EFFECT OF PLANT DENSITY ON YIELD AND YIELD COMPONENTS OF SWEET POTATO

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ABSTRACT

Total yield and yields of sweet potatoes measuring 5-9 cm diameter (No. 1 size) and 2.5-5 cm diameter (No. 2 size) were found to be highest at the closest spacing studied (30 cm between plants, 90 cm between rows) after a full season's growth (120 days). This effect occurred because as spacing between plants decreased, the number of roots per plant increased but not at an equivalent rate. Thus, when possible, sweet potato growers should practice close spacing and plan to control root size distribution by delaying the harvest date. If this is not feasible (due to various time constraints), root size distribution can be affected by wider spacings. In general, wider spacings (up to 60 cm) will result in any given root size distribution earlier, but with less yield.

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INTRODUCTION

Sweet potato roots do not "ripen" or mature but continue to enlarge as long as conditions favorable for growth exist. One technique for getting an optimum distribution of root sizes is the timing of harvests. Sweet potatoes grown for processing as canned whole roots are harvested when a majority of the yield consist of small roots (2-5.5 cm diameter). Roots grown for the fresh market (4.5-9 cm diameter) and those grown for processing as diced frozen or as puree for baby food (over 9 cm diameter) are harvested later. However, manipulating harvest dates may be limited by the required length of growing season, processing plant schedules, and other constraints. A second technique of controlling root size distribution is to adjust plant densities and/or spacings.

The experiments reported here determined the effectiveness of adjusting plant populations to change root size distributions and the differences in the responses among cultivars.

MATERIALS AND METHODS

All experiments were conducted on a Norfolk sandy loam soil at the University of Maryland Vegetable Research Farm, located in Salisbury, Maryland. Standard commercial practices were employed with regard to fertilization, cultivation and irrigation. Four sweet potato cultivars, namely, Redmar, Centennial, Nemagold and MD 2262, were grown at four spacings, 30, 40, 50 and 60 cm in the row in two separate plantings resulting in plant populations of 37,000, 28,000, 22,000 and 18,500 plants/ha. Each planting was a complete factorial with four replications. Each plot consisted of one row 15 m long spaced at 0.9 m between rows. Two weeks prior to harvest, actual stand counts were obtained for each plot, since transplanting was done with a mechanical transplanter and spacings were not exact. At harvest, storage roots were divided into three size categories, i.e., Jumbo (over 9 cm diameter), No. 1 (5-9 cm diameter), and No. 2 (2.5-5 cm diameter). Roots in each size category were weighed and counted. The first planting was harvested September 18, after having 116 growing days, while the second harvest was done on October 21, after having 132 growing days.

RESULTS AND DISCUSSION

Experimental data were analyzed using standard analysis of variance procedures (Table 1). Total yield and yields of No. 1 and No. 2 size grades were greater in the second planting, probably partly due to a longer growing season and partly due to the site of the first planting being less suited to the production of sweet potatoes. Previous data (Scott and Bouwkamp, 1975) have indicated that the cultivars studied produced an increase of approximately 3 t/ha/wk. The difference between the two plantings was 8 t/ha for total yield, 6 t/ha for No. 1 yield and 2 t/ha for No. 2 yield. Cultivar and spacing effects were significant for all yield categories and all spacing effects were predominantly linear. Interaction effects of planting x cultivar were significant for total yield and for yields of No. 1 and No. 2 size grades. These effects were found to be differences in the magnitude of response rather than in the direction of response. (All cultivars produced more total, No. 1 and No. 2 yields in the second planting but the magnitude of the response was different). The interaction effects of planting x spacing for total and No. 2 yields are similarly explained.

Regression analyses were used to study the differences in response of the various cultivars. Since the spacing effects were linear, plant density (expressed as plants/m^2) was converted to the log 10 of plant density (inasmuch as log plant density is linearly related to spacing).

Table 1. Significance of experimental effects on total yield and yields of No. 1, No. 2 and Jumbo size roots.[1]

		Yield				Number of Roots			
Effect	**df**	**No. 1**	**No. 2**	**Jumbo**	**Total**	**No. 1**	**No. 2**	**Jumbo**	**Total**
Planting (A)	1	**	**	ns	**	**	**	ns	**
Cultivar (B)	3	**	**	**	**	**	**	**	**
Spacing (C)	3	**	**	**	**	**	**	**	**
Linear	1	**	**	**	**	**	**	**	**
Quadratic	1	ns	ns	ns	ns	ns	ns	ns	*
Cubic	1	ns	ns	ns	ns	ns	ns	ns	ns
A X B	3	**	**	ns	**	**	**	ns	**
A X C	3	ns	*	ns	*	ns	ns	ns	*
B X C	9	ns	ns	**	ns	ns	ns	**	*
A X B X C	9	ns	ns	ns	ns	ns	ns	ns	ns

[1]Size categories of sweet potato tubers: Jumbo (over 9 cm diameter), No. 1 (5-9 cm diameter and No. 2 (2.5-5 cm diameter).

* - Significant, odds 19:1

** - Significant, odds 99:1

ns - Not significant

df - degree of freedom

Yields were converted to relative yield (RY) by dividing the yield per plot by the average of that cultivar in each planting x cultivar mean ($X_{pctr}/X_{pc..}$) (Table 2). Comparison of regression coefficients with a t-test revealed that Redmar responded at a different rate than Centennial both in No. 1 yield and No. 2 yield. There were no other significant differences noted among the cultivars studied.

Variance analysis of the number of roots/ha (Table 1) indicated significant effects in a pattern similar to yield response. The second planting yielded more total roots/ha and more No. 1 and No. 2 size roots. The differences were approximately 44,000, 25,000, and 20,000 for total, No. 1 and No. 2 size roots, respectively. Since previous data have shown an increase of about 4,500 roots/ha/wk (Scott and Bouwkamp, 1975), we can only account for a small amount of the difference based on a longer growing season. Most of the difference was due to a more suitable site in the second test than in the first.

Cultivar and spacing effects were significant for all yield categories. Spacing effects were primarily linear in nature, although the quadratic effect was significant for total yield.

Interaction effects were primarily due to changes in the magnitude of differences rather than reversal in nature. It appears that yield reduction due to wider spacing in the row may be related to an inability of the plant to fully exploit the larger area available to each plant. This may be related to relative sink capacities of the roots and vines.

Table 2. Regression equations and correlation coefficients of four cultivars for yields of each class size and total yield.

Cultivar	Regression Equation	r_{xy}
	No. 1 yield	
Nemagold	$\hat{y}$ = .831 + .517 log x	.164 ns
Redmar	$\hat{y}$ = .844 + .541 log x	.450 **
MD 2262	$\hat{y}$ = .683 + .750 log x	.425 *
Centennial	$\hat{y}$ = .437 + 1.331 log x	.791 **
	No. 2 yield	
Nemagold	$\hat{y}$ = .491 + 1.257 log x	.680 **
Redmar	$\hat{y}$ = .604 + .881 log x	.444 **
MD 2262	$\hat{y}$ = .315 + 1.624 log x	.748 **
Centennial	$\hat{y}$ = .184 + 1.928 log x	.723 **
	Jumbo yield	
Nemagold	$\hat{y}$ = 1.984 — 2.386 log x	—.313 ns
Redmar	$\hat{y}$ = 2.332 — 3.163 log x	-.405 *
MD 2262	$\hat{y}$ = 1.554 — 1.314 log x	-.353 *
Centennial	$\hat{y}$ = 1.776 — 1.834 log x	-.590 **
	Total yield	
Nemagold	$\hat{y}$ = .758 + .682 log x	.358 *
Redmar	$\hat{y}$ = .809 + .550 log x	.511 **
MD 2262	$\hat{y}$ = .824 + .416 log x	.380 **
Centennial	$\hat{y}$ = .819 + .427 log x	.450 **

x - Plant density (plants/m^2)
$\hat{y}$ - Predicted relative yield (RY)
ns - Not significant
* - Significant, odds 19:1
** - Significant, odds 99:1

Regression analysis was accomplished by using log plant density as the independent variable and relative root number (RN) expressed as a fraction of the mean root number for each cultivar and planting ($X_{pctr}/X_{pc..}$) as the dependent variable (Table 3). There were no significant differences noted among the regression coefficients of the cultivars Jumbo nor for No. 1 size roots. Both Redmar and Nemagold responded significantly differently from Centennial in the number of No. 2 size roots. Redmar and Centennial differed significantly in

Table 3. Regression equations of four cultivars for predicted number of roots/ha and plant density for each root size category.

Cultivar	Regression Equation	r_{xy}
	No. 1 yield	
Nemagold	$\hat{y}$ = .733 + .775 log x	r = .317 ns
Redmar	$\hat{y}$ = .725 + .858 log x	r = .614 **
MD 2262	$\hat{y}$ = .640 + .861 log x	r = .473 **
Centennial	$\hat{y}$ = .412 + 1.390 log x	r = .811 **
	No. 2 yield	
Nemagold	$\hat{y}$ = .516 + 1.225 log x	r = .743 **
Redmar	$\hat{y}$ = .577 + .928 log x	r = .513 **
MD 2262	$\hat{y}$ = .303 + 1.653 log x	r = 8.13 **
Centennial	$\hat{y}$ = .064 + 2.213 log x	r = .777 **
	Jumbo yield	
Nemagold	$\hat{y}$ = 1.839 − 2.034 log x	r = -.281 ns
Redmar	$\hat{y}$ = 2.380 − 3.365 log x	r = -.462 **
MD 2262	$\hat{y}$ = 1.357 − .847 log x	r = -.238 ns
Centennial	$\hat{y}$ = 1.792 − 1.873 log x	r = -.659 **
	Total yield	
Nemagold	$\hat{y}$ = .599 + 1.054 log x	r = .723 **
Redmar	$\hat{y}$ = .644 + .876 log x	r = .640 **
MD 2262	$\hat{y}$ = .520 + 1.139 log x	r = .827 **
Centennial	$\hat{y}$ = .401 + 1.417 log x	r = .827 **

x - Plant density (plants/m^2)
$\hat{y}$ - Predicted relative root number (RN)
ns - Not significant
* - Significant, odds 19:1
** - Significant, odds 99:1

their response to changes in plant density in the total number of roots produced.

Since there was an apparent similarity in the response of sweet potatoes to changes in plant density in relative yield and relative number of roots, this relationship was further explored through correlation and regression analyses. Regression equations were calculated for RY as predicted by RN (Table 4).

One may note the very close relationship between yield and root number in each size class. Most of the regression coefficients were

Table 4. Predicted yield as a function of number of roots of four cultivars for each size class and total yield.

Cultivar	Regression Equation	r_{xy}
	No. 1 yield	
Nemagold	$\hat{y}$ = −.169 + 1.152 x	.893
Redmar	$\hat{y}$ = .343 + .670 x	.759
MD 2262	$\hat{y}$ = .094 + .905 x	.936
Centennial	$\hat{y}$ = .077 + .923 x	.940
	No. 2 yield	
Nemagold	$\hat{y}$ = .081 + .909 x	.812
Redmar	$\hat{y}$ = −.006 + 1.02 x	.931
MD 2262	$\hat{y}$ = .059 + .941 x	.881
Centennial	$\hat{y}$ = .124 + .877 x	.937
	Jumbo yield	
Nemagold	$\hat{y}$ = −.028 + 1.027 x	.977
Redmar	$\hat{y}$ = .035 + 1.006 x	.946
MD 2262	$\hat{y}$ = −.017 + 1.106 x	.973
Centennial	$\hat{y}$ = .013 + .989 x	.905
	Total yield	
Nemagold	$\hat{y}$ = .206 + .806 x	.617
Redmar	$\hat{y}$ = .454 + .578 x	.744
MD 2262	$\hat{y}$ = .545 + .454 x	.572
Centennial	$\hat{y}$ = .669 + .331 x	.599

$\hat{y}$ - Predicted RY
x - Predicted RN

near 1.0, suggesting a 1:1 relationship between yield and root number. Correlation coefficients between RY and RN were somewhat smaller for total yield. Regression coefficients were also generally less. There were no significant differences among the regression coefficients of the various cultivars in any size class or total yield. All correlation coefficients were highly significant.

Examination of partial correlation coefficients (Table 5) reveals that RY and RN are closely related, independent of density, for all sizes and that generally the correlation coefficients are slightly lower for total yield. The pattern is similar to that revealed in Table 4, suggesting that for a given size class (No. 1, No. 2 or Jumbo), RY and RN are very closely related but for total yield some other factors are involved. In general, RY and plant density, independent of RN, are not closely related, suggesting that plant density has little effect on yield other than the influence on root numbers.

Further evidence is available from the relationship of plant density and RN, independent of RY. In general, plant density affects the number of roots in each size class but the relationship is much closer for total yield than for any individual size class. It may also be noted that there are some apparent cultivar differences with Nemagold and Redmar responding more consistently in RN of No. 1 size roots than MD 2262 and Centennial. The reverse is true with regard to Jumbo size roots. Thus, distribution of roots into the various size classes may not be the same for all cultivars.

To study the effects of spacing on distribution of number of roots and yield in the various size grades, data on yield and root number in each size grade were divided by total yield or root number as applicable. The data were then transformed by the function: $\arcsin\sqrt{\text{percentage size grade}}$ (No. 1, No. 2, and Jumbo sizes). Analysis of variance was performed on the transformed data (Table 6).

Significant differences were observed between the two plantings for percentage of No. 1 and Jumbo yield, in that a higher percentage of No. 1 yield was obtained in the second planting and a higher percentage of Jumbo yield in the first.

Changes in spacing resulted in significant effects in the percentage of No. 2 and Jumbo yield and the effects were predominantly linear. The percentage of No. 1 yield was not significantly affected by spacing treatments. This may be explained partly by an apparent shift from smaller to larger roots as the distance between plants increased. Thus, the yield of No. 1 size remained nearly constant. Another explanation is that the cultivar x spacing interaction partially masks the main effects of the spacing treatments.

Redmar produced a higher percentage of No. 1 roots as spacing between plants increased in contrast to Centennial and MD 2262, which produced a smaller per-

Table 5. Linear and partial correlation coefficients of the four cultivars for each size class and total yield.

Cultivar	r_{DN}	r_{NY}	r_{DY}	$r_{NY.D}$	$r_{DY.N}$	$r_{DN.Y}$
No. 1 yield						
Nemagold	.317	.893**	.164	.899**	-.279	.384 *
Redmar	.613**	.786**	.450**	.723**	-.065	.470**
MD 2262	.473**	.936**	.425*	.922**	-.057	.236
Centennial	.811**	.940**	.791**	.834**	.144	.323
No. 2 yield						
Nemagold	.743**	.812**	.680**	.625**	.196	.446 *
Redmar	.497**	.931**	.444 *	.914**	-.059	.256
MD 2262	.812**	.881**	.748**	.706**	.118	.487**
Centennial	.777**	.937**	.723**	.863**	-.023	.412 *
Jumbo yield						
Nemagold	-.281	.977**	-.313	.975**	-.188	.122
Redmar	-.445 *	.946**	-.405 *	.935**	.055	-.209
MD 2262	-.237	.973**	-.353 *	.978**	-.546**	.493**
Centennial	-.658**	.905**	-.590**	.850**	.017	-.361 *
Total yield						
Nemagold	.723**	.617**	.358 *	.555**	-.162	.683**
Redmar	.624**	.744**	.511**	.633**	.090	.425 *
MD 2262	.827**	.572**	.380 *	.496**	.202	.804**
Centennial	.827**	.597**	.450**	.452 *	-.101	.780**

r_{DN} - Linear correlation between RN and plant density (plants/m^2)
r_{NY} - Linear correlation between RN and RY
r_{DY} - Linear correlation between RY and plant density (plants/m^2)
$r_{NY.D}$ - Partial correlation between RY and RN holding plant density constant
$r_{DY.N}$ - Partial correlation between RY and plant density holding RN constant
$r_{DN.Y}$ - Partial correlation between RN and plant density holding RY constant

centage and Nemagold which showed no pattern. These interactions are also apparent from the regression analyses (Table 7).

Analyses of experimental effects on the root number distribution of the various size classes (expressed as a percentage of total yield) revealed significant effects due to plantings for No. 1 and Jumbo size

Table 6. Significance of experimental effects on yield and root number distribution (No. 1's, No. 2's and Jumbos expressed as a percentage of total yield and root number).

		% of Total Yield			% of Total No. of Roots		
Effect	**df**	**No. 1**	**No. 2**	**Jumbo**	**No. 1**	**No. 2**	**Jumbo**
Planting (A)	1	**	ns	**	**	ns	**
Cultivar (B)	3	**	**	**	**	**	**
Spacing (C)	3	ns	*	**	ns	**	**
Linear	1	ns	**	**	ns	**	**
Quadratic	1	ns	ns	ns	ns	ns	ns
Cubic	1	ns	ns	ns	ns	ns	ns
A x B	3	ns	**	*	ns	ns	*
A x C	3	ns	ns	ns	ns	ns	ns
B x C	9	**	ns	*	ns	ns	**
A x B x C	9	ns	ns	ns	ns	ns	ns

ns - Not significant
* - Significant, odds 19:1
** - Significant, odds 99:1

roots (Table 6). The first planting produced a smaller percentage of No. 1 size roots than the second planting. Cultivar effects were significant in the percentage of roots produced in all size categories with Centennial producing a higher percentage of roots in the No. 1 and Jumbo size classes and Nemagold producing a higher percentage of No. 2 size roots than the other cultivars.

Spacing effects were significant and linear for the percentage of roots in the No. 2 and Jumbo size categories. Although the percentage of No. 1 size roots decreased somewhat at increasing plant densities, the effect was not significant.

Since the percentage of No. 1 yield of MD 2262 and Centennial increased with increasing plant density while the percentage of roots was decreasing, it is apparent that the average size of No. 1 roots was greater at increasing plant densities. This is reflected in the slopes of the regression equations.

One may note that the percentage of Jumbo yield and roots of MD 2262 and Centennial respond more strongly to increasing plant densities than Redmar and Nemagold.

Based on the data presented and from previously reported data, one may conclude that the total yield, yield of No. 1 and No. 2 size sweet potato roots is likely to be greatest at high plant densities (35,000 to 40,000 plants/ha). This phenomenon is fairly general and may be shown for all cultivars studied. As plant densities are increased, root set per plant is decreased but not

Table 7. Regression equations and correlation coefficients for four cultivars for % yield and root numbers of each class size.

Cultivar	Regression Equation	Correlation Coefficient
	% No. 1 yield	
Nemagold	$\hat{y}$ = .506 − .094 log x	.088 ns
Redmar	$\hat{y}$ = .878 − .479 log x	.306 ns
MD 2262	$\hat{y}$ = .086 + .336 log x	.264 ns
Centennial	$\hat{y}$ = .395 + .818 log x	.695 **
	% No. 2 yield	
Nemagold	$\hat{y}$ = .157 + .160 log x	.279 ns
Redmar	$\hat{y}$ = .015 + .384 log x	.434 *
MD 2262	$\hat{y}$ = −.007 + .429 log x	.528 **
Centennial	$\hat{y}$ = −.043 + .466 log x	.603 **
	% Jumbo yield	
Nemagold	$\hat{y}$ = .461 − .050 log x	.323 ns
Redmar	$\hat{y}$ = .460 − .057 log x	.370 *
MD 2262	$\hat{y}$ = .690 − .269 log x	.514 **
Centennial	$\hat{y}$ = .849 − .426 log x	.747 **
	% No. 1 roots	
Nemagold	$\hat{y}$ = .532 − .122 log x	.132 ns
Redmar	$\hat{y}$ = .734 − .335 log x	.313 ns
MD 2262	$\hat{y}$ = .762 − .341 log x	.253 ns
Centennial	$\hat{y}$ = .439 − .016 log x	.008 ns
	% No. 2 roots	
Nemagold	$\hat{y}$ = .114 + .297 log x	.169 ns
Redmar	$\hat{y}$ = −.662 + .458 log x	.327 ns
MD 2262	$\hat{y}$ = −.150 + .571 log x	.443 *
Centennial	$\hat{y}$ = .271 + .694 log x	.575 **
	% Jumbo roots	
Nemagold	$\hat{y}$ = .462 − .052 log x	.328 ns
Redmar	$\hat{y}$ = .463 − .063 log x	.401 *
MD 2262	$\hat{y}$ = .668 − .246 log x	.504 **
Centennial	$\hat{y}$ = .800 − .377 log x	.795 **

$\hat{y}$ - Predicted arcsin /percentage of yield or number of roots
x - Plant density (plants/m^2)
ns - Not significant
* - Significant, odds 19:1
** - Significant, odds 99:1

equivalently, resulting in more roots being produced per unit area. Thus, a greater sink potential per unit area is available to accept assimilates. At higher plant densities the surface area is covered more quickly with vines and leaves. Thus, the maximum area available for photosynthesis is utilized for a greater portion of the growing season. It is likely that both mechanisms contribute to greater yield at higher plant densities. Therefore producers would be advised to plant at close spacings and control size distribution (if necessary) by adjusting planting and harvest dates.

If manipulation of growing days is impractical (for reasons of restrictions of the length of the growing season, processing plant schedules or other time constraints), yield distributions of the various size grades can be controlled by changes in plant density. Increased plant density usually resulted in a greater percentage of No. 2 size yield and a smaller percentage of Jumbo size yield although the magnitude of response may be different among cultivars. The response to changing plant densities in the percentage of No. 1 size yield was different among cultivars.

Plant density has been shown to have an effect on the percentage of yields in the various size grades. The exact nature of these effects are somewhat different among cultivars. Thus, in cases where control of yield distribution of the various size grades is important, recommendations should be preceded by experimentation to determine plant density effects on locally adapted cultivars.

LITERATURE CITED

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