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WEATHER FACTORS AFFECTING THE RESPONSE OF MAIZE TO PLANTING DATES IN A TROPICAL RAINFOREST LOCATION

By M. A. B. FAKOREDE *and* B. O. OPEKE
Department of Plant Science, University of Ife, Ile-Ife, Nigeria

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SUMMARY

Simple linear correlations, stepwise multiple regressions and path-coefficient analyses were used to determine the relation between grain yield of maize (*Zea mays* L.) and weather factors in a three year study involving several planting dates within each year. Maximum and minimum relative humidity, which demonstrated negative relationships with yield, were the most reliable factors, both directly and indirectly, for predicting yield. Temperature (including accumulated heat units), sunshine hours and total and effective rainfall generally showed negligible direct effects on yield. Potential evaporation, which showed positive correlation, had a negative direct influence on grain yield. We conclude that, whenever possible, path analysis should be used as well as correlation and regression analyses in explaining the complex multiple interactions of yield and weather factors in crop production.

INTRODUCTION

Within genetic limits, crop yield is determined by the environment. An understanding of weather–yield relationships may help determine the best time to apply specific agronomic practices in order to maximize yield. Such knowledge has been used to advantage in northern Nigeria, for example, where thousands of hectares of otherwise non-productive land have been used to produce wheat (*Triticum aestivum* L.) during the cool, dry (harmattan) season by the use of supplementary irrigation.

A recent review of literature on the climatology of maize (*Zea mays* L.) by Shaw (1977) revealed that little research has been done on this subject in the tropics. The relatively long growing season (March to October) at Ile-Ife, Nigeria, a tropical rainforest location, offers a unique opportunity for studying the weather factors affecting yield without the confounding effects of other non-quantifiable environmental factors (e.g. soil type) usually associated with different locations. From the results of a three year study at Ile-Ife, Fakorede (1985) speculated that maize yield decreases associated with delayed planting resulted from increasingly overcast skies (i.e. reduced incident solar radiation) as the season progressed. In this paper we report a more detailed statistical analysis of weather factors affecting the response of maize to planting dates at the same location.

MATERIALS AND METHODS

Details of experimental methods and materials have been reported previously (Fakorede, 1985), except that in the present study a total of 13 planting dates were analysed in 1981. The number of cultivars grown that year varied between five and eighteen, but five cultivars were common to all dates of planting. Except for the 5 May, 1 June and 8 September experiments, which involved four-row plots, all plantings were done in two-row plots with rows 5 or 10 m long spaced 0.75 m apart. In every case within row spacing was 0.5 m, to give approximately 29 300 plant ha^{-1}. Grain yield was obtained from two rows.

Analyses were performed for the individual years and the three years combined, using mean grain yield for each date of planting, adjusted to 15% moisture content and expressed in mt ha^{-1}. Thus, there were 25 environments for the combined analyses.

Climatic data recorded at 1000 and 1600 h local time were collected from a weather station less than 300 m from the experiments. Air temperatures were obtained from maximum and minimum mercury thermometers in a Stevenson's Screen of standard height and the average daily values during the period of crop growth used in this study. Total rainfall, potential evaporation (from a shielded Piche evaporimeter), sunshine hours (from a Campbell Stokes Sunshine recorder) and average daily relative humidity in the morning (maximum RH) and in the evening (minimum RH) were also used in the analyses. In 1981, total solar radiation in the 0.4 to 1.2 μm spectral region was obtained for the total growth period using an LI-COR LI-200SB pyranometer sensor connected to an LI-1776 solar Monitor programmed to integrate and store electronically solar radiation for a 24 hour period. The sensor had a very low response at 0.4 μm, increasing nearly linearly to a maximum at about 0.95 μm before decreasing to a cutoff near 1.2 μm. Thus it had a good response in the spectral region particularly favourable to photosynthesis (0.4 to 0.7 μm).

Accumulated heat units (HU) from planting to physiological maturity were obtained using the formula (Cross and Zuber, 1972):

$$HU = [\{X^H - (X_i^H - 30) + X_i^L\}/2] - 10$$

where X_i^H and X_i^L = maximum and minimum temperature for day i, i = 1, 2, . . . , n

and n = number of days from planting to physiological maturity. If $X_i^H \leqslant 30$, then $(X_i^H - 30) = 0$.

Effective rainfall was calculated as the difference between total rainfall and the sum of potential evaporation for the season.

Analysis of variance (AOV) was used to test for significant environmental effects on yield. Subsequently, correlation and stepwise multiple regression analyses were performed using grain yield as dependent and climatic data as independent variables. In addition, path-coefficient analysis (Wright, 1921; Dewey and Lu, 1959; Campbell *et al.*, 1980; Wilson *et al.*, 1981) was used for determining the interrelations among all the variables in the combined sets of data. Path analysis is primarily a method of partitioning and interpreting cause and effect relations among a set of variables. A direct causal effect or path coefficient (p) of a variable (i) on yield (y) is shown by single one-directional

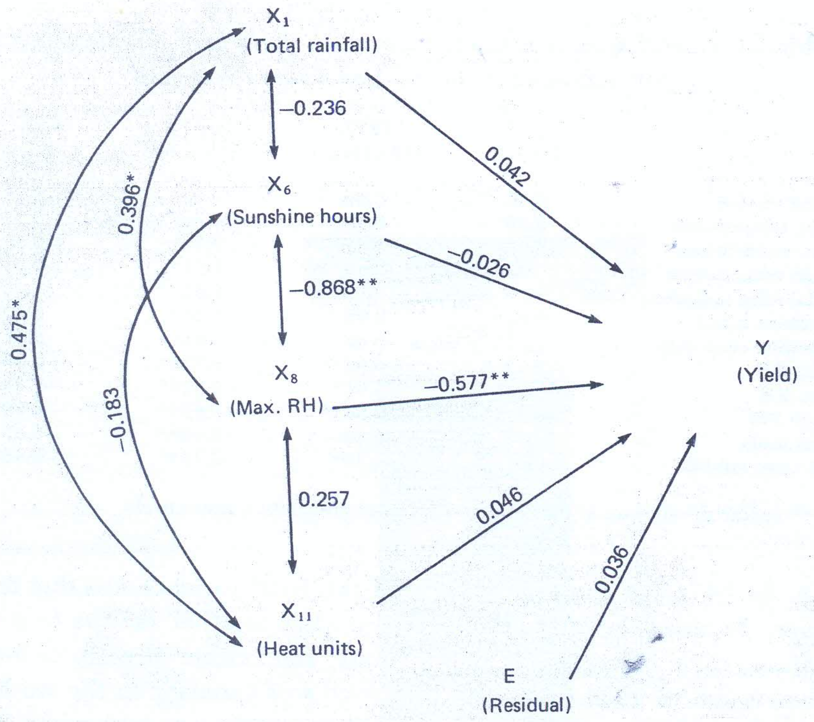


Fig. 1. Path-coefficient analysis diagram of four climatic variables on yield. One-directional arrows indicate direct effects while double arrows are correlation coefficients. *, ** indicate significance at 0.05 and 0.01 levels of probability, respectively.

arrows in Fig. 1. Indirect causal effects are shown by alternate paths from a variable (i) through another variable (j) to the dependent variable. A single indirect effect is quantitatively equal to the product of path coefficients along a given path:

$$\text{Indirect effect} = (r_{ij}) \times (p_{jy}).$$

The total indirect effect is the sum of individual one-directional indirect effects, and the effect coefficient (c) is the sum of direct and total indirect effects. Non-causal correlation, or the residual (E), is the coefficient of total correlation, (r_{iy}) minus the effect coefficient. Path coefficients, which are standardized partial regression coefficients, were obtained as described by Kim and Kohout (1975). Thus a p-value of 0.46 indicates that a change of 1.0 standard deviation unit in the independent variable would result in a change of 0.46 standard deviation unit in the dependent variable.

RESULTS

The AOV for each year (see Fakorede, 1985) revealed that differences due to sowing dates explained more of the total variance than any other source of

Table 1. *Correlation coefficients between yield and climatic variables for individual years and all years combined*

	1978 (7 dates)	1980 (5 dates)	1981 (13 dates)	Combined (25 env.)
Total rainfall	0.66	−0.86	−0.62*	−0.28
Max. temperature	0.90**	0.84	0.90**	0.81**
Min. temperature	0.89**	0.87	−0.75**	−0.05
Mean temperature	0.90**	0.86	0.61*	0.61**
Total solar radiation	–	–	0.55*	–
Sunshine hours	0.86*	0.92	0.84**	0.81**
Potential evaporation	0.77*	0.84	−0.63*	0.65**
Max. RH	−0.92**	−0.96**	−0.91**	−0.90**
Min. RH	−0.85*	−0.95*	−0.92**	−0.88**
Mean RH	−0.87**	−0.96**	−0.93**	−0.90**
Heat units	0.61	0.59	−0.93**	−0.33
Effective rainfall	0.31	−0.89*	−0.74**	−0.46*

*, ** denote significance at 0.05 and 0.01 levels of probability, respectively.

variation. In 1978 for example, 46.2% of the total variance was due to sowing date alone. It could be inferred, therefore, that weather factors (e.g. rainfall, temperature, solar radiation) played a greater role, either directly or indirectly, in the expression of yield than any other source of variation in the study.

Relative humidity generally showed negative correlations with yield (Table 1) presumably because of overcast skies and/or heavy rainfall, especially since sunshine hours showed a consistent positive relationship with yield. Because of the inter-dependence of the independent variables in a study such as this spurious correlations are common. A spurious correlation is a relationship between two variables, *a* and *b*, in which r_{ab} results largely from the fact that *a* varies along with some other variable *c* which, indeed, is the true predictor of *b*. Path coefficient analyses permit the separation of direct and indirect influences of each climatic variable on yield. From the results of stepwise multiple regression analysis for the combined data (Table 2), it would seem that maximum RH was the most important variable influencing yield, with a highly significant negative correlation ($r_{8y} = -0.90^{**}$). Simple linear regression showed that yield decreased by 431.0 kg ha^{-1} for every unit increase in maximum RH (Fig. 2a). The direct effect of this variable on yield ($p_{8y} = -0.597$) was rather large (Table 3), with fairly large positive indirect effects via sunshine hours ($r_{86}p_{6y} = 0.501$), maximum temperature ($r_{82}p_{2y} = 0.482$) and potential evaporation ($r_{67}p_{7y} = 0.440$). It would seem, therefore, that at a constant value of maximum RH, increases in sunshine hours, maximum temperature and potential evaporation would be expected to increase yield moderately. For example, multiple regression of yield on maximum RH (X_1) and sunshine hours (X_2) produced the prediction equation:

$$\hat{Y} = 34.53 - 0.3901X_1 + 0.0012X_2;\ R^2 = 0.81$$

The predicted grain yield for combinations of these two variables (Fig. 3)

Table 2. *Unstandardized partial regression coefficients (b-values), coefficients of determination (R^2) and R^2 change (DR^2) from the stepwise multiple regression of yield on climatic variables*

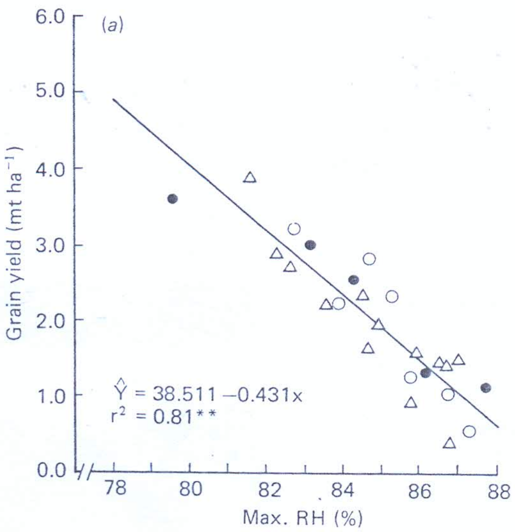
Climatic variable	b-value	R^2	DR^2
	1978		
Max. RM	2.55	0.84**	0.84
Potential evaporation	−1.05	0.90**	0.06
Total rainfall	0.05	0.93*	0.03
	1980		
Max. RH	−0.956	0.92**	0.92
Effective rainfall	0.079	0.98**	0.06
Sunshine hours	−0.007	1.00**	0.02
	1981		
Heat units	0.013	0.89**	0.89
Min. temperature	−7.130	0.92**	0.03
	Combined		
Max. RH	−0.276	0.81**	0.81
Min. RH	−0.179	0.83**	0.02
Potential evaporation	−0.162	0.86**	0.03
Mean temperature	0.380	0.88**	0.02

*, ** denote significant F-tests at 0.05 and 0.01 levels of probability, respectively.

showed clearly that at a constant rate of maximum RH, increased sunshine hours resulted only in modest increases in grain yield. On the other hand, at a constant value of sunshine hours, increased maximum RH decreased yield rapidly. Minimum RH showed similar positive indirect effects on yield (Table 3), but its direct influence ($p_{9y} = -0.686$) was even more pronounced. Its indirect effects, though of the same sign, were generally larger than those of maximum RH. The similarity between maximum and minimum RH was expected because of their highly significant positive correlation ($r_{98} = 0.917$).

Surprisingly, solar radiation was negatively correlated with yield in 1981, the only year solar radiation data were available (Table 1). However, the direct effect on yield ($p_{5y} = -0.168$) was rather low; its indirect effect via heat units ($r_{5,11}p_{11y} = 0.409$) was larger. In contrast, sunshine hours demonstrated consistent positive correlations with yield (Table 1). Linear regression showed that for the combined data yield increased by only 10.0 kg ha^{-1} for each hours increase of full sunlight (Fig. 2b). The direct effect of sunshine hours on yield, however, was small and negative ($p_{6y} = -0.026$); equally all of its indirect effects were negligible (Table 3).

Maximum and average temperatures demonstrated consistent positive correlations with yield, but the effects of minimum temperature and heat units were less predictable (Table 1). The 1981 data showed a negative relationship of yield with the latter two variables, the reverse being the case in 1978 and 1980. The combined data indicated that minimum temperature and heat units



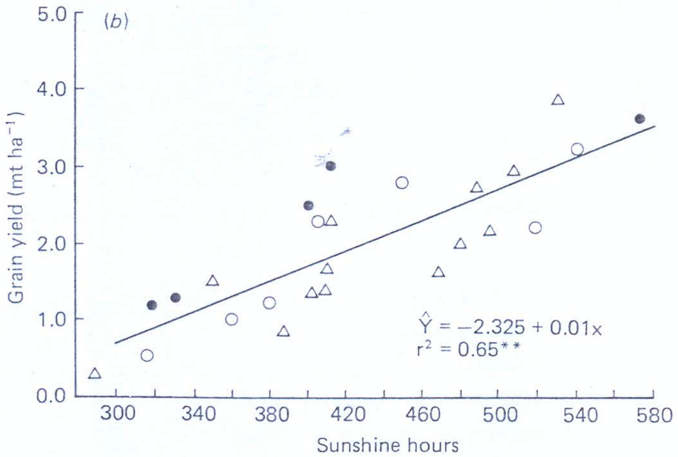


Fig. 2. Simple linear regression of grain yield on (a) maximum RH and (b) sunshine hours for the combined data. Observed values for 1978 (○), 1980 (●) and 1981 (△).

did not affect yield significantly. The results of stepwise multiple regression analyses for 1981, however, indicated that the heat unit was the most important variable affecting yield (Table 2). This variable, which alone explained 89% of the variance for yield that year, was the first to be identified in the analyses (Table 2). Across the three years, heat units had negligible direct ($p_{11y} = 0.046$) and indirect effects on yield (Table 3). Furthermore, path analysis of the combined data confirmed that minimum temperature indeed had negligible relationships with yield and therefore was not a reliable predictor of yield in this study. Maximum temperature, which demonstrated positive correlation with yield (Table 1) had a negative direct effect ($p_{2y} = -0.103$) and negative, though negligible, indirect effects via sunshine hours, evaporation, minimum temperature and total rainfall (Table 3).

Table 3. *Direct (on diagonal) and indirect (off diagonal) effects of weather factors on grain yield for the combined data*†

Variable (i)	Via variable (j) 1	2	3	6	7	8	9	11	12
1. Total rainfall	*0.042*	−0.000	0.008	0.006	−0.001	−0.228	−0.104	0.022	0.047
2. Maximum temperature	0.000	*−0.103*	0.005	−0.023	−0.543	0.482	0.648	−0.003	−0.012
3. Minimum temperature	0.009	−0.013	*0.038*	0.001	−0.235	−0.014	−0.030	0.034	0.006
6. Sunshine hours	−0.010	−0.092	−0.001	*−0.026*	−0.487	0.501	0.617	−0.008	−0.022
7. Potential evapor.	0.000	−0.090	0.014	−0.020	*−0.621*	0.440	0.596	0.015	−0.013
8. Maximum RH	0.017	0.086	0.001	0.023	0.474	*−0.577*	−0.629	0.012	0.029
9. Minimum RH	0.006	0.097	−0.002	0.023	0.546	−0.529	*−0.686*	0.005	0.019
11. Heat units	0.020	0.006	0.028	0.005	−0.207	−0.149	−0.073	*0.046*	0.019
12. Effective rainfall	0.040	0.025	0.004	0.012	0.170	−0.346	−0.270	0.018	*0.049*

Variable (i)	Total indirect effect (I)	Effective coefficient (C)	Total correlation (r)	Non-causal correlation (E)
1. Total rainfall	−0.250	−0.208	0.282	0.490
2. Maximum temperature	0.554	0.451	0.805	0.354
3. Minimum temperature	−0.242	−0.204	−0.051	0.153
6. Sunshine hours	0.498	0.472	0.806	0.334
7. Potential evaporation	0.942	0.321	0.646	0.325
8. Maximum RH	0.013	−0.564	−0.900	−0.336
9. Minimum RH	0.165	−0.521	−0.876	−0.355
11. Heat units	−0.351	−0.305	−0.335	−0.030
12. Effective rainfall	−0.347	−0.298	−0.457	−0.159

† Italicized values are the direct effects. Indirect effects can be obtained by reading variable i through variable j. For example, indirect effect of total rainfall (i = 1) via sunshine hours (j = 6) is 0.006.

As expected, total and effective rainfall generally showed similar effects on yield, with correlation coefficients of −0.28 and −0.46 respectively (Table 1). Both had negligible direct and indirect effects on yield (Table 3). In contrast, potential evaporation demonstrated large negative direct effect and indirect effects via maximum temperature and sunshine hours, and large positive effects through maximum and minimum RH. Its indirect effects through minimum temperature and heat units were moderate.

DISCUSSION

The results of this study clearly show that total and effective rainfall, maximum and minimum temperatures, sunshine hours and heat units, whether directly or indirectly, had little effect on the response of maize to planting date at this location. Maximum and minimum RH and potential evaporation appeared to be individually important in predicting yield under the conditions of this study. When considered together, however, maximum RH, which explained 81% of yield variation in the combined data, was the weather factor primarily limiting grain yield of maize under delayed planting conditions at this

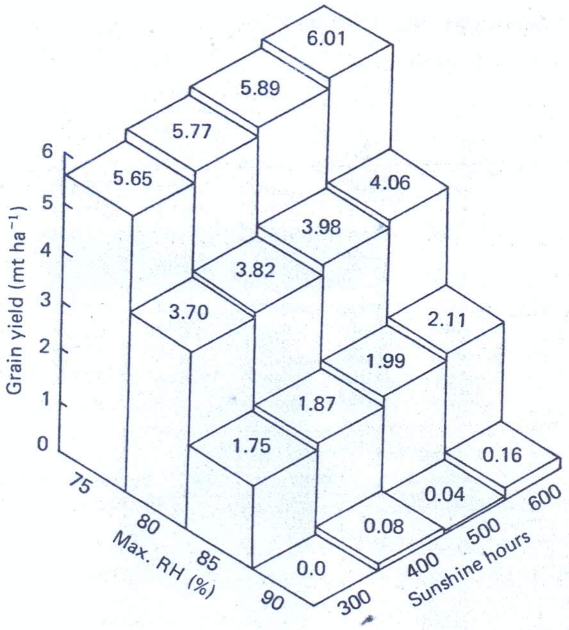


Fig. 3. Predicted response surface for grain yield to combinations of maximum RH and sunshine hours.

location. Furthermore, this variable was the first to be identified in the stepwise multiple regressions for 1978 and 1980, and accounted for 84 and 92% of yield variation for the two years, respectively. Even in 1981 when the heat unit was the most important factor, maximum RH played an indirect role, being negatively correlated with heat units ($r_{8,\ 11} = -0.79$) which in turn, were negatively correlated with yield ($r_{11y} = -0.93$). In other words, the higher the maximum RH, the lower the heat units and the lower the yield. Generally, therefore, the reduced yield performance associated with delayed planting (Fakorede, 1985) resulted primarily from increased maximum RH rather than total rainfall, both of which normally increase as the season progresses at this location.

According to Shaw (1977), total seasonal rainfall is not generally highly correlated with yield except perhaps in dry areas. In semi-arid south Dakota, USA, for example, a correlation coefficient of 0.58 was reported between total season's rainfall and yield (Pengra, 1946). Contrary to data obtained in temperate environments (Shaw and Thom, 1951; Duncan *et al.*, 1973; Shaw, 1977), our data showed that temperature, including accumulated heat units, generally showed negligible direct effects on yield. In Hawaii, Jong *et al.* (1982) found a highly significant positive correlation between yield and incident radiation ($r^2 = 0.785$). In their study, average daily irradiance during the grain-filling period explained more than 50% of the variation in yield. Our data suggest that, because of its positive relationships with evaporation and temperature, excessive solar radiation may be detrimental to maize yield at this location.

Some earlier workers (Bhatt, 1973; Campbell *et al.*, 1980) concluded that path analysis gave a somewhat different picture of interrelationships than simple linear correlations. Our data to some extent agree with theirs. For example, in the combined data correlation of yield with maximum temperature, sunshine hours and potential evaporation were all positive, thereby giving the misleading impression that yield would increase if these variables increased. In contrast, path analysis demonstrated negative direct effects of these variables on yield. It should be noted that although correlation, regression and path analyses have a common underlying principle, they measure different aspects of interrelationships. Correlation is a bivariate relationship that measures the mutual association between a pair of variables independently of other variables to be considered. Therefore, where more than two variables are involved, correlation studies *per se* are not likely to give a complete picture of the interrelationships. They do, however, measure the 'goodness of fit', strength and direction of the relationship of two variables. Stepwise multiple regression and path-coefficient analyses, on the other hand, consider all variables in the set of data to obtain the coefficients. The regression technique generally is a descriptive tool that is often used to find the best linear prediction equation. Stepwise multiple regression identifies the independent variables, one at a time, according to their relative importance in determining the dependent variable. In effect, the method controls other confounding factors in order to evaluate the contribution of a specific variable or set of variables to the dependent variables.

However, multiple regressions are not without their limitations. In Table 2, the sign and/or magnitude of the partial b-values associated with specific independent variables fluctuated from year to year and in the combined analysis. For example, the b-value associated with maximum RH was 2.55 in 1978, −0.956 in 1980, 0.0 in 1981 and −0.270 in the combined analysis. Furthermore, apart from maximum RH which was generally identified first in the stepwise regressions, the combination of variables of importance in yield determination was not consistent. This could have resulted from one or more of the following factors. First, perhaps subtle changes in the weather pattern from year to year affected the maize crop differently. Secondly, the sample sizes for the individual years were rather small. Ideally, a sample size of 30 or more should be used in correlation and regression analyses before generalized statements can be made about the coefficients. For this reason, the combined years data provide more reliable information and so were given more emphasis than the individual years data in this presentation. Thirdly, multicolinearity and spurious correlations, which are major limitations of the multiple regression technique, could have occurred. Multicolinearity is the situation in which some or all of the independent variables are highly intercorrelated. If one of the independent variables is a near-perfect (absolute $r > 0.8$) linear function of one or more of the other independent variables in the model, the partial b-value cannot be determined uniquely and will therefore be expected to fluctuate markedly from sample to sample (see also Fakorede, 1979). Most of the independent variables in our study, both in the individual years and in the combined years data, were highly intercorrelated. For example, maximum temperature, total rainfall, sunshine hours, maximum RH and potential evaporation had absolute r-values of 0.85 to 0.99 with five or more other independent variables in the combined data.

Path-coefficient analysis appears to be useful in reducing the effect of multicolinearity and spurious correlations. For example, sunshine hours, which had consistent positive correlations with yield, had direct effects (or path coefficients) of −0.354, −0.632, −0.353 and −0.026 for 1978, 1980 and 1981 and the combined three years' data, respectively. In path-coefficient analysis, the multiple regression coefficients are expressed in standard deviation units and are used to delineate complex multivariate cause-and-effect relationships. The emphasis in such an application is not on the dependence of one variable on another, nor on the relationship between any particular pair of variables. Rather, emphasis is on the entire structure of associations between independent and dependent variables. It would seem, therefore, that whenever possible path analysis should be used along with correlation and regression analyses in explaining the complex multiple interactions of yield and weather factors in crop production. This, together with well-designed experiments in which the factors can be controlled independently, should provide basic information on the phenology of maize in the tropical rainforest zone.

REFERENCES

Bhatt, G. M. (1973). Significance of path coefficient analysis in determining the nature of character association. *Euphytica* 22:338–343.

Campbell, W. F., Wagenet, R. J., Bamatraf, A. M. & Turner, D. L. (1980). Path coefficient analysis of correlation between stress and barley yield components. *Agronomy Journal* 72:1012–1016.

Cross, H. Z. & Zuber, M. S. (1972). Prediction of flowering dates in maize based on different methods of estimating thermal units. *Agronomy Journal* 64:351–355.

Dewey, D. R. & Lu, K. H. (1959). A correlation and path-coefficient analysis of components of created wheatgrass seed production. *Agronomy Journal* 51:515–518.

Duncan, W. G., Shaver, D. L. & Williams, W. A. (1973). Insolation and temperature effects on maize growth and yield. *Crop Science* 13:187–191.

Fakorede, M. A. B. (1979). Interrelationships among grain yield and agronomic traits in a synthetic population of maize. *Maydica* 24:181–192.

Fakorede, M. A. B. (1985). Response of maize to planting dates in a tropical rainforest location. *Experimental Agriculture* 21:19–30.

Jong, S. K., Brewbaker, J. L. & Chong, H. L. (1982). Effects of solar radiation on the performance of maize in 41 successive monthly plantings in Hawaii. *Crop Science* 22:13–18.

Kim, J. O. & Kohout, F. J. (1975). Path analysis and causal interpretation. In *Statistical Package for the Social Sciences*, 383–397. New York: McGraw-Hill.

Pengra, R. F. (1946). Correlation analysis of precipitation and crop yield data for the sub-humid areas of the northern Great Plains. *Journal of the American Society of Agronomy* 38:848–849.

Shaw, R. H. (1977). Climatic requirements. In *Corn and Corn Improvement* 2nd Edition, 591–623 (Ed. G. F. Sprague). Madison, Wisconsin, USA: American Society of Agronomy.

Shaw, R. H. & Thom, H. C. (1951). On the phenology of field corn, silking to maturity. *Agronomy Journal* 43:541–546.

Wilson, A. M., Cuany, R. L., Fraser, J. G. & Oaks, W. R. (1981). Relationships among components of seed yield in blue grama. *Agronomy Journal* 73:1058–1062.

Wright, S. (1921). Correlation and causation. *Journal of Agricultural Research* 20:557–385.