Preliminary studies on the agronomic requirements of Japanese taro (*Colocasia esculenta*)

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Abstract

Taro (*Colocasia esculenta* (L.) Schott) is a traditional and popular staple food in Japan. Japanese taro is more cool tolerant than Pacific Island taro, which prefers a long growing season and high temperatures. It also has a sweeter taste and stickier texture. Crop & Food Research has been evaluating Japanese taro for commercial production in New Zealand. Trials were conducted to determine the effect of irrigation, size of planting propagule, harvest time, plant density, and nitrogen nutrition on cormel yield and quality. In cold frames the average total cormel yield from planting propagules irrigated daily for 194 days was 1.9 kg/plant, compared to 1.0 kg/plant produced by planting material irrigated at the same rate for the first 82 days. Large treatment differences were also caused by planting propagule size with small propagules producing 0.6 kg/plant, medium propagules 1.5 kg/plant and large propagules 2.2 kg/plant. In field trials, cormel yields increased each month when harvest was delayed from March until June. A high density planting of 6.7 plants/m^2 produced a total cormel yield of 42 t/ha compared to 28, 30 and 38 t/ha at 2.7, 3.3 and 4.4 plants/m^2 respectively. Plant density did not affect average cormel weight. Nitrogen application up to 150 kg N/ha increased yields with a slight reduction at a higher rate. Small cormels (<30 g), and cormel cracking and sprouting were identified as major factors adversely affecting product quality. This research has shown that Japanese taro can be successfully grown in New Zealand.

Additional key words: *Japanese taro, plant production agronomy*

Introduction

Japanese taro or Satoimo (*Colocasia esculenta* L. Schott.) is one of the most widely produced traditional vegetables in Japan with 22,400 ha planted and 254,000 t produced in 1995 (Takayanagi, 1998). It produces lateral cormels (like small potatoes) on the mother corm rather than the mother corm production types grown in the Pacific Islands. Some taxonomic authorities have suggested that the cormel producing types, or eddoe, are a different subspecies (*C. esculenta* var. *antiquorum*) (Purseglove, 1972), to the Pacific Island taro (*C. esculenta* var. *esculenta*), but they are now both considered to be part of a single polymorphic species (P. Matthews *pers. comm.*). Within Japan, for example, taro are classified into four different groups depending on lateral cormel production, corm and lateral cormel production, corm production, and petiole production (Takahashi, 1994). Our research relates to the types producing lateral cormels.

The volume of Japanese taro supplied onto the Japanese wholesale vegetable market varies markedly by month. For example, the supply in December 1994 was 21,300 t (average price 236 yen/kg), but the supply in May was 3200 t (average price of 360 yen/kg) (Nisseikyo Statistics, 1994). In recent years the importation of taro into Japan from China has increased (Anon., 1995). With the strong seasonality of supply the crop could present a new export opportunity for New Zealand growers as the New Zealand harvest period coincides with the low market supply period in Japan. The Japanese taro cormels are considered sweeter and stickier than the Pacific Island taro. Whether or not New Zealand-grown Japanese taro will be an acceptable alternative, in New Zealand, to the imported Pacific Island taro remains uncertain. Production of Pacific Island taro cultivars is possible in New Zealand gardens in favoured northern locations, but any increased production is unlikely to significantly affect the importation of taro from the South Pacific (Bussell and Goldsmith, 1998).

Taro is a tropical or subtropical perennial requiring in excess of 2500 mm of rain and high soil fertility to grow well. The lateral cormel types, however, such as Japanese taro, are adapted to cooler and drier climates and are grown as annual crops (Purseglove, 1972). To grow well it requires frost-free growing conditions and warm summer conditions with good moisture supply (Larcom, 1991; Takayanagi, 1998). Typically, Japanese taro is established in the spring by cormels or stem cuttings after the last frosts when soil temperatures are rising. The crop is harvested in late autumn-early winter after the foliage dies back (Follett and Scheffer, 1996).

In 1992 an unnamed commercial Japanese taro cultivar was imported by Crop & Food Research from Japan and grown under quarantine conditions at Ruakura Research Centre for a year. Gradually the planting stock has been bulked up, and since 1994 a number of trials have been conducted at Pukekohe Research Station to determine the agronomic requirements of the crop.

Materials and Methods

All trials were conducted at Pukekohe Research Station from 1994 to 1997 where frosts are rare from November to April. Apart from the first trial, which was conducted in cold frames with a peat-pumice-soil mixture, all subsequent trials were conducted on the Patumahoe clay loam.

Experiment 1

This trial evaluated the effects of additional irrigation and size of planting propagule on the cormel yield and quality of Japanese taro. Plants were grown in two cold frames, each of which contained similar mixtures of Patumahoe clay loam, peat and pumice. Irrigation was applied to all treatments by drip tape at the rate of 2.5 l/m^2/day from planting (19 October 1994) until 9 January 1995, when the irrigation was switched off in one cold frame (low water regime), but was maintained until 1 May 1995 (high water regime) in the other. Taro plants in the low water regime received a total of 1036 mm of water (831 mm rain, 205 mm irrigation), while those in the high water regime received a supplementary 278 mm of irrigation.

The three planting propagules were small (dormant tertiary cormels weighing about 70 g), medium (secondary cormels with roots and trimmed tops weighing about 300 g) and large (mother corms weighing about 1500 g from which the cormels had been removed). Before planting, soil fertility was amended by the application of lime (2 t/ha), 15% potassic super (1.3 t/ha) and calcium ammonium nitrate (350 kg/ha). The planting depth of the propagules was twice their height, giving a planting depth range of 50-100 mm.

Plots were arranged in two rows, 500 mm apart, in each cold frame with each propagule treatment plot having four plants spaced 300 mm apart in single rows. There were no guard rows or guard plants. The propagule treatments were arranged in a randomised block with four replications in each of the two cold frames. The water regimes were not replicated; one cold frame represented the high water regime, the other the dry water regime.

Plants were harvested with a garden fork on 14-15 June 1995 and washed with a high-pressure hose. The cormels were then broken or cut off; secondary, tertiary and fourth generation cormels were kept separate. All cormels with shoots >50 mm were trimmed leaving 50 mm (measured from the ring of buds on the corm/shoot dividing line) of the base of the shoot attached to the cormel. The mother corm was trimmed to 100 mm. Cormels were dried overnight before being counted and weighed individually. Cracking (>2 mm in depth) of the epidermis was also recorded.

Experiment 2

This trial examined the effect of four harvest dates and three rates of nitrogen fertiliser on cormel yield using a complete factorial design. The taro were planted on 10 October 1995 without base fertiliser on flattened moulds and harvested on 15 March, 15 April, 20 May and 13 June 1996. Nitrogen was applied as calcium ammonium nitrate at 48, 96 and 144 kg N/ha as split applications on 18 November, 39 days after planting, and again six weeks later on 22 December 1995. Phosphorus and potassium fertiliser was applied as 15% potassic super at the rate of 1 t/ha one day before the application of the first nitrogen side dressing. The fertilisers were manually incorporated between plants into the top 50 mm of soil. Moulds were 750 mm apart. Irrigation was by drip tape at the rate of about 2 l/m^2 every other day depending on the weather conditions. The trial design was a randomised block with three replications. Plots were 1.2 m single rows of taro with plants spaced 200 mm apart with end plants as guards. Adjacent rows were 750 mm apart. Due to the shortage of plant material secondary large corms (140 g) and medium corms (100 g) were planted in replicates one and two respectively, and tertiary corms (67 g) in replicate three. Crop harvest procedures and recordings followed those used in Experiment 1.

Experiment 3

In Experiment 3 the effect on crop yield of four in-row plant spacings, 200, 300, 400 and 500 mm, in rows 750 mm apart, was measured. Plants with well developed leaves and root systems were transplanted on 5-6 December 1995 into open moulds. Just prior to planting, plots were fertilised with a base dressing of 1 t/ha of 15% potassic super and 250 kg/ha of calcium ammonium nitrate. The trial design was a randomised block with four replications. Plots were single rows of taro with 10 plants; end plants were guards. The trial was irrigated by drip tape as described for Experiment 2. The crop was lifted and corm yields recorded between 2 and 9 July 1996. Harvest procedures and recordings were the same as for previous trials.

Experiment 4

The effect of nitrogen on the corm yield and quality of Japanese taro was further investigated in a trial planted on 4 November 1997. Four nitrogen treatments (0, 75, 150 and 300 kg N/ha) were applied in the furrow prior to planting as well as a split application treatment of 300 kg N/ha, half of which was applied with the other treatments and the rest 13 weeks later, on 11 February 1998. All treatments received a basal dressing of 15% potassic super at 1.95 t/ha.

The trial design was five replications of the treatments laid out in a 5 x 5 Latin Square with plots 2.1 m long and 3 m wide, comprising four rows, 750 mm apart, with the two outer rows as guards. In-row plant spacing was 300 mm with seven plants in each datum row and guard plants on the ends.

The trial was irrigated by drip tape as described for Experiment 2. The crop was lifted and corm yields recorded between 29 September and 22 October 1998. Harvest procedures were the same as in previous trials. A quality assessment was undertaken to assess marketable yield by discarding cormels with the following faults:

- deep surface cracks (>4 mm),
- >50% of the cormel surface area cut as a result of the removal of other cormels,
- shoot area greater than the area of the cormel,
- cormels pointed at both ends,
- poor visual appearance including `hairiness' and greening,
- extensive slug damage,
- weight <30 g.

Weed control was done by hand in Experiments 1, 2 and 3. In Experiment 4 the herbicide simazine was used successfully. It was applied pre-emergence at the rate of 1 kg a.i./ha about two weeks after planting. After some hand weeding a subsequent treatment of simazine at the above rate was applied between the taro rows about two months later. Japanese taro was found to be very sensitive to Roundup herbicide. In one experiment, not reported here, young plants were exposed to spray drift of Roundup. They turned yellow within two weeks and died about a month later.

Statistical analysis

Analysis of variance was carried out on all results presented using the statistical package GENSTAT. Logarithmic transformations of count data were carried out to stabilise variance.

Results

Experiment 1

Japanese taro responded strongly to the additional moisture applied over the summer. The total cormel yield in the high water regime (1.87 kg/plant) was almost double the cormel yield in the low water regime (1.02 g/plant) (Table 1). The mean number of cormels in the high water regime was almost double that in the low (26.8 v. 14.2/plant). Increases in the size of the planting propagule significantly ($P<0.001$) increased the number of cormels produced under both irrigation regimes, and this in turn had a major effect on cormel yield ($P<0.001$).

Many of the secondary cormels, which made up about 60% of the total cormel yield, developed large leafy

Table 1. Effect of water regime and planting propagule size on total cormel yield of Japanese taro in Experiment 1.

	Cormel number/ per plant		Total cormel weight (kg/plant)	
Propagule size	Dry	Wet	Dry	Wet
Small	8.3 (2.1)[1]	18.4 (2.9)	0.38	0.78
Medium	15.8 (2.8)	29.7 (3.4)	0.98	2.1
Large	22.2 (3.1)	35.4 (3.6)	1.69	2.74
$LSD_{P<0.05}$(df=9)	(-0.16)	(-0.21)	0.18	0.35
Mean	14.2 (2.7)	26.8 (3.3)	1.02	1.87

[1] Backtransformed from mean log (corm number). Mean of transformed data in brackets, LSD applies to transformed means only.

shoots. These shoots became visible in a circle around the base of developing taro plants a few months after planting. At harvest most of these secondary cormels had prominent, 2-3 mm, thick, fleshy, white roots, and strongly developed tops measuring up to 400 mm in length. The circumference of the base of these tops was in some cases equal to the circumference of the cormel from which the tops developed. These cormels, which usually had three or four or more large cut surfaces where the tertiary cormels had been broken or cut off, were not considered to be marketable for eating but were excellent planting material.

The incidence of sprouting in secondary cormels was much greater in the high water regime (64%) than in the low water regime (43%) with insignificant sprouting in the tertiary cormels. Cormel cracking, which is considered undesirable, occurred in all types of cormels, but was of lower incidence in the high water regime (38%) than in the low water regime (52%).

The cormel size in this experiment varied up to 180 g; most uniform cormel sizes were produced by the medium size propagules in the high water regime. About 25% of the cormels harvested weighed less than 30 g and considered unmarketable, but 60% weighed 30-120 g.

Experiment 2

Harvesting taro in early autumn instead of early winter markedly reduced crop yield (Table 2). Conversely, for each month after the first harvest in March the cormel weight increased by an average of 0.15 kg/plant and the yield /plant more than doubled from March to June to give 0.81 kg/plant. Yield increased linearly with harvest dates ($P<0.001$). Part of this effect can be explained by a significant ($P<0.05$) increase in total corm numbers with harvest date. There was no significant effect of nitrogen rate ($P>0.05$) on cormel number and weight, and the nitrogen x harvest date interactions were not significant ($P>0.05$).

Experiment 3

Plant density increased with decreased row spacings, raising the density from 2.7 to 6.7 plants /m^2. The increased density increased the cormel yield/ha by 50% to 42 t/ha (Table 3). This was achieved with little change ($P>0.05$) in mean cormel weight, but a 39% decline in both the individual plant cormel number and yield ($P=0.007$, 0.009 respectively). It is recognised that there will be an inter-plant spacing that will limit yield, but under the conditions of the experiment it was not reached.

Experiment 4

Because planting material was variable in size, fitted means were adjusted using analysis of covariance on the initial weight of the planting propagule. Nitrogen application produced a 20% increase in total cormel yield/plant and a 35% increase in mean cormel weight up to the medium level of application (150 kg N/ha), but had no effect on the number of cormels produced (Table 4). Further increasing the nitrogen rate to 300 kg N/ha in a single or split dressing reduced the cormel yield. The

Table 2. Effect of harvest date on total cormel number and cormel yield of Japanese taro in Experiment 2.

Harvest date (1996)	Cormel number/plant	Cormel yield (kg/plant)
15 March	10.2 (2.42)[1]	0.39
15 April	11.3 (2.51)	0.52
20 May	12.1 (2.57)	0.74
13 June	12.4 (2.60)	0.81
$LSD_{P<0.05}$(df=22)[1]	(-0.15)	0.12

[1]Backtransformed from mean log (cormel number) Mean of transformed data in brackets, LSD applies to transformed means only.

Table 3. Effect of plant density on cormel yield components of Japanese taro in Experiment 3.

Plant spacing within rows (mm)	Plant density (no./m^2)	Mean number of cormels/plant	Mean cormel yield (kg/plant)	Mean cormel weight (g)	Cormel yield (t/ha)
500	2.7	26	1.04	40	28
400	3.3	23	0.91	39	30
300	4.4	23	0.87	37	38
200	6.7	16	0.64	38	42
$LSD_{P<0.05}$(df=12)		3.5	0.23	5.4	8.7

Table 4. Effect of applied nitrogen on the cormel yield components of Japanese taro in Experiment 4.

Nitrogen treatment (kg N/ha)	Cormel yield components				
	Total (no./plant)[1]	Total (kg/plant)	Mean cormel weight (g)	Tertiary cormel yield (kg/plant)	Marketable cormel yield (kg/plant)
0	16.5 (2.78)	0.8	48	0.35	0.61
75	17.3 (2.82)	0.92	52	0.43	0.69
150	17.4 (2.83)	0.96	65	0.48	0.63
300	17.0 (2.80)	0.89	52	0.42	0.58
300 split	17.0 (2.80)	0.89	52	0.39	0.59
$LSD_{P<0.05}$ (df=12)[2]	(0.066)	0.11	6.9	0.07	0.11

[1]Backtransformed from mean log (cormel number). Mean of transformed data in brackets, LSD applies to transformed means only. Fitted means adjusted using analysis of covariance. Tabulated means of all variates calculated at a mean propagule weight of 101g.

pattern of yield increase then decrease with increasing nitrogen was related to the pattern in the tertiary cormel yield, as there were no significant effects on the secondary cormels. Tertiary yield increased by 37% from zero nitrogen to 150 kg N/ha. Quadratic regression functions on nitrogen were fitted to these variates (P<0.05), and the predicted maxima were found consistently in each case at 180 kg N/ha. There were no significant differences in the effects of nitrogen treatments on the total marketable yields (Table 4).

Discussion

This series of trials has shown that Japanese taro can be grown successfully in New Zealand, given a frost-free growing period of five or six months. In such situations it could be grown in a similar manner to potatoes. The taro have been predominantly disease and pest-free, apart from a leaf disease caused by the fungus *Phyllosticta colocasiae* which became a problem in cool and wet autumn conditions in two trials and could defoliate the crop within a few weeks if left unchecked. Benlate or Rovral sprays successfully controlled this disease. Dasheen mosaic potyvirus (Pearson *et al.*, 1998) was also observed in some plants, but its effect on crop yield is not known. Affected plants can be rogued from the crop.

Japanese taro production is enhanced by irrigation, but the crop does not have a high demand for nitrogen fertiliser. Previous experience demonstrated large responses to nitrogen fertiliser applied either as a basal or a side dressing on potato and onion crops on the Patumahoe clay loam. Experiment 2 was planted after a grass ley whereas Experiment 4 was on a site cropped continuously for a number of years. This difference in cropping history may account for the lack of a response to nitrogen in Experiment 2. The response to nitrogen in Experiment 4 was similar to that expected from potato or onion crops on a similar site.

The propagule size trial illustrated the benefits for yield of using larger sized propagation material, but the use of mother corms grown in the previous season may not be commercially viable. Secondary cormels should provide the best planting material in that they are larger than the tertiary cormels and are likely to be of lower quality for marketing.

The highest crop yield was recorded at the highest plant density tested (0.75 m x 0.2 m), with no reduction in the mean cormel weight. Even higher plant densities may increase the cormel yield. Lowering the intra row spacing from 0.4 m to 0.3 m gave an increase in crop yield of 21%, but between 0.3 m and 0.2 m the crop yield increase had dropped to 9.5%. Further lowering the intra row spacing below 0.2 m is likely, therefore, to only result in small improvements to crop yield. The inter row width was constrained at 0.75 m by using standard potato planting equipment, but the plant density could be raised a further 33% (at 0.2 m intra row spacing) by narrowing the row width to 0.5 m. The effect of this change on crop yield has not been tested.

Taro is generally harvested in early winter when the frost kills the foliage. Nevertheless the cormels remain in good condition under the frosted tops for several months and could be harvested over an extended period into the late winter. Harvesting too early in autumn (March - April) reduces yield. If an export trade is developed to Japan during that country's low supply (May) then some reduction in yield has to be expected. Nevertheless, earlier spring planting may overcome this effect or early maturing cultivars may be used, as in northern regions of Japan (Takahashi, 1994).

Further agronomic research is required to refine the production recommendations, but with a greater focus on cormel quality. In this work cormels below 30 g were not considered marketable, but this is an arbitrary threshold as cormels weighing only a few grams are traded in Japan (P. Matthews, pers. comm.). Sprouting of the secondary cormels reduced their quality and was unexpected, as it is not prevalent in Japan (P. Matthews, pers. comm.). This effect may be due to the cultivar or the soil and environmental conditions. Cormel cracking was also a significant defect. Further research on cultivars, cormel maturity and growing conditions is needed to find ways to minimize cracking.

In addition to optimising the production systems for Japanese taro there is a need to define shelf-life and storage conditions to maintain the cormels in good condition, both for produce and for replanting. Research published by US scientists recommends that tropical taro is stored at 7-10°C at a relative humidity of 85-90% (Hardenburg *et al.*, 1990). Taro cormels keep well if left in situ in the field, even though the top growth may have frosted off. This is an alternative method of storage. The results of this series of trials indicate that a quality product can be achieved in warm conditions. However, further research is needed to determine whether Japanese taro has potential as a new commercial tuber crop for New Zealand.

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