# Agronomic requirements of ulluco (*Ullucus tuberosus*) – a South American tuber

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**Abstract**

Ulluco (*Ullucus tuberosus* Loz) is an Andean tuber vegetable not currently used in New Zealand. Fifteen ulluco accessions were collected in the Andean region of South America and imported into New Zealand in 1993. Following a lengthy period in quarantine to produce virus-free lines, five accessions were released for evaluation in 1998. Since then a series of field trials has been carried out at Pukekohe and Lincoln to determine the tuber yields of the imported lines and measure the influence of the size of the tuber at planting and depth of planting on tuber yields. All five ulluco accessions showed a similar preference for cool and moist growing conditions under which an extensive leaf/stem canopy developed. Conversely, hot and dry conditions caused leaf cupping and stunted growth. The crop has a long, 7-8 month, cropping cycle, with tuberisation occurring under short days. At Pukekohe the average total tuber yields of the five accessions was 35 t/ha. Line IVY 1225 (red tubers) produced the highest yield (43 t/ha). Tuber yields at Lincoln were very low (2 and 5 t/ha) because of early frosts. The mean tuber size in both regions was only 2-5 g, with the largest tuber in all trials weighing 94 g Thus, considerable numbers of pea-sized tubers were produced. Many tubers developed on the soil surface at Pukekohe, but fewer were observed in Canterbury. Deeper planting reduced the number of tubers on the soil surface but did not eliminate the problem. Increasing the size of the seed tuber increased tuber yields but had no effect on average tuber weight at harvest. These trials have shown that ulluco tubers can be successfully produced in New Zealand, but commercial production systems and mechanical harvesting methods have yet to be formulated.

***Additional Key Words:*** agronomy, new crop, plant production, virus-free lines

## Introduction

Ulluco (*Ullucus tuberosus* Loz, Basellaceae) is a traditional Andean tuber vegetable that is grown at altitudes of between 3000 and 4000 m in the Andes from Venezuela to northern Argentina and Chile between latitudes 10 and 25°S (National Research Council, 1989; Arbizu and Tapia, 1994). Within this ecological zone it is a more popular tuber vegetable than oca (*Oxallis tuberosa*), which is already well known as New Zealand yam. Ulluco tubers have been canned and exported from Peru to the USA (Sperling and King, 1990). Outside the Andes, ulluco is virtually unknown but its potential, especially the visual appeal of its brightly coloured tubers, has been highlighted previously (National Research Council, 1989; Sperling and King, 1990; Arbizu and Tapia, 1994). Considerable research on its botany and agronomy has been done by staff at the University of Turku, Finland (e.g. Pietila and Jokela, 1988; Lempiainen, 1988; Rousi *et al.*, 1989; Pietila, 1995).

Ulluco is a 200-500 mm high, scrambling herbaceous plant that forms trailing stalks up to 1 m long with succulent leaves that can be used as a salad vegetable. Below ground axillary stolons enlarge to form terminal starchy tubers under short-day conditions (National Research Council, 1989). It requires 11-13.5 hours of day length to achieve

tuberisation. In long days it fails to form tubers, although some clonal variation to this photoperiod requirement is known to occur (National Research Council, 1989; Kalliola *et al.,* 1990; Sperling and King, 1990). Typically, ulluco has smooth, spherical or elongated tubers the size of small potatoes, but some forms grow up to 15 cm long (National Research Council, 1989). The tubers have bright, waxy skins and occur in a wide range of colours, including white, yellow, orange, red, magenta and green. Nutritionally, ulluco tubers provide a staple diet, but there is wide variation in the protein levels and some forms have undesirably high mucilaginous levels and earthy flavours (King and Gershoff, 1987; National Research Council, 1989; Pietila and Jokela, 1988). Tuber yields are reported to range from 5 to 9 t/ha in regions where it is traditionally grown, but yields may reach 40 t/ha with more intensive management including heavy fertilisation (National Research Council, 1989; Pietila and Jokela 1988).

One accession of ulluco was introduced into New Zealand in the 1970s, but it was difficult to maintain at Lincoln (Palmer, 1989). To re-evaluate this species and continue earlier research efforts, 15 accessions of ulluco were collected from the southernmost limit of its distribution in 1993 (Grau and Halloy,1994). These plants were grown at Lincoln under quarantine, and once the virus contamination was removed (Fletcher and Fletcher, 2001) the five surviving accessions were released for preliminary agronomic assessment in July 1998.

Four field trials were conducted at Pukekohe and Lincoln from 1999 to 2001 to compare the tuber yield performance of the five ulluco accessions, to study the effect of planting tuber size on tuber yield and to determine the effect of tuber planting depth on tuber yield. The objective of the field trials was to develop cultural guidelines for this crop. This paper reports on the results of the four field trials.

## Materials and Methods

Cuttings of the five accessions, IVY 1212 (red tubers), IVY 1213 (red/yellow tubers), IVY 1219 (yellow tubers), IVY 1223 (yellow/red tubers) and IVY 1225 (red tubers), were made in August 1998 from plants grown from disease-free, exflasked plantlets following virus elimination *in vitro*. In November the rooted cuttings were transplanted into a Templeton silt loam at Lincoln and a Patumahoe clay loam at Pukekohe. Tubers harvested and cool-stored from these plantings in June/July 1999 were used to plant the field trials at both locations.

### Pukekohe trials

Three trials (1, 2 and 4) were conducted on a Patumahoe clay loam at the Pukekohe Research Station from 1999 to 2001. Soil fertility was amended with the application of 30 % potassic serpentine superphosphate (7.7 % P) @ 1 t/ha. Nitrogen was applied at the rate of 50-70 kg N/ha, 8 to 10 weeks after planting. The crops were irrigated (50 mm) four or five times during the season. Timing of irrigation was based on rainfall patterns. Weed control consisted of a pre-emergence application of diuron at 1.6 kg ai/ha (James and Follett, 2000), and glyphosate at 1 kg ai/ha applied soon after planting, followed by hand-weeding when needed. Tubers were hand dug in July and August after all the foliage had died. They were then washed and stored at 5°C. The number and weight of tubers on the soil surface (exposed) and buried (non-exposed) were recorded. The non-exposed tubers were graded into 12 size categories and their numbers and weights recorded. The grades were: Grade 1, tubers <3 g; 2, 3-5 g; 3, 5-10 g; 4, 10-20 g; 5, 20-30 g; 6, 30-40 g; 7, 40-50 g; 8, 50-60 g; 9, 60-70 g; 10, 70-80 g; 11, 80-90 g; 12, >90 g.

### Experiment 1 – accession comparison

The five ulluco accessions were compared using a randomised complete block design with four replicates. Due to limited supplies of planting material, the mean seed tuber weight of each accession varied (6.6, 10.6, 12.7, 4.8, 8.1 g respectively for IVY 1212, IVY 1213, IVY 1219, IVY 1223, and IVY 1225). The tubers were planted on 17 November 1999 in plots 4.2 m long consisting of two rows 400 mm apart in 1.5 m wide beds. There were 14 plants per row, giving a population of 4.4 plants/m2. The crop was sprayed with Monitor (methamidophos) at 1.5 l/ha on 9 February 2000 to control aphids and was harvested on 6 and 12 July 2000. All tubers were dug within two 1 m2 quadrats placed randomly within each plot, excluding guard areas of at least 500 mm long at either end of the plots.

### Experiment 2 – seed tuber size (a) Pukekohe

Three tuber sizes (6.5 g (range 5-8 g), 14.5 g (range 13-16 g) and 22.5 g (range 21-24 g)) of ulluco accession IVY 1219 (yellow tubers) were planted on 18 December 2000 in a randomised block trial with four replicates to assess the effects of seed tuber weight on subsequent tuber yield. The tubers were manually planted 30-40 mm deep, 300 mm apart and grown on mounds of 750 mm as for potatoes.

Individual plots contained four rows with nine plants and were fully guarded on all sides using IVY 1225 (red tubers) for contrast. A soil drench of Rizolex (tolclofos-methyl) 10 % dust at 8 g/2 l + Citowett (alkylaryl polyglycol ether) at 0.4 ml/$m^2$ was applied on 19 February 2001 to control an outbreak of Rolf's disease (*Athelia rolfsii).* Five plants from the inner two rows were harvested on 14 and 15 August 2001 and tuber weights recorded.

**Experiment 3 – seed tuber size (b) Lincoln**

The effect of three planting tuber sizes (< 25 mm, 25-50 mm and > 50 mm) on the yield of two accessions (IVY 1212, IVY 1219) was examined in a trial planted at the Crop and Food Research farm at Lincoln on 13 November 2000. Each accession was replicated twice in a split-plot design experiment, with tuber size as sub-plots. Each sub-plot contained two rows 5 m long. The soil was ridged in 900 mm rows with a potato ridger before planting. Tubers were planted at a depth of about 10-20 mm in the top of the ridges, at a spacing of 250 mm. Fertiliser applications were 46 kg/ha N, 60 kg/ha P and 60 kg K/ha before planting and 200 kg/ha N at crop emergence. Irrigation (200 mm) was applied throughout the season. Weed control was by inter-row cultivation and hand weeding. Four metres of both rows of each plot were harvested on 21 June 2001. Tubers were washed, graded into <15 mm, 15-25 mm and >25 mm diameter and weighed.

**Experiment 4 – planting depth**

Ulluco tubers were planted on 19 January 2001 at three depths (50, 100 and 200 mm) to assess the effect on tuber yield of the accessions, IVY 1212 and IVY 1213, using a randomised block design with four replicates. Individual plots were the same as in experiment 2 with datum plants fully guarded using accessions of different colours. The average weight of the seed tubers was 20 g. Ten datum plants were harvested and the tuber yields recorded on 22 and 23 August 2001.

**Data analyses**

Data were analysed by analysis of variance using the GENSTAT statistical package GenStat® Release 6.1 (2002).

## Results

**Experiment 1 - Evaluation of ulluco accessions**

The ulluco plants started to emerge about 2 weeks after planting with good plant establishment. The crop responded positively to rainfall or irrigation with rapid canopy growth, but was intolerant of hot dry summer conditions at Pukekohe, which caused leaf cupping and stunted growth. Plants grew most vigorously from mid-March when cooler conditions prevailed. They produced up to 1 m long trailing red or yellow (depending on tuber colour) succulent stems, with heart-shaped succulent leaves and a multitude of small star-shaped yellow flowers. The stems developed stolons at the nodes that enlarged into terminal tubers on or just below the soil surface. At harvest, 48 % of the tubers were on the soil surface with little variation between accessions and many damaged by slugs (Table 1). The red tuber accession, IVY 1225, gave the highest total tuber yield of 43 t/ha, which was significantly higher than the other four accessions (mean 32 t/ha). All accessions produced prolific numbers of very small tubers, ranging from 920/$m^2$ (IVY 1223) to 1110/$m^2$ (IVY 1225). Accession IVY 1225 had the highest mean tuber weight (3.8 g), but there was no significant difference between accessions. Combining data from all accessions, 53 % of the non-exposed tubers were <3 g and only 7 % > 10 g (Fig. 1). Only 1 % of all tubers weighed more than 20 g with the heaviest tuber weighing 57 g. Overall, individual plants in all accessions produced about 300 tubers weighing about 1 kg.

**Table 1. Tuber yields of five ulluco accessions grown on 1.5 m wide beds at Pukekohe in 1999-2000.**

| Ulluco accession (colour of tubers) | Mean tuber weight (g) | Total tuber number (no./m$^2$) | Total tuber yield (t/ha) | Exposed tuber yield ( % of total yield) |
|---|---|---|---|---|
| IVY 1212 (red) | 3.2 | 990 | 31 | 48 |
| IVY 1213 (red/yellow) | 3.2 | 970 | 30 | 58 |
| IVY 1219 (yellow) | 3.5 | 1000 | 35 | 43 |
| IVY 1223 (yellow/red) | 3.7 | 920 | 34 | 47 |
| IVY 1225 (red) | 3.8 | 1110 | 43 | 47 |
| LSD ($_{P<0.05}$) (df=5) | 0.53 | 150 | 6.3 | 16 |
| *P* value | 0.065 | 0.12 | 0.007 | 0.38 |

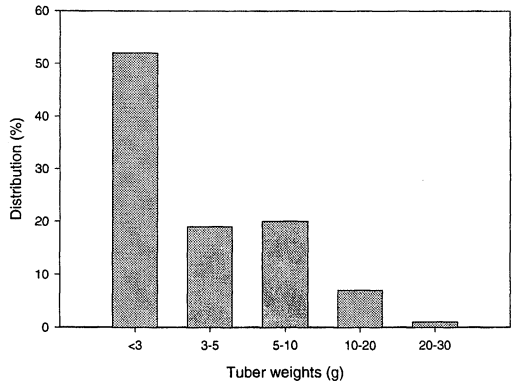


**Figure 1. Percent non-exposed tuber numbers in various size categories (mean of fiveaccessions).**

**Table 2. Effect of tuber weight at planting on tuber yield components of IVY 1219 at harvest.**

| Mean tuber weight (g) at planting | Mean tuber weight at harvest (g) | Total tuber numbers at harvest (no./m$^2$) | Total tuber weight (t/ha) | Exposed tuber yield ( % of total yield) |
|---|---|---|---|---|
| 6.5 | 4.7 | 480 | 23 | 55 |
| 14.5 | 5.2 | 530 | 27 | 55 |
| 22.5 | 5.2 | 540 | 28 | 53 |
| LSDP<0.05 (df=5) | 0.92 | 60 | 3.5 | 8.9 |
| P value | 0.40 | 0.10 | 0.023 | 0.69 |
| P value linear trend | 0.23 | 0.042 | 0.009 | 0.43 |

**Experiment 2 – seed tuber size trial**

Planted tubers heavier than 14.5 g gave the highest tuber yields, more tubers/m$^2$ and a higher mean tuber weight than the smallest planted tubers (6.5 g), but there was no difference in the percentage of exposed tubers produced by heavy and light tubers (Table 2).

Among the non-exposed tubers there was little difference between the three treatments in the distribution of tuber sizes at harvest. Overall, the largest number of tubers was recorded in the <3 g size category (mean 42 % of total weight), whilst 51 % of tubers weighed between 3 and 20 g (i.e. 16, 21

and 15 % respectively in the 3-5, 5-10 and 10-20 g size ranges). Only 4 % of tubers were in the 20-30 g size category, whilst 2.5 % were >30 g. The largest tuber weighed 94.9 g.

Rolf's disease attacked individual ulluco plants in this trial in early February 2001. The spread of the disease was controlled by a soil drench of Citowett and Rizolex, but infected plants wilted and died. Plant mortality overall was 12 % and was similar in all treatments.

This trial was brought to a premature end by seven consecutive air frosts (down to -4°C) between 21 and 27 May 2001, which killed the tops. The large seed tubers (>50 mm) produced significantly ($P<0.05$) higher total tuber yields than the small seed tubers (Table 3). This occurred because of an increase in tuber numbers rather than an increase in tuber size. Plants grown from large seed tubers established faster and had larger tops than those grown from small seed tubers. There was no significant difference in yield between accessions.

**Experiment 3 – seed tuber size trial (a) Lincoln**

**Table 3. Effect of seed tuber size on tuber yield, number and size at Lincoln.**

| Seed tuber diameter | Mean tuber weight (g) | Total tuber number (no/m$^2$) | Total tuber yield (t/ha) | Tuber size distribution ( % of weight) | | |
|---|---|---|---|---|---|---|
| | | | | <15 mm diameter | 15-25 mm diameter | >25 mm diameter |
| <25 mm | 2.02 | 140 | 2.72 | 20.5 | 67.2 | 12.3 |
| 25-50 mm | 2.08 | 194 | 4.10 | 15.0 | 71.4 | 13.6 |
| >50 mm | 2.04 | 267 | 5.48 | 16.8 | 70.6 | 12.6 |
| LSD $_{(P<0.05)}$(df=4) | (NS)[1] | 33.9 | 0.94 | (NS) | (NS) | (NS) |
| *P* value | *P*=0.953 | *P*<0.001 | *P*<0.001 | *P*=0.382 | *P*=0.186 | *P*=0.297 |

[1](NS) = Not significant.

**Table 4. Effect of planting depth on tuber yield components in IVY 1212 and IVY 1213 at harvest.**

| Planting depth (mm) | Mean tuber weight (g) | Total tuber number (no/m$^2$) | Total tuber yield (t/ha) | Exposed tuber yield ( % of total yield) |
|---|---|---|---|---|
| 50 | 6.1 | 330 | 20 | 29 |
| 100 | 6.4 | 320 | 21 | 24 |
| 200 | 6.9 | 280 | 19 | 18 |
| LSD$_{(P<0.05)}$ (df=14) | 0.74 | 35 | 3.5 | 4.6 |
| *P* value depth | 0.13 | 0.018 | 0.16 | <0.001 |
| *P* value accession | 0.75 | 0.33 | 0.77 | 0.41 |

**Experiment 4 – planting depth x ulluco accession**

Total tuber numbers and the percentage of exposed tubers decreased as the planting depth increased from 50 to 200 mm, but planting depth did not affect mean tuber weight and total tuber yield (Table 4). The distribution of tuber sizes was similar in all treatments with 28 % <3 g; 18 %, 3-5 g; 25 %, 5-10 g; 18 %, 10-20 g; 7 %, 20-30 g; and 4 % >30 g. The heaviest tuber weighed 83.4 g. There were no differences between the two accessions. Plant establishment in this trial was adversely affected by tuber rots caused by the fungal diseases *Fusarium oxysporum*, *Fusarium graminearum*, *Fusarium avenaceum* and *Colletotrichum coccodes*, and overall 22 % of all tubers failed to produce plants. The incidence of tuber rot was similar in all treatments.

## Discussion

This series of trials has shown that ulluco tubers can be produced successfully in New Zealand. However, the strong short-day requirement for tuberisation (Sperling and King, 1990) limits

ulluco's environmental adaptation to areas that allow it to tuberise after the March equinox without being killed by frost. Ulluco is reported in the overseas literature as being frost resistant (National Research Council, 1989), but in our studies ulluco was killed by a series of seven consecutive air frosts in Cantebury between 21 and 27 May 2001. At the lowest air temperature on 26 May (-4.1°C) the grass minimum temperature was -9.1°C. In some years such temperatures may occur in April, which would provide a very short period for the tubers to bulk up. Nevertheless, ulluco occupies the same ecological zone in the Andes as oca — a short-day plant that is successfully grown in cool regions of New Zealand's North and South Islands. This suggests that ulluco should be able to occupy the same niche in New Zealand. Observational plantings of ulluco in Southland alongside an oca crop support this supposition (G. Parmenter, pers. comm.).

The ulluco accessions used in this work were deliberately collected from the southern Andean limits of ulluco production (Grau and Halloy, 1994) in the expectation that they would be more day-length neutral. This region had previously been highlighted as an area where greater variation in day-length sensitivity was likely to occur (National Research Council, 1989). Two of the ulluco clones harvested at Pukekohe in early April 2000 showed vestigial tuber production with well developed tubers apparent one month later, highlighting the short-day requirement (unpublished results). The other three clones were not monitored. A much larger number of landraces are needed to adequately test for any day length variation as a forerunner to the development of a cultivar that produces tubers under long-day conditions.

Ulluco grows best under cool, moist conditions (National Research Council, 1989). Under hot summer conditions at Pukekohe it exhibited leaf stress symptoms, including leaf cupping, chlorosis and slow growth in spite of regular irrigation. When cooler autumn temperatures arrived, ulluco grew well under Pukekohe conditions and successfully tuberised. Ulluco would be more suited to regions of New Zealand with cooler summer conditions, but this must be balanced by the ability to successfully grow the crop into late autumn to get good tuber production, which is dependent on a period free from severe frosts. Southern coastal regions with cool summers and light frosts in autumn should provide appropriate conditions for ulluco production.

The tuber yield of 30-43 t/ha from the five accessions at Pukekohe was similar to that recorded under fertilised conditions in South America (Pietila and Jokela, 1988), but the high percentage of tubers that formed on the soil surface was unexpected. Fewer surface tubers were observed at the cooler Canterbury site and in the later planting at Pukekohe, and fewer tubers were formed on the soil surface after deeper planting. Surface tubers may be the result of growing ulluco in a warm humid environment. Developing growing systems with regular crop moulding may overcome this problem. Surface tubers are prone to damage by slugs and snails and they lose their glossy, bright appearance. Red tubers darken under sunlight and yellow tubers become green.

Ulluco formed prolific numbers of tubers in these trials. At Pukekohe the average number of tubers/plant was over 300 for the November plantings and over 1000/$m^2$ in one trial. The resultant tuber size in all trials was very small with the mean tuber weight at Pukekohe in the various trials ranging from 3.2 to 6.9 g whilst it was 2 g at Lincoln. The production of numerous small tubers may be the result of good herbage growth that allows a large number of sites to develop for tuber initiation under long-day conditions, followed by only a limited period of short days for the tubers to develop. Planting the seed tubers deeper, or using smaller tubers for planting in Canterbury, lessened the number of tubers formed but did not increase the average size of the tubers. Small tubers are difficult to harvest mechanically and high numbers left in the ground will grow the following spring, requiring control in subsequent crops.

Apart from the serious problem of virus infection, ulluco suffers few pests and diseases in South America (National Research Council, 1989; Arbizu and Tapia, 1994). Viruses were eliminated from the accessions introduced into New Zealand (Fletcher and Fletcher, 2001) and the crop has been free of leaf diseases. Under humid, hot summer conditions at Pukekohe some plants were killed by Rolf's disease, but its incidence was sporadic and restricted to only one trial. Tuber rotting (caused by the fungal pathogens *Fusarium* spp. and *Colletotrichum*) occurred in a second trial at Pukekohe and was probably aggravated by planting tubers into warm soil conditions in summer following a long period of cold storage. The ulluco crops were generally pest-free, although an aphid infestation occurred in one trial, and slugs and snails caused cosmetic damage to surface tubers. Our trials have shown that ulluco tubers can be successfully produced in New Zealand, but are undesirably small,

creating a significant barrier to mechanised production and highlighting the need to develop plant types with evenly sized tubers suitable for mechanical harvesting. Ulluco tubers are considered to have a slightly earthy taste that is often masked by other food flavours (Pietila and Jokela, 1988). A sensory evaluation of cooked ulluco tubers found that the tubers were only moderately, rather than highly acceptable (Busch *et al.*, 2000). The mild off-flavours are an undesirable trait, and selection and breeding to widen the culinary appeal of ulluco are necessary. Currently, the very small sample of ulluco germplasm in New Zealand is a limitation to developing new selections with evenly sized tubers and improved flavour. We suggest that further land-races should be imported to broaden the genetic base of ulluco and that development process should be continued.

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