Plant Breeding **115**, 343—346 (1996)

ISSN 0179-9541

Sequential path analysis of grain yield and its components in maize

H. A. S. Agrama

Maize Department, Agricultural Research Centre, 42 Memphis St., Camp Caesar, Alexandria 21321, Egypt

With 1 figure and 2 tables

Received January 26, 1996/Accepted July 2, 1996
Communicated by W. E. Weber

Abstract

The efficiency of a breeding programme depends mainly on the direction and magnitude of the association between yield and its components and also the relative importance of each factor involved in contributing to grain yield. The purpose of this research is to describe the application of causal path analysis to grain yield in maize (*Zea mays* L.) to take into account the sequential development of yield components. Causal-admissible path analysis was performed assuming unidirectional causal relationships among yield components of eight maize populations. Sequential path analysis of the five yield components studied revealed that ears per plant had the highest direct effect on grain yield. However, the indirect effects of component traits via number of grains per ear was maximum. It was concluded that the number of kernels per ear, prolificacy, and grain size serve as potential characters in breeding for superior lines for grain yield in maize.

Key words: *Zea mays* — correlation coefficient — path coefficient — prolificacy — kernel size — kernel number

Table 1: Analysis of covariance for each character of eight varieties (v) of maize tested in four replications (r) in two seasons (s), with 30 individuals plants/plot (p)

Source	df	Mean squares	Expected mean squares or cross-product[1]
Total	srvp-1		
Seasons (S)	s-1		
Replications/S	s (r-1)		
Varieties (V)	v-1	M_1	$\sigma_w^2+p\sigma^2+pr\sigma_{gs}^2+prs\sigma_g^2$
S × V	(s-1)(v-1)	M_2	$\sigma_w^2+p\sigma^2+pr\sigma_{gs}^2$
(R/S) × V	s (r-1)(v-1)	M_3	$\sigma_w^2+p\sigma^2$
Plants/plot	srv (p-1)	M_4	σ_w^2

[1] σ_i^2 or $\sigma_{ij}^2 = (M_1–M_2)$/prs; see Materials and Methods

Maize (*Zea mays* L.) is one of the world's economically most important crops. It occupies about 129 million ha (CIMMYT 1994) with an average yield ranging from 2.4 t/ha (less developed countries) to 6.7 t/ha (developed market economies). Maize grain yield on an area basis can be considered in terms of the two components, grain number per unit area and kernel size. Fisher and Palmer (1983) gave a biological basis for the sequential development of characters in maize and the influence of early-developing characters on late-developing characters and their contribution to yield. Path analysis, as described by Li (1956) has been used extensively to partition correlation among yield components in barley (Dofing and Knight 1992), wheat (Blue et al. 1990), rice (Rao et al. 1991), tobacco (Amarnath and Murty 1988), finger millet (Basavaraja and Sheriff 1991), pea (Singh et al. 1985), groundnut (Manoharan et al. 1990), sugarcane (Ram and Hemarpabha 1991) and maize (Chase and Nanda 1967, Saha and Mukherjee 1985, Tyagi et al. 1988, Ramesha et al. 1990, Debnath and Khan 1991, Johnson and Jha 1993, Singh and Singh 1993). Most of those researchers ignored the importance of the causal relationship, as stressed by Wright (1921), and they used a model similar to that of Dewey and Lu (1959), in which bidirectional causation among yield components is assumed. Path analysis requires the determination of causal relationships among variables, based on either *a priori* evidence or a postulated hypothesis. Yield components develop sequentially (Matsushima 1966, Fisher and Palmer 1983) with later-developing components under the control of earlier-developing ones (Thomas et al. 1970, Dofing and Knight 1992). The analysis of the values of correlation coefficients of the different characters with yield assists in deciding their relative importance and their value as selection criteria for yielding ability. The path coefficient indicates the relative importance of each component (Wright 1921, Dewey and Lu 1959, Tyagi et al. 1988, Dofing and Knight 1992). This study pioneers the application of causal-admissible path analysis of maize grain yield that reflects the sequential nature of yield component development in determining assumed causal relationships.

Materials and Methods

The experimental materials consisted of eight local and exotic populations of maize; namely: 'Giza 2', 'Comp 45', 'Comp 5', AED-Tuxpeño, Tuxpeño-1, ETD Blanco, Amarillo subtropical, and Blanco subtropical. The first three are Egyptian open pollinated varieties while the last five are CIMMYT (International Maize and Wheat Improvement Center, Mexico) maize populations. The eight populations were evaluated at Alexandria University Agricultural Research Station during the summer seasons of 1993 and 1994 in a randomized complete block with four replications. Plots consisted of four rows of 20 plants each, 6.0 m long and 0.8 m apart. Using statistical random tables, 30 plants per replication were selected and labelled.

Prolificacy was determined at harvest as the average number of ears per plant. The post-harvest observations included ear length (cm), number of kernels per ear, unfilled kernels/ear (%), kernel size as the 100-kernel weight (g), and grain yield per plant (g). Data were log-transformed to obtain linear relationships between yield and yield components (Dofing and Knight 1992). The data obtained were statistically analysed to calculate the phenotypic correlations, as suggested by Steel and Torrie (1980).

The genetic correlation coefficients for each pair of characters were calculated using the genetic variance and the covariance from Table 1. Therefore the genetic correlation coefficient (r_A) is given by:

$$r_A = \sigma_{ij}/\sqrt{(\sigma_i^2\sigma_j^2)}$$

U. S. Copyright Clearance Center Code Statement: 0179–9541/96/1505–0343 $ 11.50/0

Table 2: Means, standard errors and genotypic (G) and phenotypic (P) correlation coefficients of yield and yield-contributing factors from plants grown at Alexandria Experimental Station in the 1993 and 1994 summer seasons

Factor		No. of ears/plants	Ear length (cm)	No. of kernels/ear	Unifilled kernels (%)	100-kernel weight (g)	Grain yield/plant (g)
Mean 1993		1.05 ± 0.19	17.81 ± 2.75	398.1 ± 36.81	4.23 ± 1.43	29.30 ± 4.14	127.2 ± 12.89
Mean 1994		1.01 ± 0.22	15.65 ± 1.64	365.9 ± 34.34	6.03 ± 1.66	27.64 ± 4.22	112.2 ± 10.78
Overall mean ± SE		1.03 ± 0.17	16.73 ± 1.89	382.0 ± 29.40	5.13 ± 2.11	28.47 ± 4.20	119.7 ± 9.80
Correlation between							
No. of ears/plant	G		–0.237	–0.209	0.194	–0.225	0.668
	P		–0.335**	–0.271*	0.309*	–0.258*	0.502**
Ear length (cm)	G			0.316	0.033	0.146	–0.013
	P			0.302**	0.072	0.115	0.197**
No. of kernels/ear	G				–0.775	0.458	0.778
	P				–0.600**	0.384**	0.567**
Unfilled kernels (%)	G					–0.155	–0.382
	P					–0.207**	–0.271**
100-kernel weight (g)	G						0.401
	P						0.334**

*,** Significant at P = 0.05 and P = 0.01, respectively

where σ_{ij} is the cross-covariance, and σ_i^2 and σ_j^2 are the variances of trait i and trait j. The observed value of the phenotypic correlation coefficient is compared with the tabulated value in Table 7.6.1 of Snedecor and Cochran (1956) for (n–2) degrees of freedom. The admissible-path analysis was carried out following the method of Rao et al. (1991) to give further insight into the component characters of yield. Yield-contributing characters were arranged in sequential order of their natural development according to Fisher and Palmer (1983). Admissible paths equations are:

$$r_{1y} = P_{1y} + r_{12} P_{2y} + r_{13} P_{3y} + r_{14}P_{4y} + r_{15} P_{5y}$$

$$r_{2y} = P_{2y} + r_{23} P_{3y} + r_{24} P_{4y} + r_{25} P_{5y}$$

$$r_{3y} = P_{3y} + r_{34} P_{4y} + r_{35} P_{5y}$$

$$r_{4y} = P_{4y} + r_{45} P_{5y}$$

$$r_{5y} = P_{5y}$$

with, y = grain yield; 1 = number of ears per plant; 2 = ear length; 3 = number of kernels/ear; 4 = unfilled kernels; 5 = 100-kernel weight.

P_{iy} are path coefficients between character i and yield, and r_{ij} are genetic correlation coefficients between character i and j. Basic equations so formed following the causal relationships in sequential order of the natural development of characters exclude inadmissible paths.

Results

The analysis of variance showed that there were no significant interactions between the seasons and all the characters. The means for each season, and across both seasons, are presented in Table 2, together with the phenotypic and genetic correlation coefficients between yield and yield-contributing factors. Genotypic correlations were stronger than the corresponding phenotypic correlations with yield. In the present study, the number of ears per plant was not genetically correlated with ear length, number of kernels, unfilled kernels and 100-kernel weight.

Genetic correlation coefficients were used to calculate the path effects. Path diagrams of sequential development of characters and causal admissible direct and indirect paths is presented in Figure 1. All direct effects were positive except that of unfilled kernels. The number of ears per plant had the largest direct effect on yield, followed by 100-kernel weight and number of kernels/ear. Although the genotypic correlation between kernel weight and yield was not-significant, this character showed a positive direct effect on grain yield. Path coefficient analysis for maize by Singh and Singh (1993), Johnson and Jha (1993) and Jadhav et al. (1991) emphasized the importance of kernel number, kernel weight and number of ears, respectively. Tyagi et al. (1988) reported that the ear and kernel weight and ear length had the highest direct effect on grain yield, while Farhatullah (1990) reported that ear height had the greatest direct effect. Ear length had a low negative association with yield through its negative indirect effect. The number of ears per plant had a correlation coefficient with grain yield smaller than its direct effect. This weak association was due to negative or low positive indirect effects via ear length, kernels/ear, unfilled kernels and kernel size. Thus, ear number directly affected yield. The correlation coefficient was much higher than the direct effect on yield for the number of grains per ear. This high correlation was mainly due to higher indirect effects through unfilled kernels and kernel weight.

Discussion

Several authors have discussed the question as to whether the number of ears/plant (Jadhav et al. 1991), ear length (Tyagi et al. 1988, Shalygina 1990), number of kernels/ear (Gupta and Singh 1990, Singh and Singh 1993), kernel weight (Debnath and Khan 1991, Johnson and Jha 1993), ear height (Farhatullah 1990), or kernel abortion (Fisher and Palmer 1983, Saha and Mukherjee 1985) really represent the potential of grain yield. It may be argued that yield itself is a complex entity and depends on its main components. The maximum expression of each yield component is determined sequentially according to the order of development; characters developed early contribute directly to the grain yield but indirectly through the later-developed traits.

Path-coefficient analysis was used to analyse the direct and indirect causes of association and is valuable for use with crops such as maize. For the construction of the path diagram and the basic equations, it is necessary to arrange characters in the order of their natural sequential development. The amount that a character contributes to yield is influenced by the different characters through different pathways. Imprecise assessment of a character's contribution through incorrect pathways may

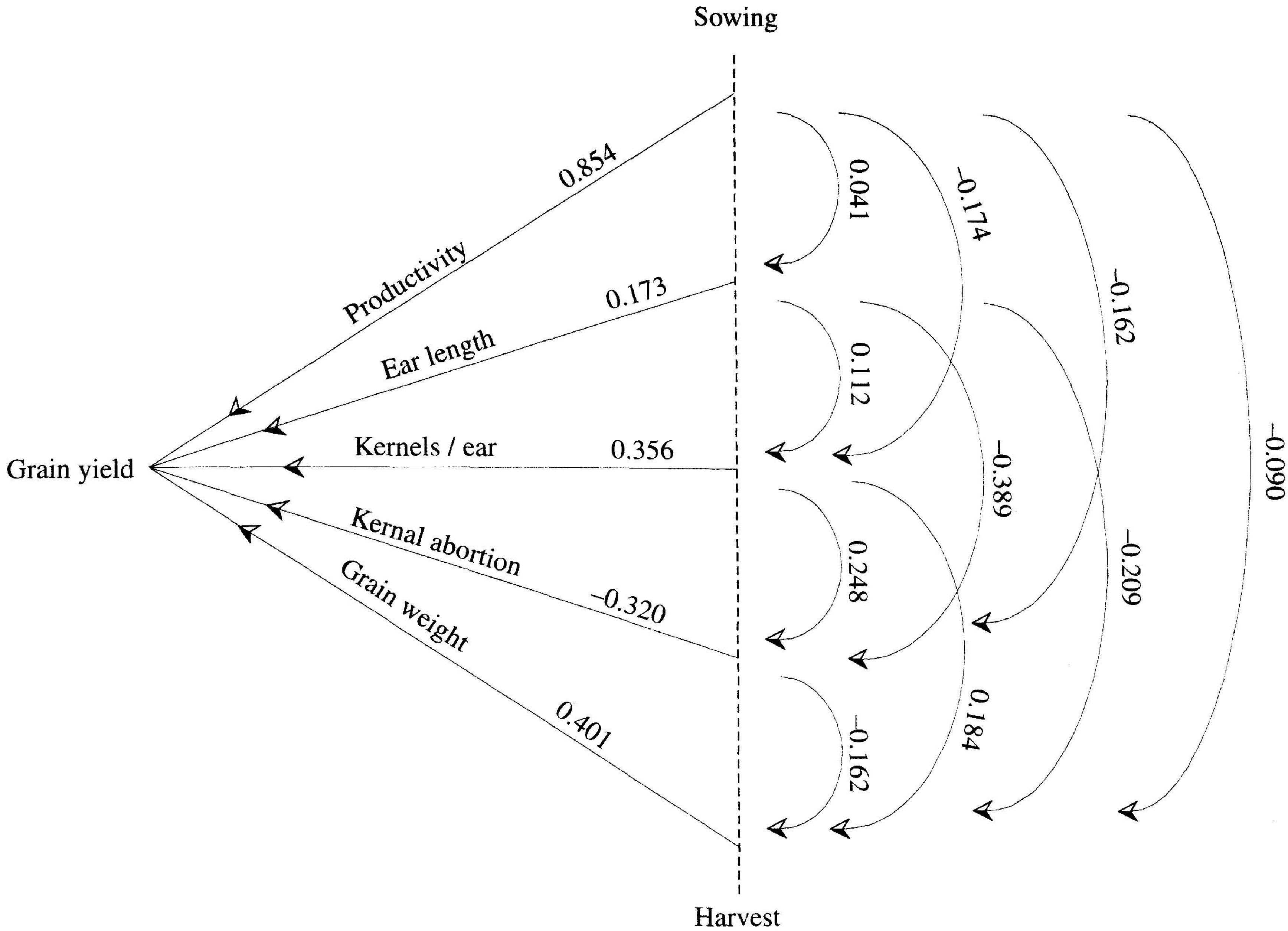

Fig. 1: Sequential development of grain yield and causal-admissible paths

misdirect breeding efforts, thus limiting efficiency in selecting better-yielding varieties.

This study has shown that higher grain yields are associated with high prolificacy and with heavy ears, which result from a high kernel weight and number, and so more emphasis should be given to these traits for the improvement of yield potential in maize. Path analysis gives a useful picture for understanding maize grain yield component compensation, and hence these traits may be taken as indices of selection purposes.

References

Amarnath, S., and N. S. Murty, 1988: Path-coefficient analysis in chewing tobacco. Indian J. Genet. **48,** 393—396.

Basavaraja, G. T., and R. A. Sheriff, 1991: Correlation and path analysis in F_2 and F_3 populations of finger millet (*Fleusine caracana*). Indian J. Agric. Sci. **61,** 774—775.

Blue, E. N., S. C. Mason, and D. H. Sander, 1990: Influence of planting date, seeding rate and phosphorus rate on wheat yield. Agron. J. **82,** 762—768.

Chase, S. S., and D. M. Nanda, 1967: Number of leaves and maturity classification in *Zea mays* (L.). Crop Sci. **7,** 431—437.

CIMMYT, 1994: 1993/94 CIMMYT World Maize Facts and Trends. Maize Seed Industries, Revisited: Emerging Roles of the Public and Private Sectors, CIMMYT. Mexico, DF.

Debnath, S. C., and M. E. Khan, 1991: Genotype variation, covariation and path coefficient analysis in maize. Pakistan J. Sci. Indus. Res. **34,** 391—394.

Dewey, D. R., and K. H. Lu, 1959: A correlation and path-coefficient analysis of components of crested wheat-grass seed production. Agron. J. **51,** 515—518.

Dofing, S. M., and C. W. Knight, 1992: Alternative model for path analysis of small-grain yield. Crop Sci. **32,** 487—489.

Farhatullah, A., 1990: Correlated response of maize yield with yield contributing traits. Sarhad J. Agric. **6,** 455—457.

Fisher, K. S., and A. F. E. Palmer, 1983: Maize. In: W. H. Smith, and S. J. Banata (eds), Symp. on Potential Productivity of Field Crops under Different Environments, 155—180. Int. Rice Res. Inst., Los Banos, Philippines.

Gupta, R. B., and K. N. Singh, 1990: Effect of leaf characters on grain yield in winter maize. Crop Improv. **17,** 76—77.

Jadhav, A. S., S. D. Pawar, and M. S. Dukare, 1991: Correlation and regression studies in maize. J. Maharashtra Agric. University **16,** 372—373.

Johnson, D. L., and M. N. Jha, 1993: Blue corn. In: J. Janick, and J. E. Simon (eds), New Crops, 228—230. John Wiley and Sons, New York.

Li, C. C., 1956: The concept of path coefficient and its impact on population genetics. Biometrics **12,** 190—210.

Manoharan, V., R. S. Ramalingam, and S. Kalaimani, 1990: Genetic advance and path analysis in the F_2 generation of an intrasubspecific cross in groundnut. Indian J. Genet. **50,** 244—247.

Matsushima, S., 1966: Theory of yield determination and its application. In: M. D. Winslow (ed.), Crop Science in Rice, 284—339. Ruijoo Publishing Co. Ltd, Tokyo.

Ram, B., and G. Hemarpabha, 1991: Character inter relationships in cultivar × species progenies in sugarcane. Indian J. Genet. **51,** 89—95.

Ramesha, M. S., S. J. Patil, J. V. Goud, and S. S. Patil, 1990: Correlation combining ability and heterosis studies on husk number and shank length in maize. Indian J. Genet. **50,** 338—341.

Rao, C. S., A. V. Rao, and A. S. R. Prasad, 1991: Effect of inadmissible paths in path analysis. Indian J. Agr. Sci. **61,** 471—475.

Saha, B. C., and B. K. Mukherjee, 1985: Analysis of heterosis for number of grains in maize (*Zea mays* L.). Indian J. Genet. **45,** 240—246.

Shalygina, O. A., 1990: Correlation of yield in maize plants with its yield components and biological characters under irrigation in the lower Volga area. Maize Abstr. **7,** 433.
Singh, G., and M. Singh, 1993: Correlation and path analysis in maize under mild-hills of skim. Crop Improvement **20,** 222—227.
Singh, K. N., U. S. Santoshi, and J. B. Singh, 1985: Path coefficient study in pea (*Pisum sativum* L.). Indian J. Genet. **49,** 499—504.
Snedecor, G. W., and W. G. Cochran, 1956: Statistical Methods. Iowa State University Press, Ames.
Steel, R. G. D., and J. H. Torrie, 1980: Principles and Procedures of Statistics, 2nd Ed. McGraw–Hill Inc., New York.
Thomas, R. L., J. E. Grafius, and S. K. Kahn, 1970: Genetic analysis of correlated sequential characters. Heredity **26,** 177—188.
Tyagi, A. P., G. P. Pokhariyal, and O. M. Odongo, 1988: Correlation and path coefficient analysis for yield components and maturity traits in maize (*Zea mays* L.). Maydica **33,** 109—119.
Wright, S., 1921: Correlation and causation. J. Agric. Res. **20,** 557—585.