Evaluating groundnut (*Arachis hypogaea* L.) seed yield determinants in northern Ghana: A breeding perspective

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ABSTRACT

The direct and indirect effects of groundnut physiological responses on seed yield were investigated with genotypes of a wide range of maturity periods in advanced replicated yield trials. The trials were conducted at four locations in the savanna zone of Ghana in the 1996 and 1997 cropping seasons. The objective of the trials was to enhance selection efficiency by concentrating on trials which increase seed yield. In 1996, 27 genotypes of groundnut of different maturity groups were grown. However, in 1997, 22 out of the 27 genotypes used the previous year were used. The partitioning coefficient, crop growth rate, reproductive duration, shelling percentage, biological and seed yields were determined. The path coefficient analysis for both years indicates strong, direct effects of photo-assimilate partitioning to pods and crop growth rate on seed yield. The direct effect of reproductive duration was positive but relatively weak while the biological yield had negative direct effect on seed yield. The efficiency of photo-assimilate partitioning to pods and crop growth rate in determining seed yield were assessed through a regression analysis for each year. This analysis showed highly significant portions of the total variation of the two traits. The results suggest that long reproductive duration, slow crop growth rates, high biomass production, and low dry matter partitioning to pods do not match the ideotype of groundnut species adapted to most of the ecologies of northern Ghana.

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RÉSUMÉ

MARFO, K. O. & PADI, F.: *Evaluation des déterminants du rendement de graine d' arachide* (Arachis hypogea *L.*) *au nord du Ghana : Une perspective de reproduction.* Les effets directs et indirects des réactions physiologiques d' arachide sur le rendement de graine étaient étudiés, en se servant de génotypes d' un grand choix des périodes de maturité dans les essais de rendement réplicatifs supérieurs. Les essais se sont déroulés à quatre emplacements dans la zone savane du Ghana pendant les saisons de culture de 1996 et 1997. Le but des essais était d' améliorer l'éfficacité de sélection par la concentration sur les traits qui augmentent le rendement de graine. En 1996, 27 génotypes d'arachide de différents groupes de maturité étaient cultivés. Cependant, en 1997, 22 de 27 génotypes utilisés l'année passée étaient employés. La coefficient de partition, la proportion de croissance de culture, la durée de reproduction, le pourcentage d' égrenage, le rendement biologique et le rendement de graine étaient déterminés. L' analyse de coefficient de pathologie pour les deux années indique des grands effets directs de photo-assimilation de partition aux cosses et la proportion de croissance de culture sur le rendement de graine. L'effet direct de la durée de reproduction était positive mais relativement faible alors que le rendement biologique avait un effet direct négatif sur le rendement de graine. L' efficacité de photo-assimilation de partition aux cosses et la proportion de croissance de culture pour la détermination de rendement de graine étaient évaluées à travers une analyse de regression pour chaque année. Cette analyse montrait des portions hautement considérable de la variation totale des deux traits. Les resultats suggèrent que la durée de reproduction longue, les proportions lentes de croissance de culture, la production élevée de biomasse et la faible partition de matière sèche aux cosses n'égalent pas les idéotypes des espèces d' arachide adaptées à la plupart d' écologies du nord du Ghana.

Introduction

Groundnut yields fluctuate with variation in environmental factors which constrain efforts in developing stable-yielding genotypes across different ecologies. A good knowledge of the basis for the differential response of genotypes to different environments would offer the potential to maximize yields at the farm level by the exploitation of the appropriate varieties in specific environments (Williams, 1992).

The low heritability of yield has led to the general interest in selecting for crop characters that strongly influence the physiological processes determining final seed yield. In addition to high heritabilities, the usefulness of the characters identified as selection criteria depends on other aspects such as their measurability. It will be rewarding if the quantitative effects of these traits on seed yield and their mutual compensatory effects are understood. Numerical estimates of the independent contribution of single traits to seed yield formation across environments, and an understanding of their compensatory patterns during development provide options for stabilizing yield across environments.

The differences in grain yield within 120 chick pea genotypes, for example, were atrributed to differences in crop growth rates (CGR) by William & Saxena (1991). Reproductive duration (RD) and partitioning coefficient (P) were, however, observed to have no direct effects on grain yields. These observations were contrary to those made by Duncan *et al.* (1978) who attributed yield differences observed in groundnut to mainly partitioning. However, Ntare, Williams & Batiano (1993), in their studies on the effect of phosphorus fertilizer and sowing dates on cowpea intercropped with millet, made observations which supported those of Williams & Saxena (1991).

The objective of this study was to determine how some physiological traits affect groundnut yields in northern Ghana, and how effective selection of such traits can enhance breeding efficiency.

Materials and methods

During the 1996 cropping season, 27 groundnut genotypes were tested at Manga (Sudan savanna), Damongo (woodland savanna), Nyankpala (Guinea savanna), and Wa (Transition between Sudan and Guinea savanna) which represent the ecologies in northern Ghana. Maturity periods of these genotypes ranged from 85 to 120 days. For the 1997 trial, 22 groundnut genotypes from the materials tested in 1996 were evaluated at four locations as in the 1996 trial. In both years, the materials were planted when the rains stabilized during the 2nd week of June, after the land had been prepared by disc ploughing and harrowing.

At each location, the design used was a randomized complete block with four replications. Sowing was done at a spacing of 20 cm × 50 cm at the rate of two seeds per hill. Each plot was 4 m long, with five rows. The crop received 45 kg P_2O_5 ha^{-1} as single superphosphate before planting. The data, which were collected on only the two inner rows, included the number of days from sowing to flowering and pod maturity, and the weights of pod and crop residues dried for about 10 days in the sunlight to a moisture level of about 8 per cent measured with a moisture metre. The crop growth rate (kg/ha/day) was estimated for each plot of the experiment by using the energy adjusted final biomass (Williams, 1992) according to the following formula:

$$C = \frac{[HM + (PM \times 1.65)]}{DM}$$

where C = crop growth rate,
HM = above-ground biological yield,
PM = pod yield, and
DM = number of days from sowing to maturity.

Reproductive duration (in days) was taken as the days from 50 per cent flowering to physiological maturity. Partitioning of photo-assimilates to pods was calculated by dividing the dried above-ground biological yield by the dried pod yield. The path coefficient analysis which partitions single trait effects into direct and indirect effects and, therefore, establishes the respective strengths of each physiological trait in determining yields, was used.

The contribution of each trait was determined by path analysis of phenotypic correlations involving partitioning coefficient, reproductive duration, crop growth rates, shelling outturn, and biological yield by using mean data from the four locations for each year.

Crop growth rate and partitioning coefficient were used as independent variables in the construction of regression equation on seed yield:

$$Y = c + \alpha X_1 + \beta X_2$$

where Y = seed yield (t/ha)
X_1 = partitioning coefficient
X_2 = crop growth rate

Results

Table 1 shows, for the 1996 trials, the phenotypic correlations between traits of the 27 genotypes. Partitioning coefficient had a significant positive relationship with reproductive duration, while crop growth rate had a significant negative relationship with reproductive duration and a significant positive correlation with biological yield. There was no significant linear relationship between seed yield and shelling percentage on reproductive duration, but significant positive associations with biological yield, crop growth rate, and partitioning to pods. In 1997, partitioning coefficient had no significant linear relationship with crop growth rate, biological yield or shelling percentage (as in 1996) and reproductive duration (Table 3). Thus, partitioning coefficient did not show any significant relationship with any other parameter aside seed yield. Reproductive duration had significant negative correlations with crop growth rate and shelling percentage, but a significant positive correlation with biological yield. Shelling percentage had significant positive association with crop growth rate and negative significant relationship with biological yield.

The path coefficient analysis (Tables 2 and 4) shows how compensatory effects between pairs of traits modified their association with seed yield. In both years, crop growth rate and partitioning coefficient had the strongest positive direct effects on seed yield; the direct effects of reproductive duration and shelling percentage

TABLE 1

Correlation Matrix of Independent Variables and Seed Yield of 27 Groundnut Genotypes Tested in Multi-locational Trials in 1996

	Partitioning coefficient	*Crop growth rate*	*Reproductive duration*	*Shelling percentage*	*Biological yield*
Partitioning coefficient	1.00				
Crop growth rate	-0.073	1.00			
Reproductive duration	0.412*	-0.658*	1.00		
Shelling percentage	-0.039	-0.061	0.305	1.00	
Biological yield	-0.098	0.964*	-0.500*	0.008	1.00
Seed yield	0.731*	0.418*	0.171	0.170	0.428*

*Significant at $P \leq 0.05$; n = 27

TABLE 2

Direct and Indirect Effects of Yield Determinants on Seed Yield as Estimated from Path Analysis of 27 Groundnut Genotypes Tested in 1996

	Partitioning coefficient	*Crop growth rate*	*Reproductive duration*	*Shelling percentage*	*Biological yield*
	Indirect effect through				
Partitioning coefficient	0.625*	-0.046	0.258	-0.024	-0.061
Crop growth rate	-0.071	***0.971***	-0.639	-0.059	-0.936
Reproductive duration	0.157	-0.251	***0.381***	0.116	-0.191
Shelling percentage	-0.005	-0.009	0.043	***0.139***	0.001
Biological yield	0.025	-0.248	0.129	-0.002	***-0.257***

Residual = 0.039

Italic & bold face types are the direct effects of the parameter on seed yield.

TABLE 3

Correlation Matrix of Independent Variables and Seed Yield of 22 Groundnut Genotypes Tested in Multi-locational Trials in 1997

	Partitioning coefficient	*Crop growth rate*	*Reproductive duration*	*Shelling percentage*	*Biological yield*
Partitioning coefficient	1.00				
Crop growth rate	0.136	1.00			
Reproductive duration	0.173	-0.546*	1.00		
Shelling percentage	0.271	0.520*	-0.698*	1.00	
Biological yield	0.021	0.251	0.697*	-0.444*	1.00
Seed yield	0.822*	0.591	-0.013	0.452*	0.266

*Significant at $P \leq 0.05$; n = 22

TABLE 4

Direct and Indirect Effects of Yield Determinants on Seed Yield as Estimated from Path Analysis of 22 Groundnut Genotypes Tested in 1997

	Partitioning coefficient	*Crop growth rate*	*Reproductive duration*	*Shelling percentage*	*Biological yield*
Partitioning coefficient	***0.614***	0.087	0.106	0.166	0.013
Crop growth rate	0.081	***0.593***	-0.324	0.308	0.149
Reproductive duration	0.065	-0.205	***0.375***	-0.262	0.207
Shelling percentage	0.064	0.121	-0.154	***0.234***	-0.104
Biological yield	-0.002	-0.003	-0.006	0.005	-0.011

Residual = 0.025
Italic & bold face types are the direct effects of the parameter on seed yield.

were positive but weak, and the biological yield had negative direct effects on seed yield. Also, the indirect effects of crop growth rate through reproductive duration and biological yield on seed yield were negative in both years. For 1996, the realized regression equation was $y = 0.318 + 0.03 x_1 + 0.008 x_2$ with an efficiency of 76 per cent which is highly significant at $P \leq 0.05$. Constructing the equation with all five parameters increased the efficiency to only 84 per cent.

In the 2nd year, the relationship was $y = -0.919 + 0.038 x_1 + 0.0151 x_2$ with an efficiency of 90 per cent which is highly significant ($P \leq 0.05$). The partial regression coefficients associated with both parameters were significant.

Fig. 1 and 2 represent the linear relationships between dry matter partitioning and crop growth rate with seed yield in 1996 and the 1997 cropping seasons, respectively. The figures indicate that yield increases are influenced to a greater extent by increasing photosynthate partitioning to pods than by increasing crop growth rates.

Discussion

The results of the 2-year study indicated the importance of dry matter partitioning to pods and crop growth rate in determining seed yield. These traits had the strongest positive direct effects on seed yield in both years. The efficiency of these two traits in determining seed yield as estimated for regression analysis were highly significant for both years. This corroborated with earlier findings of Duncan *et al.* (1978) that seed yield improvement in groundnut has been largely attributed to breeding and selecting for higher photo-assimilate partitioning to pods. A rapid crop growth rate that provides adequate dry matter production during the critical phenological phases and seed-filling period impacts favourably on seed yield.

Experiments conducted by Bell, Wright & Harch (1994) indicated that the level of dry matter production in groundnuts before the flowering phase is a major determinant of pod set and pod filling. In general, biotic and non-biotic factors that affect seed yield operate mainly through these traits. A low soil calcium and/or phosphorus content, foliar diseases, and high temperatures all reduce photosynthate availability and/or dry matter partitioning to pods, while soil nitrogen content and soil-borne pathogens may act to

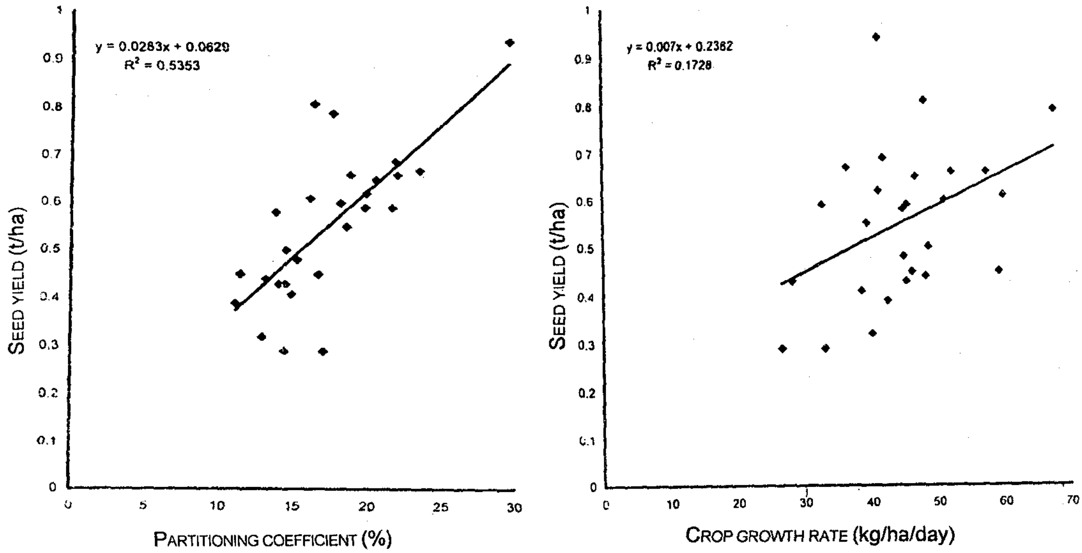

Fig. 1. Regression of partitioning coefficient and crop growth rate on seed yield for 27 groundnut genotypes tested in 1996.

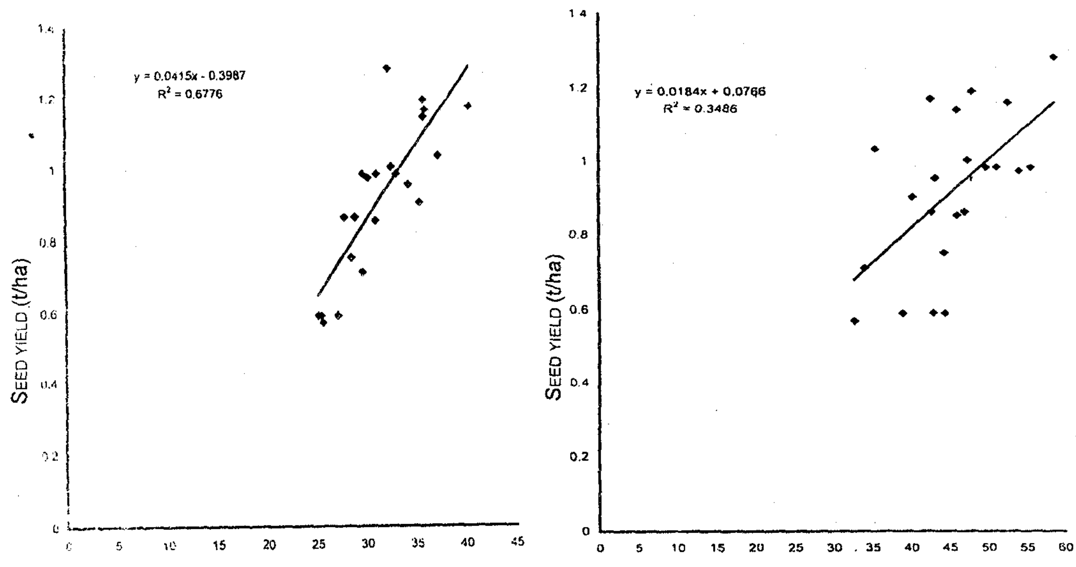

Fig. 2. Regression of partitioning coefficient and crop growth rate on seed yield for 22 groundnut genotypes tested in 1997.

determine the crop growth rate. The performance of a crop genotype in relation to these two traits indicates its tolerance to environmental stresses. Williams (1992) noted that crop growth rate and dry matter partitioning to pods would be better to select for, since the traditional criterion, pod yield, is unstable. The total indirect effects on seed yield were positive only for partitioning coefficient and crop growth rate, indicating that improvement in these two traits would positively influence the relationship between reproductive duration, shelling percentage, and biological yields.

The weak, direct effect of reproductive duration on seed yield in both years is partly due to the negative compensatory effects between it and the crop growth rate. Although increasing length of the reproductive period might be expected to provide opportunities for increased seed filling (McCloud *et al.*, 1980) and high shelling percentages, reproductive duration is more commonly a function of the maturity period of a cultivar and may be a limiting factor in longer duration cultivars by decreasing crop growth rate, as the growth conditions later in the season become less favourable. The indeterminate nature of the crop and its subterranean fruiting habit imply that water deficits during any part of the reproductive phase would affect pod initiation and/or pod development. For both years, the available rainy period was adequate only for a reproductive duration of 70 days or less (Table 5) after which reduced rainfall, accompanied by high temperatures averaging 34 °C during day time, restricted seed filling. Selection for increased reproductive duration in these savanna ecologies might, therefore, not be rewarding for the medium-maturing and late-maturing materials with reproductive periods ranging between 75 and 90 days, especially in Wa and Manga, where the rainfall after 60 days drops sharply.

A high biological yield would be inappropriate to select for as indicated by the negative direct effects on seed yield in both years. Excess top growth might have competed for assimilates during the reproductive period.

TABLE 5

Total Rainfall (mm) Received during Reproductive Period in the 1996 and 1997 Growing Season

Reproductive duration (days)	*Nyankpala 1996*	*Nyankpala 1997*	*Damongo 1996*	*Damongo 1997*	*Manga 1996*	*Manga 1997*	*Wa 1996*
1-10	24.3	81.9	29.2	11.4	86.6	75.7	47.8
11-20	3.9	59.4	44.2	99.2	80.9	59.0	79.0
21-30	73.7	51.4	65.3	65.5	123.6	145.8	107.7
31-40	62.4	82	121.6	7.1	60.1	13.3	51.1
41-50	38.5	109.5	47.7	51.9	90.6	39.6	40.7
51-60	57.6	61.2	87.3	13.5	61.8	32.5	58.3
61-70	72.6	40.2	32.1	30.2	14.2	9.7	8.5
71-80	24.0	10.4	13.1	10.2	0.0	2.5	0.0
81-90	0.0	0.0	0.0	0.1	0.0	0.0	0.0

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