Application of a simple crop physiological model based on some yield determinants to assess the productivity of pigeonpea genotypes in northern Ghana

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SUMMARY

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is cultivated in northern Ghana mainly on marginal soils towards the end of the rainy season. The crop, therefore, subsists on residual soil moisture for most part of its growth. Little is known, however, about varieties best adapted to this zone under such harsh conditions. Twenty early-maturing pigeonpea lines were, therefore, evaluated in the northern Guinea savanna ecology of Ghana with the objective of determining the physiological basis of their yields. Grain yields (Y), reproductive development (RD), total biomass (T), crop growth rates (CGR), harvest indices (HI) and the rate of partitioning (*p*) of photosynthates to reproductive sinks were estimated. Wide variations were observed for pod yields and the yield determinants. No direct links were observed between RD and the other parameters. However, there were close correlations between grain yield, T, CGR, HI and *p* on the other. The possibility of developing genotypes which combine high grain yield, T, CGR, HI and *p* in a single genetic background is, therefore, achievable. Genotypes with such attributes are most desirable to produce grains for human consumption and fodder for livestock. This study provides an example of how a simple physiological model can enhance the selection efficiency of plant breeders, through a better understanding of the genetic materials that are handled.

Original scientific paper. Received 16 Jul 96; revised 6 Jan 97.

RÉSUMÉ

Marfo, K. O., Waliyar, F. & Payne, W.: *Application d'un simple modèle physiologique culturel basé sur quelques déterminants de rendement pour estimer la productivité de génotypes de pigeonpois au nord du Ghana.* Le pois de pigeon (*Cajanu cajan* (L.) Millsp.) est cultivé au nord du Ghana principalement sur les sols marginaux vers la fin de la saison des pluies. Par conséquent la culture subsiste sur l'humidité de sol résiduaire pour la plupart de sa croissance. Peu est connu, cependant, concernant les variétés mieux adaptées à cette zone sous telles conditions rigoureuses. Vingt lignes de pois de pigeon de tôt-mûrissement étaient donc évaluées dans l'écologie savanne-guinéenne nordiste du Ghana avec l'objectif de déterminer la base physiologique de leurs rendements. Les rendements de grain (Y), le développement productif (RD), biomasse totale (T), les taux de croissance culturelle (CGR), les indices de la récolte (H I) et le taux de partition (*p*) de photosynthates aux éviers reproducteurs étaient estimés. Des variations étendues étaient observées pour les rendements de cosse et les déterminants de rendements. Des liens directs n'étaient observés entre RD et les autres paramétres. Cependant il y avaient des correlations intimes entre le rendement de grain, T, CGR, H et *p* de l'autre côté. La possibilité de développer les génotype qui combinent le haut rendement de grain T, CGR, HI et *p* dans un seul élément de base génétique est donc, réalisable. Les génotypes de tels attributs sonts les plus désirés à produire les grains pour la consommation humaine et le fourrage pour le bétail. Cette étude fournit un exemple de la maniére dont un simple modèle physiologique peut améliorer la sélection efficace des phytogénéticiens, à travers une meilleure compréhension de matériels génétiques qu' ils manipulent.

Introduction

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is becoming increasingly important in the dry areas of northern Ghana because its grain serves as a source of high protein in human diets, while its foliage is used to feed livestock. Available records indicate that little or no research has been carried out on the crop in northern Ghana. Thus, little is known about varietal adaptation to the region's erratic rainfall conditions or the marginal soils on which the crop is typically cultivated. Detailed crop physiological studies requiring expensive and sophisticated instruments are often not practical for national crop breeding programmes in Africa for the determination of varietal adaptation. The authors, therefore, adapted a simple crop physiological model developed by Duncan *et al.* (1978) to help improve the understanding of the basis of pigeonpea yields in northern Ghana, and thereby its selection efficiency.

The model of Duncan *et al.* (1978) states:

Y = RD × CGR × p where

Y = Pod, fruit or seed yield

RD = Reproductive growth duration

CGR = Crop growth rate

p = Ratio of pod growth rate to crop growth rate i.e. partitioning coefficient.

This model has been successfully used for understanding genotypic and environmental effects upon yield in groundnut (Duncan *et al.*, 1978; Witzenberger, Williams & Lenz, 1988; Flohr, Williams & Lenz, 1990; Greenberg *et al.*, 1990); Ndunguru *et al.*, 1992), cowpea (Ntare & Williams, 1993; Ntare, Williams & Bationo, 1993) and chickpeas (Williams & Saxena, 1991). Duncan *et al.* (1978), for example, attributed yield differences in groundnut varieties to genotypic differences in partitioning of assimilates. In field studies carried out in 1989, Williams & Saxena (1991) observed that yield differences in breeding lines were mainly caused by variation in crop growth rates, and found no association between seed yield and reproductive growth duration. Witzenberger, Williams & Lenz (1992) determined that differences in kernel yields in groundnut under different day lengths can be partly due to differences in crop growth rates. The variation in groundnut yields under high temperatures in the Sahel was attributed to differences in partitioning coefficient by Ndunguru *et al.* (1992) and Greenberg *et al.* (1990). Ntare *et al.* (1993) observed that partitioning coefficient (p) was a more stable parameter than pod yield in cowpea since the latter was highly influenced by the environment.

Materials and methods

Twenty early-maturing pigeonpea lines originally developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India, were evaluated at Nyankpala in the northern Guinea savanna zone of Ghana. After land preparation with a chisel plough, 45 kg P_2O_5 ha^{-1} as single super phosphate was broadcast and harrowed in. Each plot was made up of four rows, 5 m long. The rows were 0.75 m apart with plants spaced 0.20 m within rows. The seeds were treated with Thiram^R dust at 5 g.a.i. kg^{-1} seed to prevent seedling mortality. Two seeds per hill were sown on 23 Jun 92 and later thinned to a plant per hill when the seedlings were 19 days old. The design employed was randomized complete blocks with four replications. Weeds were controlled by hand-weeding as and when necessary. No insecticide was applied, hence the crop was not protected from insects. However, the early nature of these lines enabled the crop to escape the build up of *Helicoverpa armigera*, the major insect pest of economic importance on the crop in northern Ghana.

The number of days to 50 per cent flowering and maturity were recorded. At maturity (between 111 and 128 days after planting, depending on the line), the two inner rows were harvested. Grain and haulm weights were recorded after thorough sun-drying for about 3 weeks to a moisture level of about 5 per cent, measured with a moisture meter. Duncan *et al.* (1978) model, which approximates plant growth as a linear function, was used to estimate the following parameters:

DFF = Number of days to 50 per cent flowering

DH = Number of days to maturity

RD = DH - DFF

Y = Grain weight

H = Haulm weight which includes leaves and stems

T = Total biomass = Y + H

CGR = T/DH

PGR = Pod growth rate = Y/RD

p = PGR/CGR

The harvest index (HI) was also computed as Y/T. From the foregoing, whilst *p* measures the levels of indeterminacy and the various processes such as crop and pod growth rates, HI measures only the end products.

Grain yields and other yield determinants were statistically analyzed using GENSTAT 5 Release 3.1[R] programme. Means of treatments were also correlated for the various physiological traits and *r* values were considered significant at 1 per cent level of probability.

Results and discussion

Variations within the pigeonpea lines were large for grain yields, reproductive duration, crop and pod growth rates as well as partitioning and harvest index. This is evidenced by not only the significant differences between the various lines for these traits but also the CV per cent values (Table 1). Grain yields were low, ranging between 129 and 1872 kg ha^{-1}, with a mean of 946 kg ha^{-1}, compared to average yields of over 2600 kg ha^{-1} of most of these lines in India. The low grain yields may be partly attributed to the erratic rainfall conditions which prevailed during that year. Total rainfall received in 1992 was 69 per cent of the long term average, with the most erratic distribution occurring in August (Fig. 1) when reproductive development of the crop should have peaked. The total rainfall for that month at the experimental site

TABLE 1

Mean Performance of 20 Early Maturing Pigeonpea Lines in 1992

Line	Y (kg ha^{-1})	RD (days)	T (kg ha^{-1})	CGR (kg ha^{-1} day^{-1})	PGR (kg ha^{-1} day^{-1})	p	HI
ICPL4	1413	52	4088	34.86	27.17	0.78	0.35
ICPL83015	1872	59	6088	52.34	31.73	0.61	0.31
ICPL84023	1255	57	4472	39.35	22.02	0.56	0.28
ICPL85010	340	59	3918	32.94	5.76	0.18	0.09
ICPL87095	1393	59	4503	38.97	23.61	0.61	0.31
ICPL88001	124	60	3204	25.87	2.07	0.08	0.04
ICPL88003	1458	60	5421	47.03	24.30	0.52	0.27
ICPL88007	1168	64	6814	31.79	18.25	0.57	0.31
ICPL88009	247	73	5046	38.11	3.38	0.10	0.05
ICPL88015	1282	61	5985	49.56	21.02	0.42	0.21
ICPL88017	473	57	3062	26.75	8.29	0.31	0.15
ICPL89020	579	58	2793	24.08	9.98	0.42	0.21
ICPL89024	965	76	3095	23.61	12.70	0.54	0.31
ICPL89027	1521	70	4868	38.33	21.73	0.57	0.31
ICPL90001	129	59	3631	30.69	2.19	0.07	0.04
ICPL90004	261	58	4141	34.51	4.50	0.13	0.06
ICPL90005	840	76	3360	25.03	11.05	0.44	0.25
ICPL90008	1855	64	6602	55.04	28.98	0.53	0.28
ICPL90011	893	70	4308	31.84	12.76	0.40	0.21
ICPL90012	851	57	4618	39.29	14.93	0.38	0.18
Mean PE	946	63	4351	36.00	15.01	0.42	0.22
LSD (0.05)	142	2	631	3.49	2.35	0.05	0.03
CV (per cent)	41.63	6.02	36.37	37.08	46.07	25.83	19.71

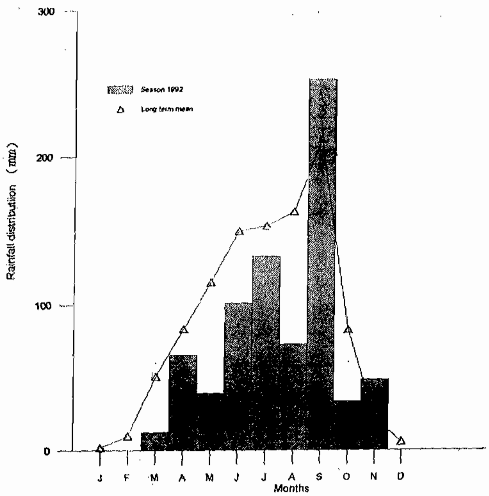

Fig. 1. Rainfall distribution at Nyankpala in 1992 compared with the long term mean (1957-1986)

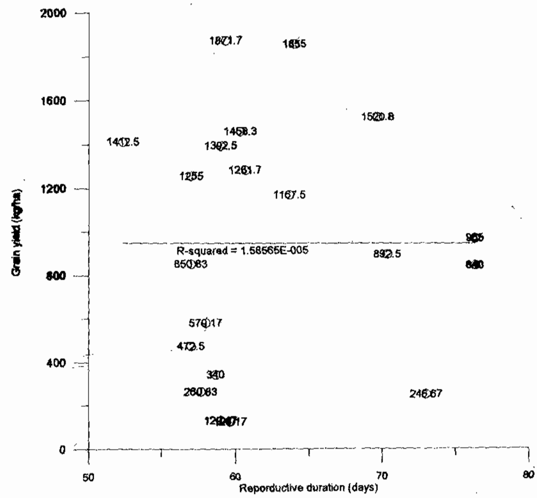

Fig. 2. Relationship between grain yield (Y) and reproductive duration (RD) for 20 early pigeonpea lines

was 44 per cent of the expected rains. Despite the low yields, the weather conditions offered the opportunity to identify potential drought tolerant genotypes. This is essential since pigeonpea is usually cultivated in this area on marginal soils with low water-holding capacities.

The line ICPL 4, which was among the top grain producers, was the most efficient in the distribution of photosynthates to reproductive sinks (Table 1) by having the largest *p* and HI values. Similarly, ICPL 83015 combined high grain yield with high biomass production as well as acceptable level of partitioning coefficient as defined by Ndunguru *et al.* (1992). All poor grain yielders had relatively low *p*. This is in contrast with observations in groundnut (Ndunguru *et al.*, 1992), in which certain lines yielded poorly despite large *p*.

There was poor relationship between grain yield and RD (Fig. 2), similar to observations made by Williams & Saxena (1991) for chickpea. Since pigeonpea is an indeterminate crop, as new reproductive nodes develop, one might expect strong competition between the existing and developing seeds or fruits for the limited photosynthates, resulting in a negative correlation between RD and *p*. However, Table 2 shows that the relationship between *p* and RD was rather insignificant (r= -0.061). This may be partly attributed to the strong environmental influence as evidenced by poor rainfall distribution during the

TABLE 2

Correlation Matrix between Grain Yield and some Physiological Parameters in Pigeonpea

	RD	*T*	*CGR*	*PGR*	*p*	*HI*	*Y*
RD	1.000						
T	-0.042	1.000					
CGR	-0.210	0.980**	1.000				
PGR	-0.163	0.664**	0.713**	1.000			
p	-0.061	0.224	0.267	0.848**	1.000		
HI	-0.073	0.221	0.249	0.835**	0.985**	1.000	
Y	-0.004	0.664**	0.687**	0.984**	0.838**	0.853**	1.000

** Significant at 0.01 level of probability.

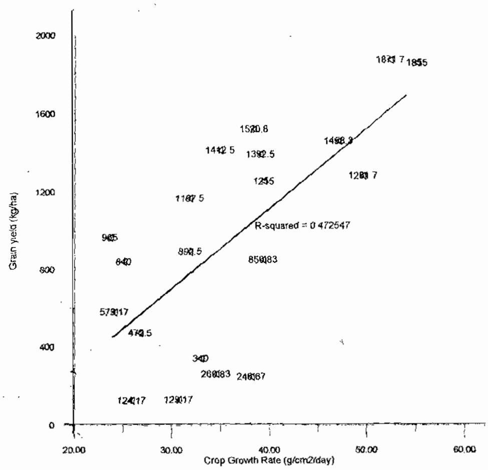

Fig. 3. Relationship between grain yield (Y) and crop growth rate (CGR) for 20 early pigeonpea lines

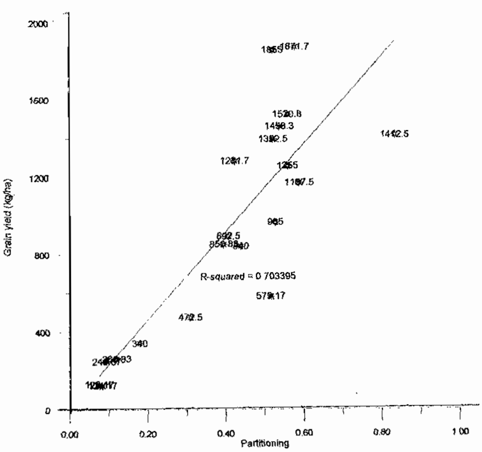

Fig. 4. Relationship between grain (Y) and partitioning coefficient (p) for 20 early pigeonpea lines.

peak reproductive development. This might have adversely affected the rate of mobilization of photosynthates to the reproductive sinks.

Crop growth rate and p strongly influenced grain yields (Fig. 3 & 4). Harvest index as well as total biomass produced were also closely associated with grain yields. This is confirmed by the strong coefficients of correlation (r) of 0.687, 0.838, 0.853 and 0.664, for CGR, p, HI and T, respectively, with grain yields (Table 2). The close linkage of grain yield with T is important in the dry areas of northern Ghana where the livestock industry is as important as food crop farming. Thus, a variety which combines these traits in a single genetic background would successfully serve a dual role of providing grain for human consumption and haulm for livestock.

Conclusion

The model of Duncan *et al.* (1978) has assisted in identifying potential high-performing lines under the dry conditions which prevailed in 1992. This model was not only inexpensive but also very simple. The high correlation between T and pod yields should enable pigeonpea breeders to develop varieties which can be used both as food and forage.

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