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Experimental Growing of Pre-European Cultivars of Kūmara (Sweet Potato, *Ipomoea batatas* [L.] Lam.) at the Southern Margins of Māori Horticulture

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ABSTRACT

The Cook Strait region of central New Zealand has generally been considered climatically marginal for pre-European Māori horticulture. Experimental cultivation of three pre-European Māori cultivars of kūmara ('Taputini', 'Rekamaroa' and 'Hutihiti') has shown that it is possible to grow these varieties under present climatic conditions, even though the soil fertility in the experimental gardens is far from ideal for kūmara. Tuber losses during storage between harvest and planting are significant, suggesting that kūmara could not be kept as a significant source of carbohydrate beyond the next planting season. One cultivar, 'Taputini', performed extremely well during the drought in the region in 2000–2001. The existence of such a drought-resistant variety has important implications for discussions of dry-land horticulture in tropical Polynesia as well as New Zealand.

Keywords: EXPERIMENTAL GARDENING, SWEET POTATO, KŪMARA, *IPOMOEA BATATAS*, TRADITIONAL CULTIVARS, STORAGE LOSS, DROUGHT-RESISTANCE.

INTRODUCTION

The kūmara or sweet potato (*Ipomoea batatas* [L.] Lam.) has figured largely in interpretations of New Zealand prehistory (e.g., Hiroa 1949: 33; Duff 1949: 173; Green 1963; Golson 1965; Groube 1967; Simmons 1969). It was the most successful of the cultivated plants introduced by Polynesian settlers from the tropical Pacific. The adaptation of this neo-tropical South and Central American plant to temperate New Zealand conditions, involving its cultivation as an annual crop and the successful storage of tubers[3], has been seen as a

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[3] Most literature on sweet potatoes refers to the storage root as a tuber. This is based on early definitions of a tuber as "a thickened usually subterranean part of a stem or root" (Allan 1982: 993). In a strict botanical sense tubers are modified stems while the storage roots of sweet potato are modified roots. Tubers and roots differ in both anatomy and general physiology (Kays 1985: 85). We retain the term tuber, because of its familiarity to archaeologists. 'Seed' or 'seed tuber' are used for tubers kept for planting.

major achievement of pre-European Māori gardeners (Yen 1961, 1974: 305). Even so, kūmara horticulture was important mainly in the northern parts of the country. At least in historic times, the plant was not grown in the southern South Island and is considered to have been marginal in central coastal regions and inland parts of the North Island.

Much is known about the plant, its origins, and its modern horticultural requirements and performance. Its introduction to and use in the Highlands of Papua New Guinea have been the subject of extensive debate (Bourke 1982: 46). There is also a considerable amount of ethnographic information about its cultivation by Māori in New Zealand in historic times (e.g., Best 1925; Colenso 1880; Walsh 1902). However, many questions remain about the practicalities of Māori cultivation, and the performance of the various Māori cultivars under differing environmental conditions.

Some of these questions are of particular importance in the Cook Strait region of central New Zealand, long considered marginal for kūmara cultivation. Archaeological research in Palliser Bay on the eastern side of Cook Strait showed conclusively that gardens, interpreted as being for kūmara and gourds, had been an important component of the economy of the early Māori inhabitants (Leach 1976, 1979). A combination of environmental degeneration and climatic deterioration was seen as responsible for the virtual abandonment of Palliser Bay in the later part of the pre-European period (Leach and Leach 1979; Leach 1981). The earliest European visitors to the Cook Strait region, James Cook and his companions between 1770 and 1777, observed that the inhabitants of Queen Charlotte Sound had no gardens at all and were living on fish and gathered plants, particularly the rhizome of the bracken fern (*Pteridium esculentum*). By 1820, when Bellinghausen's expedition visited the same part of the Sounds, the introduction of the white potato (*Solanum tuberosum*) had already transformed the Māori economy in the region (Barratt 1979: 82B84).

As part of a wider exploration of pre-European Māori subsistence in the Cook Strait region, an experimental kūmara gardening project was established in 1999 (Harris *et al.* 2000). The initial objectives were, firstly, to see whether it was possible to grow a pre-European Māori cultivar in the vicinity of a pre-European archaeological garden site under modern climatic conditions and, secondly, if it did prove possible, to measure the return of yield for effort in producing the crop. It was hoped in this way to gain some practical understanding of the potential value of kūmara as a food resource for pre-European Māori in this region. As a result of a successful first season, a second garden was established in 2000. It so happened that the 2000–2001 growing season was exceptionally dry, providing an opportunity to observe the performance of the plants under drought conditions. The project is now a long-term one, which aims to study the performance of several pre-European cultivars over successive growing seasons.

This paper describes the cumulative results of the first two seasons, with additional data from the third season, and discusses some of the implications. More detailed discussions of the advantages and limitations of an experimental archaeology project of this kind, and modelling of aspects of the subsistence economy of pre-European Māori communities in this region, including a full discussion of the return of yield for effort, will be published at a later date. The research so far has concentrated on cultivation. No attempt has been made to replicate pre-European Māori storage of the crop.

As a background to the experiment, general information on sweet potato cultivation and storage and on Māori varieties of kūmara is presented.

SWEET POTATO CULTIVATION AND STORAGE

The edaphic and environmental requirements of sweet potatoes have been summarised by Bouwkamp (1985: 3–33) and Woolfe (1992: 27–29). Elsewhere in the world they are grown from 40°N to 32°S of the equator. On the equator they are grown from coastal lowlands to 3000 m above sea level (Woolfe 1992: 27). Many studies show a range of cultivar-dependent responses and it is therefore somewhat dangerous to apply the following general conditions to the traditional Māori cultivars, but in summary, sweet potatoes can be produced successfully on a wide range of soils, although best root shape and appearance are produced on light sandy soils. A well aerated soil appears to be a requirement to produce best yields (Bouwkamp 1985: 10; Ravi and Indira 1999: 305). Good drainage is essential. They will produce satisfactory yields within a pH range of 3.8 to 5.6 but a soil pH of 5.6 to 6.6 is preferred. While they produce good yields with the addition of all the major nutrients, direct response to potassium applications is most marked, with many studies showing significant increases in yields after the application of potassium (Bouwkamp 1985: 17).

Sweet potatoes will grow within the temperature range of 15–38°C, with best growth at or above 24°C. When temperature falls below 10°C, growth is severely retarded. Cultivation in temperate regions is restricted to areas with a minimum frost-free period of four to six months with relatively high temperature during this period. The plants can be grown with reduced yields in semi-shaded conditions. While the sweet potato is considered to be drought tolerant it produces best yields under regular irrigation (Bouwkamp 1985: 24). Optimum rainfall is 75–100 cm per annum with at least 50 cm falling during the growing season.

However, it is important to emphasise the adaptability of the sweet potato to a wide range of growing conditions because of its broad genetic base (Woolfe 1992: 29). This is illustrated by its adaptability to a wide range of conditions in New Guinea (Bourke 1985) and its drought resistance in parts of East Africa (Jana 1982).

The contemporary recommendation for curing kūmara is to subject the crop to three to five days at 30°C and relative humidity of 85–90% and it should then be stored at 13°C and 85–90% relative humidity (Brash *et al.* 1999: 20). In temperate climates like New Zealand, storage of kūmara through the winter was a difficult task. Pre-European Māori had pit storage systems where the crop underwent a curing process by filling pits quickly after harvest and sealing the pit for a prescribed period of time (Cooley 1951: 385). The temperature and humidity generated by the transpiring crop no doubt played a role in curing it. Conditions in the pit itself would thereafter protect from extremes of temperature and maintain a more or less constant humidity. However, without some experimental work replicating pit storage, the actual range of storage conditions can only be estimated.

MĀORI VARIETIES OF SWEET POTATO

Between 1955 and 1958, Yen collected several varieties "considered by Māori informants to be of pre-European origin or introduction" (Yen 1963: 33). 'Rekamaroa' was collected from Ruatoria, the East Coast, and the Bay of Plenty; 'Hutihuti' from the East Coast, Bay of Plenty, and Northland; 'Taputini' from Northland, and 'Houhere' from two locations in Northland (Yen 1963: 33–37). Between 1959 and 1988 the collection resided at Tsukuba in Japan. When they were returned to New Zealand in 1989, the varieties acquired the status of "ancient" or "pre-European Māori" cultivars (Harvey *et al.* 1997). Following the

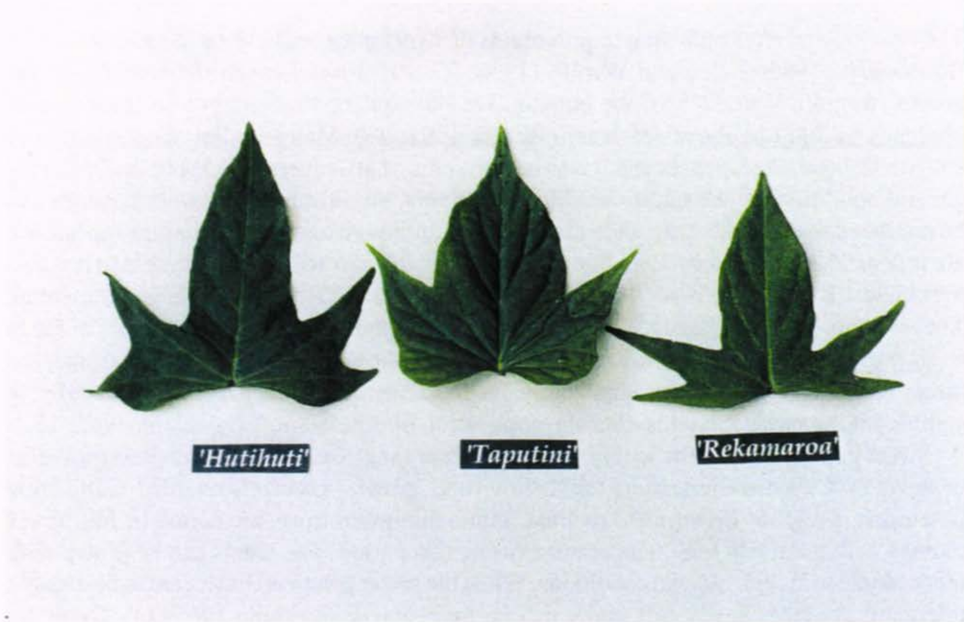

Plate 1: Foliage morphology of three 'traditional' kūmara cultivars. Photo Graham Harris.

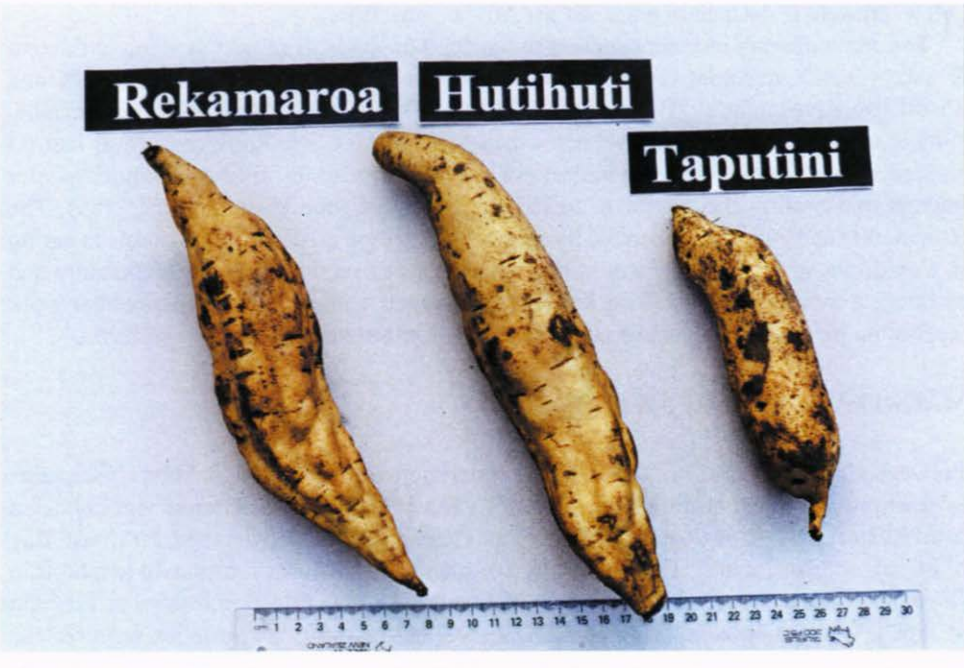

Plate 2: Tuber morphology of three 'traditional' kūmara cultivars. Photo Graham Harris

Plate 3: 'Taputini' plants at Whatarangi in February 2001. Photo Mike Burtenshaw.

Plate 4: Harvested 'Taputini' plant. Photo Graham Harris.

Plate 5: Stone mulched mound at Whatarangi, December 2000. Photo Mike Burtenshaw.

Plate 6: The Robin Hood Bay main garden in February 2001, with sparse weed growth.

Plate 7: Variability in tuber size and number from individual *puke*. Photo Graham Harris.

Plate 8: 'Taputini' plants at Whatarangi at harvest time 2001. Photo Mike Burtenshaw.

return, the New Zealand Institute for Crop and Food Research spent considerable time using heat treatment and tissue culture to rid the plants of virus infection (J.D. Fletcher pers. comm., 30 May 2000).

The cultivars used in our experiments are 'Taputini' obtained from Northland in 1996, and 'Rekamaroa', 'Hutihuti', and some additional 'Taputini' obtained from Crop and Food Research at Pukekohe in 2000. They were all derived from Yen's returned collection, and have been authenticated by comparing morphological characters with the descriptions and photographs published by Yen (1963: 33–37) We have not located any specimens of 'Houhere'.

Plates 1 and 2 illustrate the foliage and tuber morphology of these three cultivars. Plate 3 shows the tufted rather than trailing growth habit of 'Taputini' plants in Palliser Bay in February 2000. A harvested 'Taputini' plant, showing the foliage and attachment of the tubers, is seen in Plate 4.

There is no record of any of these traditional cultivars flowering in New Zealand but somatic mutations are reported by Yen (1963: 33–35). In the three years these kūmara have now been grown no somatic mutations have been observed, and it is assumed that the cultivars used have the same genotype as those released by the New Zealand Institute for Crop and Food Research.

The question as to whether these kūmara cultivars were infected with virus in pre-European times needs further investigation and is one that may never be adequately answered. However, we recognise that there would have been a reduction in yield potential if virus infection were present in these cultivars. So far in three years of field trials we have not observed any virus symptoms that would indicate consequent new infection by virus.

The kūmara, and in particular the traditional cultivars, are part of a Treaty of Waitangi claim (Wai 262) and are regarded by Māori as a cultural symbol in addition to their significance as a traditional food crop. Before the gardens were established, iwi authorities in the two areas were consulted and their support for the project obtained (Te Ati Awa, Rangitāne, Ngāti Rārua, Ngāti Toa Rangatira, Ngāti Hinewaka).

METHODS

This experimental archaeology project arose out of a trial that set out to determine whether pre-European kūmara cultivars would produce viable crops in the vicinity of pre-contact Māori garden sites in the Cook Strait Region. It was not designed to be a scientific agronomic experiment with replicated plots and randomly determined sampling methods. The funding resources available did not support this level of experimental design. However, we believe the measurements taken and data reported provide useful indicative figures for anyone interested in pre-European kūmara production in New Zealand.

The initial garden plot was established at Robin Hood Bay on the northeast coast of the South Island in September 1999 and tubers were planted there on 28 November. In the spring of 2000 this plot was cultivated again and a new garden was established on the coastal strip at Whatarangi in Palliser Bay, near the southern tip of the North Island. The locations of these two gardens and the nearest climate stations are shown in Figure 1. Despite being located in the North Island, the Whatarangi garden (Latitude 41° 29′ 49″ S; Longitude 175° 12′ 31″ E) is actually slightly south of the Robin Hood Bay garden (Latitude 41° 21′ 00″ S; Longitude 174° 04′ 01″ E).

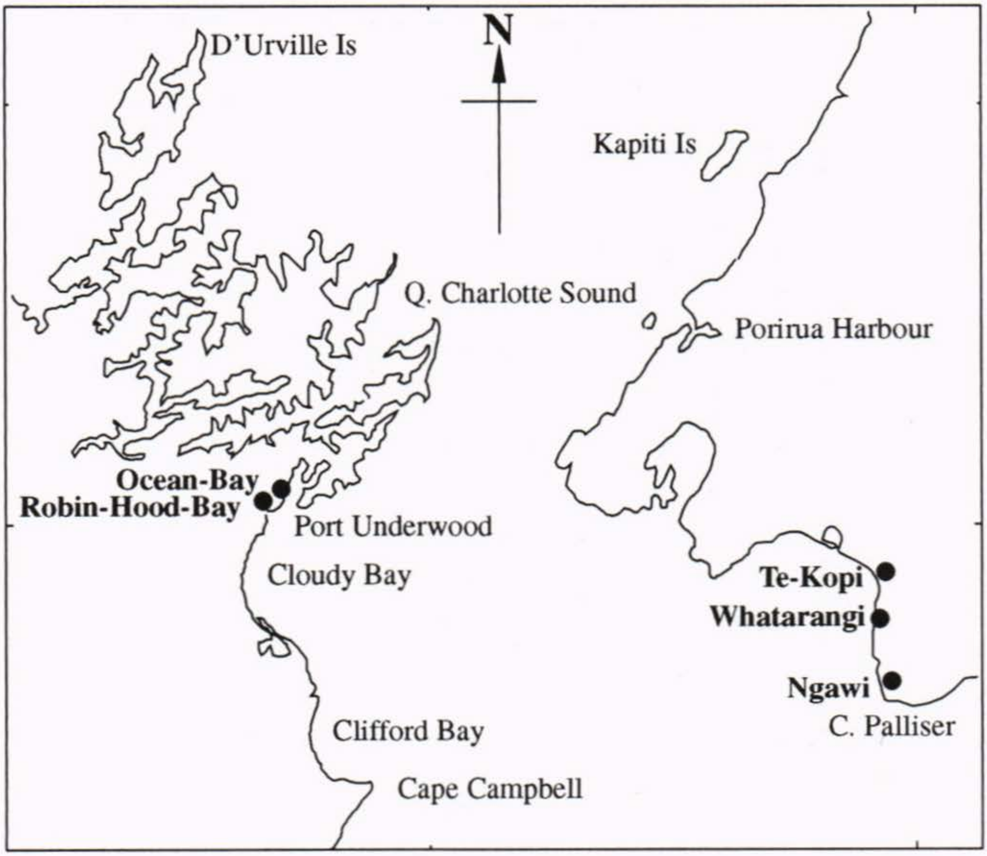

Figure 1: The location of the experimental gardens and the nearest climate stations.

Both gardens are adjacent to but not actually in previously recorded archaeological garden sites, with visible stone walls and mounds. Both are in established farm land which has been under pasture for many years.

The Whatarangi garden is sited on the narrow coastal plain over 60 m from the tidal zone. The garden is very exposed to the southerly wind and consequent salt spray drift. The prevailing wind is north-westerly with occasional shifts to southerly storms lasting several days. The vegetation cover before cultivation consisted of introduced pasture species and associated introduced weed species. The soil is a dark brown coarse sandy silt derived from eroding greywacke.

The Robin Hood Bay garden is also coastal but within a relatively sheltered bay. The garden plot is over 400 m from the tidal zone and is less exposed to salt spray drift. It is sheltered from the southerlies and the prevailing wind blows from the north. The vegetation cover was introduced pasture and pasture weed species. The soil here is a schistose pale yellow clay loam, quite different from the soil at Whatarangi.

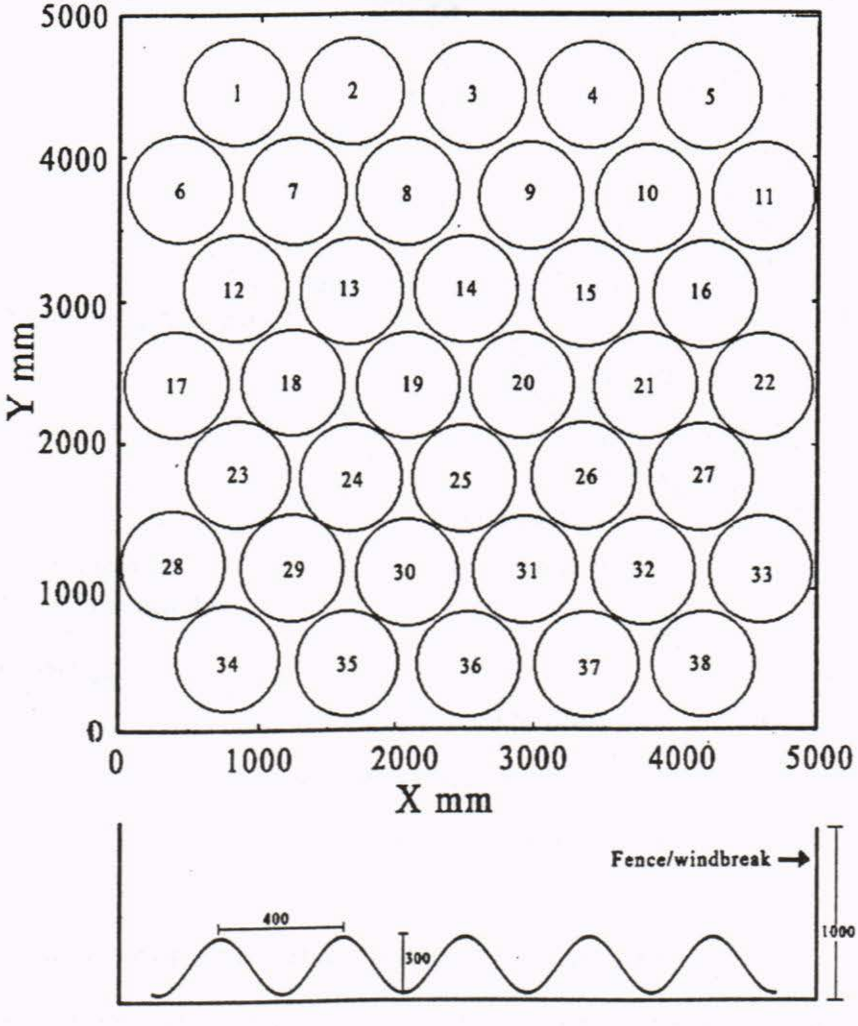

Figure 2: The layout of planting mounds in the main plot at each site, showing orientation, mound (*puke*) numbers, spacing, and height, and fence/windbreak position.

At each garden, the main plot is 5 x 5 m, in which the cultivar 'Taputini' has been grown. The same plot has now been cultivated for three years at Robin Hood Bay and for two at Whatarangi. Within each plot, tubers were planted in *puke* (small mounds), which were arranged in 'quincunx' fashion (staggered rows). There are 38 *puke* in each 5 x 5 m plot (Fig. 2). In the first season, two tubers were planted in each *puke*, one on the northern side and one on the southern side. In subsequent seasons, only one tuber was planted in each *puke*, on the northern side.

In 2000, a 5 m x 2.5 m annex was established at Robin Hood Bay and a 5 x 5 m annex at Whatarangi. These were used mainly to increase stocks of 'Hutihuti' and 'Rekamaroa' and are not included in consideration of yield for effort to date. A 1 m high fence of metal stakes and 30 mm wire mesh encloses each garden to exclude sheep and rabbits. Wind break cloth has been placed over the wire netting to provide protection for the plants. The same plots have been planted again in the 2001–2002 and 2002–2003 seasons.

The 2000–2001 growing season in the Cook Strait region was described as a one-in-100-years drought. Monthly rainfall during the growing season was significantly lower than monthly averages (see below). However, in view of Colenso's (1880: 11) statement that Māori never watered their gardens, no water was applied to the experimental plots.

Weed species present in both plots were recorded. Soil fertility analyses were carried out by a registered soil laboratory on samples from each of the plots.

Soil temperature measurements were conducted during the 2000–2001 growing season using thermal cells buried at 10 cm depth on the north and south sides of mounds at both gardens. Cells were inserted at both gardens on 10 November 2000 and removed from Robin Hood Bay on 27 April 2001 and from Whatarangi on 1 May 2001. At Whatarangi, a stone-pebble surface mulch was used on one mound to assess whether there was any difference in soil temperature under a stone mulch compared with a bare soil mound (Plate 5; see also Plates 3 and 8). The use of thermal cells is described by Ambrose (1980) and Leach and Hamel (1984). The mean temperature during the period the cells are buried is calculated as follows:

Temperature in degrees Kelvin = $1/((\mathrm{Ln}(Q/T)-B)/M)$

where:
T = Number of Days buried
Q = Delta Weight g
$B = 11.364$ and $M = -5047.9$, which are two constants experimentally verified for the batch of zeolite thermal cells manufactured.

The thermal cells are weighed before and after burial with a precision of 10 μg with a repeatability of 50 μg. An overall experimental error of 1000 μg would give a mean integrated temperature error of 0.03°C over a period of 172 days. This shows that experimental errors are very small compared with other sources of variation such as the exact and repeatable depth at which a thermal cell has been buried or local variations in thermal properties of soils due to rocks.

Following the first harvest on 14 April 2000, 'Taputini' tubers weighing 6.95 kg in total were set aside as planting stock for the next season. The tubers were dried in the sun for a day. This was the only form of curing they received. Each tuber was placed in a separate brown paper bag. The tubers were kept in an unheated building at the Open Polytechnic of New Zealand with a temperature range of 6–27°C over the six months in storage. No record of relative humidity during storage was available. Tubers showing rot symptoms on 40% or more of their tuber length (visually assessed) were recorded and set aside but as they were in separate bags they continued to be weighed as part of the total stock. The tubers were weighed regularly and records were kept of losses. Proximate analyses of kūmara tubers, begun after the first harvest to build up a picture of the food value of 'Taputini', were continued and extended to the other two cultivars.

RESULTS

R00T LOSSES DURING STORAGE

Figure 3A shows the weight loss per month of the stored 'Taputini' tubers from the 1999–2000 season. The total weight of tubers at planting time in October 2000 was 4.37 kg, compared with 6.95 kg at harvest. Up until August, the weight loss was due to transpiration of water and some small loss of carbon due to respiration.

After August, the loss resulted from rotting tubers. The drop in weight after the onset of the fungal rot, Fusarium end rot *Fusarium oxysporum*, was apparent at the final weighing when rotted tubers had a mean percentage weight of 24% that of the first weighing while sound tubers had a mean percentage weight of 82%. Figures 3B and 3C illustrate the weight losses per month and the increasing percentage showing symptoms of rot after August. Figures 3B and 3C illustrate how after August the losses per month increased as a result of fungus rot infection caused by the pathogen Fusarium end rot, *Fusarium oxysporum*. Losses from rot were higher in tubers of the cultivars obtained from Crop and Food Research — 40% of the 'Taputini' cultivar from this source was wasted by rot. These tubers were obtained on the understanding they were to be used immediately for rooted cutting production but were subsequently stored through the winter. The high rot losses presumably resulted from the lack of any form of curing.

HUMAN LABOUR INPUT

The numbers of person hours spent on digging, planting, weeding and harvesting at the two gardens over the first two seasons are given in Table 1. Most of the input is for preparing and planting the garden and harvesting the crop. Weeding is not a major task. The lower input at Whatarangi is due to the ease of preparing the lighter sandy soils there, and the relative ease of harvesting the brittle tubers in these soils. The implications of the labour input will be discussed in a future paper.

TABLE 1
LABOUR INPUT INTO KŪMARA GARDENS (person hours/25 m^2)

A: Robin Hood 1999–2000, B: Robin Hood 2000–2001, C: Whatarangi 2000–2001.

Task	**A**	**B**	**C**	**Mean**
Digging soil	3.0	2.6	5.0	3.53
Second cultivation	1.0	1.0	1.0	1.00
Mound forming	2.0	1.4	1.5	1.63
Planting	1.0	2.0	1.5	1.50
First weeding	1.0	0.8	0.3	0.70
Second weeding	2.0	0.9	0.2	1.03
Harvesting	5.0	4.9	2.1	4.00
Total Hours	**15.0**	**13.6**	**11.6**	**13.40**

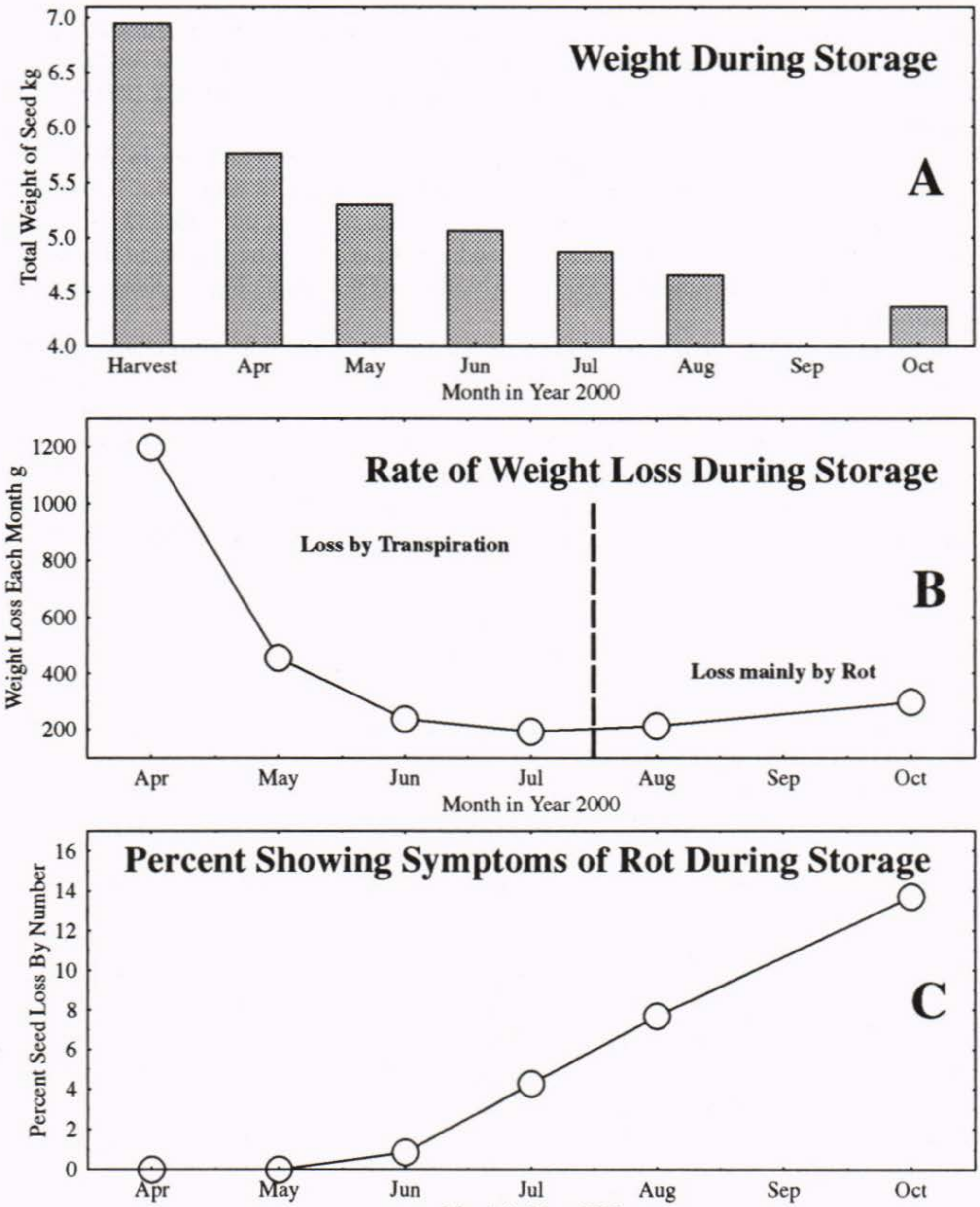

Figure 3: Weight loss and the onset of rotting during storage of 'Taputini' tubers kept for seed (no data for September). A: Total weight of tubers each month. B: Rate of weight loss each month showing that transpiration losses stabilise after about 2.5 months. C: Rate of tuber loss due to rot. A tuber was considered rotten if more than 40% was affected.

SOIL FERTILITY

The results of soil analyses to date are given in Table 2. Although the current soil fertility cannot tell us anything about the soil fertility in pre-European times, the analyses will indicate changes in mineral nutrient status as a result of continued kūmara cultivation in successive seasons.

The first sample from the main garden at Robin Hood Bay was taken in 2000 from between two *puke*. The sample taken in 2001 was from Mound 18 which was in the same general part of the garden as the previous year. The sample taken from Mound 48 in 2001 was from the newly cultivated annex area, and should in theory be similar to the sample taken from the main garden in 2000. However, the results indicate higher phosphorus and potassium levels.

In the main garden, the potassium level changed from 0.45 to 0.35 milli equivalents per 100 g from the first year to the second. Experimental errors are about 4% coefficient of variation (0.45 ± 0.02). Thus, it appears that the potassium level has fallen significantly over time. However, although the samples were taken from one small area of the garden, it was cultivated each year before planting. This apparent change, and the difference between the main garden and the annex, may therefore be due to soil chemical variation within the garden. In future years, multiple samples will be taken and homogenised before analysis.

TABLE 2
SOILS ANALYSIS FOR KŪMARA GARDENS

A=Robin Hood Bay 2000, B=Robin Hood Bay Mound 18 2001, C=Robin Hood Bay Mound 48 2001, D=Whatarangi Mound 18.
me = milli-equivalence.
E=The normal range for kūmara cultivation suggested by R.J. Hill Laboratories Ltd.

Test	**Units**	**A**	**B**	**C**	**D**	**E**
pH		5.0	5.0	5.0	4.8	5.8–6.5
Olsen P	μg/ml	12	12	20	9	20–30
Potassium	me/100g	0.45	0.35	0.68	0.15	0.5–0.8
Calcium	me/100g	6.1	6.4	6.0	1.7	6–12
Magnesium	me/100g	1.40	1.45	1.58	0.78	1–3
Sodium	me/100g	0.11	0.14	0.13	0.24	0.1–0.3
CEC	me/100g	18.2	17.4	17.6	6.6	12–25
Base Saturation	%	44	48	47	44	50–85
Volume Weight	g/ml	0.94	0.77	0.81	1.23	0.6–1.0
K/Mg Ratio	-	0.3	0.2	0.4	0.2	0.3–1.0

MEAN INTEGRATED SOIL TEMPERATURES

Results of soil temperature measurements from the thermal cells are given in Table 3. The mound at Whatarangi with the stone mulching had a mean temperature during the growing season of 21.29°C, compared with 20.34°C in the mound with no stone mulching. Thus, the surface stone mulching has increased the temperature by 0.95°C.

The Palliser Bay thermal environment is somewhat warmer than that at Robin Hood Bay. The mean temperature at Robin Hood Bay is 19.08°C, compared with the un-mulched mound at Palliser Bay of 20.34°C, a difference of 1.26°C. These differences may not appear to be very large, but it must be remembered that the values are integrated mean temperatures, and are therefore quite significant.

The four cells at Whatarangi provide mean and standard deviation temperature of 20.8 ± 0.4 and 0.7 ± 0.3, compared with that from the two Robin Hood Bay cells of 19.1 ± 0.1 and 0.2 ± 0.1. The difference between the two gardens of 1.7°C far exceeds the standard errors, showing that the Whatarangi soil is significantly warmer than at Robin Hood Bay.

TABLE 3
SOIL TEMPERATURES MEASURED BY THERMAL CELLS DURING THE 2000–2001 GROWING SEASON.
Weight in g

Site	**Weight 1**	**Weight 2**	**Δ Weight**	**Days**	**°C**
Whatarangi Mound 19 Nth	11.64976	12.15820	0.50844	172	20.54
Whatarangi Mound 19 Sth	11.81279	12.30937	0.49658	172	20.14
Whatarangi Stone Mound Nth	11.80738	12.32275	0.51537	172	20.77
Whatarangi Stone Mound Sth	11.72338	12.27052	0.54714	172	21.80
Robin Hood Bay Mound 19 Nth	11.71057	12.16097	0.45040	168	18.88
Robin Hood Bay Mound 19 Sth	11.84573	12.30704	0.46131	168	19.28

As noted above, in the 1999–2000 season, two tubers were planted in each mound at Robin Hood Bay. The plants on the north sides produced a significantly greater total yield, although there was considerable variability from mound to mound. Since there is no clear pattern of north to south difference in thermal soil environment, this increased yield is probably due to greater exposure to sunlight for photosynthesis, with the north side plant shading the south side plant.

WEEDS

As in the 1999–2000 season, the weed growth was vigorous after the initial mounding and planting. However, in the 2000–2001 season, the weeds did not compete as well in the much drier conditions after the first weeding in December (Plate 6). The species present, all introduced in post-European times, were: black nightshade (*Solanum nigrum*)[4], catsear (*Hypochaeris radicata*), woolly mullein (*Verbascum thapsus*), dock (*Rumex obtusifolius*), puha/sow thistle (*Sonchus oleraceus*), yarrow (*Achillea millefolium*), narrow-leaved plantain (*Plantago lanceolata*), Scotch thistle (*Cirsium vulgare*), red clover (*Trifolium pratense*), white clover (*T. repens*), sheep's sorrel (*Rumex acetosella*) and pennyroyal (*Mentha pulegium*).

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[4] Both Banks and Solander described a nightshade growing in New Zealand in 1769–1770, which has often been assumed to have been *Solanum nigrum* (e.g., Beaglehole 1963 (II): 8 fn.). However, Bayliss (1958: 379) argued that the species seen by Banks and Solander was the now extinct *S. nodiflorum*, and that the genetically distinct *S. nigrum* was introduced in the nineteenth century.

RAINFALL

The 2000–2001 growing season in the top of the South Island and lower North Island was a one-in-100-year drought. The Ocean Bay climate station close to Robin Hood Bay recorded only 35% of the historical mean monthly rainfall for this period (Fig. 4).

The rainfall records for the seven-month kūmara growing season from October to April are shown in Table 4. Historical rainfall figures for Ngawi near the Whatarangi garden in Palliser Bay show that less rain falls in this area than at the South Island garden, and drought conditions during the 2000–2001 period were even more severe here than at Robin

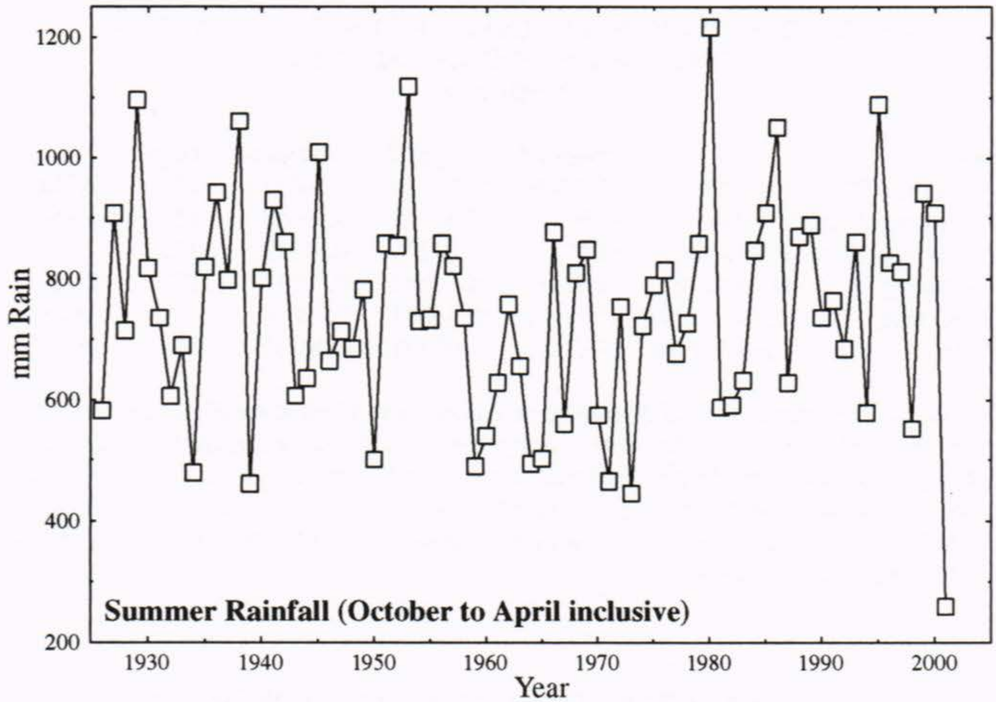

Figure 4: Rainfall figures from 1925 to the present day for Ocean Bay near the Robin Hood Bay experimental garden. Rain falling in the summer growing season averaged 748 mm during this period. The 2000–2001 drought had only 259 mm in these seven months (35% of the mean value, and only 58% of the next most severe drought recorded).

Hood Bay. In Table 4 figures for the growing period include only rain falling on the days in which plants were in the ground.

As discussed earlier, optimum rainfall for modern kūmara varieties is regarded as 500 mm, falling during the growing season. Robin Hood Bay received only 259 mm during the 2000–2001 season, yet the plants there produced a greater yield than in the previous season.

TABLE 4
RAINFALL (MM) AT THREE CLIMATE STATIONS NEAR TO THE TWO EXPERIMENTAL GARDEN SITES.

Mean monthly values are shown, and compared to the rain over the drought conditions of the 2000–2001 growing season. The dates for planting and harvest at Robin Hood Bay were 21-10-00 and 27-4-01 respectively, and for Whatarangi 31-10-00 and 1-5-01. Rain falling only between these sets of dates are noted for the growing seasons.

Climate Station Rain		**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Total**
Ocean Bay	(mean month)	125	109	108	100	93	100	122	757
Ngawi	(mean month)	83	79	62	67	85	76	86	538
Te Kopi	(mean month)	84	69	64	56	50	72	74	469
Growing Season Rain									
Ocean Bay	(2000–2001)	18	0	67	22	16	20	25	168
Ngawi	(2000–2001)	0	52	66	7	13	9	5	152

PRODUCTIVITY AND YIELD

Table 5 gives yields from Robin Hood Bay in the 1999–2000 season and from both sites in 2000–2001, with comparisons between mean yield per mound and a conversion to give yield per hectare. The yield per mound data are plotted out in Figure 5. This shows a wide range from practically zero to 1800 g, with a mean of 748 ± 34 g (σ 404 ± 24, N = 143). Plate 7 illustrates the variation in both size and number of tubers from mounds harvested at Robin Hood Bay in the first season.

The estimate of kilocalories per hectare is calculated from a mean energy value of 92.74 kcal/100g for freshly harvested kūmara. It will be noticed in Table 7 that a mean energy value is given as 114 kcal/100g. However, this value is the gross energy, not all of which would be available to humans. Instead, we estimate the available food energy from the mean constituents of protein, fat and carbohydrate, using standard energy values for these of 4, 9, and 4 kcal/g respectively (Smith 1985: 131). The calculation is:

Constituent	**kcal/100g**
Protein 0.22 g x 4 kcal	1.98
Fat 1.79 x 9 kcal	7.16
Starch	20.51
Glucose	0.14
Fructose	0.13
Sucrose	0.12
Carbohydrate total 20.90 x 4	83.60
Available Energy	**92.74**

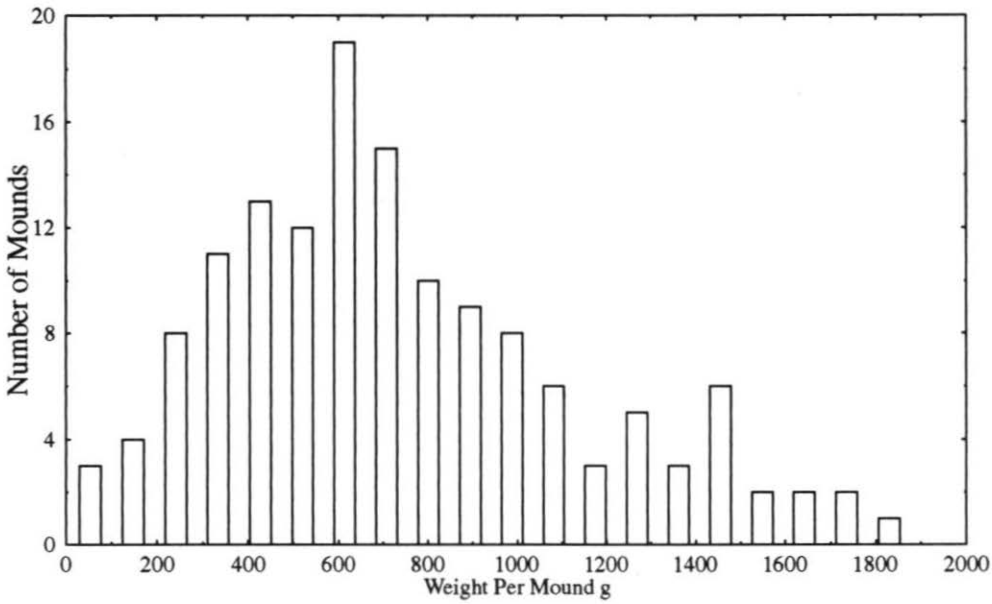

Figure 5: Size frequency histogram of individual plant yield (g weight of tubers) from 143 mounds combined from the Robin Hood Bay and Whatarangi gardens. The mean yield is 748 ± 34 g and the SD is 404 ± 24 g.

TABLE 5
YIELDS PER SITE FOR 'TAPUTINI'(OVER TWO SEASONS AT ROBIN HOOD BAY)

Energy calculations are based upon 92.7 kcal/100g (see text).
* In this year two tubers were planted in each puke. The other plantings were one tuber per puke

	Robin Hood Bay		**Whatarangi**
	1999–2000*	**2000–2001**	**2000–2001**
Yield/25 square metre (kg)	29.432	19.140	30.555
Yield/ha (tonne)	11.8	7.6	12.2
Mean yield/plant (g)	437.75	503.68	804.9
Kcal/ha	10,943,320	7,048,240	11,314,280

Yields per hectare allow contemporary and international comparisons and will be useful to archaeologists seeking to estimate historical production figures. Note that in the 1999–2000 season two tubers were planted in each mound at Robin Hood Bay, whereas in the 2000–2001 season, only one tuber was planted in each mound at both gardens.

Six tubers rotted and failed to grow in the main plot at Whatarangi. This resulted from the planting of tubers showing signs of rot and indicates the importance of planting sound tubers with no sign of rot. The six missing plants have been compensated for in the total by including the mean weight per mound times six.

Sandy soils and the higher mean integrated temperature at Whatarangi produced larger tubers which were also straighter and less deformed.

It was considered useful to keep track of tuber size at planting to see if there was any tendency for larger seed tubers to produce larger yields. Walsh (1902: 18) in his account of Māori kūmara gardening, reported that "the seed consisted of the tubers which were too small to be eaten". If this practice was widespread and the small seed tubers consistently produced small yields, there would obviously be a major effect on productivity. The combined data from 38 mounds at Whatarangi in 2000–2001 and 37 mounds at Robin Hood Bay in 2001–2002 are plotted out in Figure 6. This shows a weak correlation ($r = 0.43 \pm 0.09$) for larger tubers to produce larger yield. This weak correlation is significant $p<.01$ ($t = 4.2$ with 74 df).

PRELIMINARY COMPARISON OF PRE-EUROPEAN CULTIVARS

Both the 'Hutihuti' and 'Rekamaroa' cultivars started to sprout later in the season than 'Taputini'. These cultivars were grown only at Whatarangi and the plants were rooted cuttings planted out at a later date than the main 'Taputini' trial plot. As yet we do not have enough data to produce valid yield comparisons. However, both 'Hutihuti' and 'Rekamaroa' were observed to produce smaller and fewer tubers than 'Taputini'. The relatively poor performance of these cultivars under these conditions may indicate that they are better suited to a wetter and warmer climate or different soil conditions.

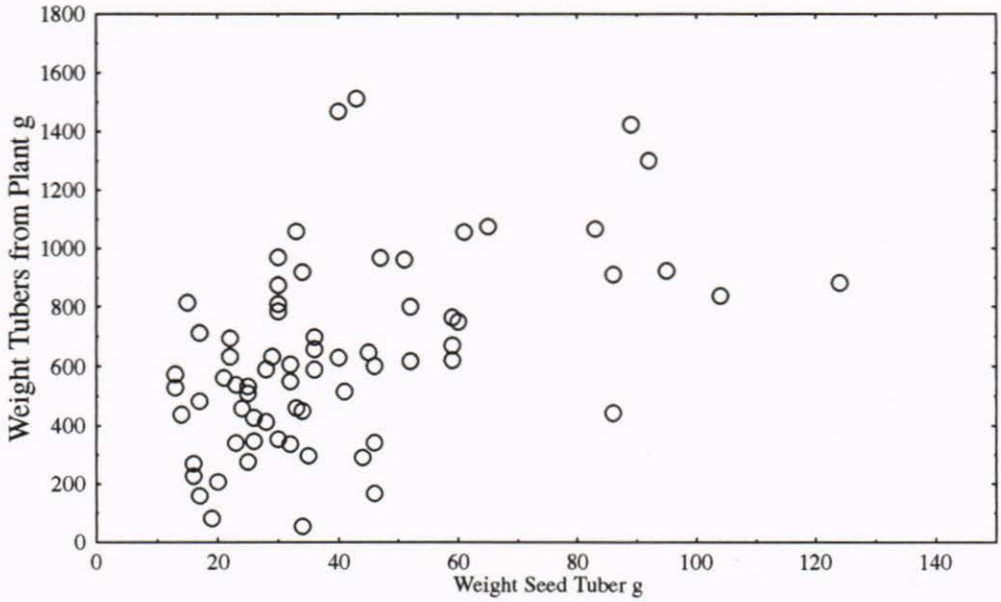

Figure 6: Yield of individual plants plotted against the weight of seed tubers planted in 75 mounds (38 at Whatarangi in 2000–2001 and 37 at Robin Hood Bay in 2001–2002).

PROXIMATE ANALYSIS OF TUBERS

Several kūmara samples have been analysed for their constituent food values (Tables 6 and 7). Sample numbers are those assigned in the Archaeozoology Laboratory at the Museum of New Zealand Te Papa Tongarewa.

AK1002 1 large kūmara, '*Taputini*' Robin Hood Bay 1st season
AK1003 1 large kūmara, '*Taputini*' Robin Hood Bay 1st season
AK1004 5 small kūmara, '*Taputini*' Robin Hood Bay 1st season
AL451 '*Hutihuti*' Whatarangi, 2nd season
AL452 '*Taputini*' Whatarangi, 2nd season
AL453 '*Rekamaroa*' Whatarangi, 2nd season
AL454 '*Taputini*' Robin Hood Bay, 2nd season
AL457 '*Taputini*' Robin Hood Bay, 1st season kūmara, after one year storage

For comparison, some results reported by the US Department of Agriculture for raw sweet potato are:

Quantity	**Value/100g**
Water	72.84
Energy	439 kJ
Energy	105 kcal
Ash	0.95
Fat	0.3
Carbohydrate by difference	24.28
Fibre	3

Where the same analysis was conducted, these figures converted to equivalent units fit within the range of values obtained by our proximate analyses. For example, the energy value of 439 kJ/100g or 4.39 kJ/g fits neatly within the range of values in Table 7.

DISCUSSION

The monthly weighing of the stored tubers, and in particular the observation that losses due to Fusarium end rot start to increase from August through to planting, suggest that further research into curing and storage of the kūmara crop is needed. It is possible that even where sufficient quantity of crop could be produced, the continuance of kūmara as a food source much beyond planting time (October/November) was a rare event because of the increasing incidence of storage rot at this time. This observation supports Walsh's (1902: 21) statement that "the storing of the crop required greatest care and judgement, as, in spite of every precaution, it was barely possible to preserve the stock until the next planting-time".

It is clear from the ethnographic record that protection from rot was an important consideration for pre-Contact Māori (Colenso 1880:12). The causal organism of Fusarium end rot identified on stored tubers, *Fusarium oxysporum*, is cosmopolitan throughout the world. While it is not possible to assert that this is of the same genetic origin as pre-contact organisms causing rot on kūmara, some similar strain undoubtedly existed at this time.

TABLE 6
PROXIMATE ANALYSIS OF KŪMARA SAMPLES BY DRY WEIGHT %.

A dash (-) indicates analysis not carried out.
NB: Specimen AL457 had been stored for 12 months before analysis, and was not included in the calculation of mean values.

Sample	**AK1002**	**AK1003**	**AK1004**	**AL451**	**AL452**	**AL453**	**AL454**	**AL457**	**Mean**
kJ/g	16.713	16.689	16.800	17.006	16.955	16.739	16.891	18.65	16.83
kcal/100g	399	399	402	406	405	400	404	571	402
NDF	-	-	-	-	-	-	-	35.37	-
ADF	-	-	-	-	-	-	-	18.64	-
Soluble carbohydrate	-	75.32	-	-	-	-	-	31.32	75.32
Ash	3.82	3.25	3.67	3.70	4.18	4.13	3.39	8.26	3.73
Fat	0.93	0.86	0.81	0.97	0.73	0.62	0.59	-	0.79
Protein	5.40	4.16	5.25	6.48	7.77	8.78	5.68	9.44	6.22
Starch	-	66.10	-	70.7	71.3	66.7	69.9	30.5	68.9
Glucose	-	6.20	-	-	-	-	-	0.96	6.2
Fructose	-	5.80	-	-	-	-	-	0.88	5.8
Sucrose	-	5.10	-	-	-	-	-	0.67	5.1
Lignin	-	22.9	-	-	-	-	-	11.70	22.9
Hemicellulose	-	8.9	-	-	-	-	-	16.73	8.9
Cellulose	-	23.23	-	-	-	-	-	6.93	23.23
Total	**-**	**83.93**	**-**	**-**	**-**	**-**	**-**	**86.43**	

TABLE 7
PROXIMATE ANALYSIS OF KŪMARA BY WET WEIGHT %.

A dash (-) indicates analysis not carried out.
NB: Specimen AL457 had been stored for 12 months before analysis, and was not included in the calculation of mean values.

Sample	**AK1002**	**AK1003**	**AK1004**	**AL451**	**AL452**	**AL453**	**AL454**	**AL457**	**Mean**
kJ/g	3.894	3.782	4.431	5.882	4.963	5.068	5.304	-	4.76
kcal/100g	93	90	106	141	119	121	127	-	114
NDF	-	-	-	-	-	-	-	35.37	-
ADF	-	-	-	-	-	-	-	18.64	-
Soluble carbohydrate	-	-	-	-	-	-	-	31.32	-
Dry Matter	23.30	22.66	26.37	34.59	29.27	30.28	31.40	64.65	28.27
Water	76.70	77.34	73.63	65.41	70.73	69.72	68.60	35.35	71.73
Ash	0.891	0.737	0.967	1.28	1.22	1.25	1.06	-	1.06
Fat	0.22	0.20	0.21	0.34	0.21	0.19	0.19	-	0.22
Protein	1.26	0.94	1.39	2.24	2.27	2.66	1.78	-	1.79
Starch	-	14.98	-	24.52	0.92	0.22	2.0	-	20.51
Glucose	-	0.14	-	-	-	-	-	-	0.14
Fructose	-	0.13	-	-	-	-	-	-	0.13
Sucrose	-	0.12	-	-	-	-	-	-	0.12

It is widely recognised that to store kūmara safely it is important to maintain storage temperature at above 10°C. If the temperature falls to 4.5°C it will make further prolonged storage impossible (Leach 1976: 151). The storability of tuber crops has been shown to be a function of the ratio of relative humidity over temperature and sweet potatoes have a narrow range of ideal storage temperatures and relative humidity (Matthews 2002: 140–141). Evidence of small hearths or fires in the floors of kūmara pits (e.g., Ambrose n.d.) may well be indicative of attempts to maintain a safe storage temperature during cold winter nights. Clearly, experimental replication of archaeological examples of storage pits would help to answer questions relating to kūmara storage in pre-European New Zealand.

The labour input figures only record the effort required from cultivation through to harvest for each crop. Missing are the hours that would be required to clear and burn forest or bush for planting, the time required to prepare boundary walls or fences for a new garden area and the time spent building or renovating storage structures. It is worth noting that at both Robin Hood Bay and Whatarangi, but particularly at Robin Hood Bay, some stone clearance has taken place each season as a natural part of cultivation and mound building. The simplest way of disposing of the stones removed from the plot is to pile them along the base of the surrounding fence, which is also an obvious place to put weeds, and kūmara tops after harvest.

A major objective of the project is to develop a satisfactory model of input effort and consumption for a hypothetical community of 30 people. This will allow adjustment of input on the basis of the individuals undertaking the work. This is important because human calorie expenditure varies considerably depending on the age, size and metabolic rate of each individual.

Converted to calorie yields per hectare, the gardens yielded a mean of 10,461,121 kcal. This will provide the basis for a more precise calculation of returns for effort and give greater precision in estimating the population that various areas of garden could be expected to support.

The soil fertility test results do not inspire much confidence that these soils could be used for highly productive kūmara horticulture. The Palliser Bay soil in particular appears to be deficient in almost all respects. However, as is clear from the harvest results and the general performance of these Māori cultivars at these two experimental gardens, the results of soil analysis alone are not necessarily the best guide to productivity. The plants at both gardens looked very healthy and vigorous throughout the growing seasons, and produced good yields of tubers, despite the worst drought for 100 years in the 2000–2001 season. By harvest time 2001, the green foliage of the plants was in striking contrast to the surrounding pasture (Plate 8).

Of some interest is the fact that the potassium values are a little lower than is considered normal for kūmara (Table 2). This nutrient is considered to be the key element in the fertiliser programme for the production of modern kūmara varieties. Lewthwaite (1999: 22) noted that corrections of mild deficiencies of potassium can result in large increases in kūmara yield.

The mean soil temperature difference of 1.7°C between the two garden sites is significant. It is possibly due to the albedo effect, with the darker Whatarangi soils attracting greater thermal energy than the lighter coloured Robin Hood Bay soil. Sunshine hours are another factor contributing to the accumulation of thermal energy. This variable is yet to be fully investigated.

The fact that all the weeds are introduced species raises the question as to what weeds might have been present in pre-European times. The following Māori proverb gives one clue. *Tēnā te ringa tango parahia* (translated as "this is the hand which pulls out the weeds") was applied to a hard worker because in some places the kūmara plantations were overrun by a small plant called parahia which had to be weeded in order to give the kūmara plants room to grow (Brougham and Reed 1975). Williams (1971: 263) defines parahia as

Chenopodium allanii, a small perennial herb, now named *Einadia allanii,* in the Chenopodiaceae Family. This weed has been recorded close to the seashore near both garden sites. Its ecological niche in the gardens has probably been occupied by more aggressive introduced species. As noted above, there was a pre-European species of nightshade, which was apparently at its southern climatic limit in this area. It has been replaced by the presumably more aggressive *Solanum nigrum*, introduced in the nineteenth century.

Walsh (1902: 19) reported that "the work of cleaning the growing crop was a comparatively light one in the old days, as the host of troublesome weeds that have accompanied European cultivation had not then made their appearance" and noted that one weeding during the season was considered sufficient. This report, coupled with our observations of the exotic origin of the weeds, suggests that weeding would not have consumed the same amount of effort as it does today. The relatively small amount of weeding required, even today with a number of aggressive introduced species present, supports Māori oral accounts that some gardens, once planted, might not be visited again until harvest time (Sullivan n.d., Chapter 4).

The yields from these experimental kūmara gardens (7.6 to 12.2 tonne per hectare) compare favourably with world production figures. The world average yield for sweet potato is 14.4 tonne per hectare, ranging from 1 tonne/ha at Mauritius to 24.7 in Japan (FAO 2001). Our yields support Leach's estimate of approximately 10 tonne/ha (Leach 1976: 181) but are considerably more than some other estimates for pre-European kūmara in New Zealand (Jones and Law 1987:105; Jones 1989: 39).

Our data also support the idea that sandy soils are more suited to production of the 'Taputini' cultivar, with larger tubers and better production at Whatarangi, despite the nutrient deficiency of its soil, although the higher mean temperature at Whatarangi may also have been important.

In many parts of New Zealand, where a ready source of sand or gravel was available, pre-European kūmara production was accompanied by extensive soil amelioration with additions of charcoal, shell, sand and gravel (Leach 1984: 48–49; Davidson 1984: 120–121; McFadgen 1980). Challis (1976: 253) compared the temperatures of a gravel soil and an unmodified soil and found the gravel soil to be warmer. Worrall (1993: 119–122) showed that addition of sand, gravel and charcoal either as a surface layer or incorporated into the surface layer raised soil temperatures. Horn (1993) found that the addition of sand as a surface mulch raised the soil temperature and increased yield.

Māori gardeners had clearly perfected the growing of kūmara in *puke*. As well as assisting soil to heat up faster in spring, absorbing extra thermal energy during the growing season, and assisting drainage around the plant, both *puke* and sand additions help facilitate the plant's physiological requirement for oxygen to initiate and grow storage roots (Kays 1985: 83; Ravi and Indira 1999: 305).

One of the most important results of the project to date is the productivity of 'Taputini' during the drought conditions of 2000–2001. This is significant in the New Zealand context, but also has implications for discussions of dry-land horticulture elsewhere in Polynesia. Although the 2000–2001 season in parts of central New Zealand, including both Robin Hood Bay and Palliser Bay, was described as a one-in-100-year drought, dry summers are not uncommon in central New Zealand and the North Island east coast, and a drought-resistant variety of kūmara would undoubtedly be a valuable asset in these areas.

The sweet potato is typically described as growing in tropical or warm temperate regions with moderate rainfall, although Yen (1974: 316) emphasised its tolerance of a restricted water regime and strong wind conditions. It is known to have been grown successfully on the 'dry' leeward sides of the Hawai'ian islands (e.g., Kirch 1985: 223–231) and on Rapanui (Easter Island). However, various scholars such as Hommon (1986: 57) for Hawai'i and most recently Stevenson *et al.* (1999) for Rapanui have argued that dry-land agriculture in Polynesia is susceptible to drought and pointed to techniques such as irrigation (Hawai'i) and stone mulching (Rapanui) as ways of ameliorating this problem. It would be very interesting to know whether drought resistant cultivars comparable to 'Taputini' were present elsewhere in Polynesia, particularly in Hawai'i and Rapanui, for example. This, in turn, raises the question of how and where the known Māori cultivars originated.

A genetic study (Harvey *et al.* 1997), which compared the traditional cultivars, 'Taputini', 'Rekamaroa' and 'Hutihuti' with modern cultivars and several cultivars introduced to New Zealand in the nineteenth century, found that 'Rekamaroa' and 'Hutihuti' are very closely related, while 'Taputini' is quite distinct. All three are distinct from modern cultivars.

Whereas watering of crops was apparently not practised by Māori gardeners, soil modification is part of a body of gardening practices very widespread in time and space in New Zealand (Leach 1984: 49). Whatever its intention, its effect seems to have been to raise the temperature (Worrall 1993; Horn 1993), as was also demonstrated at the stone mulched mound at Whatarangi. It is worth asking whether supply to or retention of water in sweet potato gardens was in fact necessary in either Hawai'i or Rapanui.

CONCLUSIONS

The cumulative results of the first two seasons of experimental gardening suggest that under conditions resembling those of the present day, climatic factors would not have inhibited kūmara production in the Cook Strait region. This supports the archaeological evidence of quite extensive gardening in parts of the region during the first centuries of Polynesian occupation, when the climate is thought to have been not unlike that of today.

Decline in soil fertility, the traditional limitation of shifting agricultural systems, is likely to turn out to be important. Several further years of experimental kūmara gardening will be required to assess this variable. Further experimentation with soil amelioration may also throw some light on input effort and the existence of borrow pits in some areas of New Zealand.

The research has raised some important questions about the curing and storage of the kūmara crop. The increase in loss through rot after August reinforces the view that kūmara could only be a source of carbohydrate for a limited season. There is a real need for trials that replicate Māori storage pits to provide data on storage conditions and crop survival.

The discovery that at least one traditional Māori cultivar is drought resistant raises important questions about traditional cultivars and gardening practice in those other parts of Polynesia, notably Hawai'i and Rapanui, where kūmara was an important food crop. The possibility of significant difference in performance between the various pre-European cultivars in New Zealand deserves further exploration. We hope to be able to produce some better data on the performance of 'Hutihuti' and 'Rekamaroa' from our current ongoing research. It is known that localised cultivars were available to Māori and that these had probably been selected over many seasons for their performance under local conditions. Our preliminary results have certainly suggested that 'Taputini' may be more suited to Cook Strait conditions than the other two cultivars.

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