Two-Dimensional Partitioning of Groundnut (*Arachis hypogaea* L.) Response to Plant Density and Thinning Intensity after Flowering

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Abstract

The two-dimensional partitioning (TDP) technique of yield component analysis (YCA) was evaluated using a groundnut (Arachis hypogaea L) crop at four plant population densities or five thinning intensities (%) after flowering. The experiments were carried out during the 1989/90 cropping season at the University of Queensland's Redland Bay Farm, Australia. Two cultivars (Improved Virginia Bunch and Red Spanish) were grown. In Experiment 1, the plant densities were 10, 21, 28 or 42 m^{-2} while in Experiment 2, the five thinning intensities were 0%, 33%, 50%, 66% or 75%, from an initial density of 42 plants m^{-2}. Thinning was carried out 32 days after planting. Total dry mass (TDM), kernel yield and some plant morphological characteristics were measured. The results show that variations in TDM and kernel yield m^{-2} were significantly influenced by the intrinsic variances of yield components analyzed in this study. For example, in both experiments, variation in TDM m^{-2} resulted from variations observed in the planting density which influenced growth performance of plant morphological components during the season. The components included, TDM/number of pegs+pods, ratio of peg+pod number/leaf area, and the number of branches/plant. Similarly, differences in kernel yield m^{-2} were associated with the variation in the above components in addition to number of kernels/pod and kernel mass. Thus, TDP-YCA gave a better analysis of groundnut response to planting density and thinning intensity after flowering than when the analysis of variance (ANOVA) technique was used alone.

Key words: *Arachis hypogaea* L., kernel yield, density, thinning, TDP-YCA

Introduction

Two-dimensional partitioning-yield component analysis (TDP-YCA) is an objective-laden protocol to evaluate treatment and yield component effects on crop growth and yield (Freeman *et al.*, 1989). In this technique, analysis proceeds by partitioning yield into a set of components whose relationship with yield is then examined. Since the work of Engeldow and Wadham (1923), yield components have been expressed as ratios of simple plant measures, in which yield is both the mathematical and biological product of the ratios (Jolliffe *et al.*, 1982). This technique of analysis is widely used in agronomic and horticultural research (Fraser and Eaton, 1983; Tarimo, 1997), and in plant breeding (Eaton *et al.*, 1986) to study plant responses to various management practices, and differences among breeder's lines, respectively. The objective of this paper is to examines the application of the TDP-YCA technique as a tool for investigating groundnut responses to planting density or thinning intensity treatments under field conditions.

Materials and Methods

Two experiments were carried out during the 1989/90 cropping season at the University of Queensland Redland Bay Farm (27° 37' S; 153° 17' E), Australia. The area has a deep, friable, fertile red loam soil (Krasnozem) with 60% clay, 15% silt and 25% sand (Keating,

1981). This soil was considered suitable for groundnut production in southeast Queensland.

The Experiments were established on land previously under a fallow crop of sorghum (*Sorghum bicolor* Moench.). The land was ploughed one month before planting. Five days before planting, a compound fertilizer was broadcast at the rate of 25 kg N, 30 kg P and 25 kg K ha^{-1}. Both experiments were planted by hand on November 21, to match the cropping season in southeastern Queensland.

The plant density experiment was sown in rows, 60 cm apart and four within-row spacings of either 4, 6, 8 or 16 cm. These spacings resulted in densities of either 42, 28, 21 or 10 plants m^{-2}, respectively. The layout of the experiment was a randomized complete block design (RCBD), with three replications. The plot size was 3.0 x 3.0 m.

In the second experiment, same cultivars as for Experiment 1 were planted at an initial plant spacing of 60 x 4 cm, resulting in an initial density of 42 plants m^{-2}. Thinning was manually carried out on December 21, 1989 (32 days after planting (DAP)), removing either 0%, 33%, 50%, 66%, or 75% of the plants within a row. The percentages were achieved by: no plant removal; removal of every third plant while skipping two plants; removal of every alternate plant; removal of every two plants skipping one plant or removal of every three plants skipping one plant within a row; respectively. The new spacings resulted in densities of 42, 28, 21, 14 or 10 plants m^{-2}. Treatments were arranged in a randomized complete block design (RCBD) with three replications. The plot size was 3.2 x 3.0 m. Five rows, each 3.2 m long, were established per plot to allow for enough plants to be sampled for data at each harvest.

In both experiments, plots were maintained weed free throughout the season using a combination of mechanical and hand weeding operations. A broad spectrum insecticide, Lannate (225 g l^{-1} methomyl) was sprayed at the recommended rate when foliar pests appeared on the crop. Attempts were made to ensure that Lannate was used only when there was an evidence of insect pest damage to avoid environmental contamination. Foliar diseases were controlled by frequent application of Bravo (500 g l^{-1} Chlorothalonil) at the rate of 2 ml l^{-1} of water, particularly during periods of high humidity and following heavy rainfall.

At harvest, six adjacent plants in a row were removed from each plot, ensuring that there was no loss of pods. The data recorded included leaf area (A_L), number of branches (N_B), leaves (N_L), pegs (N_{PG}), pods (N_P) and kernels (N_K) per plant. Other data were dry mass (DM) of stems (W_{ST}), leaves (W_L), pods (W_P), kernels (W_K) which were used to compute total dry mass (TDM) per plant.

Plant parts were used as yield components to study variation in TDM and kernel dry mass (KDM) in the groundnut cultivars. A yield component in this study was defined as the ratio of one plant part to another or to the whole plant. Thus, the following ratios were used as yield components: number of plants (N) per area (A) (N/A); number of branches per plant (N_B/N); leaf number per branch (N_L/N_B); area per leaf (tetrafoliate) (A_L/N_L); peg+pod number per leaf area (N_{PG}/A_L); ratios of pod number to peg+pod number (N_P/N_{PG}) and kernel number to pod number (N_K/N_P); individual kernel dry mass (KDM/N_K); branch number per g of TDM (N_B/TDM); and, ratio of TDM to peg+pod number (TDM/N_{PG}). These yield components were selected and arranged in a chronological sequence as described by Jolliffe *et al.* (1982) to determine their association with TDM and KDM m^{-2} in this study.

In both experiments, variation in TDM was partitioned to several components assuming a chronological sequence of plant development as suggested by Jolliffe *et al.* (1982). Thus, N/A x N_B/N x N_L/N_B x A_L/N_L x N_{PG}/A_L x TDM/N_{PG} = TDM (g m^{-2}). In this relationship, TDM was assumed to depend on plant density (N/A), branches per plant (N_B/N), leaves per branch (N_L/N_B), area per leaf (A_L/N_L), peg+pod number per leaf area (N_{PG}/A_L), and TDM per peg+pod number (TDM/N_{PG}). The ratio, N_{PG}/A_L, provides a link between assimilate source and assimilate sinks during reproductive growth, while N/A converts data on a per plant basis to per unit area basis (Jolliffe *et al.*, 1982).

Kernel yield variation was similarly analyzed using the following relationship: N/A x N_B/N x N_L/N_B x A_L/N_L x N_{PG}/A_L x N_P/N_{PG} x N_K/N_P x KDM/N_K = KDM (g m^{-2}). In this

model, plant population density (N/A) was considered essential in determining variation in crop yield (Donald, 1963), hence, its inclusion as the first component in the model. The four components following N/A were as defined for TDM. The other components included the ratio of pod number to peg+pod number (N_P/N_{PG}), kernels per pod (N_K/N_P) and kernel size (KDM/N_K).

In both cases, symbols used are those proposed by Jolliffe *et al.*, (1982). The geometric models were transformed into additive models by taking natural logarithms of the ratios (Eaton *et al.*, 1986). The additive models were then analyzed by the TDP-YCA technique as described by Eaton *et al.*, (1986). The results have been summarized in tables as percentage intrinsic variances of treatments and yield components contribution to yield.

Interpretation of TDP-YCA results

Interpretation of TDP-YCA results requires an appreciation of step-wise multiple regression procedures (Shawa *et al.*, 1981). To evaluate yield component relationships in the tables of results, they should be read vertically in the order of component entry into the step-wise multiple regression analyzes preceding each TDP analysis. In that order, values in Part (a) of each table are successive increments in the total sum of squares (TSS) attributed to components after accounting for effects of earlier components in the regression. Part (b) of each table shows percentages of TSS contributed by each cell in Part (a) of the table, generally referred to as increments in the coefficients of determination in step-wise multiple regression analysis (Eaton *et al.*, 1978). The last column (right-hand side) of each TDP table, shows the regression coefficients used in the transformation of secondary data into tertiary orthogonal variables (intrinsic variances) analyzed by the analysis of variance (ANOVA) technique to complete the TDP-YCA table.

In both step-wise multiple regression and TDP-YCA analysis, if the final component entering the regression is found to be significant, then it can be considered to have made a direct contribution to yield variation. The contribution by the last component is direct because earlier components have already been accounted for in the regression (Eaton *et al.*, 1986).

Results

Effects of plant density on TDM m^{-2}

In Experiment 1, the results show that N/A, A_L/N_L and TDM/N_{PG} accounted for 34%, 5% and 6% of the TSS associated with effects of plant population density on TDM (Table 1). No other yield component was significantly associated with those effects. Differences among cultivars accounted for about 7% of the variation in total SS for TDM, mainly through N_B/N (4%). Treatment interactions contributed 19% to the overall variation in TSS for TDM, but this was not significant. These results suggest that a model comprising of N/A, A_L/N_L, N_{PG}/A_L and TDM/N_{PG} would provide an accurate estimate of TDM variation among treatments at maturity. Apart from A_L/N_L, these components accounted for most of the variation in the TSS for TDM at maturity.

Effects of thinning after flowering on TDM m^{-2}

In Experiment 2, thinning accounted for 54% of the total SS for TDM at maturity, mainly through N/A (43%) (Table 2). No other component was significantly affected by thinning after anthesis at maturity, indicating compensation in the low plant population density environment. Cultivar differences accounted for 12% of the TSS for TDM at maturity mainly through N_B/N (17%). No other yield component was significantly affected by cultivar differences at maturity. Treatment interactions on TDM accounted for 14% of the TSS, but the overall effects were not significant (Table 2). It was also noted that A_L/N_L, i.e. leaf size, did not influence TDM at maturity in groundnut following the thinning treatments.

Table 1: Two-dimensional partitioning of variations in total dry mass (TDM) (gm^{-2}) and components at maturity in two groundnut cultivars grown at four plant densities

Yield component[1]	Source of variation: Block	Plant population density	Line spacing	Interaction	Error	Total	bi
(a) Partitioning of total ss							
N/A	0.000	0.354	0.000	0.000	0.000	0.354	0.240
Nв/N	0.002	0.001	0.045	0.001	0.004	0.052	0.119
Nʟ/Nв	0.000	0.001	0.000	0.005	0.008	0.014	0.057
Aʟ/Nʟ	0.002	0.057	0.004	0.009	0.073	0.145	0.212
Nрɢ/Aʟ	0.013	0.009	0.003	0.035	0.057	0.117	0.394
TDM/Nрɢ	0.018	0.061	0.003	0.161	0.130	0.373	1.000
Source of products	-0.018	0.100	0.018	0.006	-0.095	0.000	
Ln(TDM)	0.017	0.583*	0.073*	0.205*	0.177*	1.055	
(B) Coefficients of determination (%)							
N/A	0.00	33.55*	0.00	0.00	0.00	33.55*	
Nв/N	0.19	0.09	14.27*	0.09	0.38	4.93*	
Nʟ/Nв	0.00	0.09	0.00	0.47	0.76	1.33*	
Aʟ/Nʟ	0.19	5.40*	0.47	6.85	6.92	13.74*	
Nрɢ/Aʟ	1.23	0.85	0.28	3.32	5.40	11.09*	
TDM/Nрɢ	1.73	5.78*	0.28	15.26	12.32	35.36*	
Sum of Products	1.71	9 48	1.71	-0.57	-9.00	0.00	
Ln(TDM)	1.61	55.26*	6.92*	19 43	16.78	100.00	

*Significant ($p<0.05$; as observed from the results of the analysis of variance of components and yiled); symbols are as defined in text

Table 2: Two-dimensional partitioning of variation in total dry mass (TDM) (gm^{-2}) and components at maturity in two groundnut cultivars thinned at five intensities at 32 days after planting

Yield component[1]	Source of variation: Block	Thinning intensity	Line	Interaction	Error	Total	bi
(a) Partitioning of total SS							
N/A	0.000	1.124*	0.000	0.000	0.000	1.124	0.394
NB/N	0.015	0.002	0.446*	0.042	0.072	0.576	0.286
NL/NB	0.000	0.006	0.000	0.002	0.023	0.032	0.067
AL/NL	0.005	0.013	0.001	0.035	0.122	0.175	0.252
NPG/AL	0.004	0.010	0.031	0.067	0.143	0.256	0.268
TDM/NPG	0.115	0.081	0.006	0.085	0 139	0.246	1.000
Source of products	-0.122	0.158	0.185	0.137	0.012	0.000	
Ln(TDM)	0.017	1.394*	0.299*	0.368	0.511	2.589	
(b) Coefficients of determination (%)							
N/A	0.00	43.41*	0.00	0.00	0.00	43.41*	
NB/N	0.58	0.08	17.23*	1.62	2.78	22.25*	
NL/NB	0.00	0.23	0.00	0.08	0.89	1.24	
AL/NL	0.19	0.50	0.04	1.35	4.71	6.76	
NPG/AL	0.15	0.39	1.20	2.59	5.52	9 89	
TDM/NPG	4.44*	3 13	0.23	3.28	5.37	16 45*	
Sum of products	-4.71	6.10	-7 15	3.28	0.46	0.00	
Ln(TDM)	0.00	53.84*	11.55*	14.21	19.74	100.00	

*Significant ($P<0.05$; as observed from the results of the analysis of variance of components and yield); symbol are as defined in text

Effects of plant density on kernel yield m^{-2}

Through the TDP-YCA, it has been shown that variation in plant density accounted for 34% of TSS for kernel yield m^{-2} (Table 3). Treatment interactions accounted for 19% of the TSS. The contribution of variation in plant density to total SS for kernel yield was mainly through N/A (20%) and A_L/N_L (0.3%). No other component significantly contributed to variation in kernel yield through the effects of plant density. The contribution by cultivars to TSS for kernel yield (21%) was whole dependent upon variation in N_B/N (21%). Thus, increased number of branches per plant decreased kernel yield at maturity (Table 3). At the low density, plants partitioned more DM to vegetative than to reproductive growth.

Effects of thinning after flowering on kernel yield m^{-2}

Effects of increased thinning intensity after anthesis on kernel yield m^{-2} were similar to those of plant density (N/A) at crop maturity. Generally, growth compensation was low where greater than 50% of plants were removed after anthesis (32 DAP, Table 4). Both vegetative and reproductive components played significant roles in determining variation in kernel yield during reproductive growth and at maturity. Most of this variation was accounted for by KDM/N_K, which indicated greater dependency of kernel yield on DM partitioning to reproductive growth than on plant densities resulting from thinning intensities. Aspects of plant development, particularly the ratio of pegs+pods to leaf area, i.e. divergence of assimilate to greater reproductive development, ratio of pod number to pegs+pods (reproductive index) and kernel number per pod were important sources

Table 3: Two-dimensional partitioning of variation in kernel yield (KDM) (g m-2) and components at maturity in two groundnut cultivars grown at four plant densities

	Source of variation					
Yield component	Block	Plant population density	Line	Interaction	Error	Total	bi
(a) Partitioning of total SS							
N/A	0.000	0.731*	0.000	0.000	0.000	0.731	0.345
N_B/N	0.031	0.020	0.041*	0.010	0.065	0.868	-0.482
N_L/N_B	0.000	0.003	0.000	0.017	0.027	0.047	0.105
A_L/N_L	0.000	0.009*	0.001	0.001	0.011	0.022	0.083
N_{PG}/A_L	0.084	0.062	0.018	0.234	0.377	0.774	1.015
N_P/N_{PG}	0.054	0.042	0.000	0.011	0.177	0.284	1.082
N_K/N_P	0.005	0.076	0.000	0.263*	0.179	0.523	1.247
KDM/N_K	0.026	0.081	0.011	0.024	0.205	0.347	1.000
Source of products	-0.100	0.181	0.001	0.107	-0.190	0.000	
Ln(KDM)	0.100	1.205*	0.772*	0.667*	0.851	3.595	
(b) Coefficients of determination (%)							
N/A	0.00	20.33*	0.00	0.00	0.00	20.33*	
N_B/N	0.86	0.56	20.61*	0.28	1.81	24.12*	
N_L/N_B	0.00	0.08	0.00	0.47	0.75	1.31*	
A_L/N_L	0.00	0.25*	0.03	0.03	0.31	0.61*	
N_{PG}/A_L	2.34	1.72	0.50	6.51	10.49	21.53*	
N_P/N_{PG}	1.50	1.17	0.00	0.31	4.92	7.90*	
N_L/N_P	0.14	2.11	0.00	7.32*	4.98	14.55*	
KDM/N_K	0.72	2.25	0.31	0.67	5.70	9.65*	
Sum of products	-2.78	5.03	0.03	2.98	-5.29	0.00	
Ln(KDM)	2.78	33.52*	21.47*	18.55*	23.67	100.00	

*Significant ($P<0.05$; as observed from the results of the analysis of variance of components and yield); [1]symbol are as defined in text

Table 4: Two-dimensional partitioning of variations in kernel yield (KDM) M^{-2} and components at maturity in two groundnut cultivars thinned at five intensities at 32 days after planting

	Source of variation						
Yield component	Block	Thinning intensity	Line	Interaction	Error	Total	bi
(a) Partitioning of total SS							
N/A	0.000	1.187*	0.000	0.000	0.000	1.187	0.405
NB/N	0.001	0.000	0.029	0.003	0.005	0.037	0.073
NL/NB	0.000	0.014	0.000	0.005	0.051	0.071	-0.101
AL/NL	0.003	0.009	0.001	0.023	0.081	0.117	0.206
NPG/AL	0.017	0.045	0.131	0.283	0.607	1.083	0.552
NP/NPG	0.015	0.065	0.002	0.040	0.128	0.250	1.029
NK/NP	0.063	0.002	0.000	0.105	0.179	0.350	0.992
KDM/NK	0.065	0.018	0.019	0.025	0.256	0.382	1.000
Sum of products	-0.070	1.153	-0.173	0.167	-0.077	0.000	
Ln(KDM)	0.094	1.493*	0.009	0.651	1.230	3.477	
(B) Total SS(%)							
N/A	0.00	34.17*	0.00	0.00	0.00	34.17*	
N_B/N	0.03	0.00	0.83*	0.09	0.14	1.06*	
N_L/N_B	0.00	0.40	0.00	0.14	1.47	2.04*	
A_L/N_L	0.09	0.26	0.03	0.66	2.33	3.36*	
N_{PG}/A_L	0.49	1.29	3.77*	8.14	17.46	31.15*	
N_P/N_{PG}	0.43	1.87	0.06	1.15	3.68	7.19*	
N_K/N_P	1.81	0.06	0.00	3.02	5.15	10.07*	
KDM/N_K	1.87	0.52	0.55	0.72	7.36	10.99*	
Sum of products	-2.01	4.40	-4.98	4.80	-2.21	0.00	
Ln(KDM)	2.70	42.94*	0.26	18.72	35.38	100.00	

*Significant ($P<0.05$; as observed from the resuts of the analysis of variance of components and yield); [1]symbol are as defined in text

of variation in kernel yield following thinning after flowering.

Discussion

The results of TDP-YCA on TDM and kernel yield greatly improved our understanding of the physiology of groundnut response to plant density and thinning after anthesis. Economic yield in legumes is determined by TDM accumulated during crop growth (Muchow and Charles-Edwards, 1982). A large proportion of vegetative DM is mobilized to grain growth during the maturation growth phase, i.e. the period from anthesis to maturity. The current results have strengthened our knowledge of cultivar interactions with cultural practices in determining TDM and kernel yield in groundnut. The results have indicated possible avenues of manipulating the crop for improved productivity. It is apparent that, variation in TDM during reproductive growth in groundnut depends on plant density and performance of various plant morphological components, including N_{PG}/A_L, TDM/N_{PG} and A_L/N_L, during crop growth. These components are manipulable through improved agronomic practices or plant breeding. Increased leaf size, for example, increases TDM at maturity through increased net photosynthesis or more directly as an additive component of TDM (Jolliffe *et al.*, 1982; Tarimo, 1993). In addition to the components of biological yield (TDM), economic yield in groundnut, also, could be improved through establishment of an optimum plant density (N/A), N_{PG}/A_L, N_K/N_P and KDM/N_K (Quijada *et al.*, 1985; Bell *et al.*, 1987). It was noted that the optimum plant density for both TDM and kernel yield for the two cultivars was 21 plants m^{-2}. The 21 plants/ha is close to the recommended 20 plants ma^{-2} for groundnut in Tanzania.

In the thinning experiment, in addition to significant components in Experiment 1, N_B/N, was also a significant component in determining variation in TDM at maturity among the treatments. These results show that, compensation in plant size with increased thinning intensity increased TDM at maturity. Branches per plant (N_B/N) and N_{PG}/A_L were components of compensation for TDM following reductions in plant density after thinning. Thinning has been

shown to increase formation of branches per plant during subsequent growth in groundnut (Williams, 1979). Indeed, net photosynthetic efficiency and DM partitioning are improved after thinning (Williams, 1979). These responses significantly contribute to variation in kernel yield at maturity because of increased assimilate synthesis and partitioning to reproductive growth in high thinning intensity plots. As reported by Williams (1979), increased vegetative growth after thinning compensated for kernel yield at maturity in the thinned plots. Thus the extent of yield reduction depends on the thinning intensity and plasticity of the cultivar in compensating for the removed neighbour plants.

Conclusion

In the two experiments, variation in TDM and kernel yield m^{-2} was associated with variation in the planting density. Plant density influenced growth performance of both vegetative and reproductive yield components in groundnut.

Both direct sown populations and thinning intensity treatments gave similar responses in terms of growth and yield performance of groundnut during the period from flowering to maturity. These results suggest that insect pests or rodents damage on field crops could be effectively simulated using data from such experiments. Usually, these pests do not cause mechanical or toxic injury to unaffected plants, implying possibility of growth compensation later in the season.

The two-dimensional partitioning of yield component responses to treatments is a robust technique for studying physiological responses of crops to environmental factors under field conditions.

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