Effects of plant population and planting date on growth and development of kumara cultivar Owairaka Red

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Abstract

There is a steady increase in demand for high value gourmet produce. This paper presents results from work aimed at designing a production system for gourmet sized (small) kumara (*Ipomoea batatas* L.). Plant growth theory suggests that higher plant populations should increase yield of gourmet-sized (ca. 20 - 40 mm diameter) kumara and may reduce time to harvest, the effects of which may interact with planting date. However, there is no data available on this for New Zealand conditions. A planting density and planting date experiment using kumara cv. Owairaka Red was established at Hastings in the 2007 - 08 growing season. Row spacing was 75 cm row and in-row plant spacing's were 10, 20 and 30 cm. Planting dates were 19 November 2007 (early) and 17 December 2007 (late). Increased plant population positively affected LAI, root and shoot biomass, yield of gourmet-sized kumara and the number of roots m^{-2} whilst reducing mean root size. Late planting also increased the number of roots m^{-2} and yield of gourmet-sized kumara. Late planting at the 10 cm plant spacings gave the highest yield of gourmet-sized roots. Economic analysis indicated that the most profitable combination was late planting at 20 cm plant spacing. The reason for this was that the additional yield of gourmet roots in the 10 cm plant spacings was offset by the additional cost of planting the crop.

Additional Key words: Sweet potato, gourmet produce, planting density.

Introduction

Plant population density is a management variable that affects the production and quality of most crops. In root crops, increasing planting density usually results in the production of more, smaller, roots. In the case of kumara, where a premium may be paid for gourmet (small, visually appealing, easy cooking) roots, there may be an economic advantage in increasing planting density. However, no data are available on the effect of planting density on production of gourmet-sized kumara under New Zealand conditions.

In North Carolina, in the United States, higher plant population densities have increased total root yield and the number and yield of gourmet-sized (canner) sweet potato roots (Schultheis *et al*., 1999). Providing that root quality (e.g. shape, colour, and eating quality) is not adversely affected, higher plant populations should produce greater yields of higher value gourmet kumara. Further, the time from planting to harvest may be reduced (Schultheis *et al*., 1999) which may enable growing of two crops in one season. The recommended plant spacing for most sweet potato (kumara) plants is 23 to 40 cm (Swaider *et al*., 1992; Rubatzky and Yamaguchi, 1997). In New Zealand, the standard plant spacing is about 30 cm.

In New Zealand, three main varieties of kumara are grown. Owairaka Red, currently comprising about 80% of the national annual crop and Toka Toka gold and Beauregard which make up most of the rest (Fletcher *et al*., 2000). Owairaka Red roots are highly variable in shape which may make it less suitable than other cultivars for the production of gourmet roots. However, as the name suggests Owairaka Red has strong links with Maori who have a tradition of growing kumara dating back to pre-European times (Fletcher *et al*., 2000). Given that a major part of the funding for this project was geared towards Maori growers[1] this variety was given priority over the other commercially available varieties that may (or may not) have better "gourmet" characteristics.

At present only a small amount of fresh, gourmet-sized kumara are marketed in New Zealand both in supermarkets and by small growers supplying the market directly. It seems likely that these gourmet-sized roots are a by-product of standard production rather than being grown specifically to supply this market. At this stage the size of the gourmet kumara market and specifications of the product are yet to be defined although the trends and characteristics for other crops (e.g. baby peas, baby carrots, gourmet potatoes etc) suggest that gourmet kumara could gain a significant share in this high value niche market. Further, with a focussed international marketing plan and full-scale gourmet kumara production there is potential to significantly increase export earnings, which are currently only a fraction of the domestic earnings.[2]

This paper presents the results of a field experiment undertaken in Hastings during the 2007 - 08 season aimed investigating the effects of plant population density and planting date on kumara growth and development, focussing on the production of gourmet-sized kumara. The work is aimed at developing production systems that will enable prospective gourmet kumara producers to supply the market with a product that is in specification and on time.

Materials and Methods

Experimental

A split-plot experiment with 3 replicates was set up at Crop and Food Research, Hastings. Main plots were planting date (19 November and 17 December 2007; PD_1 and PD_2 respectively). Subplots were within-row plant spacing (10cm, 20cm and 30cm; PS_1, PS_2 and PS_3 respectively). Rows were 75 cm apart to give plant populations of 13.3, 6.6 and 4.4 plants m^{-2} respectively. Sub-plots were 4 rows wide and were 4.5 m, 9 m or 13.5 m long for the 10 cm, 20 cm and 30 cm spacings respectively giving a total of 180 plants $plot^{-1}$.

Long-term average temperature over the summer growing season (October to April) at this site is ca. 16 ^oC and solar radiation ca. 19.5 MJ m^2 day^{-1}. The soil was a Mangateretere silt loam soil (Typic Haplaquept).

Harvests were taken periodically over the season (Table 1). At each harvest date (HD) six plants were collected, three from each of the two central rows. A buffer of two to three plants in each harvested row was left between each harvest date. For each HD the first harvest was collected soon after the first storage (visibly swollen) roots were set. The last scheduled harvest of PD_2 was not taken because extreme wet weather delayed harvest and subsequent frosts destroyed the crop canopy.

The exact harvest area at each HD was calculated by measuring and summing the distance between the outer two plants of the three plants harvested from each row, and half

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[1] Under the FRST program "Science for Community Change" (C02X0305).
[2] http://www.freshvegetables.co.nz/products/roots_tubers.html

the distance between their adjacent neighbouring plants outside the harvest area. This was done to account for differences in PS to minimise sampling error, which can have a marked affect on yield/biomass calculations particularly when such small harvest areas are used.

Plant material was separated into pencil roots (thin parallel roots), storage roots (visibly swollen roots) and shoots. Storage roots were separated into size classes (up to 6; in 10 - 20 mm increments) based on maximum root diameter. The fresh mass and number of roots in each size class was recorded. Roots from each size class were recombined, sub-sampled, weighed, oven dried at 70 ^{o}C and reweighed.

Table 1: Harvest schedule for the early (19 November 2007) and late (17 December 2007) planting dates (PD_1 and PD_2 respectively). DAP = days after planting.

Sample date.	PD_1 (date; DAP)	PD_2 (date; DAP)
1	9-Jan-08; 51	31-Jan-08; 45
2	22-Jan-08; 64	11-Feb-08; 56
3	11-Feb-08; 84	10-Mar-08; 84
4	10-Mar-08; 112	2-Apr-08; 107
5	2-Apr-08; 135	24-Apr-08; 129
6	24-Apr-08; 157	-

Shoots were weighed and sub-sampled, then split into stems and leaves (which included petioles). These were weighed and the stems oven dried at 70 ^{o}C and reweighed; whereas the leaves were sub-sampled again (to between 40 and 50 g), weighed and put through a (LICOR) leaf area meter, oven dried at 70 ^{o}C and reweighed.

Crop management

The site was sprayed with Glyphosate about two weeks prior to cultivation. Fertiliser (40 kg N ha^{-1} as urea and 80 kg P ha^{-1} as triple superphosphate) was applied and incorporated using a power harrow just before planting. Planting beds were raised immediately afterwards.

Rootless plantlets were hand planted with three to four nodes under the soil, in the standard "J" formation (see above for planting dates). Irrigation was applied regularly throughout the season using overhead sprinklers. Weeds were controlled by paraquat (applied at 100 g A.I. ha^{-1} in 400 l ha^{-1} of water) and by hand weeding.

Statistics

All data was analysed using Genstat V9. Probability levels were set to P = 0.05. ANOVA of yield and biomass data was conducted for each PD separately. This was because in most cases the number of days after planting (DAP) that sample dates occurred differed between PDs. However, harvest date three (SD_3) for each PD was 84 DAP so SD_3 was used for a mid-season comparison. The HD_5 for PD_1 was 135 DAP and HD_5 for PD_2 was 129 DAP so SD_5 was chosen as the nominal final harvest comparison. This gave two comparisons between PDs at similar relative growth stages.

An ordinal logistic model (Genstat) was used to analyse the size distribution data on HD_3 and HD_5.

Results

Root and shoot growth

For the reasons mentioned above, PD treatments were separated; and instead a two-way ANOVA was undertaken on each PD using PS and SD as factors. Where there were no interactions between PS and SD the data presented are averaged across all SDs (Table 2).

Table 2: The effect of plant spacing on LAI and crop components for two planting date (PD_1 and PD_2; 19 November and 17 December 2007 respectively) and three plant spacing treatments averaged across harvest dates.

			Plant spacing (cm)				
		Units	10	20	30	F-pr	$LSD_{0.05}$
PD_1	LAI	$m^2\ m^{-2}$	3.2	2.9	2.9	0.079	0.3
	Leaf Biomass	g DM m^{-2}	210	204	183	0.061	20
	Stem Biomass	g DM m^{-2}	99.1	87	83.8	0.074	11.6
	Shoot biomass	g DM m^{-2}	309	291	266	0.024	25
	Root weight[a]	g DM	18.6	27.5	36.5	<0.001	5.0
	Root No.	m^{-2}	39.6	23.8	17	<0.001	3.4
	Root biomass	g DM m^{-2}	788	681	657	0.016	79
PD_2	LAI	$m^2\ m^{-2}$	3.2	3.0	2.4	0.075	0.7
	Leaf Biomass	g DM m^{-2}	215	195	169	0.182	50.3
	Stem Biomass	g DM m^{-2}	106	99.2	72.5	0.004	19.3
	Shoot biomass	g DM m^{-2}	321	294	241	0.051	64.6
	Root weight	g DM	8.6	12.7	21.3	0.005	7.3
	Root No.	m^{-2}	51.3	27.7	17.7	<0.001	7.0
	Root biomass	g DM m^{-2}	474	439	407	0.098	61.1

There were significant differences between PSs, for most crop variables measured, in both PDs, although some were only significant at the 10 % probability level.

There was a significant PS by SD interaction ($P = 0.002$) in mean root weight in PD_1.This was caused by differences in the rate of increase in root weight among PS treatments over time (Table 3). The PS_1 plants had a slower rate of increase, with a lower maximum mean root weight apparent at HD_6 (35.8 g), compared to PS_3 which increased more rapidly to a maximum mean root weight of 77.7 g by HD_5. In PS_2 increased rate was between PS_1 and PS_3 with a maximum mean root weight of 52.0 g by HD_6. There were no other interactions in either PD.

Generally, in both PDs, increasing planting density increased LAI, shoot and root biomass and the number of roots but decreased mean root weight.

ANOVA of the HD_3 and HD_5 data indicated that there were no significant differences or interactions between PSs or PDs in total root yield on either HD (Table 4).

Root size distribution

An ordinal logistic model was used to analyse the size distribution data for HD_3 and HD_5. This type of model fits a normal distribution curve to sets of ordered variables. In this case the ordered variable was the percentage of total root yield in each size class, which were ordered left to right for small to large size classes respectively. A shift of the centre (or peak) of the curve to the left indicates a greater percentage of the total kumara yield in smaller size classes, and to the right a greater percentage yield in the larger size classes. On HD_3 (84 DAP) PD_2 PS_1 had the most leftward falling curve indicating that it had the greatest proportion of small roots, whilst PD_1 of PS_3 was the curve furthest to the right indicating that it had the greatest proportion of larger roots (Table 5). Other treatments fell between these two in the order of PD_2 PS_2, PD_1 PS_1, PD_1 PS_2 and PD_2 PS_3 (left to right respectively). Similarly at HD_5 (final harvest) PD_2 PS_1 and PD_1 PS_3 held the most leftward and rightward falling curves respectively, and again the other treatments fell between these two in the order of PD_2 PS_2, PD_1 PS_1, PD_2 PS_3 and PD_1 PS_2 (left to right respectively) (Table 6).

Table 3: Effect of plant spacing on mean root weight (g DM) for two planting dates (PD_1 and PD_2; 19 November and 17 December 2007 respectively) and three plant spacing treatments over time (see Table 1 for sample date details). F-pr and LSD values are for the interaction plant spacing and sample date for each corresponding planting date.

		Harvest date					
	Plant spacing (cm)	1	2	3	4	5	6
PD_1	10	1.5	5.3	13.4	22.5	32.7	35.8
F-pr = 0.002	20	1.4	6.9	23.8	31.2	49.2	52.5
$LSD_{0.05}$ = 12.2	30	1.7	6.8	23.4	42.5	77.7	67
PD_2	10	0.6	2.3	7.9	13.3	19.1	-
F-pr = 0.329	20	0.7	3.9	14.6	22.9	21.5	-
$LSD_{0.05}$ = 16.4	30	1.2	3.8	22.9	34	44.7	-

[a]There was a significant (P = 0.002) plant spacing by sample date interaction (see Table 3).

Table 4: Total root yield for the two planting date treatments (PD_1 and PD_2; 19 November and 17 December 2007 respectively) and three plant spacing treatments on harvest dates 3 (84 d after planting for both PDs) and 5 (135 and 129 d for PD_1 and PD_2 respectively).

		Harvest date	
	Plant spacing (cm)	3	5
PD_1	10	20.9	38.5
	20	17.9	37.9
	30	14.7	44.4
PD_2	10	23.5	35.2
	20	22.2	33.4
	30	18.1	31.9
F-pr	PS	0.121	0.805
	PD	0.127	0.054
	PS*PD	0.945	0.447

Generally increased planting density increased the percentage of total yield in the smaller, gourmet-size range (20 - 40 mm) on HD_3 ($P = 0.009$) and HD_5 ($P < 0.001$). Delaying planting also increased the percentage of total yield in the gourmet-size class on both harvest dates ($P < 0.001$). At final harvest (HD_5) the percentage of total root yield in the gourmet-size range was 59 % for PD_2 PS_1, 48 % for PD_2 PS_2, 38 % for PD_1 PS_1, 31 % for PD_2 PS_3, 17 % for PD_1 PS_2 and 9 % for PD_1 PS_3.

Table 5. Percentage of yield in each size class at harvest date 3 (84 d after planting) for the two planting dates (PD_1 and PD_2; 19 November and 17 December 2007 respectively) and three plant spacings. Data are the fitted values from the ordinal logistic model.

	Plant spacing (cm)		Size classes (maximum root diameter; mm)						
			<20	20-30	30-40	40-50	50-70	70-90	>90
PD_1	10	b	3	16	20	29	25	7	0
	20	b	3	14	18	29	28	8	0
	30	c	1	5	9	22	42	22	0
PD_2	10	a	8	31	25	22	11	2	0
	20	ab	3	16	21	30	24	6	0
	30	b	2	13	18	29	29	9	0

Treatments followed by the same letter (column 3) are not significantly different at the 5% probability level.

Table 6. Percentage of yield in each size class at harvest date 5 (final harvest) for the two planting dates (PD_1 and PD_2; 19 November and 17 December 2007 respectively) and three plant spacing treatments. Data are the fitted values from the ordinal logistic model.

	Plant spacing (cm)		Size classes (maximum root diameter; mm)						
			<20	20-30	30-40	40-50	50-70	70-90	>90
PD_1	10	b	1	11	27	25	24	10	1
	20	c	0	4	13	20	34	25	4
	30	c	0	2	7	13	33	38	8
PD_2	10	a	4	23	36	20	13	4	0
	20	ab	2	16	32	24	19	7	1
	30	c	0	4	13	20	34	25	4

Treatments with the same letter (Column 3) are not significantly different at the 5% probability level.

Discussion

The data indicate that increasing planting density and delaying planting both increase the yield of gourmet-sized kumara but do not affect total yield. This would suggest that a plant spacing of 10 cm would be the best plant spacing for production of gourmet-sized kumara. However, kumara plantlets are expensive (ca. 6.5 c plantlet^{-1}) so increasing planting density to 133,000 plants ha^{-1} (10 cm spacing) from 44,000 plants ha^{-1} (30 cm spacing) significantly increases establishment costs. Kumara planting is labour intensive, and is governed by the speed at which people can feed the planter mechanism with plantlets. This means that planting costs will also be increased. The proportional increase in planting costs is determined by factors such as the change in the rate of planting (e.g. tractor speed) and fuel costs. If we assume that at standard plant spacings (e.g. 0.3 m) planting is as fast as possible, then a decrease in plant spacing will result in a decrease in planter speed and increase costs directly proportional to the decrease in plant spacing.

Thus, even though a plant spacing of 0.1 m produces the highest yields of gourmet-sized kumara and therefore the greatest revenue (assuming gourmet kumara achieve a premium in the market), the additional costs of crop establishing may offset any additional revenue.

To understand this and determine the optimum economic plant density the following economic analysis was performed.

Economic analysis

An economic analysis is important because any benefits associated with increased planting density in terms of increased revenue may be offset by increased costs associated with crop establishment.

Because of uncertainties in the market specifications for gourmet kumara roots we were uncertain of the percentage of roots that were "marketable". This made it impossible to determine the "pack-out" from the yields achieved (i.e. Table 4). To overcome this uncertainty we decided to use a marketable yield of 20 t ha^{-1} on which to base our economic calculations; 20 t ha^{-1} is the average marketable yield of fresh Owairaka Red kumara roots in New Zealand (Fletcher *et al*., 2000).

By using the percentages of roots in the gourmet-size classes (20 - 40 mm) and the remaining (standard) size classes (+40 mm) (Table 5, 6) and an assumed marketable yield of 20 t ha^{-1}, we calculated the yield of gourmet and "standard" roots for each treatment (Table 7). We then calculated total the cost of establishment of each treatment and the gross returns (after planting) for each treatment using a cost of 6.5 c $plantlet^{-1}$ and planting costs of \$1,000, \$2,000 and \$3,000 for PS_3, PS_2 and PS_1 respectively; based on the assumption that planting speed would decrease and costs would increase proportionally to the increase in the number of plants planted as described above (Table 7).

Based on these figures an additional 39 c kg^{-1} across all (size) classes/grades would need to be achieved for the 10 cm plant spacings to break even with the 30 cm spacings, and for the 20 cm spacing to breakeven with the 30 cm spacings an additional 12 c kg^{-1} would be needed.

Table 7: Establishment cost, yield of gourmet and large kumara (assuming 20 t ha^{-1} marketable yield), revenue and margin after planting (revenue – costs) for the two planting dates (PD_1 and PD_2; 19 November and 17 December 2007 respectively) and three plant spacings. Revenue based on a price of \$1.50 kg^{-1} for large kumara and \$2.10 kg^{-1} for gourmet kumara.

	Plant	Costs (\$ ha^{-1})		Yield (t ha^{-1})			
	spacing (cm)	Plantlets	Planting	Gourmet	Large	Revenue	Margin
PD_1	10	9360	1000	7.6	12.4	34,560	24,200
	20	4290	2000	3.4	16.6	32,040	25,750
	30	2860	3000	1.8	18.2	31,080	25,220
PD_2	10	9360	1000	11.8	8.2	37,080	26,720
	20	4290	2000	9.6	10.4	35,760	29,470
	30	2860	3000	3.4	16.6	32,040	26,180

The current price paid to kumara growers largely depends on quality (e.g. size, shape, defects etc) but also on supply (timing), and can range from \$1.00 to over \$2.20 kg^{-1}. For this economic analysis we used a price of \$1.50 kg^{-1} for standard sized kumara (+40 mm) and an estimated 40% premium for gourmet kumara i.e. \$2.10 kg^{-1}.

Although the 10 cm plant spacings generated the greatest revenue the 20 cm plant spacing (PS_2) was the most profitable, and that delaying planting until mid-December (PD_2) using 20 cm plant spacings gave the highest economic return (Table 7). These results closely match the economic analysis of Schultheis *et al*. (1999), who found that for a late harvest (>110 DAP) of Beauregard, a 23 cm plant spacing was the most profitable.

Conclusions

Increasing kumara planting density and delaying planting until mid-December increased the proportion of yield of gourmet-size (20 - 40 mm maximum diameter) kumara whilst earlier planting and lower planting density increased the proportion of yield of larger size class kumara. None of the treatments significantly affected total yield.

The potential for increased revenue from crops with higher planting densities was offset by increased costs. At a marketable yield of 20 t ha^{-1} an additional 39 c kg^{-1} and 12 c kg^{-1} for 10 cm and 20 cm plant spacings respectively would be required over and above the payout for 30 cm plant spacing to break even with the 30 cm spacing.

Clearly, with any production system, there will be a proportion of the crop that falls outside market specification. Even with a 10 cm plant spacings and mid-December planting date only 59 % of the total yield was in the target "gourmet" size class, and 41 % was in the larger sizes. Current production systems which use 30 cm plant spacings may yield much less kumara in the gourmet-size range (9 to 17 % depending on planting date).

Our figures indicate that a mid-December planting using 20 cm plant spacings (66,000 plants ha^{-1} at 75 cm row spacings) gave the greatest economic return of $2,750 more than the next profitable system (mid-December planting at 10 cm spacings; 133,000 plants ha^{-1}) and $5,270 more than the least profitable system (mid-November planting at 30 cm spacings; 44,000 plants ha^{-1}).

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