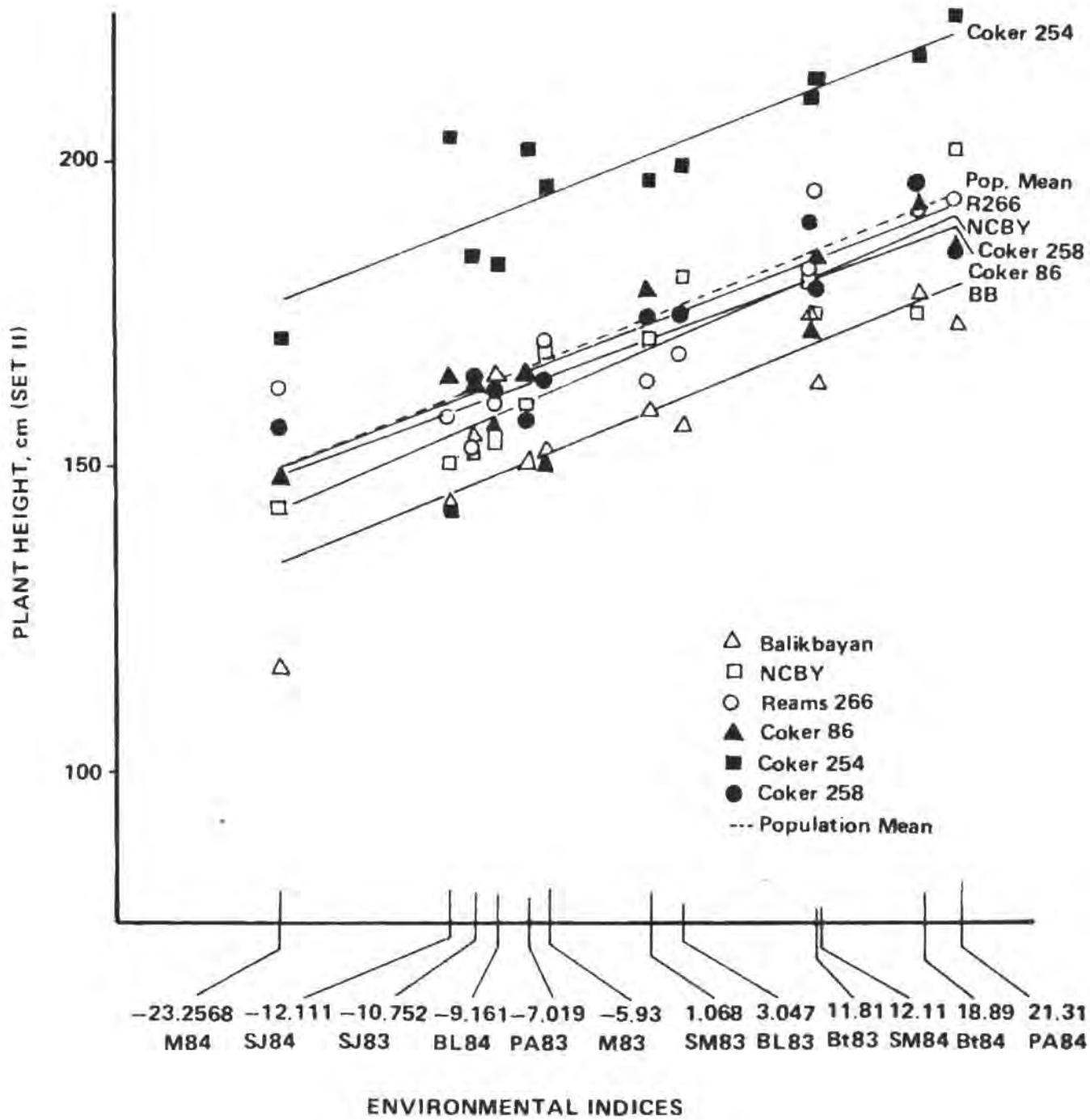

Fig. 9. Regression lines (SET II) showing the relationship of plant height of 6 tobacco varieties and population mean grown at different locations and years – Bt., Batac, Ilocos Norte; M., Marcos, Ilocos Norte; S.J., San Juan, Ilocos Sur; SM, Sta. Maria, Ilocos Sur; PA., Pidigan, Abra, BL., Balaoan, La Union; 83 and 84 represent crop year 1982-83 and 1983-84, respectively.

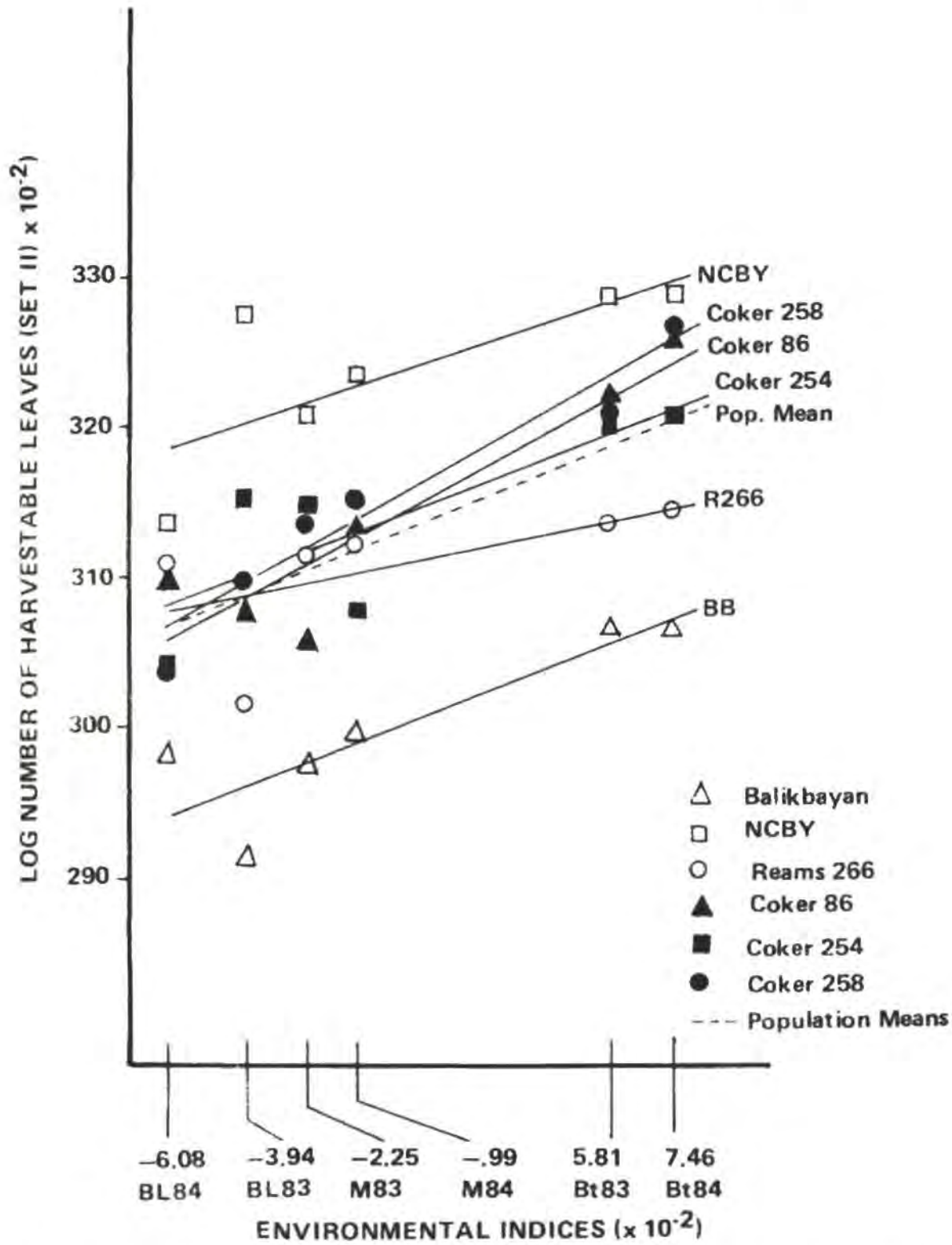

Fig.10. Regression lines (SET II) showing the relationship of log number of harvestable leaves of 6 tobacco varieties and population mean grown at different location and years – Bt., Batac, Ilocos Norte; M., Marcos, Ilocos Norte; S.J., San Juan, Ilocos Sur; PA., Pidigan, Abra; BL., Balaoan, La Union; 83 and 84 represent crop year 1982-83 and 1983-84, respectively.

Table 7. Summary of variety means, adaptation and stability parameters for log days to flower of 6 tobacco varieties grown at 6 environments (Set II)[1]

Variety	*Mean performance (tons/ha)*	*Adaptability (b-values)*^{ns}	*Standard deviation from regression* (s_d^2)	*Classification*
Balikbayan	84.41	.9646	5.0×10^{-4}**	unstable
NCBY	82.20b	.9990	2.0×10^{-5}	stable
Reams 266	80.66bc	1.0833	-4.0×10^{-5}	stable
Coker 86	80.50bc	0.9175	0.2×10^{-4}*	unstable
Coker 254	79.28c	1.0891	-4.0×10^{-5}	stable
Coker 258	79.70c	0.9444	1.0×10^{-4}	stable

[1]Any two means having a common letter are not significantly different at 5% level of significance.
* and ** – significantly different from zero (0) at 5% and 1% level, respectively.
ns – not significant

Table 8. Summary of variety means, adaptation and stability parameters for plant height of 6 tobacco varieties grown at 12 environments (Set II)[1]

Variety	*Mean performance (tons/ha)*	*Adaptability (b-values)*^{ns}	*Standard deviation from regression* (s_d^2)	*Classification*
Balikbayan	157.86c	1.0290	42.6916*	unstable
NCBY	162.99b	1.0901	19.0737	stable
Reams 266	172.12b	.9662	21.4069	stable
Coker 86	170.02b	.9207	11.8852	stable
Coker 254	200.51a	1.0008	17.4160	stable
Coker 258	170.76b	.9933	21.6453	stable

[1]Any two means having a common letter are not significantly different at the 5% level of significance.
*Significantly different from zero (0) at 5% level of significance.
ns – not signficant

Ideal genotype

An ideal genotype, may be defined as one with maximum yield potential, adaptable to a wide range of environments and stable. Stable genotype shows minimum variation in a wide range of environments.

Among the six varieties, Balikbayan and NCBY ranked first in cured yield, and both varieties were adaptable to any environment and stable. Balikbayan had the best cured leaf quality but unstable based on s_d^2. Also in grade index, NCBY and Reams 266 ranked second but the latter was unstable. Hence considering

cured yield and cured leaf quality, NCBY meets the definition of an ideal genotype. In addition, NCBY had the most number of harvestable leaves which indicated its good vegetative potential.

Table 9. Summary of variety means, adaptability and stability parameters for number of harvestable leaves of 6 tobacco varieties grown at 6 environments (Set II) [1]

Variety	*Mean performance (tons/ha)*	*Adaptability (b-values)*	*Standard deviation from regression* $(s_d^2)^{ns}$	*Classification*
Balikbayan	29.09c	.94779	2.0×10^{-5}	stable
NCBY	25.47a	.80234	1.02×10^{-3}	stable
Reams 266	22.39b	.50669	6.8×10^{-4}	stable
Coker 86	23.16b	1.36445	2.5×10^{-4}	stable
Coker 254	23.10b	.97218	1.02×10^{-3}	stable
Coker 258	23.39b	1.40691@	-6.0×10^{-4}	unstable

[1] Any two means having a common letter are not significantly different at the 5% level of significance.
@ – significantly different from 1.0 at 5% level of significance.
ns – not significant.

Summary and Conclusion

$\hat{\sigma}_y^2$ and $\hat{\sigma}_\ell^2$ were not significant for all the tobacco traits except for $\hat{\sigma}_y^2$ of cured yield. Highly significant $\hat{\sigma}_{y\ell}^2$ was observed which indicates that the ranking of the different locations based on the mean performance of the genotypes used differed from year to year. Genotypic differences were present. The small $\hat{\sigma}_{gy}^2$ and $\hat{\sigma}_{g\ell}^2$ and for most of the traits were not significant. $\hat{\sigma}_{gy}^2$ was significant for days to flower, plant height and number of harvestable leaves but it was a small fraction of the genotype variance.

The results indicate that there was some differential response to environments, but it was not accounted for by the location or year grouping. The large $\hat{\sigma}_{y\ell}^2$ and significant second order interaction ($\hat{\sigma}_{gy\ell}^2$), compared to first order interaction ($\hat{\sigma}_{gy}^2$ and $\hat{\sigma}_{g\ell}^2$) suggest that the variation of the environment falls under the unpredictable category of interaction.

Estimates of $\hat{\sigma}_g^2$ were much greater than those of $\hat{\sigma}_{gy}^2$, $\hat{\sigma}_{g\ell}^2$ and $\hat{\sigma}_{gy\ell}^2$ for all characters except for grade index where $\hat{\sigma}_{g\ell}^2$ was slightly greater than $\hat{\sigma}_g^2$. The implication of small $\hat{\sigma}_{ge}^2$ components is that promising lines identified in preliminary trials (single season-location test) can be entered into advanced trials.

It was observed that when number of replications and years were kept at a fixed point, and the number of location was increased, the variance of a variety

mean decreases. The increment in the decrease of variance decreased when it reached the optimum plot allocation. Substantial reduction in variance from addition of a single year for a given number of replication and location reduces the expected variance more effectively than increasing the number of replication.

Several plot allocations were compared to the PTRTC testing procedure (4 replications, 7 locations and 2 years). Giving equal importance to the five parameters, the acceptable optimum plot allocation for tobacco varietal testing would be 3 replications, 6 locations for 2 years but a reduction of plots from 56 to 36 (20 plots reduced) and with an average of 10% increase in cv from the PTRTC procedure.

In the fixed model (set II), the adaptation and stability for all traits with significant GE interaction was estimated. All of the tobacco varieties were highly adaptable to a wide range of environment except for Coker 258 which is adaptable only to favorable environments considering grade index and number of harvestable leaves.

An ideal genotype is one with maximum yield potential, adaptable to a wide range of environment and stable. NCBY met this criteria considering cured yield, grade index and number of harvestable leaves and was therefore recommended as the check variety for PTRTC varietal improvement trials.

Literature Cited

Bilbro, J.D. and L.L. Ray. 1976. Environmental stability and adaptation of several cotton varieties. *Crop Sci.* **16**: 821-824.

Comstock, R.E. and R.H. Moll. 1963. Genotype-environment interaction. In: *Statistical Genetics and Plant Breeding* (eds. Hanson, W.D. and H.F. Robinson). NAS-NRC Pub. 982 p. 164-196.

_____ and H.F. Robinson. 1952. Genetic parameters, their estimation and significance. Proceedings of the Sixth International Grassland Congress, **1**: 284-291.

Eberhart, S.A. and W.A. Russell. 1966. Stability parameters for comparing varieties. *Crop Sci.* **6**: 36-40.

Finlay, K.W. and G.N. Wilkinson. 1963. The analysis of adaptation in a plant breeding programme. *Aust. S. Agric. Res.* **14**: 742-754.

Hanson, W.D., H.D. Robinson and R.E. Comstock. 1956. Biometrical studies of yield in segregating populations for Korean hespodeza. *Agron. J.* **45**: 268-272.

Jones, G.L., D.F. Matzinger and W.K. Collins. 1960. A comparison of flue-cured tobacco varieties repeated over locations and years with implications on optimum plot allocation. *Agron. J.* **52**: 195-199.

Sprague, G.F. and W.T. Federer. 1951. A comparison of variance components in corn yield trials. II. Error, year x variety, location x variety and variety components. *Agron. J.* **43**: 535-541.

Yates, F. and W.G. Cochran. 1938. The analysis of groups of experiments. *S. Agric. Sci.* **28**: 556-580.