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Plant Population and Irrigation Effects on Spanish Peanuts (*Arachis hypogaea* L.)[1]

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ABSTRACT

Both irrigated and nonirrigated conditions were imposed on various populations for three years using the peanut (*Arachis hypogaea* L.) cultivar Argentine. Row spacings were 0.25, 0.5, 0.75 and 1 m. Within-row plant spacings ranged between 2 and 27 plants/m.

The dependent variables of yield (kg/ha and g/plant), other kernels (%) and net return ($/ha) were fitted with a surface response equation $Y = \beta_1 + \beta_2X_1 + \beta_3X_1^2 + \beta_4X_2 + \beta_5X_2^2 + \beta_6X_1X_2$, with X_1 spacing between rows and X_2 spacing between plants within the row. This model fitted all dependent variables very well for both irrigated and nonirrigated conditions. Resulting interpolation of the data using the above equation indicated that the 0.25 m row spacing gave the highest yield of unshelled peanuts for both irrigated and nonirrigated conditions. Approximately 15 plants/m was the optimal plant spacing (in all row spacings) for maximum yield and quality. Integrating yield and quality in terms of net returns, the 0.25 m row spacing was optimal for production of Argentine peanuts. Computations based on the above equation and evaluated at constant population density (plants/ha) showed yield was still increased to the narrowest row spacing in the study.

Subsequently, row spacing vs. yield studies with Starr and Comet cultivars were conducted over seven growing seasons at a spacing in the row of about 10 plants/m. Row spacing varied from 0.15 to 1 m. In every year, the narrow spacings outyielded the wider spacings.

Key Words: Peanut yield, crop row spacing, plant population, irrigation

One method for increasing yield of row crops is to use optimal plant population. This can be achieved without drastic modification of farming equipment. For spanish peanuts (*Arachis hypogaea* L., ssp. *fastigiata* var. *vulgaris*), Sturkie and Buchanan (9) recommended a row spacing of 0.46 to 0.67 m and plant spacing of 7 to 10 plants/m. This recommendation was based on results of field trails conducted between 1919 and 1969 in the southern United States.

Another method for increasing yield of spanish peanuts is by irrigation. This practice is also documented by Sturkie and Buchanan (9). Yield enhancement is most evident in arid and semi-arid regions, but irrigation may or may not be valuable in more humid areas.

Matlock (Matlock, J. W. 1961. Effects of Plant Population, Planting Date and Irrigation on the Yield and Grade of Two Peanut Varieties. Unpublished M. S. Thesis, Oklahoma State University Library, Stillwater, OK 74074) conducted field trails on the interaction between planting density and irrigation of two cultivars of spanish peanuts. The cultivar Spantex was not sensitive to plant population under either irrigated or nonirrigated conditions, while the cultivar Argentine was sensitive to plant population for both water treatments. For the cultivar Argentine, the plant spacing within the row varied with the row spacing to realize optimum yield. Cultivar Spantex realized optimum yield at the 8 plants/m spacing.

The purpose of this work was to determine the optimum within-row plant spacing and spacing between rows for spanish peanuts under both irrigated and nonirrigated conditions in the semi-arid southwest and to obtain mathematical coefficients for use in modeling peanut production functions.

Materials and Methods

This work reports two studies. The initial study was conducted in 1960, 1961, and 1964 at the Agronomy Research Station, Perkins, Oklahoma. In 1960 and 1961 the tests were conducted on soil classified as Teller fine sandy loam, fine-loamy mixed thermic Udic Argiustolls. Spanish peanuts, Argentine cultivar, were planted in late May each year. In each of the 3 years plots were replicated four times in a completely randomized design with 2 "locations": irrigated and nonirrigated. The plot size was 5.8 m long by 4 rows wide. Outer plots were surrounded by a border planting 4 rows wide. In 1960 seeds were planted at the rate of 8, 15, and 32 viable seeds/m. The row spacings were 1, 0.75 and 0.5 m.

In 1961, an additional row spacing of 0.25 m was included in the experiment. Planting densities were 7, 15, and 22 viable seeds/m. These same plants and row spacings were used in 1964 at the Caddo Research Station, Ft. Cobb, Oklahoma on soils classified as Cobb fine sandy loam, fine-loamy mixed thermic Udic Haplustalfs and Meno fine sandy loam, loamy mixed thermic Aquic Arenic Haplustalfs.

For each of the three years, the irrigated treatment consisted of 2.5 cm of water applied whenever the soil moisture of the 15 to 30 cm zone of the profile dried to approximately -1 bar soil water pressure. This provided 3 to 5 irrigations per season. Irrigation was provided by sprinklers set in an overlap design. Fertilizers and pesticides were provided at the prevailing recommended rates.

At maturity, the center 2 rows of each plot were hand harvested and the yield of cleaned, air-dried, unshelled pods, along with the final plant population were determined. Samples of the unshelled pods were sent to Oklahoma Federal-State Inspection Service at Durant, Oklahoma. They determined the sound mature kernels (% SMK), other kernels (% OK), and the shelling percentage. The net value of the crop was calculated from the price schedule published in the Southwestern Peanut Grower's News (Gorman, Texas), representing that season's market value of the crop, minus the seed costs. Seed value was based on that season's costs of medium sized, certified seeds. A least-squares technique for response surface was used in the evaluation of the parameters of regression models.

The second study was started in 1967. The purpose was to hold the within-row spacing at about 19 plants/m of row to obtain greater detail on row spacing and irrigaiton effects. Seven years of additional investigations compared yields on 0.3 and 0.9 m row spacings. In 1967, row spacings of 0.15 m and 0.45 m were studied additionally. Descriptions of the cultural practices for the 7-year study can be found in Chin Choy et al. (1) and McCauley et al. (6). Briefly, these investigations were conducted at the Caddo Research Station, Ft. Cobb, Okla. For these years, Spanish peanuts (cv. Starr or Comet) were planted within 2 weeks of 1 June, (no later than 6 June). Plots were 30 m long in three replications in randomized complete blocks. Recommended cultural practices were used. The peanuts were hand harvested in late October and the yield of cleaned, dried, unshelled pods and the number of plants harvested were recorded. The Federal-State Inspection Service graded the harvested samples, as before.

Irrigation was with a solid-set sprinkler system set in an overlap design for uniform water application. Nominal 5-cm applications of water were made at 7 to 10-day intervals, depending upon equipment and weather limitations. This provided 5 to 8 irrigations in the July to early September irrigation season.

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Results

The results of the studies with both row-spacing and plant-spacing variables are summarized in Fig. 1. The response surface model which provided the best fit to the data was $\hat{Y} = \beta_1 + \beta_2 X_1 + \beta_3 X_1^2 + \beta_4 X_2 + \beta_5 X_2^2 + \beta_6 X_1 X_2$, in which X_1 = row spacing; X_2 = plant spacing within the row. This model consistently had the lowest standard error of the estimate ($s_{y, x1, x2}$) of the models tried. Preliminary plotting of the data suggested that the smallest linear polynomial model which could be used was a quadratic and hence the model was of this form. Donald (4) and Willey and Heath (10) have presented comprehensive reviews of equations for fitting yield versus plant density. In this study greater value was placed on accurate interpolation rather than fitting the data for extrapolation to the origin. Therefore, skewing the lower end of planting densities with a parabolic fit was considered undesirable. The magnitude of $s_{y, x1, x2}$ is shown for each response surface in Fig. 1 in terms of 2σ (two standard deviations) for both the irrigated and the nonirrigated response surfaces. The range of the observed data is shown in each response surface. Where practical, surfaces were extrapolated to common bounds for convenience of presentation. Coefficients of the equations for the response surfaces are listed in Table 1.

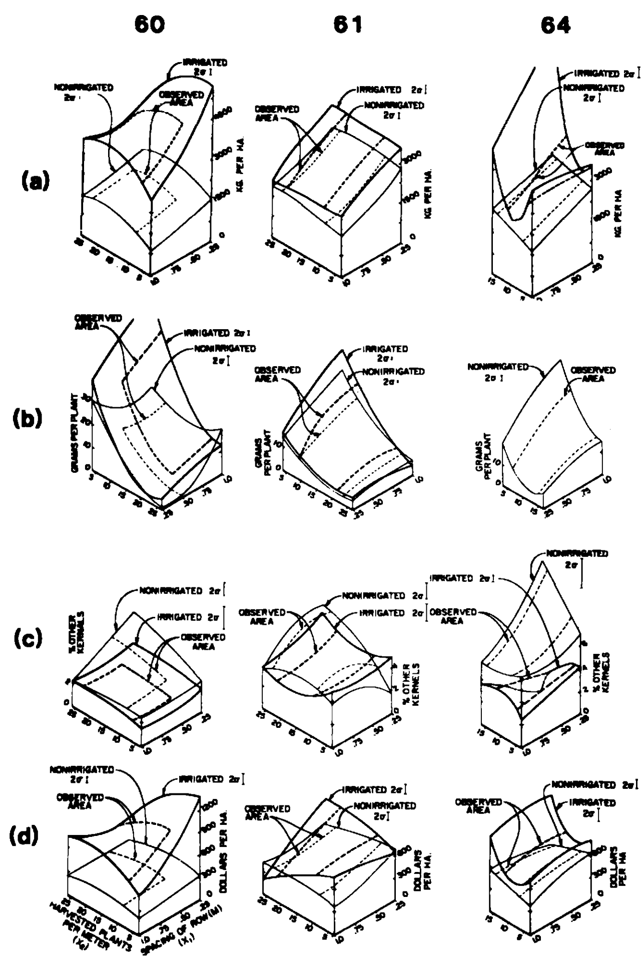

Fig. 1. Effects of row spacing and plant spacing within row on peanuts in 1960, 1961, and 1964. Response surfaces were calculated with regression data from Table 1. Horizontal axes are captioned at lower left, d 60. Ranges of twice the standard deviation from regression are shown as vertical ticks labeled $2\sigma_S$

Table 1. Regression parameters and correlation index for the years 1960, 1961, and 1964. The model was $\hat{Y} = \beta_1 + \beta_2 X_1 + \beta_3 X_1^2 + \beta_4 X_2 + \beta_5 X_2^2 + \beta_6 X_1 X_2$; X_1 = distance between rows (m); X_2 = number of plants harvested per meter of row length.

Variable		β_1	β_2	β_3	β_4	β_5	β_6	R^2
				Nonirrigated				
Yield (kg/ha)								
unshelled peanuts	1960	1600	-1330	269	89.0	-2.89	19.3	0.99**
	1961	3310	-2990	1060	26.6	-0.943	16.0	0.96**
	1964	3010	-1580	92.9	24.4	-0.0386	31.8	0.89**
Yield (g/plant)								
shelled peanuts	1960	54.9	-76.1	46.6	-3.13	0.0483	1.61	0.85 NS
	1961	11.9	28.5	-5.64	-1.30	0.0349	-0.0686	0.95**
	1964	17.9	54.7	-17.4	-3.51	0.143	-1.31	0.97**
Percent other kernels	1960	2.59	-1.13	0.958	0.198	-0.00181	-0.155	0.75 NS
	1961	-2.18	12.7	-7.23	0.473	-0.00761	-0.258	0.75**
	1964	7.27	-5.24	4.76	0.342	-0.00660	-0.535	0.76**
Net value								
(dollars/ha)	1960	318	-122	-29.8	14.6	-0.651	5.78	0.83 NS
	1961	861	-765	251	-6.18	-0.252	14.9	0.78**
	1964	508	-624	350	16.2	-0.827	18.9	0.13 NS
				Irrigated				
Yield (kg/ha)								
unshelled peanuts	1960	7360	-7650	2560	11.5	-4.78	160	0.98**
	1961	3710	-696	-687	2.94	0.178	-15.4	0.97**
	1964	4460	2190	-500	-483	44.2	-338	0.79**
Yield (g/plant)								
shelled peanuts	1960	40.8	46.5	-10.8	-4.19	0.0987	-0.833	0.99**
	1961	11.3	48.2	-13.4	-1.41	0.0415	-1.24	0.99**
	1964	36.4	111	-6.84	-11.6	0.902	-9.22	0.99**
Percent other kernels	1960	2.65	-3.59	2.29	0.061	-0.00153	0.00927	0.75 NS
	1961	6.39	-3.24	2.68	-0.225	0.00898	-0.0954	0.41 NS
	1964	4.40	-3.07	-0.344	0.126	-0.0280	0.462	0.43 NS
Net value								
(dollars/ha)	1960	1890	-2250	757	-14.5	-1.25	61.6	0.89*
	1961	454	600	-240	31.7	-0.505	-41.9	0.84**
	1964	1020	470	-478	-115	6.87	0.859	0.43 **

The yield response of the peanuts to irrigation was greater in 1960 than in 1961 and 1964 (Fig. 1, row a). Yield for the irrigated study in 1960 more than doubled that of the nonirrigated study for all row and plant spacings. Overall enhancement of yield by irrigation was not pronounced in 1961. Linear increases of yield with plant populations for both irrigated and nonirrigated treatments were obtained (Fig. 1, a61). A number of timely rains (Table 2) occurred during the 1961 and 1964 growing seasons masking the effects of irrigation. In 1961 irrigation caused a greater difference in yield at the highest plant population than at lower populations. The response surface for the irrigated treatment in 1964 showed a peculiar peak (Fig. 1, a64). This resulted from failure to attain the desired range of plant spacing within the row. Even a small extrapolation produced the unrealistically high peak. The nonirrigated treatment exhibited a strong linear yield increase with increasing plant population, i.e., a linear yield increase in both row spacing and plant spacing within rows.

The beneficial effect of supplemental water on the performance of individual plants is shown in Fig. 1, row b.

The particular enhancement of yield per plant is evident in b60 for the plants grown in wide spacings in the row. In 1961, yield per plant for both irrigated and nonirrigated treatments had a similar surface for similar plant populations at the 0.25 m row spacing (Fig. 1, b61). The curve for irrigation in 1964 corresponding to Fig. 1, b64 resembled the irrigated curve in Fig. 1, a64, but was more confusing and is not shown.

Table 2. Rainfall (cm) during months of vegetative growth. Measurements were made within 2 km of the plots.

	1960	1961	1964	1967	1968	1969	1971	1972	1973	1974
	cm									
JUN	5.3	19.1	2.8	4.1	7.9	10.0	11.1	2.4	5.4	1.4
JUL	13.7	9.9	1.8	7.5	11.2	3.3	7.5	7.3	9.1	0.9
AUG	8.0	3.4	16.3	5.4	3.5	7.2	11.1	1.4	1.5	12.5
SEP	3.1	28.2	7.8	15.6	16.0	11.3	12.3	2.2	19.3	8.6

Peanut market quality is expressed in terms of % SMK and % OK. The % SMK was essentially independent of population and is not shown in Fig. 1. Effect of year and irrigation are shown in Table 3. Irrigated means were 2 to 4% SMK above the nonirrigated treatments.

Table 3. Sound mature kernels (%) for three years of study. Standard deviation of the mean is σ.

	Year		
Treatment	1960	1961	1964
	% SMK		
Non Irrigated	70.1	63.0	65.1
σ	0.3	0.6	0.9
Irrigated	71.9	65.7	69.3
σ	0.5	0.4	0.4

The lowest % OK tended to be in the irrigated treatment (Fig. 1, row c). These data and the % SMK results tended to demonstrate quality enhancement due to irrigation. The year 1961 was somewhat exceptional where low plant populations gave a lower % OK for nonirrigated than irrigated treatments (Front corner of Fig. 1, c61). This clearly resulted from annual variation in crop environment (Table 2).

Figure 1, row d, shows the response surfaces for net returns ($/ha). The 0.25 m row spacing had the highest net return within the observed plant populations. The contours of these net return surfaces were similar to those of the yields for 1960 and 1964 but not for 1961. In 1961 the high plant population for the 1 m rows had a lower net return for the irrigated than nonirrigated treatments. This could be because of lower quality of peanuts as seen in Fig. 1, c61.

Figure 1 clearly shows year to year variation. However, some important trends are shown. Accordingly, the coefficients listed in Table 1 may be of use to modelers.

The experimental design from 1967 to 1974 was based on the results shown in Fig. 1. The intent was to hold within-row plant spacing constant at about 15 plants/m and study row spacing as the primary variable. The within-row spacing was usually less than the optimum, Table 4. In every year the more narrow row spacings gave the highest yield, even though in some years the statistical confidence in the difference was low. Yields shown in Table 4 for 1960, 1961, and 1964 were calculated from the response surface equations of Table 1 for an assumed within-row spacing of 10 plants/m. Table 4 summarizes results from three varieties over ten growing seasons.

Table 4. Yield (kg/ha) of cleaned, dried, unshelled peanuts. Data from 1960, 1961 and 1964 were calculated from equations of Table 1 and assuming constant within-row plant spacing of 10 plants/m.

	Water		Row Spacing (m)				LSD
Year	Treatment	Cultivar	.15	.30	.45	.90	.05
			kg/ha				
1960	Irrigated	Argentine			4790	3480	160
	Nonirrigated	Argentine			1740	1400	50
1961	Irrigated	Argentine		3440	3240	2430	200
	Nonirrigated	Argentine		2730	2420	1790	170
1964	Irrigated	Argentine		3650	3410	2570	300
	Nonirrigated	Argentine		2850	2670	2150	260
1967	Irrigated	Starr[‡]	3600(7.1)[†]	2830(6.2)	2330(7.2)	2020(6.3)	600
	Nonirrigated	Starr[‡]	2500(7.2)	1670(7.0)	1230(7.9)	1110(7.3)	400
1968	Irrigated	Starr[§]		4360(7.9)		3550(10.2)	410
	Nonirrigated	Starr[§]		3120(7.7)		3040(8.6)	560
1969	Irrigated	Comet[¶]		4060(8.4)		3490(9.0)	610
1971	Irrigated	Comet[¶]		3640(12.1)		2950(14.9)	540
1972	Irrigated	Comet[¶]		3510(12.0)		3400(12.4)	620
1973	Irrigated	Comet[¶]		3390(16.2)		2970(17.4)	490
1974	Irrigated	Comet[¶]		3110(10.0)		2330(11.5)	410

[†]Numbers in parenthesis are the number of plants per meter of row harvested.

[‡]Mean of 8 replications.

[§]Mean of 4 replications.

[¶]Mean of 6 replications.

Discussion and Conclusions

The high level of significane obtained from the response surfaces (Table 1) indicates the goodness of fit for all dependent variables considered. One might hope to calculate a general mathematical model for predicting the various yield components as shown by Willey and Heath (10). However, the magnitude of variability of the parameters in Table 1 definitely shows that, because of environmental differences, this could not be done. Probably the greatest effect of environment interaction is shown in the quality component of % OK (Fig. 1, row c). Figure 1 shows a striking influence of year to year variation. Obviously no single model would adequately describe the three year results. However, some of the grosser aspects of the curves are informative and set bounds for models.

Correlation indices for 1960 nonirrigated results on the % OK and net return tended to be lower than those for the other variables (Table 1). This result was even more pronounced for the irrigated treatment; there was a lack of significance for the % OK for all three years. This indicated a poorer fit for the model. A higher % OK was found for the non-irrigated treatments of all three years but not at constant within-row spacing. Highest % OK tended to be at high plant populations per unit area (back corner of graph Fig. 1, row c). This is logical in light of data of Chin

Choy et al. (1). Their work showed that peanut row spacings of 0.3 m commonly had lower evapotranspiration than 0.9 m spacings once a full canopy was developed. In addition, the soil surface was generally more moist in the plots with narrow row-spacings. This would imply that under nonirrigated conditions narrow rows would tend to enhance the peg environment conditions because of the higher moisture content at the soil surface. Evidence of such enhancement can be seen in Fig. 1, row c 61 and 64. The relatively high % OK seen in these graphs was probably caused by peg and pod development late in the season when summer stress had abated (Table 2). The irrigated environment generally brought about a lower % OK than the nonirrigated treatment for all three years. Response to irrigation was more uniform over the various spacings.

In all three years, row spacing and row population had little effect on % SMK. (Table 3). The % SMK was low in 1961 and 1964. Cox (2) and Stansell et al. (8) indicated that a decrease in % SMK could be expected if the plants were severely wilted. The 1960 season showed greatest response to irigation and the lowest nonirrigated yield. Nonetheless, the effect of any drought stress on % SMK was the least in 1960. Differences between irrigation and nonirrigation effects on % SMK are apparent in 1961 and 1964. The 1961 season had 22 consecutive rain free days in June, 11 in July and 6 and 16 in August. Except for the 22 days in June, these dry spells were typical of the three summers. However, unseasonably wet periods prevailed in the later summers of 1961 and 1964. These periods may have contributed to the low % SMK values noted in those seasons.

In the 1960, 1961, and 1964 studies, the yield per plant decreased as the population was increased, but the population effect prevailed in the yield. Population clearly influences yield. Evidently as population increases, the total yield increases "faster" than the yield per plant decreases. The equations of Table 1 can be examined for effect of row spacing under conditions of constant population level by combining the yield equation with the condition $X_2 = cX_1$ where c is a constant. Differentiating the resultant equation with respect to X_1 and setting limits on X_1 and c to be within the range observed in the field gives positive slopes showing that even at constant population the yield increased with decreasing row spacing. Constant population means as row spacing is decreased, the plants/m of row would decrease to give constant plants/ha. The striking relationship between row spacing and yield is evident in Table 4. In all seasons the mean yield increased as row spacing decreased, although some of the differences were of low statistical confidence. The row spacing component of population seems to be most effective in determing yield as evident from Fig. 1, row a, and Table 1. In Table 1 the β_2 values are much larger than thew β_4 values indicating that reasonable changes in X_1, row spacing, make greater changes in yield than reasonable changes in X_2, within-row plant spacing. Table 4 shows the general production level to vary with years. A comparison with Table 2 suggests this variation is not conditioned by amount of rainfall. Some years with high yield have low rainfall and vice versa. Differences may be influenced more by planting date, temperatures or rain-free periods.

When one considers the optimum row spacing in terms of net return, the narrow row spacing consistently showed the highest returns for both irrigated and nonirrigated treatments (Fig. 1, row d). The increase due to irrigation is well documented (3, 5). The use of high plant population by decreasing row spacings increased the net returns of the crop.

Throughout the course of the studies, plots were watched for susceptibility to disease and insect infestation. No differential effect was noted in any of the 10 years of the study.

In conclusion, the results showed that narrow row spacings increased yeild and net return for 10 years of study with Spanish peanuts in Oklahoma. No specific within-row plant spacing showed a consistent optimum, but approximately 10 plants/m gave relatively high yields for both irrigated and nonirrigated conditions. A word of caution is in order. Some of the spacings employed in these studies were not adaptable to commercially available digging machinery and were harvested by hand.

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