



# **A Grower's Guide to Cultivating Chinese Waterchestnut in Australia**

**A report for the Rural Industries Research  
and Development Corporation**

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# Foreword

Chinese water chestnut is a traditional Asian vegetable used to garnish salads, soups and casseroles. While currently most water chestnuts consumed in Australia are imported as either frozen or canned products, there is now an increasing demand for the fresh product. This has created a new opportunity and a network of Australian water chestnut growers is developing.

The purpose of this growers' manual is to provide information to ensure that production quality and quantity are consistent with market demands. The manual addresses a range of issues identified by growers at an earlier workshop, including identification and characterisation of premium planting material, a number of issues on cultivation practices, postharvest storage, marketing and production costs and economic viability of the industry.

A key message is that attention to quality is needed not only in the production system but also in the harvesting, grading and storage process if water chestnuts are to reach the consumer in good condition.

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This report, a new addition to RIRDC's diverse range of over 500 research publications, forms part of our Asian Foods R&D program, which aims to provide an R&D program that supports industry in its drive to develop new products and markets and to gain competitive advantage through improving productivity in, and achieving price premiums for, Australian production..

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**Peter Core**

Managing Director

Rural Industries Research and Development Corporation

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# Introduction

Chinese waterchestnut is a traditional Asian vegetable used to garnish salads, soups or casseroles and has the redeeming features of being crunchy and sweet with a mild coconut flavour. Most Australians would have consumed waterchestnuts if they have ever eaten Asian stir-fry dishes, although few would recognise the fresh product, which at first glance resembles the European tree chestnut.

Currently, most waterchestnuts consumed in Australia are imported as either frozen or canned products. However, due to changing eating habits and greater awareness for food quality, there is increasing demand for fresh and high-quality foods. In recent years a network of Australian waterchestnut growers, the Australian Aquatic Vegetable Growers Network, has initiated an Australian industry to supply fresh corms to the Australian consumer, with a longer-term view to supply foreign markets in the Asian region. This industry has the potential to generate additional employment and income in rural areas through production, even at a small scale. However, various constraints currently restrict most cultivated lots to less than 0.4 hectares (ha) and these production areas must expand in order to be economically viable. Seasonality of harvest and lack of supply have also limited expansion of the industry.

A major reason for the relatively minor development of a waterchestnut industry has been the lack of research conducted on this crop. This has been especially true while trying to ensure that quality and quantity are consistent with market demands. Therefore, from 1996 to 2000, research was conducted in Queensland (Qld), New South Wales (NSW) and Victoria (Vic) funded by the Rural Industries Research & Development Corporation (RIRDC) on the most important issues identified by growers in a preceding workshop. These topics ranged from identification and characterisation of premium planting material to a number of issues on cultivation practices, postharvest storage, marketing and production costs and economic viability of the industry.

To the discerning consumer, the quality characteristics of a fresh Chinese water chestnut are corms with dormant sprouts, peel burgundy to black in colour, flesh bleach white, sweet with a sugar (°Brix) level greater than 8° and a mild presence of a coconut flavour.

In order to deliver these quality parameters consistently, it is important for growers to incorporate quality assurance programs into their production systems. It will be relatively easy for growers to focus on agronomic production systems and successfully produce the quality Chinese water chestnut; this after all should be the growers' area of expertise. However, corms must then go through a harvesting, grading and storage process, each of which can easily cause damage to the corm. The product reaching the consumer is generally in a much poorer condition than to when the corm was in the paddy just prior to harvest.

This booklet is intended to assist growers to produce a consistent quality product that will please the customer and still return a profit.

Growers can expect to achieve typical yields of 20 tons per hectare suitable for the fresh market with gross returns of approximately \$4,000 per ton. Net returns are quite variable, depending on production, harvesting and grading systems, but an experienced grower should expect to achieve a net return of \$1,000 per ton or more.

The Chinese water chestnut industry in Australia is in its infancy and potential growers should view commercial production as a speculative venture. The collective knowledge on how best to commercialise Chinese water chestnuts in Australia is gaining momentum and it is envisaged this booklet will assist in the formation of a viable new and emerging rural industry. The content is based on the research and development recently undertaken in Australia, and is presented herein on good faith that it will be used for

the purposes of improving Chinese waterchestnut production and marketing. Neither the authors nor RIRDC accept responsibility in any way to any person who relies in whole or in parts on the content of this booklet.

## **Background**

Chinese waterchestnut is an emergent, upright, aquatic sedge (a grass-like plant). As such it is grown under flooded conditions. Aboveground, the plant consists of green cylindrical stems with very reduced, almost invisible leaves. In addition to the roots, the belowground parts comprise two types of modified stems: rhizomes and corms. Rhizomes, or horizontally growing stems, run laterally under the soil surface from the parent (planted) corm, and variously either produce daughter plants or corms. The corms, the swollen tips of the underground stems, are the marketable part of the plant. Under long-daylength conditions (ie late spring and summer), daughter plants with green aboveground stems are formed when rhizome tips grow upwards. This causes the aboveground foliage or canopy to increase in size to approximately 0.5 square metres per plant. Under short-daylength conditions (ie during autumn and winter), corms are formed at the tips of rhizomes. Stems reach 1.5 m height and die off after the first frost or at 6-7 months after planting, depending on climatic conditions. Corms can then be harvested. Plants are inundated with water for most of the growing period to optimise crop yield.

# Chapter 1 - Planting material and the environment

As for all crops, the yield and quality of Australian-grown Chinese waterchestnuts depend on three major factors: (1) the genetic information of plants (genotype), (2) the temperature and natural day length (environmental conditions) and (3) cultivation management (eg planting time and fertiliser applications).

## 1.1 Genetics of cultivated Chinese waterchestnuts

### 1.1.1. Genetic analysis

As a member of the family of sedges (*Cyperaceae*), Chinese waterchestnut (*Eleocharis dulcis* (Burm. f.) Hensch) is native to the Asia region including northern Australia and appeared in cultivated form in China and India some two thousand years ago. Currently widely cultivated, extending from China, Japan, India, Central Africa, southern United States, to the Philippines, Malaysia, Hawaii and other Pacific Islands, waterchestnut was known to Australian indigenous communities before European colonisation and given names such as ‘Woogarou’.

In China, several distinct varieties of Chinese waterchestnut are known to exist. These varieties differ in plant and corm size, corm appearance, texture and taste, tolerance to extremes of growing temperature and disease, duration of growth cycle, and yield. The differences in appearance and quality are only slight since identification of varieties in China is made through corm appearance. Varieties with a short terminal bud and concave corm navel apparently contain more water and sugar and less starch and fibre, so the flesh is tender and sweet. In contrast, varieties with a long terminal bud and flat corm bottom are small, with more starch and fibre and not suitable for eating raw. In practice, these criteria are subject to the influence of environmental factors and cultivation management as well as individual interpretation.

Cultivated Chinese waterchestnut was introduced into Australia in the 1980s. Since then, various introductions have been made from China, Taiwan, Thailand, Singapore and the USA. The imported waterchestnuts were mainly brought from overseas markets with unknown origin and cultivar names. The types currently available in Australia are generally of the sweeter type, with less starch and fibre.

To identify whether differences in yield and quality found across Australia reflect differences in the genetic characteristics or simply differences in environmental factors and cultivation management, genetic relationships of Chinese waterchestnut growing in Australia were investigated with molecular methods. A total of thirteen cultivated Chinese waterchestnut samples, each with a different source of seed corm, were provided by Australian producers, and three overseas samples from Taiwan, China and the USA were also investigated.

The result of this analysis put the sample from Taiwan into a distinct group. Only the other two overseas samples and a sample from Coffs Harbour (NSW) were distinct from all other samples. The remainder were very closely related.

This genetic analysis indicates that most or all planting materials in Australia are very closely related and more or less the same genotype. Therefore, the currently most popular planting materials in Australia (eg ‘Hon Matai’, ‘Matai Supreme’, ‘Singapore’ and ‘Thailand’) should be called ‘origins’ rather than ‘varieties’. The dissimilarity of the cultivars from Taiwan (cv. Shu-Lin), Hangzhou (cv. Da Hong Pao),

New South Wales (unknown variety) and the USA (unknown variety), and possibly many other varieties not tested in this analysis offers the opportunity for genetic improvement.

### 1.1.2 Origins

To test whether the genetic similarity of waterchestnut origins would result in comparable performance under commercial field conditions, four materials ('Hon Matai', 'Matai Supreme', 'Singapore' and 'Shu-Lin') were tested across three Australian states (New South Wales, Queensland and Victoria).

There were significant differences in yield between origins with Hon Matai at the lower end and Matai Supreme at the upper (Table 1). However, these differences were mainly due to the non-performance of Hon Matai in 1998 in New South Wales (many rotten corms). All quality parameters were near identical across origins. The genetic differences between Shu-Lin, the variety recently imported from Taiwan, and the other origins were reflected in yield and quality parameters: the Shu-Lin variety yielded less and weight per corm was lower but sweetness was much higher than that for the other origins.

**Table 1. Yield and quality of Chinese waterchestnut origins in Australia**

Origin	Marketable yield (ton per hectare)	Corm weight (g per corm)	Sweetness <sup>a</sup> (°Brix)
Hon Matai	8.8	12.1	8.6
Matai Supreme	12.0	12.9	8.6
Singapore	10.3	12.4	8.5
Shu-Lin	4.6	11.4	9.4

<sup>a</sup> total soluble solids (TSS)

These results confirm that the origins currently in commercial use in Australia are genetically very similar. Shu-Lin offers the opportunity not to replace but through genetic improvement to enhance crunchiness and sweetness in local origins of waterchestnut.

## 1.2 Site effects on seed production and cultivation

It is quite logical that the growing conditions at the cultivation site will exert significant effects on crop growth and consequently yield and quality in waterchestnut. The waterchestnut corm is not only the commercial product but also the planting material for this crop. This contrasts to some other vegetatively propagated crops (eg by stem cuttings, such as sweet potato) and crops propagated by seed. To some extent, waterchestnut physiology resembles that of tuber crops such as the potato, in which good crop growth depends to a large extent on good quality seed tubers. Characteristics of corms, which consumers favour, may not be ideal for corms used as planting material. For example, a big potato tuber may be a good market tuber but not a good seed tuber. Quality of such planting material may be more dependent upon quality characteristics such as dry matter content, as in seed tubers of potatoes, rather than on the genetic information, stored within them.

### 1.2.1 Seed propagation site

Unpublished reports from China suggest that waterchestnut corms used as planting material for commercial production in the south is produced in the cooler north. Successful commercial production of potatoes in warm and hot tropical climates depends upon the use of good quality seed tubers as planting

material. This is usually reflected in a high dry matter content and absence of viruses in seed tubers. When such seed tubers are produced in hot climates, their dry matter content is usually low and virus content high and these negatively affect vigour, growth and eventually yields in potato. Therefore, it is recommended that potato seed tubers be produced under cooler conditions, for example in tropical highlands. Chinese waterchestnut may, therefore, respond favourably as for potato to cooler conditions during production of corms for plantings, and such a scheme would appear suitable for waterchestnut in Australia.

With the range of climates afforded in eastern Australia, the benefits of producing corms as planting material under cold conditions were investigated. Production of Chinese waterchestnut was monitored in three cultivation sites: (1) Mackay (Qld), (2) Burrupine (central coast NSW) and (3) Dhurringile (northern Vic). The analysis of seed-corm material produced in the three propagation sites indicated that with increasing latitude (ie cooler region), corm size decreased but sugar content (ie sweetness) increased. Seed corms from Queensland were big but low in sugar, seed corms from New South Wales were intermediate in size and sugar and seed corms from Victoria were small but high in sugar content.

Although the site of production of seed corms affected the size and sweetness of seed corms, the effect of planting seed corms of varying quality on yield and quality of Chinese waterchestnut in Australia was only slight. To maximise marketable yield and weight per corm, there was a trend that the preferred seed-corm production sites should be in southern Australia. This indicates that yield and quality parameters of commercially-produced waterchestnut are improved by seed corms, which are comparably high in sugar. It is apparent that it is not the greater total amount of energy (in the form of starch) in bigger corms from Queensland that promotes growth, yield and quality of waterchestnut. Rather it is the greater amount of quickly available energy (in the form of sugar) in corms from southern Australia and particularly Victoria that promotes early growth. Therefore, seed corms for commercial production of Chinese waterchestnut should be produced in the very south of Australia, and possibly even in Tasmania. Common production practice in the more southern parts of China also reinforces the suggestion to isolate areas for seed-corm multiplication from waterchestnut production areas. This should prevent possible degenerative decline (ie loss of potential to result in good yield and quality) in waterchestnut that would result from repeatedly sourcing seed corms from the previous year's crop in warm growing conditions.

### 1.2.2 Cultivation site

The effects of cultivation site on waterchestnut yield and quality are much more pronounced than those of seed-corm propagation site. Corms produced in the tropical north of Australia (Qld) are of greater size and weight and therefore yields are high but their sweetness is low (Table 2).

**Table 2. Average yield and quality of Chinese waterchestnut in Australia as affected by production site during 1998 and 1999**

Propagation site	Marketable yield (ton per hectare)	Corm weight (g per corm)	Sweetness (°Brix)
Qld	22.9	16.1	7.1
NSW	13.4	11.4	8.4
Vic	4.7	8.8	9.5

Due to improved agronomic practices implemented in Victoria since this trial, average yields are now more comparable across sites.

Our research to date shows that while cooler temperatures favour sweetness of corms, the shorter growing season in southern parts of Australia prevents corms developing to match the greater size achieved in the tropics of Australia, although corms are still within optimal marketable size. If large corms alone are desired by consumers, waterchestnuts from northern Australia may be preferable. However, most consumers favour a set of quality parameters including sweetness, mild coconut flavour as well as a large corm size, so corms from 'northern' temperate Australia (ie NSW) are premium.

# Chapter 2 - Cultivation and harvest

Chinese waterchestnut is cultivated in a paddy culture system similar to rice. It is an aquatic plant that can tolerate anaerobic conditions including stagnant water.

## 2.1 Paddy design and construction

Paddy design is an integral component in optimising the efficiency of crop management, including the manipulation of water depth to control soil temperature, weed establishment, crop vigour, and ensuring compatibility with the weeding, fertilising, predator protection and chosen harvesting technique.

Similar to cultivation of rice, size of paddies depends to some extent on the topography of the land. Larger land areas with only slight slope can accommodate greater-sized paddies whereas steeper-sloped land must be divided into a greater number of smaller paddies in which slope can be more easily managed.

### 2.1.1 Creating a level paddy

Levelling is required to keep all parts of the paddy inundated. To assist in uniform crop development, it is also desirable to have no more than 10 cm-elevation difference through out the paddy. Minor levelling in small paddies (less than 250 square metres) can be achieved by partially flooding the paddy so half the surface area is inundated and then manually moving the soil with a rake, from the high locations into the low areas. Another effective technique suitable for areas less than say, 1,500 square metres is ploughing and rotary-tilling towards the lower-elevated areas to move soil towards that direction. Although this next step may be new to Australian farmers, the soil can then be levelled with a self-propelled rotary-till, when the field is in an inundated condition ('puddling'). This is a standard practice in cultivation of rice and aquatic crops in many Asian countries. Puddling is not only effective in moving the inundated and loose soil to level the paddy, but also in creating a plough pan which is a relatively impermeable soil layer that reduces vertical water seepage.

For growers who wish to cultivate in larger paddies, it is advisable to survey and design the paddies and use laser-guided precision earthmoving machinery, such as scrapers, to achieve uniform design slope within 100 mm tolerances. A slight slope (1:1,000) and/or a drainage sump will facilitate draining the paddy before harvest if a dry-harvest technique is used in wet-winter climates (eg southern Australia).

### 2.1.2 Paddy design to accommodate harvester

Besides providing inundation of the whole area, paddy design must accommodate access requirements for crop management (eg fertilising and weeding) and particularly harvesting. Mainly for these reasons, most waterchestnut paddies in Australia are rectangular rather than square in shape. Disadvantages of rectangular-shaped paddies are that they have relatively longer banks per paddy area that increases labour for their construction, increases water loss through them and increases edge effects and potential invasion of weeds. The length of paddies in Australia is variable and currently most are up to 100 metres (m).

Paddy design should be influenced by the adopted harvesting technique. The suction type harvester requires at least 50 cm water depth for the machine to become buoyant so paddy banks need to be approximately 1m high. If trench type paddies are adopted, then the paddy will need to be excavated sufficiently to accommodate this water depth. If harvesting equipment is pulled by a tractor, (eg modified potato harvester), then provision for access into the paddy as well as sufficient turning area at each end

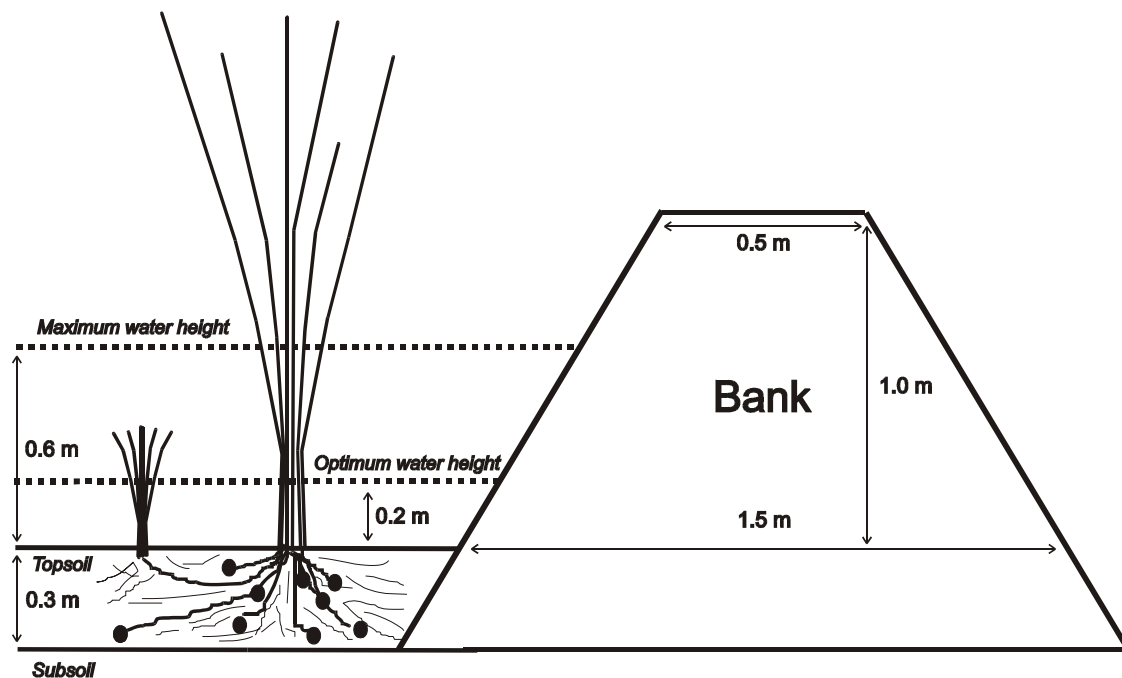
will be required. To minimise soil disturbance caused by a towing vehicle, the selection of broad tyres or better still tracked belts such as those on bulldozers are desirable.

For crop management practices during the growing season, a paddy width of less than 5 m allows good access from 'land' either side without requiring (inconvenient) physical entry to the paddy. If the paddy is designed for mechanical harvest, width depends largely on the size of the harvesting equipment. When suction-type harvesting equipment is used, any paddy width is possible, although some growers prefer a narrow width (*c.* 2-3 m) so harvesting can be done in one sweep without requiring back tracking which may inadvertently miss or redo a section. Excavation-type harvesters, which reach into the paddy, require access along the paddy length. Paddy width depends on the reach of the excavator and accessibility of the paddy. Reach is typically 7.5 m and this should be the paddy width if there is access only along one side (length-wise), and twice that width if there is access on both sides. The bigger the equipment, the more space must be provided between paddies for harvesting and at the end of paddies for turning.

### **2.1.3 Paddy bank design**

Banks that surround the paddy must be designed to hold the required volume of water and withstand seepage and damage from burrowing yabbies. Suitable dimensions mean having at least 1.5 m width at the base, 1 m height from the paddy floor and 0.5 m width at the crest. Broader banks (up to 8 m wide) are required if the harvester must travel on top of the bank. Constructing these banks can be done with a tractor-mounted blade coupled with a front-end loader to gain the final height requirements. This technique is rather slow so it is best suited to smaller paddies up to approximately 1,500 per square metre. A road grader is an efficient and cost-effective machine when forming banks for larger paddies. The bank should be progressively compacted during construction so as to reduce the likelihood of seepage. Prior to constructing the bank, top soil should be removed from the bank foundation area and then cultivated so the base of the bank is well sealed into the soil. Simply constructing the bank over topsoil will most likely result in bank failure. The depth of excavation required to expose the subsoil for the bank foundation should be added to the 1 metre bank height. If no suitable clay is available, lining of banks with (UV-proof) plastic materials can be helpful to reduce water loss through the banks and can also reduce weed encroachment. Depending on the traffic along the bank, the plastic should last for at least 5 years. A 50-70 cm wide and deep trench adjacent and internal to the banks can also assist in preventing weed encroachment from the bank to the paddy. Special attention is required when flooding the paddy for the first time to minimise the risk of a bank blow-out. The paddy should be filled slowly (6-12 hours) to 50% capacity and then drained to 10-20 cm depth before being refilled to the required depth (according to method of planting).

Figure 1 presents an ideal cross-section of a Chinese waterchestnut paddy. A wider bank will be necessary if excavators are to travel along the length of the bank during harvest. Keeping the height of the bank to 1 metre above the base of the paddy provides free board that can minimise irrigation frequencies and provides sufficient depth for a floating suction type harvester (if applicable).



**Figure 1. Cross section of a Chinese waterchestnut paddy**

### **2.1.4 Growth media**

Chinese waterchestnut apparently tolerates a wide range of soil types. Literature and Australian anecdotes provide some evidence that larger corms are formed in heavier (clay) soils compared with those on lighter (sandy) soil types. Under natural conditions, heavy soils are best suited to Chinese waterchestnut due to retention of soil moisture. There must be a distinction between topsoil in which waterchestnut produces roots and corms and the subsoil beneath. In the presence of a compact subsoil, waterchestnut may grow as well in a sandy as in a clay topsoil. Nutrient availability may also affect observed differences in corm growth across different soils: clay having a much greater capacity to hold (and release) nutrients compared to sand. The optimum depth of topsoil for Chinese waterchestnut production is untested, however most corms are found at a depth of only 15-30 cm, even when there is greater depth of topsoil. Whilst it is unclear if a shallower topsoil will reduce crop yield, there are some growers who advocate shallower topsoil so as to reduce the soil volume to be processed with a suction-type harvester.

Under Australian conditions, virtually any type of sub- and topsoil can be managed, and would be suitable for production of Chinese waterchestnut. A sandy-loam topsoil with heavy-clay subsoil is probably ideal and can be used without modifications.

If the topsoil is too heavy, particularly for mechanised harvest operations, its structure can be improved, eg by amendments of sand, or it may be completely replaced. Several Australian growers have either replaced the topsoil in their paddies with sand or simply placed sand on top of the existing soil along with raised banks, with a view to facilitate waterchestnut harvest using the dry-sieve type harvesting system. This has created problems with nutrient management. It is apparent that the nutrient-exchange capacity of coarse sand is negligible. If such a system is to be employed, close attention should be paid to nutrient management (macro- and micronutrients) and a fine 'packing sand' should be selected. This does not cause the pitting of the corm surface associated with coarser sand. Other aspects to be considered when

choosing sand include the negative environmental impacts of sand harvesting, and the fact that the suction-type harvester does not lift the heavier sand particles as efficiently as it lifts finer clay particles that are easily placed in suspension.

If the subsoil contains less than 60% clay then seepage rates are likely to be unacceptably high. Intensive rotary-tilling (hoeing) can create a 'plough-pan' to help seal the paddy. In Australia, many rice growers seal their paddies with heavy Sheepfoot rollers, and in many Asian countries rotary tillers are used to glaze the top of the subsoil to achieve a similar effect.

Another technique to reduce paddy seepage is the use of a compacted clay or a plastic film liner.

### **2.1.5 Plastic liners**

Due to restrictions in dimensions of plastic materials set by industrial standards, the most convenient way of introducing plastic lining to waterchestnut production is to design paddies according to the width of the plastic liner. If this is not possible or if the lining is introduced to previously-constructed paddies, then special attention to sealing all joins is required (consult a plastics distributor for compatible sealing material). Alternatively, overlapping folds of sheets will reduce leakage.

If topsoil is to be retained as the growing media, then it must be removed and the liner placed in the bed of the paddy and then the top soil repositioned over the liner. As the liner is prone to puncturing, no traffic should come into direct contact with the liner. Soil, which is to be placed over the liner, is positioned from the edge of the paddy and pushed towards the centre. If vehicular access is required into the paddy, then it must be over the sections where the soil has already been placed. Similarly, imported sand or soil should be applied over the liner in this manner, although the plastic liner can be placed on top of the natural surface profile and over the already-constructed banks and then covered with the sand or soil, to a depth of 15 – 30 cm.

For backyard garden enthusiasts, small paddies can be constructed using plastic lined ditches. Alternatively, any water-tight containers such as cherry barrels or 220 litre (44 gallon) drums cut in half may be used.

### **2.1.6 Clay liners**

A clay liner could be used to seal the bed and banks of a paddy in a similar manner to channel and dam clay-lining. As with plastic, the clay liner can be punctured if the soil layer is disturbed. To reduce this risk, it is advisable to apply a thicker layer of clay than is required to simply seal the paddy so as to off-set any soil loss from accidental disturbance. The depth of clay required will vary depending on the nature of the soil. However, as a guiding principle the clay layer should be at least a depth of 30 cm, compacted with either a vibrating or Sheep's foot roller, or several passes with heavy machinery such as tractor or scraper under moist conditions. It is desirable to receive technical expertise on clay selection at the optimum moisture level and installed at the appropriate compaction. Failure to adopt a thorough approach with a clay installation will most likely result in an ineffective liner.

Mechanical field operations must be adapted to the lining (if any) of waterchestnut paddies, so as not to puncture the material. In general, the suction-type harvester is better suited for paddies with liners due to its relatively gentle mechanism compared to excavation and sieve type harvesting systems. With careful handling, the plastic liner should last for at least five years, and the clay liner indefinitely depending on the amount of traffic in the paddy and the chosen harvesting technique.

### 2.1.7 Soil preparation for planting corms or seedlings

Both techniques of direct planting and transplanting of seedlings require preparation of the paddy. Due to its big ‘seed’ size, paddies for waterchestnut cultivation do not require a fine seedbed customary for small-seeded crops. If required, bigger clods can be broken down to a clod size of approximately 5 cm by ploughing the paddy. Additional cultivation may be required if there is an existing pasture that has an established root system and leaf mat. With or without preceding ploughing, the paddy should be rotary-tilled to a depth of at least 20 cm. If a plastic liner is used, then it is desirable to select a friable growing media that does not need to be rotary tilled. Alternatively, provision of at least 40 cm depth of soil can reduce the risk of damaging the plastic lining, although this will increase the volume of soil to be processed during harvest. Paddy preparation through puddling (rotary-tilling the field in an inundated condition) destroys soil structure, and is effective in forming an impermeable layer at the depth of the tilling, so this will reduce water seepage from the paddy. If cultivation were to be undertaken in dry conditions, then inundation should follow soon after to prevent emergence of (non-aquatic) weeds. When moist cultivated soil is exposed to air, then rapid weed establishment will occur, whereas if the soil is inundated, fewer weeds will become established. Planting corms or transplanting seedlings should also follow within a few days after paddy preparation so as to minimise the likelihood of weeds getting a head start on the crop.

## 2.2 Planting material

A Chinese waterchestnut crop can be established by;

- regrowth of corms from the previous year’s planting (‘ratooning’),
- direct planting of corms,
- transplanting of nursery-raised ‘seedlings’.

Since the planting material is actually a corm and not a seed, the young plants are not real ‘seedlings’; they are vegetative parts of the parent plant – a type of clone. This means that all seedlings from the one parent (ie one origin) will theoretically have the same genetic composition.

### *Corm selection for planting*

It was shown (Section 1.2.1) that the preferred corms for planting are those, which are high in sugars as they have energy quickly available for sprouting. By storing seed corms at low temperature (eg at 4°C for 4 months), their sugar content can be maximised (Chapter 3). Alternatively, seeds could be sourced from cooler climates. Seed corms stored at lower temperatures (0°C) have displayed chilling injury and grower observations suggest seed viability is also adversely affected. The advantage in selecting larger corms is the greater potential reserve of energy and nutrients available for the seedling. This advantage of large corm size and sweetness is only extended over a short period (perhaps 1-2 months) by which time the root system and the canopy are sufficiently developed to absorb nutrients and produce photosynthates, and thereby lessen the dependency on the seed corm as the source of energy and nutrients.

### *Ratooning*

Although requiring no labour for paddy preparation and planting, establishing Chinese waterchestnut by regrowth of corms from the previous year’s planting cannot be recommended. If the previous year’s crop had been harvested, then the population of emerging new plants from those few remaining un-harvested corms and the final yield would be too low. If the previous year’s crop had not been harvested, plant density would be too high (c. 100 plants per square metre) and result in a yield of large numbers of corms (high yield) of small size (weight) and low sweetness.

### *Direct corm planting*

Direct planting of seed corms into the paddy has labour-saving advantages over the more intensive method of using seedling transplants. However, offsetting this, it has been found that in the cooler temperatures of temperate southern Australia direct-planted corms develop slower during the first two months compared to nursery-raised seedlings. Weed competition can become a critical management issue with a slow developing crop. Other complications include dealing with non-sprouting corms, which need to be replaced, (although this is seldom a problem due to very high corm viability rates) and damage by pests (eg water fowls). On the other hand, directly planted corms may have an advantage over transplants raised in a greenhouse since they do not experience “transplanting shock” (ie where plants must acclimatise to field conditions), nor do they experience root damage from handling during the transplanting procedure.

With direct planting, corms are planted by hand into the prepared paddy at 2-5 corms per square metre at a soil depth of 2–3 cm. As with the effects of ‘ratooning’, higher planting densities tend to increase total yields through greater numbers of corms but corm-size will be smaller. Lower planting densities have the potential to produce bigger corms, but paddies are more prone to weed infestation because canopy closure (ie cover over the soil by green stems) will take longer. If weeds are a problem, hand-removal until the canopy has a 75% closure appears effective. Aquatic and waterlogging tolerant weeds become more prevalent with each successive season as a weed seed bank builds up within the paddy. Leaving a paddy fallow once every 4-5 seasons will help contain weed populations and help break the life cycle of possible crop pests and diseases. During this fallow period it is beneficial to provide 1-2 short irrigations during the summer period to wet up the soil profile to stimulate weed seed germination, only to then have them dry out and die. This will further reduce the weed seed bank.

### **2.2.1 Nursery-grown seedling transplants**

The cost for materials and labour to propagate Chinese waterchestnut seedlings in a nursery will most likely be far less than the inputs required to maintain paddies for 2-3 months with sown corms. However, the higher costs associated with transplanting to some extent outweigh the transplanting advantage. Seedlings are raised either in plant pots, netted trays, or loosely scattered in 10 kg fruit boxes, or as bare rooted field grown stock. One grower even scatters corms over a prepared and flooded out-door seed bed to produce seedlings for transplanting. Growth rates in semitropical regions (outside) are rapid for seedlings to reach transplantable size, (3-4 weeks) whereas in temperate regions growth of seedlings even under plastic is slower (2-3 months).

Corms can be planted in trays (c. 2 cm deep and 2 cm apart) with the shoot end facing upwards. The placement of corms and orientation of the apical shoot is not absolutely critical, especially if corms have shoots less than 10 mm.

Corms sown loosely into a tray/box will tend to form a dense interwoven root mass, which must be either teased out or cut at transplanting time. This root disturbance will induce more transplanting shock compared to seedlings raised individually in pots, although this disturbance can be minimised by having less corms in the box or by transplanting at an earlier age. This propagation technique is simple and quick and cheap to set up. Alternatively, corms can be sown individually into pots to minimise root disturbance at transplanting and, of special importance in cooler climates, to enable more advanced seedlings to be transplanted into the field. The choice of plant pot size will influence how long the seedlings remain in the hothouse before being transplanted into the field. If a pot size of 50 mm wide x 150 mm deep is chosen (standard tree pot) then seedlings can stay in the hothouse for 2-3 months. If smaller pots such as the standard vegetable ‘speedling’ (25 mm wide x 50 mm deep) are chosen, then plants will be ready for

transplanting at 2 months, although these plants will have much smaller root systems and less stem growth.

Whilst the larger pot size provides greater flexibility in producing a more advanced seedling, there are more labour and material costs (hothouse space, potting media, and pots) compared to the seedling system. On the other hand, the nursery irrigation system becomes more critical to manage with seedlings as there is less water holding capacity in the smaller plant pots.

The potting media should be friable with good water-holding capacity (if pots/trays are free draining) and should preferably be sterilised to reduce both soil-borne disease and weed-seed contamination. Hand-weeding seedlings is time consuming and whilst granulated pre-emergent herbicides are used in the nursery industry for plant pot weed control, there are no products registered for Chinese waterchestnut production. Seedlings can be either irrigated with sprinklers if in free draining pots, or be inundated in larger-sized containers or boxes (eg polystyrene fruit boxes). These hold a larger amount of water to save irrigation cycles, and protect seedlings against low temperatures in cool climates. These boxes will require a plastic liner to hold water. There is some evidence to suggest that seedlings should preferably be inundated rather than put in free-draining pots during the seedling-raising period.

### **2.2.2 Field grown transplants**

Bare-rooted seedlings raised in the field before transplanting is probably the least labour intensive seedling-raising technique. A temporary plastic enclosure can be erected over the seed-bed to increase soil and air temperatures and humidity levels if necessary. This temporary hothouse technique is often used by early season strawberry producers and can simply consist of looped wire pushed into the soil to form the frame for an enclosing sheet of plastic. The plastic edges are buried with soil to secure the structure. The size of this structure is arbitrary, although it does not require personal access so the height need only be 30-60 cm. The plants are irrigated with either furrow irrigation or a pressurised sprinkler/dripper system. Corms can be sown at very high densities (2 cm apart at 4 cm depth) in well-cultivated light sandy soil for easy lifting after 2-3 months. Weed encroachment is normally minimal due to the high seedling density. Mulch will reduce weed establishment and assist in the retention of soil moisture, although it can also keep the soil cold so thin layers (2 cm) are desirable. Alternatively, the hothouse can be placed over a section of unharvested crop from the previous season (ratoon) and seedlings will emerge at a density of approximately 100 plants per square metre. Lifting these seedlings is a little more difficult as they are located at a depth of approximately 20 cm. Root disturbance also applies with field grown bare-rooted seedlings and this impact can be reduced if the soil is sandy and well cultivated.

## **2.3 Planting techniques**

There are several planting techniques available for Chinese waterchestnut seedlings, mostly adapted from forestry or vegetable production systems. Seedlings can be planted by pushing the root ball into spongy cultivated inundated soil. Accelerated planting rates are achieved by using a specialised (and widely used) tree-planting tool (Potti putki), an invention from Finland. This tool has a guiding tube (c. 1.5 m long) where plants are placed from a standing position and slide down to the moist soil where two blades at the tube base create a hole in the soil similar in size to the plant pot. Planting rates could be approximately 2,000 seedlings per day. A tractor-mounted vegetable planter can become cost effective in moist soil when planting more than approximately 4,000 plants (ie for 2,000 square metres or more) and can achieve planting rates of at least 5,000 plants per day.

### **2.3.1 Transplanting shock**

Transplanting seedlings into the paddy is usually very successful (more than 90% survive), although the degree of transplanting shock and subsequent growth setback (stem die-back) can vary depending on the condition of transplants, the handling technique and field conditions. The main concern with transplanting shock is the possible growth setback that may provide an opportunity for weed encroachment, which may then out-compete the emerging crop and prevent crop canopy closure.

‘Stem die-back’ is associated with injury to the root system, which is no longer capable of supplying sufficient water and nutrients to the plant. Subsequently, the plant becomes stressed and some or all of the foliage desiccates. This retards plant vigour for several weeks. To avoid this ‘transplanting shock’, nursery-raised seedlings should be removed from the igloo/hothouse approximately two weeks before transplanting and placed in full sunlight where the lower humidity will toughen the plants (‘hardened off’). If this is not possible, approximately 50% of the total stem area should be pruned prior to transplanting so the plant is more likely to sustain this reduced foliage once root damage from transplanting has occurred.

### **2.3.2 Root acclimatisation to inundation**

Raising seedlings in water to a depth which covers the root system will stimulate the formation of a root morphology which is more succulent with greater root volume than found under free draining conditions. Root hairs are replaced with succulent roots, a characteristic of hydroponic cultivation.

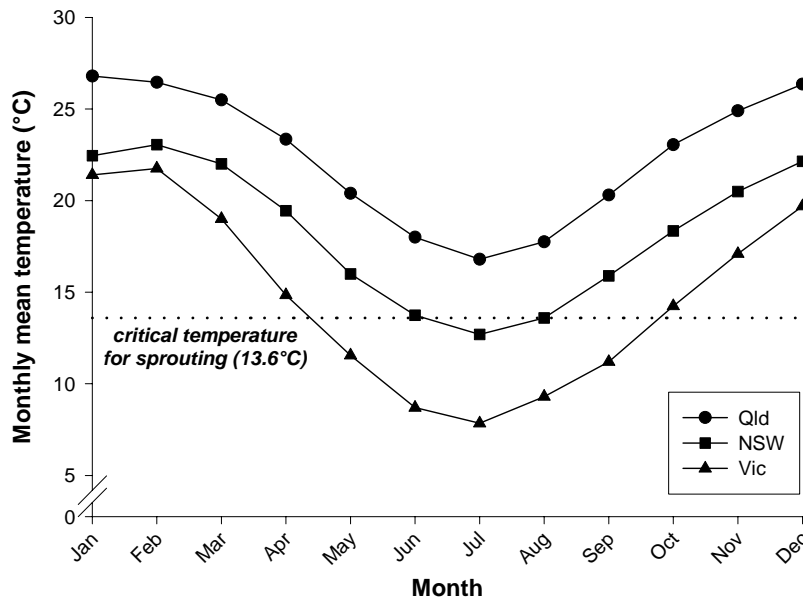
Although corm viability is usually around 90%, it is still advisable to propagate an extra 20% of plants above the required number to account for dead or non-vigorous seedlings.

### **2.3.3 Dates for planting corms**

Due to cooler temperature conditions, waterchestnut crops develop more slowly in the temperate than in the sub-tropical parts of Australia. Therefore, growers in the cooler south make full use of the growing season by planting corms as early as possible in spring. Typically, corms are planted in a hothouse in mid-August and transplanted in mid-October, once the frost period has passed. Alternatively, growers plant corms directly in late September-October into flooded paddies. These direct-planted corms are prone to minor frost damage resulting in ‘burnt’ stem tips if water depth is not sufficiently high (20 cm). Due to faster crop growth under sub-tropical conditions, planting date for corms is less critical and can occur from September to the end of November.

### **2.3.4 Temperatures for planting corms**

Seed corms are best planted when the minimum soil temperature is above 13.6°C, the critical temperature for induction of sprouting (see Chapter 3). In spring, this temperature is easily attained in sub-tropical regions and can also be attained in temperate regions under a hothouse. Field planting of corms or transplants in these temperate regions is delayed until at least October until the mean temperature exceeds 13.6°C. If temperatures fall below 13.6°C, seedling growth is virtually stopped. Figure 2 shows that monthly mean temperature in Qld is above the critical temperature all year, but below 13.6°C between June and August in NSW and in Vic from the end of April until October.



**Figure 2. Monthly mean temperatures in Queensland, New South Wales and Victoria and the critical temperature for sprouting in Chinese waterchestnut (Data for Mackay, Coffs Harbour and Tatura from the Bureau of Meteorology)**

For protection against soil and air temperatures below 13°C in cool regions, the paddy must be inundated to a depth of approximately 20 cm for the 1-2 months after transplanting seedlings into the field. Stems will be about 30-45 cm in height at transplanting time and rapid growth occurs in the following 2-3 months to achieve complete canopy closure. Paddy water depth is then lowered to approximately 10 cm and kept inundated until crop senescence.

However, in warmer regions, it is sufficient to keep the soil saturated at transplanting time and thereby save on water usage, but this method promotes growth and multiplication of weeds, unless the soil is covered in a mulch layer.

## 2.4 Irrigation

### 2.4.1 Irrigation techniques

Irrigating a Chinese waterchestnut paddy is fairly unsophisticated and the choice of methodology can be based on available infrastructure. The open-channel gravity-irrigation networks found in most irrigation districts will enable satisfactory delivery. Since paddies will usually only require low flows it may be preferable to install a 5 cm diameter polypropylene pipe rather than having to construct and maintain an open channel. However, a pipe will require more supply level or “head” to allow gravity flows and if this is insufficient then a pressurised system may be necessary. Whilst a pressurised delivery system will avoid complications associated with supply levels to the paddy, the grade within the paddy will still need exactly the same specifications as a gravity supply system.

It may be desirable to construct a small holding dam to ensure a steady supply of water. This is filled from the public channel system on a regular basis and then used to top up the paddies as required.

Irrigating a series of paddies with a terrace-like watering system with water flowing from higher to lower-elevated paddies appears to be unsatisfactory for optimum crop establishment. While there is no plausible

explanation for retarded growth of waterchestnut seedlings observed in the lower paddies, there may be effects of accumulation of excessive nutrients and/or pathogens, or even of allopathic compounds (ie naturally occurring growth retardants that leach from some plants). Therefore, an isolated compartmental system with separate water supply to each paddy appears more preferable.

These channel and paddy earth works are best constructed using survey plans and laser guided earth moving equipment so as to take the guess-work out of matching water levels with soil levels. Also many Australian municipalities require a planning permit for any earthworks and design plans must be submitted to obtain these permits.

## **2.4.2 Surface drainage**

The paddy design should include a facility to dispose of tail water from paddies into a sump and retain nutrient-laden water on the property. This may be necessary if the paddy over-flows from a rainfall event or if the paddy is required to be drained as part of the vermin control or harvest operations. This collected tail water may need to be stored and later reapplied into the paddies or applied on other crops or pasture. Some municipalities require irrigators to construct facilities to re-use irrigation tail water for production areas greater than 1 hectare.

## **2.4.3 Water management in paddies**

In contrast to rice, Chinese waterchestnut is an aquatic plant that can survive extended flooded conditions even when the complete canopy goes under water. One exception to this statement is when plants are grazed or cut so all stems are below the water line, then these plants will die. A water depth that partially covers the stems does not harm plants, although it does reduce photosynthesis by stems, especially if the water is muddy. If the soil is not inundated, plants will suffer, yields will decline and in extreme cases the plants will die. The optimum water depth for Chinese waterchestnut may be 10-20 cm. However, plant water demand varies during the growing season and is lower after transplanting when plants are small and much greater particularly during the peak of the growing season. Therefore, water height can safely be lower at the beginning of the growing season. This prevents newly planted corms or transplants from floating to the water surface before their root system is sufficiently established in the soil (2-3 weeks). Later in the season, the water should be kept at a higher level to avoid the frequent irrigation necessary to prevent drying out of the soil.

In temperate regions, greater water depth can buffer the cool conditions at the beginning and at the end of the growing season. Greater water depth is also an effective means for reducing non-aquatic weeds (Section 2.9). Drainage of paddies before the first frosts and ensuing stem senescence of waterchestnut can help advance maturity and bring forward the harvest, thereby reducing the number of over-mature or rotten corms during the harvest.

## **2.4.4 Manipulating soil temperature by water depth**

Chinese waterchestnut responds well to warm humid conditions as typically found in tropical and sub tropical regions. However, successful cultivation is not confined simply to these regions. Commercial crops are being successfully cultivated in temperate climates although more attention is required to offset the deleterious effects from lower temperatures during the active growth period.

Growers in temperate climates such as southern NSW and northern Victoria can extend the optimum growing period by using water to insulate soil and seedlings from low minimum temperatures including frosts in a similar manner to rice production. Soil, which is exposed to air, will have a faster rate of heat

loss during cold conditions compared to soil inundated by water, which has an average temperature warmer than the air. The insulating capacity of water will increase as the water depth increases. The challenge faced by the grower is to determine the critical water depth that will allow the sun to warm the water sufficiently. The minimum water temperature at the soil surface (ie the bottom of the ponded water) over a 24 hour period should be greater than the minimum air temperature over the same period. Further refinement in determining optimum water depth based on local conditions, will allow both the average and minimum water temperatures to be greater than the average and minimum air temperatures.

To optimise crop development in temperate zones it is desirable to establish a deeper water level (approximately 15-20 cm) early in the season so as to raise both the minimum and average soil temperatures. As the minimum air temperature increases above approximately 14°C, a shallower water depth is desirable (10 cm) to maximise both the water and soil temperature.

Water depth is less critical early in the season in tropical zones due to higher night temperatures.

## **2.5 Plant nutrition**

High productivity in all commercial crops, including waterchestnut, can only be achieved if plants are properly supplied with nutrients. The goal of plant nutrition is to supply quantities of required nutrients to support and promote optimum distribution of biomass to the plant parts that are of use to the grower. There are numerous examples of how deficient and excessive supply of individual nutrients, and of sub-optimal proportions between individual nutrients, negatively affects plant productivity.

In soilless culture, all nutrients have to be supplied from an external source. ‘Fertility’ of soils depends on their nutrient-supplying capacity and not on their nutrient content *per se*. The nutrient-supplying capacity is difficult to assess but we do know that ‘infertile’ soils need greater nutrient supplements than ‘fertile’ soils. Application rates of nutrients are simply calculated as the difference between crop demand and nutrient supply of the soil. Crop demand is basically the content of nutrients in the biomass of plants at harvest. For long-term sustainability at the production site, the total quantity of all nutrients that have been removed by harvesting plants or lost through paddy seepage should be replenished in one or other form to the soil. These can be introduced to the soil as inorganic or organic fertiliser, as green manure and/or in the form of mulch.

### **2.5.1 Nutrient content of plants**

Table 3 shows average concentrations of major and minor elements in Chinese waterchestnut. Data are presented for a crop grown in soilless culture with nutrient solution in Rockhampton. Seedlings were transplanted in the middle of December and plants harvested in the middle of June, thus the growth period was 6 months. The average diameter of corms harvested was 27 mm and sweetness was 8.2° Brix. Figures for the distribution of plant material into the corm, stem or root (biomass partitioning) and element contents are presented in Table 4.

**Table 3. Element concentrations in dry plant parts of Chinese waterchestnut**

Element		Plant part		
		Corm	Stem	Root
Nitrogen (N)	%	0.86	0.69	0.60
Phosphorous (P)	%	0.33	0.27	0.45
Potassium (K)	%	2.06	0.97	0.47
Carbon (C)	%	41.60	39.62	27.82
Aluminium (Al)	ppm	37.00	145.67	943.00
Boron (B)	ppm	5.67	31.67	31.67
Barium (Ba)	ppm	3.63	17.97	145.07
Calcium (Ca)	%	0.05	0.86	0.78
Cobalt (Co)	ppm	0.70	1.23	50.53
Chromium (Cr)	ppm	3.73	18.27	318.67
Copper Cu)	ppm	4.43	4.07	31.30
Iron (Fe)	ppm	110.33	278.00	15678.00
Magnesium (Mg)	%	0.08	0.31	0.12
Manganese (Mn)	ppm	9.00	358.00	334.33
Sodium (Na)	%	0.06	0.89	0.48
Nickel (Ni)	ppm	5.90	12.23	216.73
Lead (Pb)	ppm	<3	<3	24.67
Sulphur (S)	%	0.22	0.60	0.44
Zinc (Zn)	ppm	14.67	18.33	38.00

About one-quarter of the total biomass (ie the dry weight) of 12 tons per hectare is allocated to corms and the rest to stems and roots (Table 4). The total contents of N, P and K in the biomass are 213:104:372 kg per hectare N:P:K, thus the N:P:K uptake ratio was 1.00:0.50:1.75. Other elements that are required in quantity were Ca, Fe, Na, S and Mg. These figures can be used as a fertiliser recommendation for Chinese waterchestnut in soilless culture under climatic conditions similar to Rockhampton. Although there may be slight variations in plant nutrient requirements in other regions, these fertiliser figures should be used as an initial estimate of plant requirements. For cultivation in soil, they should be corrected, (ie reduced), by the (expected) amount of nutrients supplied from the soil during the life of the crop.

### 2.5.2 Optimum nutrient supply

Chinese waterchestnut has been used in treating waste water by absorbing large quantities of readily available nutrients and particularly N (more than 800 kg N per hectare within 6 months). N uptake is particularly rapid early in the season, as much as 300 kg per hectare can be taken up by the crop within 2 months in tropical climates. It is at this time that waterchestnut dominantly produces vegetative biomass (stems and roots, and daughter plants on rhizomes). Nitrogen has the most significant effect of all the mineral nutrients on crop growth and biomass partitioning. With increasing N, more biomass is partitioned into stems and less into roots. Higher N results in a greater number of corms, although their size is smaller and consequently the marketable yield decreases.

**Table 4. Biomass partitioning and element contents in a Chinese waterchestnut crop**

Parameter	Unit	Plant Part				Total
		Corm	Stem	Root	Stem & Root	
Fresh biomass	Tons per hectare	13.2	9.3	17.3	26.6	39.8
Water content	%	75.1	50.5	76.1		
Dry biomass	Tons per hectare	3.3	4.6	4.1	8.7	12.0
Nitrogen	Kg per hectare	111.1	40.8	60.7	101.5	212.6
Phosphorous	Kg per hectare	42.6	16.0	45.4	61.4	104.1
Potassium	Kg per hectare	266.1	57.4	48.2	105.6	371.7
Carbon	Kg per hectare	5374.1	2344.9	2830.0	5174.9	10549.0
Aluminium	Kg per hectare	0.5	0.9	9.6	10.5	10.9
Boron	Kg per hectare	0.1	0.2	0.3	0.5	0.6
Barium	Kg per hectare	0.0	0.1	1.5	1.6	1.6
Calcium	Kg per hectare	6.5	51.1	79.7	130.8	137.3
Cobalt	Kg per hectare	0.0	0.0	0.5	0.5	0.5
Chromium	Kg per hectare	0.0	0.1	3.2	3.4	3.4
Copper	Kg per hectare	0.1	0.0	0.3	0.3	0.4
Iron	Kg per hectare	1.4	1.6	159.5	161.2	162.6
Magnesium	Kg per hectare	10.3	18.2	11.9	30.0	40.4
Manganese	Kg per hectare	0.1	2.1	3.4	5.5	5.6
Sodium	Kg per hectare	7.3	52.9	48.5	101.4	108.7
Nickel	Kg per hectare	0.1	0.1	2.2	2.3	2.4
Lead	Kg per hectare	0.0	0.0	0.3	0.3	0.3
Sulphur	Kg per hectare	28.0	35.3	44.4	79.7	107.7
Zinc	Kg per hectare	0.2	0.1	0.4	0.5	0.7

Most notably at high nutrient levels, ammonium ( $\text{NH}_4$ ) and phosphate ( $\text{PO}_4$ ) ions interact during absorption. High application rates of N promote absorption of  $\text{PO}_4$  ions, leaving less of them in the growing solution. This is well documented for growth of many crops. However, high P application rates hinder absorption by waterchestnut of  $\text{NH}_4$  ions, which is, to our knowledge, an undocumented process. The C concentration in plants is an indicator of accumulated photosynthetic activity during the growing phase and declines with increasing P rates. It appears that excessive application of P to Chinese waterchestnut reduces photosynthesis and, therefore, absorption of N or *vice versa*. Care must be taken by growers not to apply too much P to Chinese waterchestnut, especially in the form of organic fertilisers, some of which are quite rich in P (Section 2.6).

Our research has shown no relationship between nutrient application rates or nutrient ratios and sweetness in Chinese waterchestnut, although skin colour is strongly related to the N:K ratio in the nutrient solution.

Skin colour of corms changes from black to dark red and light red when the nutrient mix contains relatively more N than K. Consumers prefer dark skin colour in waterchestnut and, therefore, care must be taken to ensure that potassium supply matches nitrogen supply. The N:K ratio should be at least 1:1 and from the tissue analyses (Table 3) it can be seen that corms contain about twice as much K as N. If there is excessive N available to waterchestnut for any reason (eg high N-supplying capacity of soil), additions of K may improve visual corm quality.

Across the different climatic regions of Australia and largely in relation to temperature, Chinese waterchestnut shows differing potential for production of biomass and, as a consequence, different requirements for nutrients. Therefore, nutrient application rates in each production area should be based upon biomass potential of waterchestnut in that region. For example, if total fresh biomass production of waterchestnut in central Queensland is 40 tons per hectare (nutrient demand: 212:104:372 kg per hectare, N:P:K) but elsewhere only 30 tons per hectare, then nutrient demand in Victoria would only be 160:78:279 kg per hectare, N:P:K. For 40 tons per hectare fresh weight biomass (c. 13 tons per hectare, fresh corms), an application of 460 kg urea, 547 kg triple super phosphate and 744 kg muriate of potash per hectare would be appropriate if the soil were completely inert. Soil analysis is essential in order to be able to precisely calculate fertiliser requirements, for over-application can reduce quality of corms.

### 2.5.3 Optimum nutrient application and scheduling

As for most crops, additions of P and K in Chinese waterchestnut should be made before planting. However, N should be split between two applications, one before planting (ie 'basal application') and one at the onset of the corm-enlargement phase, which may be indicated, in aboveground stems as the onset of flowering. Flowers form at the tip of stems, and they are very small in size. The flower 'head' is approximately 2-5 cm in length. In temperate regions, flowers are seldom produced and whether this has any impact on corm yield or quality is unknown to the authors. When too much N is applied before planting, waterchestnut produces excessive stem biomass at the expense of yield. Therefore, not more than 50% of the total N rate should be applied before planting.

## 2.6 Organic mulching

Application of mulch can effectively suppress weeds early in the growing season when waterchestnut canopy is insufficiently developed to shade the paddy floor. For this, a dense layer of mulch about 2 cm thick can be applied to moist soil before planting corms or seedlings. Mulch will also conserve soil moisture if the paddy is not kept flooded.

Organic mulches contain nutrients that can become available to waterchestnut during the growing season, acting as an organic fertiliser. These mulches do not supply significant quantities of N to Chinese waterchestnut but there is release of K and presumably also micronutrients during anaerobic decomposition of the organic materials. Particularly when the growing medium contains insufficient K levels, organic mulches can improve waterchestnut quality (ie, darker skin colour) by release of K during the growing season.

Waterchestnut shows good response to mushroom compost. However, not all of organic materials are suitable for production of waterchestnut. The application of fresh animal manures into the aquatic environment may increase contamination of corms with microorganisms and can pose a potential risk for human health. A cheap and readily available organic material in Australia's sugarcane areas is sugarcane ash (ie burnt sugarcane biomass). However, this organic material is rich in P and probably due to the negative effects of excessive P (Section 2.5.2), sweetness of waterchestnut is low when sugarcane ash is applied.

*Azolla* is a suitable living and floating mulch for Chinese waterchestnut only under conditions of low nitrogen and without addition of inorganic N. *Azolla* requires other nutrients such as P and K for its own growth but fixes nitrogen from the air. N is gradually supplied to waterchestnut when some *Azolla* plants die and their biomass decomposes. However, when inorganic N is applied to a paddy, all *Azolla* dies shortly thereafter and decomposition of plants results in a peak of N. Such a rapid decomposition process may not be favourable for waterchestnut growth. *Azolla* has been cultured with Chinese waterchestnut

grown in a sand media and all waterchestnut plants died within 2-3 months after planting. This might have been due to formation of phytotoxic compounds during *Azolla* decomposition.

The rapid propagation of *Azolla* in paddies has blocked pumps for the suction-type harvest system, and is therefore considered unsuitable for cultivation with Chinese waterchestnuts. Additionally, *Azolla* may act as a thermal blanket preventing heating of water in the spring/early summer in temperate climates.

For all organic mulches, there are negative effects of anaerobic decomposition under cool environmental conditions. Under cool conditions, phytotoxic organic compounds (volatile fatty acids) can be formed which are known to damage roots of crops such as rice. In Chinese waterchestnut, application of excessive amounts of organic mulch (more than 2 cm deep) is thought to have an adverse effect on corm taste and is, therefore, not recommended, particularly in Australia's south.

## **2.7 Light management**

Light is one of the important environmental factors governing the growth and development of plants. Growth and development of Chinese waterchestnut are influenced by the intensity (photointensity), and the duration (photoperiod) of light.

### **2.7.1 Photointensity**

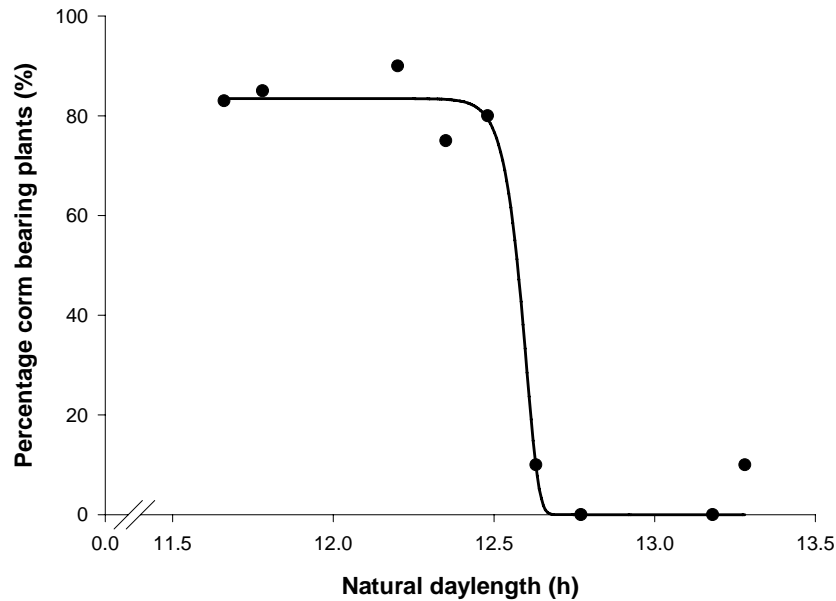
Plants absorb light and convert it to chemical energy during photosynthesis that supplies the plant with carbohydrates. These sugars are then the building blocks upon which the whole of plant metabolism depends.

Under low light intensity waterchestnut produces stems, which are longer and bigger in diameter than under higher intensity, thus compensating for the loss in light by maximising area and thereby making more efficient use of the (limited) light. Under Rockhampton conditions, Chinese waterchestnut could tolerate up to 30% reduction in photointensity without significant reductions in corm yield. Therefore, it is unlikely that insufficient light intensity restricts growth of waterchestnut in any part of Australia.

### **2.7.2 Photoperiod**

For many plant species, photoperiod plays an important role in controlling the formation of underground organs. For example, tuberisation in potato is promoted by days shorter than a critical photoperiod. The critical photoperiod for Chinese waterchestnut was determined in Rockhampton as 12.36 daylight hours (Fig. 3). When plants were exposed to photoperiods below this daylength, significantly more plant biomass was allocated to corms and rhizomes whereas when photoperiods were above the critical daylength, corm formation was strongly retarded.

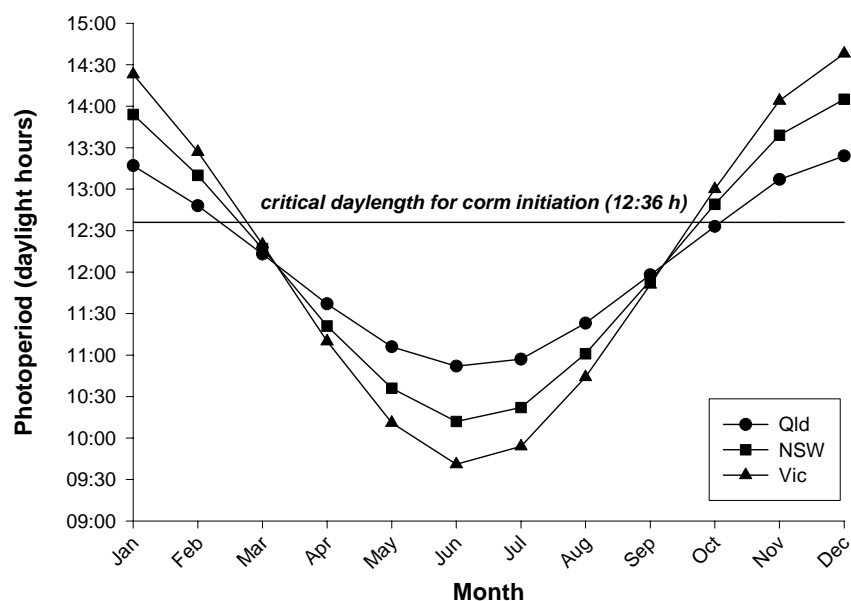
Figure 4 presents the course of natural photoperiod during the year in Queensland, New South Wales and Victoria. In all locations, daylength is greater than the critical daylength after the beginning of October.



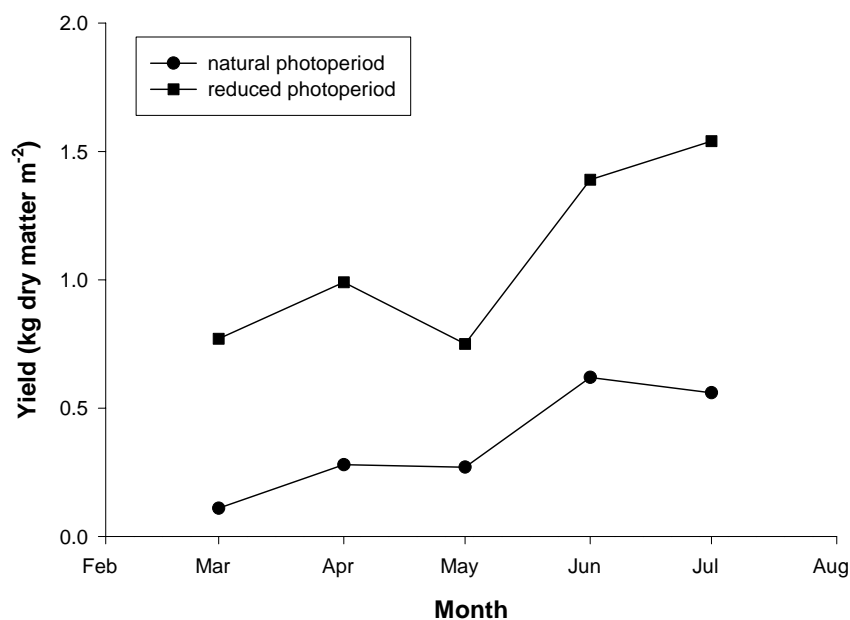
**Figure 3. Effect of natural daylength on corm initiation in Chinese waterchestnut**

Due to lower ambient temperature in southern parts of Australia, the growing season is restricted (see Section 2.3.4). To make better use of the shorter season, corms are usually planted in nurseries as early as possible. If Chinese waterchestnut is planted in nurseries in early September, artificial extension of daylength to 14-16 h during September using suspended lamps should promote better (vegetative) growth of transplants. Transplants from corms planted in the subtropics from July to September under natural daylength were notably weaker than plants from later planting dates. They also had visible young corms at transplanting while those from later planting dates did not. Typically, a grower in southern Australia might nurse corms from early September keeping temperatures above 13.6°C, and with extra light (14-16 daylight hours) until after the beginning of October.

To promote earlier corm formation in southern Australia, and thereby bring forward the date of harvest and the availability of waterchestnut on markets, photoperiod should be sequentially (eg for about 6 weeks after end of December) reduced to less than 11:30 h. Quite evidently, shortening the photoperiod (by means of covering plants with light-proof plastic in the early evening and/or early morning) enhances early yield of waterchestnut in Victoria (Fig. 5). While this has been achieved experimentally, the economic benefit of the practice has yet to be confirmed.



**Figure 4. Monthly mean daylength in Queensland, New South Wales and Victoria and the critical daylength for corm initiation in Chinese waterchestnut (Data for Mackay, Coffs Harbour and Tatura from the Bureau of Meteorology)**



**Figure 5. Effect of shortening photoperiod (for 6 weeks starting in early January) in Victoria on corm yield measured during the growing season of Chinese waterchestnut**

In contrast, warmer temperature conditions in northern parts of Australia allow growth into the ‘winter’. To capitalise on the longer growing season within the tropics, corm formation may be delayed by superimposing long photoperiods after the end of February, using a series of lamps held 1 m above plants, to manipulate the timing of corm formation and subsequent harvest. This could extend seasonal supply of freshly harvested waterchestnuts in markets. However, delayed harvest of corms may result in poor-quality corms with low storability (see Section 2.11).

The seasonal differences between temperate and tropical regions can be utilised to extend the collective harvest period and supply of fresh Chinese waterchestnuts to retail outlets throughout Australia.

## **2.8 Plant protection**

### **2.8.1 Water fowl**

Ducks and other water fowl (including maned geese and ibis) can damage a waterchestnut crop at every life stage, especially when plants are younger than 4 months. Stems and particularly corms are palatable and the water level is ideal for wading and dabbling. The vigorous stem growth of waterchestnut can tolerate light browsing which does not appear to have an impact on crop yield. However, if all of the stems from a plant are browsed to a level below the water line, then plants may die. Chinese waterchestnut corms are particularly vulnerable to damage by water fowl shortly after sowing or transplanting and after stem senescence. Corms on transplanted seedlings and directly-planted corms are vulnerable to be eaten by ducks and although this may not actually kill the plant; it will most likely be uprooted and remain afloat unless the water level falls sufficiently so roots can re-attach to the paddy base. Plant development is severely stunted whilst being uprooted. Serious crop damage can also occur when the soil is exposed after stem senescence and/or stem removal (burning) and the decaying root system make it easier for water fowl to rummage through the soil and locate corms. Depending on the number of local birds, water fowl can decimate a crop (usually at night) over a period of 1-2 weeks.

Water fowl deterrent devices such as nets or nylon lines (triangular shaped) across the paddy at 1-5 m intervals are effective techniques adapted from other horticulture and aquaculture industries. Also the use of flashing lights or scare guns can be effective. Allowing paddies to dry out after plant senescence will prevent damage by ducks, as it is difficult to rummage through semi-hardened soil. If water fowl are frequently visiting the paddies in large numbers before draining, then this is a good indication that the crop is mature and ready for harvest.

### **2.8.2 Rodents and grazing stock**

Although waterchestnut cultivation attracts rodents (damaging corms), and rabbits and hares (damaging green stems), these animals do not usually pose a serious threat to overall production except under plague conditions. Damage can be minimised by keeping the paddy inundated for as long as possible, and then (if required) drained and harvested shortly thereafter. However, this creates ideal conditions for water fowl which potentially create a more serious threat to corm yield so the different potential pest threats need to be assessed to determine an optimum strategy.

Stems are vulnerable to grazing by livestock and other animals throughout the season. If they enter the paddy, they can damage corms and root systems by trampling. Additionally, they may deposit faeces, which can increase numbers of harmful microorganisms in corms destined for human consumption. It is, therefore, critical to keep all livestock out of the paddy at all times by installing a robust fence around the paddy.

### 2.8.3 Caddis fly and other larvae

Aquatic caddis fly larvae (*Trichoptera* sp.) and a range of other leaf-eating caterpillars feed on waterchestnut stems, but plants can normally tolerate this damage unless the complete foliage has been eaten to below the water line. The crop is more vulnerable during the first 2-3 months when the young plants have only few stems and the caddis fly larvae are at the stage of gathering hollow stems for use as a body camouflage. There are currently no insecticides registered for use on Chinese waterchestnut so control options are limited. Each caddis fly larva bites off one whole stem below the water line although it usually only uses a portion of this stem equivalent to the length of its own body (5-10 mm) as a protective camouflage during this development stage. The paddy can be littered with floating intact stems which have a 5-10 mm segment removed from their bases. Seldom would there be segmented stems afloat in the paddy, suggesting that each larva bites off its own stem. Therefore, a relatively small number of larvae can inflict serious damage to the developing crop.

One technique to kill caddis fly larvae is to partly or completely dry out the paddy for perhaps one week. Drying out a paddy completely allows predatory ants to feed on larvae but this may result in weed growth and crop damage due to lack of water. Alternatively, the water level can be lowered to a minimum depth without exposing the soil, and then water temperature will rise and kill most larvae, although this is likely to also kill aquatic predatory insects. For these reasons, caddis fly infestations can be tolerated up to extreme infestations with 20-30% of the young plants damaged.

Damage from other browsing insects such as grasshoppers and locusts can usually be tolerated without taking corrective measures. The situation may prove very different under insect plague conditions and to further complicate matters there are no registered pesticides for this crop. No specific advice is available to rectify this possible scenario.

Stocking paddies with insect-eating fish or creating appropriate habitat such as rank grass along the bank verge for other predatory insects such as Mud-eye may reduce insect attack. Caddis fly is an indicator species for healthy aquatic environments, so imbalances in population may simply be transitional. If fish are to be stocked in the paddy, then a deep (2 m) sump will be beneficial for providing cool water that will provide shelter during warmer periods and protection from other predators during daylight hours.

### 2.8.4 Plant hoppers, scale and other insects

Plant hoppers (*Fulgoridae*) and scale insects are common pests in other crops and feed on plant sap in stems of Chinese waterchestnut that subsequently die. Plant hoppers can be identified by their excreta that are white, cottony fuzz on stems, and scale insects by their coverings that they leave behind after their death. They can reach large population sizes very quickly but infections may only be serious under hot and humid conditions. Adults of the sucking insect species *Nisia grandiceps* and the mole cricket (*Gryllotapa* species) are also known to damage the crop in warm conditions.

### 2.8.5 Rusts

A rust (*Uromyces* species) attacks waterchestnut in warmer climates. It occurs in most years, although it is a major problem less frequently. Rust is controlled in its early stages by sulphur sprays. Chemicals such as tebuconazole (Folicur) are effective, but not registered for use.

## 2.9 Weed control

There is no simple remedy to control weeds in a paddy. Every effort must be made to manipulate growing conditions to favour the crop and discourage weed seed germination. As there are no registered selective herbicides for this crop, there is a greater reliance on manual and mechanical weeding compared to most other commercial crops.

Ensuring the paddy is inundated for the entire season discourages weed establishment. Most weeds germinate when the water level is low enough to expose the soil to air. Some weed germination will still occur with constant inundation, especially early in the season when intense sunlight is reaching the paddy bed. Once canopy closure of the crop is complete, the risk of weed establishment is negligible, so water management is less critical from the weed management perspective.

Weeds are opportunistic by nature and will fill any space suitable for plant growth. Crop establishment is therefore a race against opportunistic weeds. To lessen the likelihood of weed encroachment some growers transplant 2-3 month old seedlings into the field. These seedlings require less time in the field to reach canopy closure compared to sowing corms directly into the field. Consequently, a direct-planted crop may have a greater risk of weed infestation compared to using seedling transplants. The labour efficiency gains from direct planting techniques may be negated by additional weed maintenance.

Depending on the type and number of weeds present, a delay in reaching canopy closure may enable more opportunity for weed establishment and this could result in a significant increase in labour requirements for manual weeding, or worse still, possibly losing the crop to weed domination.

Manual weed control should be maintained until the establishment of daughter plants prevents walking through the paddy without crushing stems (ie 75% canopy cover). It usually takes 3-4 months to reach this 75% canopy cover and then it usually only takes a further 2-3 weeks to reach canopy closure so any remaining weeds will normally be smothered. The number of times a paddy will require weeding is dependent on the weed seed bank in both the soil and water and germination is influenced by how the water level is managed. Hand weeding is very labour intensive. As a general rule, most paddies will require 3-4 weedings before canopy closure, unless mulch has been applied, when only one weeding is normally required.

There are several plant weed species prevalent in paddies and if left unchecked during the first 3-4 months, will impact on both crop development and complicate harvesting activities.

Nut grass, also known as umbrella sedge and drain flat-sedge (*Cyperus eragrostis*) is an aggressive sedge which can potentially out-compete the emerging crop. A similar species, dirty dora or rice sedge (*Cyperus difformis*), also invades paddies, although it is less invasive than the nut grass. These weeds will re-emerge only after crop senescence, which is during the cooler months and this is when these weed species grow slowly.

Couch grass (*Cynodon dactylon*), and water couch (*Paspalum paspaloides*) are aggressive plants with rhizomes and stolons which form a dense prostrate vegetative mat. While the emerging crop can penetrate this prostrate form and smother this weed once canopy closure occurs, the durable couch stolons remain intact through to crop maturity and can foul harvesting activities.

### **2.9.1 During site preparation**

When preparing a seedbed, it is advisable to kill all existing weeds so as to reduce the risk of weed establishment within the paddy. Fortunately, most weeds will not survive inundation, but removal before planting is usually more effective than later. One application of a knockdown herbicide is usually effective. Alternatively, cultivating the soil and leaving it to dry out will kill most plants. A light irrigation will trigger germination of some soil-borne weed seeds and surviving plant fragments of vegetatively propagated species. These can be killed by a second application of a knockdown herbicide or alternatively, allowing the paddy to dry out again.

Constructing a 70 cm deep and wide trench around the internal perimeter of the paddy will reduce the encroachment of weeds from the paddy bank. Covering the bank with plastic will also reduce weed encroachment although the plastic will split and fragment after 5 years.

For growers who wish to avoid the use of synthetic herbicides, there are two alternative approaches that should be considered as part of an attack on weeds. These are the use of a flame-thrower, and a super-heated spray unit. Specialists should be consulted before using either of these.

### **2.9.2 During early crop establishment**

Weed control during the first 3-4 months after planting or 2 months after seedling transplanting are the most critical periods for weed control. Irrigation water may need to be filtered to reduce entry of water-borne weeds. The types of weeds that arrive in the water are generally more resilient and difficult to eradicate.

Some growers create a settling pond to trap floating weed seeds and have a submerged water off-take pipe to supply the paddies so as to avoid entry of floating weed seeds. As this settling pond becomes weed-infested it filters more water and reduces the likelihood of weed seeds encroaching into the adjoining paddies. These weeds can then be removed by hand, by spray application or by cutting, prior to seed formation.

### **2.9.3 Mid to late season**

Weed management is negligible once canopy closure is complete, except for encroachment from the paddy banks. It is important to reduce weed seed production along paddy banks as these areas will produce seed and most likely contaminate the paddy later in the season which may then affect the following season's crop. Strategically timed mowing or slashing along the paddy bank will prevent most seed production. Alternatively, several applications of herbicide will kill most weeds, although care must be taken to minimise spray drift, as the crop is sensitive to knockdown herbicides. Also, the habitat value of this rank grass designed to encourage predatory insects is less critical once canopy closure has occurred.

## **2.10 Environmental weed potential**

Almost any introduced crop has the potential to escape from cultivation, become naturalised and potentially have a detrimental impact on natural ecosystems. Aquatic weeds are inherently more difficult to control than terrestrial plants. Special care is required to contain Chinese waterchestnut within isolated constructed paddies clear from natural waterways or flood prone areas, channels or drainage systems, especially in more tropical climates.

It is still unclear as to what extent Chinese waterchestnut will be invasive into wetland systems and irrigation infrastructure in Australia. It is possible that cultivated origins will become naturalised in the sub-tropical/ tropical regions over-lapping with the natural distribution of this species. The indigenous waterchestnut is the same species as that under cultivation. However, the indigenous plant normally produces few corms and these are usually less than 25 mm. Genetic analyses of indigenous corms revealed similarities to the imported origins currently under cultivation, suggesting that they may have been imported from Asia at some earlier period. The indigenous form is widely distributed in wetland systems and a common aquatic weed for irrigators in northern Australia although it is unknown in similar infrastructure in the south eastern regions of Australia. The natural watering regimes for wetland systems in south eastern Australia are usually dry during the warmer periods which coincide with the Chinese waterchestnut growth periods. There are several *Eleocharis* species naturally occurring in south eastern Australia although their adaptation to dry summer periods and cooler winters is likely to out-compete the cultivated form. There are no known escapees or naturalised populations of any cultivated variety in Australia.

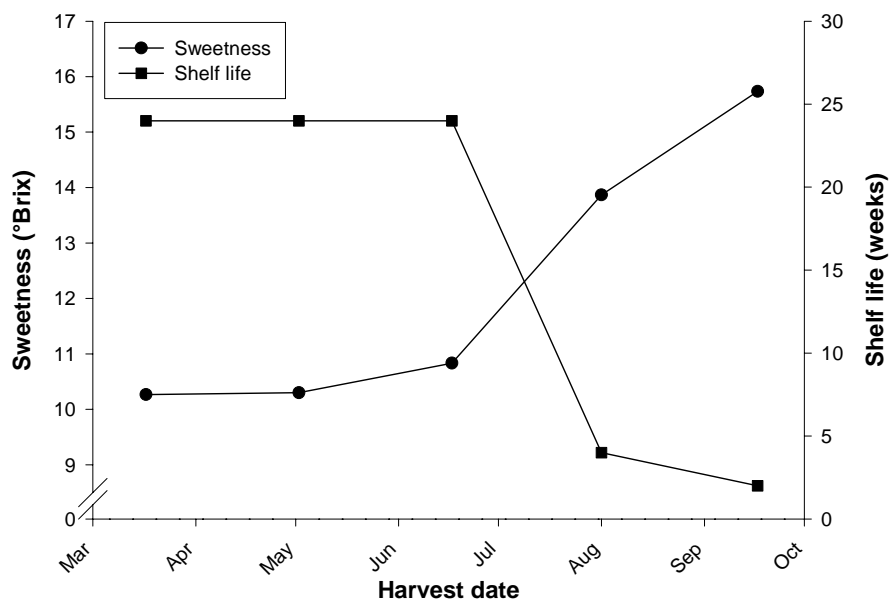
Whilst there is no evidence that water fowl disperse corm or plant fragments, it is quite feasible that this could occur as water fowl are known to disperse plant material between wetland systems. Effective vermin control is required to not only protect the crop, but also to reduce unwanted dispersal. It is important to adopt a precautionary approach and put in place measures to restrict plant escapees.

## 2.11 Crop maturity

Stem senescence can occur by stem damage from either the first frost, through implementing a water deficit by draining the paddy, or after 6-7 months in a sub-tropical region when the plant naturally enters this growth phase. The water deficit technique has been applied successfully in temperate climates to draw growth to a close and to reduce the incidence of over-mature or rotten corms. Further trials are required to confirm this crop response.

Once stems have dried off, a sample of corms should be collected at weekly intervals to determine their maturity. The crop is ready for harvest when corms are reddish-burgundy to dark-brown-black in colour and there are less than 10% white corms. The crop is over mature when corms exhibit a subtle muddy off-flavour, soon followed by an abundance of rotten corms.

Corms will sweeten if they are left in the paddy where environmental temperatures are less than the critical temperature for accelerated sugar formation (13.6°C, see Section 3.5). However, this may result in over-maturity of the entire crop and this can deteriorate to an unmarketable condition within as little as 2-3 weeks. Quality of harvested corms in temperate climates deteriorates rapidly beyond July but under tropical conditions, corms can be harvested through to October with a notable rise in sugar content over that period. However, storability of corms harvested after July is low due to greater susceptibility to fungal infection and internal rots that dramatically reduce shelf life (Fig. 6). Since corms can be 'sweetened' in cool storage, harvesting even in tropical climates should probably not be extended beyond July. Although corms will mature in either inundated or in drained, moist soil, it would appear from anecdotal evidence that corms in drained paddies can have an extended storage life whilst left in situ.



**Figure 6. Effect of harvest date on sweetness after 1-month storage at 8°C and on shelf life of Chinese waterchestnut in Rockhampton**

## 2.12 Harvesting equipment

Until recently, harvesting has been the most serious factor limiting the expansion of the Chinese waterchestnut industry in Australia. Commercial growers have invested considerable effort to develop mechanised harvesting equipment although most success stories are protected by commercial confidentiality agreements. The following is a discussion of the main principles associated with each harvesting system known to the authors.

### 2.12.1 Hand implements

Manual harvesting with simple hand utensils such as garden forks, spades and sieving-screens are suitable for small non-commercial areas such as domestic backyard plots (less than 100 square metres). Harvest rates working in pairs are approximately 0.5-1.0 square metres per hour or 1-2 kg per hour.

### 2.12.2 Water-suction harvester

Modified gold-dredge harvesters are based upon the 'venturi-suction principle' of injecting high-pressure water from a small pipe (25 mm) into a bigger pipe (100 mm) and thereby creating a vacuum. This vacuum sucks water, soil and corms from the paddy. When passed through screens or nets, corms are separated from the other material. The process is relatively gentle, with minimal corm damage, although current prototypes are probably too abrasive for corms going into long-term storage. For efficient operation of the floating platform with pump and associated hoses, water in the paddy must be at least 50 cm deep. Harvest rates are approximately 10-25 square metres per hour (20-40 kg per hour).

### **2.12.3Excavator harvester**

There are several variations of harvesters based on excavating soil from the paddy using a bob-cat, a front-end loader or an excavator. Corms are then separated from the soil by pressurised water jets that also wash corms. Harvest rates are approximately 40 square metres per hour with three operators, including one for cleaning lumps of soil and damaged corms.

### **2.12.4Modified potato harvester**

A modified potato harvester ('Lehman's prototype') has also been developed although in its current form it is too abrasive on corms. This harvester requires entry into the paddy so care is required to ensure soil moisture is correct, otherwise the weight from the towing machine will damage corms. Harvest rates are approximately 50-60 square metres per hour (100-120 kg per hour) with a driver and two operators.

## **2.13 Corm quality**

Grading systems for Chinese waterchestnut should guarantee the supply of consistently high-quality corms to markets. First priority is to discard damaged corms. Sound corms are then graded according to corm size, and in the future may include skin colour and internal quality, as the market is developed. Mechanised size grading has been achieved with a slotted vibrating belt that was adapted from existing horticultural grading equipment. Processing rates of up to 1 ton per day are achieved with three operators. For small operations (less than 1,500 square metres) manual size grading with a mesh screen is effective, although less efficient than the mechanised system.

### **2.13.1Washing and screening for damaged corms**

Bruising is a serious problem for most commercial producers and is the major cause for loss in internal quality. Even small drop heights of only 5 cm can cause bruising and 15 cm can cause splitting of corms. On close visual inspection, harvested corms are commonly bruised and split and commonly display injuries consistent with drop heights of 60 cm. Therefore, reduction of physical injury of corms through further refinement in harvest design is crucial to reduce wastage, and to increase quality and extend shelf life.

Even minor cuts as small as 1 mm or light bruises may cause microbiological contamination that can further decrease shelf life of corms and be potentially harmful for human health. Several fungi can be present on the external surface of corms including food spoilage micro-organisms such as *Trichoderma* and *Fusarium*. These postharvest plant pathogens cause rotting of corms and can be introduced by unsafe washing water. However, they do not invade corms unless there is a physical injury present.

Corms should only be washed in clean water during and/or shortly after harvest to remove soil and allow inspection for damage. Abrasive brushing techniques have been used to clean soil from corms, but these may result in minor physical injury. Pressurised water sprays are used effectively. Secondary washes after cool storage may only increase fungal contamination.

### **2.13.2Surface sterilisation of corms**

Calcium hypochlorite is widely used as a sanitiser in other sectors of the horticultural industry and Bavistin is an effective fungicide particularly against *Trichoderma* and *Fusarium* registered for postharvest use on other crops. Postharvest dips (for 5 minutes) in calcium hypochlorite (200 mg per litre) and Bavistin (1 ml per litre) were ineffective in controlling fungi growth and preventing rots in corms

during a 3-month storage period at 0°C. It appears that due to physical injuries during harvesting, handling and washing, microorganisms reach the internal tissues of corms and surface-sterilisation procedures are ineffective unless they are applied immediately after the corms have been damaged.

### **2.13.3 External quality**

The Australian Aquatic Vegetable Growers Network has established three official size classes for Chinese waterchestnut on Australian fresh markets. These comprise 25's (25-32 mm), 32's (>32-40 mm) and 40's (>40 mm). These size classifications have not been adopted across Australian markets since growers negotiate size classes with individual purchasers, some of which have indicated that corm sizes below 28 mm are too small for fresh markets. Dark-brown to black coloured corms are standard, although a dark-red-burgundy colour is also acceptable.

### **2.13.4 Internal quality**

Parameters of internal quality such as coconut flavour and crunchiness are difficult to grade under commercial conditions. However, sweetness (ie sugar content) can be estimated by measuring the content of total soluble solids (TSS, unit = °Brix) in corms. Corm sap is extracted (eg with a garlic press), centrifuged (eg at 3,000 rpm for 2 min) and analysed with a hand-held refractometer. Under large-scale production of Chinese waterchestnut, corms could possibly be automatically graded with a non-intrusive sampling technique using near-infrared reflectance spectroscopy (NIRS). This method yields absorbance spectral data that, after calibration, can precisely estimate TSS content of Chinese waterchestnut. Similar machines are used in fruit and vegetable grading systems however it will require a larger industry to warrant use of such elaborate machinery for Chinese waterchestnut.

## **2.14 Soilless cultivation**

Cultivating Chinese waterchestnut without soil but rather using imported sand into paddies has been adopted as a cultivation method to make harvesting easy. A variation of this theme is placing soilless media into containers and growing waterchestnut therein.

### **2.14.1 Containers, growing medium and irrigation**

Polystyrene boxes that are standard in Australia for packing fruits, vegetables and seafood can be used. To save on the costs of purchasing new boxes, second-hand boxes may be obtained through local food stores, although new boxes only cost about \$2.50 each, and this is likely to be less than the cost of gathering used boxes. Compared with other materials, polystyrene boxes are lightweight and provide some thermal insulation. However, experience shows that these boxes may not be perfectly waterproof and plant rhizomes can grow through the material, so they need to be lined with plastic film.

Since plants have new stems from mother corms and rhizomes, in contrast to other hydroponics systems, boxes cannot be enclosed from above. Therefore, a solid growth medium such as sand is required to protect the root system from light. It is recommended to sterilise the sand before use to avoid microbiological and seed contamination.

To sterilise, simply spread the moist sand in full sunlight over a clean surface such as washed concrete to a depth of approximately 3 cm and cover with a black plastic film. The sun will heat the sand and kill most pathogens so long as the temperature is at least 60°C for 60 minutes. Use a thermometer to confirm the temperature and if possible leave for at least a week so multiple heat exposures occur.

The sand should not occupy more than two thirds of the height of containers to make space for water that should cover the sand throughout the growth period. Water consumption is great due to high rates of transpiration and evaporation, particularly during the summer season so an automatic irrigation system is desirable.

Boxes can be placed in an area with full sun and protected from the wind. Rainfall may supply some of the irrigation water required and nutrient loss may occur when boxes overflow during heavy rainfall. A top-up fertiliser application may be required.

### 2.14.2 Fertilisation for soilless cultivation

As a guide to fertiliser application rates for these boxes, a total of 20-30 g per square metre each of N, P and K should be applied. Nitrogen (N) should be in the form of ammonium (eg as urea) rather than nitrate. Phosphorous (P) and Potassium (K) can be applied entirely before planting but N should be split into two applications: 50 percent before planting and 50 percent about 3 months after planting. A volume of 100-200 ml per square metre per month of a standard micronutrient solution seems to be sufficient. Such solutions can be obtained from suppliers of hydroponics equipment around Australia.

### 2.14.3 Harvest, quality and yield for soilless cultivation

When most stems have died off in autumn, irrigation should be discontinued and/or water drained off to facilitate easier handling of boxes. After washing off the growth medium, corms can easily be separated from roots and rhizomes with no further washing being required. Cultivation operations can be scheduled as illustrated in Table 5 and may vary according to climatic conditions. Quality and yield of waterchestnut grown without soil are comparable with those cultivated in soil so long as the correct amount of fertiliser is applied.

**Table 5. Scheduling of cultivation operations for culture of Chinese waterchestnut in Rockhampton (Qld), Burrupine (NSW) and Dhurringile (Vic)**

<b>TASK</b>	<b>QLD</b>	<b>NSW</b>	<b>VIC</b>
1) Place corms in storage (ambient temp. and moist)	July	August	July
2) Take corms from storage, plant and put in nursery	November	1 <sup>st</sup> October	15 <sup>th</sup> August-15 <sup>th</sup> September
3) Transplanting of most vigorous plants	November/December	15 <sup>th</sup> November	1 <sup>st</sup> November/1 <sup>st</sup> December
4) Fertiliser basal application (N, P, K)	November	15 <sup>th</sup> November	1 <sup>st</sup> November/1 <sup>st</sup> December
5) Micronutrient application (monthly for soilless)	November/December – June/July	November-June	November-May
6) Fertiliser side dressing (N)	February/March	February/March	February/March
7) Harvest	June/July	1 <sup>st</sup> July/1 <sup>st</sup> August	15 <sup>th</sup> May/15 <sup>th</sup> June

# Chapter 3 - Postharvest storage

After harvest, corms lose weight from both water loss through transpiration and loss of some biomass due to respiration. Other changes in stored Chinese waterchestnut are growth of sprouts and deterioration of external and internal tissues. The latter can be caused by physical damage (bruises), infections by microorganisms and temperature-related damage of tissues.

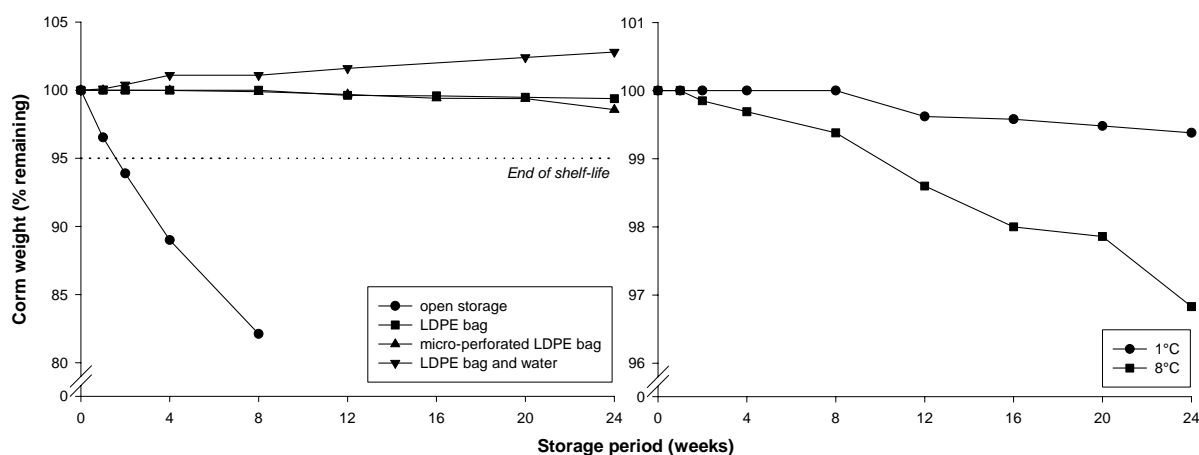
## 3.1 Weight loss

In nearly spherical-shaped objects such as Chinese waterchestnut, the surface area/volume ratio decreases dramatically with increase in volume. Therefore, bigger (heavier) corms lose less water through transpiration and these should be preferentially selected for storage.

Packaging is the most important measure to reduce weight loss in stored Chinese waterchestnut. When stored unpackaged, corms rapidly lose weight (Fig. 7, left). Although reputedly preferred by customers at Asian food outlets, open storage reduces the shelf life of Chinese waterchestnut to not more than 1-2 weeks (5% weight loss), especially when stored at the higher temperatures found for many vegetables in food stores. If corms are to be displayed in open storage, then this should be limited to corms likely to be sold the same day.

Low-density polyethylene (LDPE) materials such as ‘Snap-lock’ bags and the micro-perforated ‘Long-life’ bags are widely available and are suitable for packaging Chinese waterchestnut. When stored in LDPE, corms lose only little weight during a period of several months and if some water is added to the bags (eg 1 ml per corm), corms will even gain some weight (Fig. 7, left). Therefore, corms should not be surface-dried before packaging.

Reducing storage temperature will reduce respiration rates within the living corm that will minimise expenditure of energy and contribute to preserving the sound condition of the corm. Figure 7 (right) shows that weight loss of corms in LDPE bags was much less at the lower storage temperature (1°C compared to 8°C). While our earlier research tested temperatures as low as 1°C, we now do not recommend storage of corms at temperatures less than 4 °C, to avoid possible freezing damage.



**Figure 7. Effect of packaging (average of 1°C and 8°C – left side of figure) and temperature (corms stored in LDPE bags – right side of figure) on weight loss of stored Chinese waterchestnut**

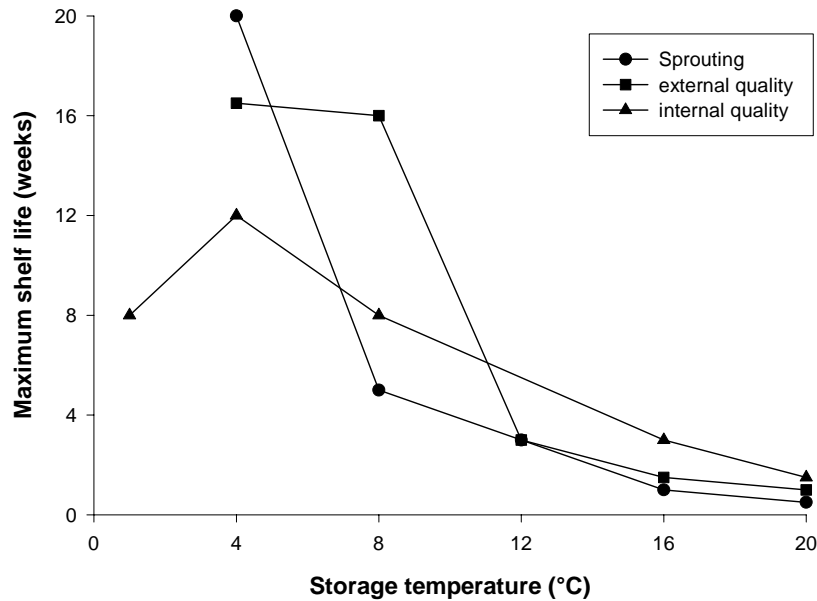
Weight loss in Chinese waterchestnut is due to both transpiration and respiration. Since the respiration rate is kept very low due to cool storage conditions (1.2-3.0 ml CO<sub>2</sub> per kilogram per hour after 30 days of storage at 0°C), only a very small percentage of total corm weight is lost after 30 days. Compared to other horticultural crops this is considered a 'low' to 'very low' respiration rate. Respiration causes modification of atmosphere in LDPE packages with increasing CO<sub>2</sub> and decreasing O<sub>2</sub> levels. This appears to provide benefits in internal quality with significantly lighter flesh colour and reductions in yellow stains. Nevertheless, this respiration rate is sufficiently high that it will cause anaerobic respiration ('fermentation') if there is no access to oxygen. Therefore, vacuum packaging is not suitable for long-term storage of waterchestnut corms.

### **3.2 Sprouting, and external and internal quality**

Corm shoot elongation or sprouting is the development of new stems from corms. This is the most obvious form of quality loss in corms. There are always some signs of sprouting but when sprouts are longer than 1.5 cm corms become unacceptable to most consumers. These corms are probably at their sweetest, and they are nearing the end of their storage life, as rapid deterioration in eating qualities is imminent. Long sprouts are easily removed and to the non-discerning consumer, this can conceal the state of over-maturity and short shelf life. Colder temperatures will delay the onset of further shoot elongation and associated deterioration. It is desirable to have negligible shoot growth for optimum corm quality. This can be achieved by ensuring the crop is not over-mature and harvested corms are placed in 4°C storage as soon as possible. Storage at 4°C is effective in controlling sprouting for at least 6 months.

Bruising, discolouration, rots and fungal infection reduce external quality of Chinese waterchestnut. Injuries range from 1-2 mm of soft, discoloured tissue immediately below the skin to large areas of brown and discoloured tissue often associated with fractures. End of shelf life is reached when more than 10-15% of the corm surface is affected.

The optimum flesh colour of corms is bleached-white and poorer quality is indicated by creamy-white to yellow flesh colour and off flavours. These changes in colour coincide with increases in internal rots, so it is assumed that microbial spoilage organisms (eg fungi or bacteria) are responsible. Internal flecking is expressed as dark specks in the flesh that are usually 0.5-1.0 mm in diameter. Bruises, discolouration, rots, flecks and yellow stains reduce internal quality of Chinese waterchestnut, terminating their shelf life when more than 10-15% of the internal tissue is affected. Many of these deteriorations result from physical injury during harvest and postharvest handling and become more pronounced during storage, especially at temperatures above 4°C.



**Figure 8. Effect of storage temperature on maximum shelf life of Chinese waterchestnut through induction of sprouting and deterioration in external and internal quality**

Figure 8 shows how storage temperatures affect shelf life of Chinese waterchestnut by their effects on sprouting and on external and internal quality. Shelf life of corms decreases dramatically with increasing storage temperature due to sprouting and loss in external and internal quality. However, at temperatures below 4°C, internal quality becomes unacceptable after 2 months probably due to cool-temperature chilling injury.

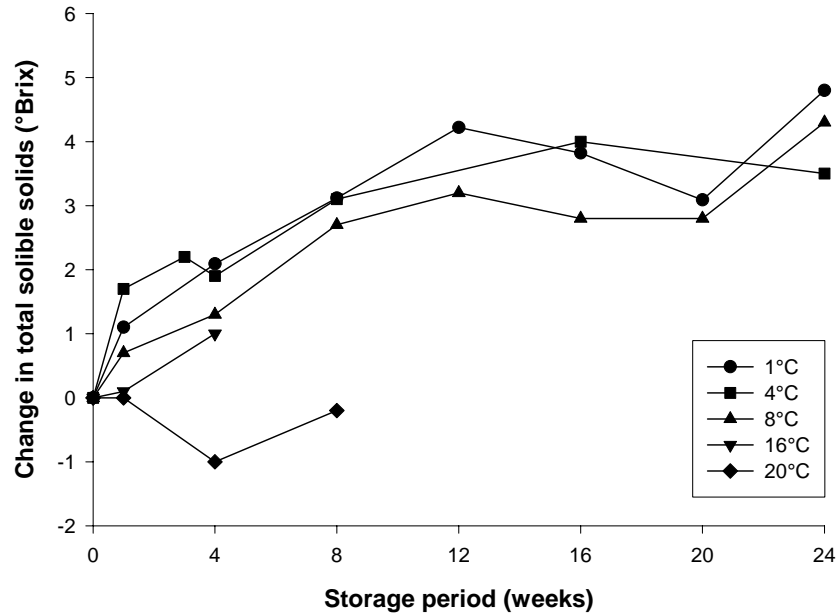
### 3.3 Traditional Asian storage

There is another possible storage approach worthy of consideration and more akin to traditional Asian post-harvest storage. It has been demonstrated for a wide range of root or tuber crops that they store far better if stored dirty. Unwashed corms are commonly presented for retail sale in many Asian countries, so it is anticipated this type of presentation will be accepted in the Australian market. Washing causes injuries and is a source of inoculum to infect wounds. Samples of washed and unwashed corms have been moist-incubated to identify the fungal species present that may cause quality loss during storage. No fungal growth was observed on the unwashed corms while seven species, some of which are potential pathogens, grew on the washed corms. It should also be noted that the majority of plant pathogens, both bacterial and fungal, cannot infect intact, healthy tissue; they require a wound site to infect corms. Furthermore the natural soil microflora can generally out-compete pathogenic organisms if the normal microflora is not disrupted. When sectors of the natural microflora are destroyed, an opportunity is provided for pathogenic organisms to become established.

However, if such a storage option does improve shelf-life, it may be difficult to implement for exported produce, due to quarantine considerations with soil attached to corms.

### 3.4 Sweetness

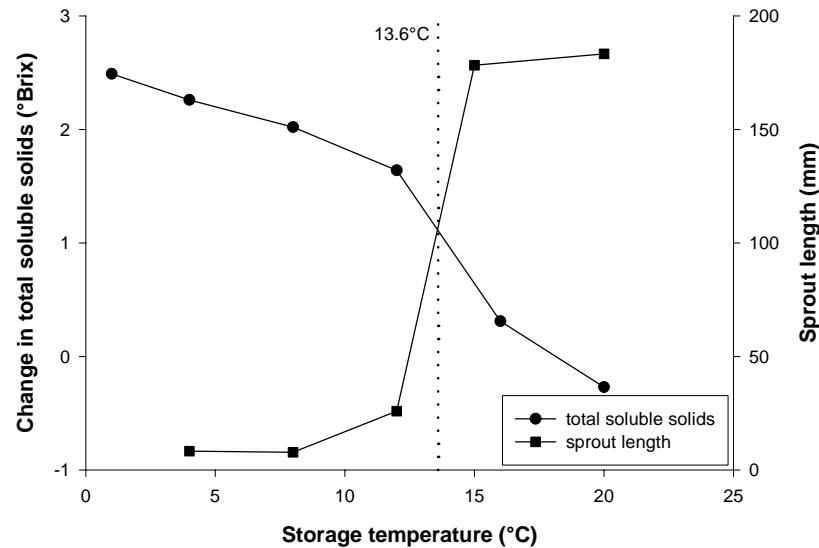
Together with several other factors, temperature regulates a dynamic equilibrium of starch and sugar in tuber crops such as potato. As with those crops, low temperatures trigger sugar accumulation in Chinese waterchestnut. Sweetness (ie sugar content) of waterchestnut can be measured as total soluble solid content (TSS) in corms (Section 2.11.0). There is no sweetening of corms stored at 20°C and only little at 16°C, but at cooler temperatures, sweetening is enhanced (Fig. 9). A storage period of 3-4 months appears optimum to promote sweetness of corms since further increases after 5 months of storage may be attributed to other sweetening mechanisms such as sugar formation due to sprouting, senescent sweetening and/or sugar formation caused by fungal infection. These observations could also be compounded by physical injuries.



**Figure 9. Effect of storage temperature on total soluble solids content (ie ‘sweetness’) of Chinese waterchestnut**

### 3.5 Preferred storage technique

Figure 10 indicates a ‘critical storage temperature’ below which sweetening is accelerated and above which sprouting is accelerated. This temperature (13.6°C) can be regarded as a ‘minimum’ storage temperature for Chinese waterchestnut.



**Figure 10. Effect of storage temperature on total soluble solids content and length of sprouts after 4 weeks storage period in Chinese waterchestnut**

Table 6 highlights which factors are responsible for limiting shelf life of waterchestnut at specific storage temperatures.

**Table 6. Effect of storage temperature on maximum shelf life of Chinese waterchestnut<sup>a</sup> and cause of deterioration**

Storage temperature (°C)	Maximum shelf life (weeks)	Cause for deterioration
1	9	Internal quality
4	12	Internal quality
8	6	Sprouting
12	3	Sprouting, external quality
16	1.5	Sprouting, internal and external quality
20	0.5	Sprouting, internal and external quality

<sup>a</sup> Packaged in LDPE bags

Chinese waterchestnut is successfully stored in LDPE snap lock plastic bags for 3 months at 4°C. This procedure minimises loss of internal and external quality of corms, maximises their sweetness, and extends their availability on Australian markets. Most commercial growers harvest, grade, pack and transport Chinese waterchestnut at ambient temperatures of 15-20°C (tropical and subtropical climates). Corms typically reach the fresh market in good quality within three days from harvest and have a shelf life of several days at ambient temperature.

Reducing corm temperature down to 4°C as soon as possible after harvest will extend shelf life, however until handling procedures are improved and the incidence of physical injury is greatly reduced, corm quality will be inconsistent and this will limit industry expansion.

The preferred packaging system for specialist fruit and vegetable retailers is loose corms in 4 kg plastic lined and sealable cardboard boxes or 1 kg sealed plastic bags. Supermarket outlet stores prefer 150-250 g tamper-proof sealed packages.

### **3.6 Packing sheds**

Packing sheds become just one more link in this production chain and they must be hygienic to minimise the possibility of disease outbreak. It is necessary to register packing sheds with the local government to ensure they comply with Government food handling requirements, as this product is not being modified before reaching the consumer. Most growers would currently operate without documented quality assurance systems nor have the appropriate shed registration for packing food. A food poisoning case with Chinese waterchestnuts would be deleterious to the industry, and of course to the consumer, so it is essential that growers adopt food safety handling protocols stipulated by the relevant Health Authorities. Further information can be obtained through Local Government Offices.

# Chapter 4 - Marketing

## 4.1 Domestic and overseas market potential

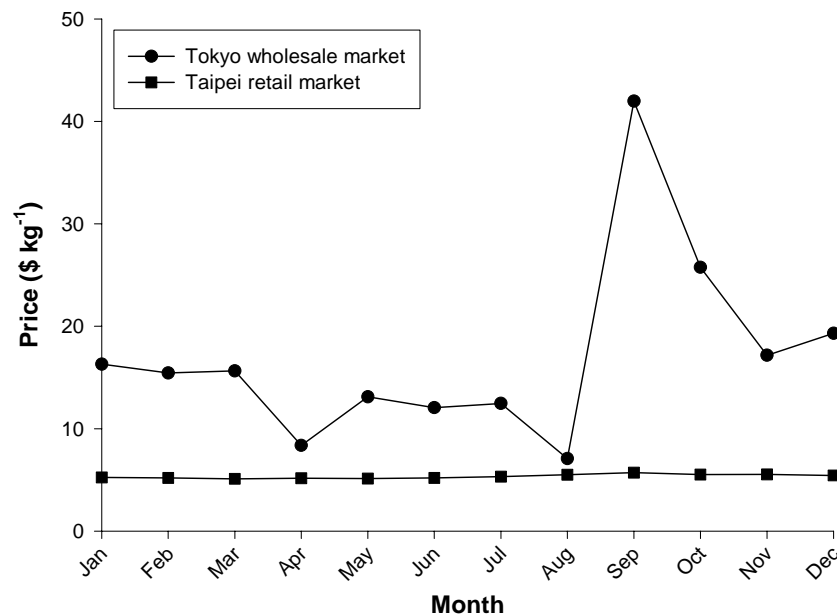
Approximately 20 tons per year of fresh produce were sold on the Australian domestic market in 1997 with the majority going to the end-consumer in supermarket outlets. Production levels have fallen during 1998-2000 due to withdrawal of a major successful producer, along with numerous smaller growers who have encountered difficulties in their production systems and failure to coordinate market outlets. It is anticipated that the annual domestic fresh market will expand up to 100 tons over the next five years based on expanding production systems rather than any documented consumer demand. It is very difficult to estimate the domestic fresh market potential as this product is currently unavailable to most consumers in the target market sector (Asian cultural background), and only has very limited circulation in mainstream food outlets. Also, there are no public statistics on Australian consuming habits for the imported canned or frozen corms. Reports from existing growers and Asian fruit and vegetable store owners indicate that fresh corms are keenly sought by those familiar with this food item and most of these consumers are people with an Asian cultural background. These consumers have a strong preference for fresh corms due to presence of pleasant flavours compared to canned or frozen products.

There are approximately 600,000 Australian citizens with an Asian cultural background and most are clustered in suburbs of state capitals. This demographic situation is advantageous for developing a new product to this discrete market sector. The mainstream Asian restaurant trade is reluctant to use fresh corms due to the peeling requirements, despite it being a very popular ingredient in many meals. In Australia, there are only a few speciality Asian restaurants currently being supplied with fresh corms for their discerning customers who know there is a marked difference in flavour between fresh and processed corms.

Development of a peeling system is required to capitalise on the wider restaurant sector and producers of semi-processed food (eg Asian stir-fry packs). A small-scale punch-type peeling system has been successfully developed to add value to small-sized corms (< 25 mm diameter) unacceptable to the local markets. After peeling, the corms are covered in batter and deep-fried, opening up a new marketing option.

If the domestic market is to expand beyond the 100 tons per year level, then further promotional work is required to expose the wider (non-Asian) Australian community to the fresh product. Before this promotional work should happen, there needs to be further refinements in commercial production systems. To date there are few commercial growers currently meeting consumer demands for consistent supply of quality corms. Until production systems become reliable, it is advantageous to maintain a low profile of fresh Chinese waterchestnuts. An unsuspecting customer is more valuable than a dissatisfied customer who experienced off flavoured corms.

Chinese waterchestnuts are consumed in Asia and by Asian cultural groups in most western countries. Japan experienced a decline in production over the past decade from 1,600 t in 1984 to 1,200 t in 1992. There are export opportunities for Australian-grown Chinese waterchestnut to Singapore, Japan and Taiwan, especially after the July-August period that coincides with limited supplies (off-season) in the Asian region (Fig. 11). When Australian-grown Chinese waterchestnuts are harvested in July and stored for 3 months, high prices could be achieved, particularly in Japan. Consistency of supply and quality are required if the export market is to be developed. It is anticipated that several growers will initiate this market opportunity over the next 5-7 years. The availability of effective mechanical harvesting, washing and grading will underscore this opportunity.



**Figure 11. Prices of Chinese waterchestnut at Tokyo/Japan wholesale market and Taipei/Taiwan retail market (1991-1995)**

## 4.2 Coordination of marketing

Currently, growers undertake their own marketing of Chinese waterchestnuts to supermarkets and grocery stores in communities with strong Asian cultural backgrounds. Although accessing the supermarket network is a little more difficult, much higher volumes can be sold through this marketing channel.

There are some growers who offer a service to wash, grade, pack and coordinate distribution of corms for other growers. The development of quality control processes, including the registration of these “processing sheds” will underpin the success of this developing industry. The skills associated with cultivation are clearly different to processing and these again are different to marketing. Recognition of these specialised skills will undoubtedly advance this new and emerging industry.

The Australian Aquatic Vegetable Growers Network is one potential mechanism for growers to coordinate marketing of Chinese waterchestnut on domestic and potential export markets. It is anticipated that growers will only use this industry group or a similar marketing service when production volumes increase to the point that market demand appears to be a limiting factor. A coordinated marketing approach will undoubtedly access new and bigger markets for both the domestic and export sectors.

### **4.3 Market prices**

Wholesale prices for canned Chinese waterchestnut in Australia range from \$3.70 to \$6.00 per kg. Once fresh corms are packed and ready for distributing to wholesale outlets, then wholesale prices are approximately \$6 per kg, although this price varied depending on size, sweetness and colour. The range of wholesale prices in the late nineties was \$4-5 per kg for 25's (25-32 mm), \$6-10 per kg for 32's (>32-40 mm) and \$10-12 per kg for 40's (>40 mm). Retail prices range from 20% to 100% above the wholesale price, depending on the marketing chain. The most recent wholesale figures (1999) suggest that these prices are holding up. The economic analysis of production (Chapter 5) suggests that the wholesale price of at least \$4.95 per kg from 1000 square metres with a yield of 25 tons per hectare will be necessary for a grower to breakeven. As the scale of production increases, lower breakeven figures will be evident as discussed in the next chapter.

# Chapter 5 - Economics of production

The estimated costs of production in Table 7 are based upon a compilation from three growers. There are great variations in costs for some items (eg excavation and harvest) that are due to different levels of mechanisation. It is apparent that mechanisation of harvest is crucial for profitability of waterchestnut production and further improvements in financial returns will be achieved through larger production systems. Within this chapter we present detailed costs associated with the setting up of a 1,000 square metres Chinese waterchestnut enterprise, essentially starting from scratch. Comparative production costs for a one hectare system are also included. The basis for some of these calculations is presented in Appendix 1.

All growers are advised to undertake their own estimates for cost of production and crop yield prior to entering the Chinese waterchestnut industry. The crop yield and cost of production are influenced by the scale of operation, specific site conditions and the skill of the grower. The following information is provided as a guide only and confirmation of current costs should be undertaken to assist in an informed decision.

Table 8 summarises, using calculated low and high costs of production of Chinese waterchestnut and identified low, medium and high yields, the breakeven prices at which all costs of production are covered by returns. Currently, the 1,000 square metres production system is only viable if the cost of production is low and the yield is high. In contrast, the one hectare production system is considered viable under all scenarios for the cost of production and yield estimates with the exception of the high cost of production and the low yield.

## 5.1 High production cost option

The high production cost option has assumed that the grower will invest in all the desirable components of a Chinese waterchestnut system, which will facilitate the achievement of consistent corm quality and greater economies of scale through the adoption of specialised machinery.

### 5.1.1. Additional expense items for the 1,000 square metres option

The paddy is lined with a plastic film and back-filled with original media, protected from water fowl, has a pressurised irrigation system, a vibrating slotted and graduated belt grader, and a fully functional packing shed and cool room. The additional variable costs include nursery raised seedlings, organic fertilisers, an additional hand weeding session, the higher end of costs for harvesting, packing, transport, maintenance, and vehicle use.

### 5.1.2. Additional expense items for the one hectare option

Survey and design costs are incorporated into this larger scale development but the task of lining with plastic is not required due to appropriate site selection. The other additional expense items discussed in the 1,000 square metres system are also relevant for the one hectare production scale.

**Table 7. Estimated annual costs of production <sup>a</sup> of Chinese waterchestnut**

Item	(\$ per 1000 square metres)	(\$ per one hectare)
<b>Fixed costs <sup>b</sup></b>		
Paddy construction		
Survey, design,	500	700
Planning permit	600	600
Soil testing (structure)	50	360
Excavation	1,200	5,500
Plastic lining (paddy base)	1,800	10,000
Addition of growth media		
Original media	1,500	7,600
Imported sand	4,000	25,000
Irrigation system		
Water right <sup>d</sup>	800	8,000
Open-channel system	200	420
Pressurised system	800	800
Harvesting equipment		
Water suction	5,000	5,000
Modified potato-harvester	40,000	40,000
Excavation-harvester	30,000	30,000
Grader	500 - 5,000	5,000
Mechanical plant protection		
Netting	1,500	5,130
Nylon-line deterrent	650	1,320
Packing shed <sup>c</sup>	10,000	10,000
Coolroom <sup>c</sup>	2,000 - 5,000	5,000
Sub total fixed assets	8,950– 32,100	31,280- 34,280
Amortised (7-14%)	1,135- 3,514	5,387- 3,825
Contingencies (10%)	114- 351	539 - 383
Total annual costs	1,250- 3,865	5,925 - 4,209

**Table 7 (continued)****Variable costs**

Corms	100	260
Soil levelling and cultivation	240	1,200 - 2,400
Nursery raised seedling transplants	1,600 - 2,400	10,000
Planting		
Corms directly	75	600 – 700
Transplanting seedlings	120	3,400 – 4,000
Irrigation water	100	325
Fertiliser	250 – 600	1,500 – 3,000
Weed control		
Hand-weeding	120 – 240	1,200 – 2,400
Mulching	300	1,850
Herbicide	70	600
Brush-cutter	60	500
Burn stems	15	120
Harvesting system		
Manual harvest	15,000	-
Water suction harvester	1,280 – 1,500	12,800 – 15,000
Modified potato harvester	1,275	12,750
Excavation harvester	2,400	24,000
Grading	2,000- 4,000	18,000 – 23,000
Packaging	1,500 – 2,000	13,000 – 17,000
Registration for packing shed	150	150
Transport	800 – 1,000	4,000 – 5,000
Maintenance and repairs	280 – 500	1,000
Vehicle	1,000 - 2,400	2,400
Agent fee		
(5% of wholesale price @ \$6 kg <sup>-1</sup> , yield @ 15 ton)		4,500
@ 20 ton	-	6,000
@ 25 ton	-	7,500
Sub Total	10,120 - 13,425	58,255 - 94,705
Contingencies (10%)	1,012 - 1,343	5,825 - 9,471
Total variable	11,132 - 14,768	64,080 - 104,176
<b>TOTAL COSTS</b>		
(Fixed + Variable)	12,382 - 18,633	70,005 - 108,385
includes 5% @ 20 ton		110,035
includes 5% @ 25 ton		111,685

<sup>a</sup> Including labour (opportunity) costs (\$15 work-hour<sup>-1</sup>)<sup>b</sup> Amortised over a 7-year period (before paddies need major repair)<sup>c</sup> Amortised over 14 years.<sup>d</sup> Incorporated into capital value of property and not included in fixed cost.**5.2 Low production costs**

### 5.2.1. Reduced production costs for the 1,000 square metres option

This cost estimate is derived from a reduction in the main capital items and reliance more on manual processes and sending produce to market promptly with minimal storage facilities. There is a greater risk of inconsistent corm quality because of this reduced infrastructure.

The main savings for this system include site conditions not requiring paddy liner nor protection from water fowl, using a gravity irrigation supply system, direct planting of corms into paddy, no grading machine, nor packing shed nor cool room.

### 5.2.2. Reduced production costs for the one hectare option

Production cost savings are derived from selecting the lower range of cost estimates. There is limited scope to reduce essential infrastructure as manual systems are too intensive and are considered not viable options for the higher production yields.

**Table 8. Estimated breakeven farm-gate price for Chinese waterchestnut production at various yields and levels of input costs for holdings of 0.1 and 1.0 hectare**

Yield estimate (tons per hectare)	1,000 square metres Low - High	1 hectare Low - High
Low (15 tons per hectare)	\$8.25 - \$12.42	\$4.66 - \$7.22
Medium (20 tons per hectare)	\$6.19 - \$9.31	\$3.50 - \$5.50
High (25 tons per hectare)	\$4.95 - \$7.45	\$2.80 - \$4.46

<sup>a</sup> Data based upon production cost estimates presented in Table 6.

The crop yield and cost of production are influenced by the scale of operation, specific site conditions and the skill of the grower. Consequently, all growers are advised to undertake their own estimates for cost of production and crop yield prior to embarking of an investment into the Chinese waterchestnut industry. A detailed list of the current costs and assumptions associated with the commercial growing of the crop is presented in Appendix 1.

# Conclusions

The technical and practical basis for the commercial production of Chinese waterchestnut in the Australian environment has been researched, and the crop has been shown to be commercially viable under a range of input and predicted yield scenarios. When starting up production, particular attention should be turned towards the choice of good quality planting material (those with comparably high sugar content at planting), the appropriate balance of N:P:K fertilizer and the timing of planting. These will have important implications for the yield and quality of waterchestnut corms. With the span of natural climatic conditions across Australia, and with the manipulation of daylength through artificially lengthening with suspended bulbs or shortening through light exclusion, it will be possible to supply freshly harvested produce for at least six months out of every year. Cold storage at 4°C will allow a further three months supply of fresh corms. With this span of supply, and with the adoption of various innovative production and harvesting approaches, it should be based upon economics of production be very feasible to gain access to overseas markets.

The existence of the Australian Aquatic Vegetable Growers Association, and the Asian Vegetable Growers Association (Contact details in Appendix 2) makes possible the continued development of the Chinese waterchestnut industry, where mutual cooperation between members can guide the industry forward, for cooperation, and not competition, will underpin the success of this nascent industry.

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# Appendices

## Appendix 1

This section is to provide an explanation for the itemised costs of production presented in Table 7 for the 1000 square metre option.

### (a) FIXED COSTS

#### **Survey and Design @ \$500**

The area is to be surveyed and designed to identify all earthworks required to deliver irrigation water to the paddy, and ensure the paddy base is sufficiently level for uniform water depth. The plans will also include sufficient area to demonstrate how the proposed earth works will affect surface drainage on the property, and include the source of clay for earthwork construction and a dam/reuse system. As paddy areas do not currently exceed 1 hectare, the base costs will be the major cost component and the total price could be \$500.00.

#### **Planning Permit @ \$600**

Any earthworks including a dam or a paddy bank will require a planning permit. Typical cost is \$600.00.

#### **Testing for soil structure @ \$50**

Auger to a 1.2 metre depth with samples taken every 30 cm to determine clay content (4 tests per hole), four evenly spaced selected sample sites over proposed paddy. Hire of soil auger (\$20.00) and time to dig holes and perform soil tests (2 hours @ \$15 per hr.). Total cost is \$50.00

#### **Soil Excavation and Construction @ \$1,200**

The construction of paddy banks and the levelling of the paddy base can be achieved by a range of machinery, although specialised equipment becomes more cost-effective as the paddy size increases above 1,500 square metres.

A tractor with a front-end loader attachment, a set of “off-set discs” and a blade or land plane will complete all small-scale earthworks @ \$40 per hr. Cultivation of site could take 5 hours @ \$40 per hr = \$200.00

A 220 metre linear bank equivalent (to enclose 1,000 square metres) x 1.3 soil compaction factor = 285 cubic metres of soil, plus removal of topsoil and cultivating bank foundation could take 20 hours @ \$40 per hr = \$800.00.

Level paddy base using a tractor mounted land plane or blade with spot survey levels as guidance. This could take 5 hours @ \$40 per hr = \$200.00.

Alternatively, a laser guided scraper (3 metre wide) and a road grader could produce a neater, more accurately levelled and banks more uniformly compacted for a similar price (so long as machinery is locally available).

#### **Plastic lining for paddy base and banks @ \$1,800**

Material will cost \$1,500 to cover base and banks and installation will require 20 hours of labour @ \$15 per hr = \$300.00

**Addition of growth media**

Original media @ \$1,500

Depositing soil over the plastic film will require 30 hours with a front end loader @ \$40 per hr = \$1,200.00 and one labourer to finish smoothing soil for 20 hours @ \$15 per hr = \$300.00.

**Imported sand @ \$4,000**

A total of 300 cubic metres of sand @ \$13.33 per cubic metre including delivery is required and should be placed over the plastic in the same manner as placing original media (see above). Total cost is (300 cubic metres x \$13.33) = \$4,000.

**Soil levelling and cultivation @ \$240**

Cultivate paddy with a rotary tiller and level with a set of harrows, using a tractor @ \$40 per hr for 6 hours.

**Open-channel irrigation system @ \$200**

Construction of a 100 metre supply channel could take 5 hours @ \$40 per hr = \$200.00

**Pressurised irrigation system @ \$ 800**

Purchase 200 metre of 5 mm poly pipe and fittings for \$210, and a pressure pump for \$500 and 6 hours to set up the system @ \$15/hr = \$90.

**Harvesting equipment**

Water suction @ \$5,000

Modified potato-harvester @ \$40,000

Excavation-harvester @ \$30,000

**Grader @ \$5,000**

A vibrating slotted (graduated) belt.

**Netting @ \$1,500**

Netting will cost \$0.25 per square metre (mesh size 10 cm) and approximately 1,225 per square metre are required to cover a 1,000 per square metre paddy. 154 steel posts and 800 metre fencing wire to make a 3 wire fence plus one wire down the central length of the paddy (include 4 stays as wire should be tensioned). Installation will take 2 people 3 days @ \$15 per hr. Total cost is (\$0.25/ per square metre x 1,225 per square metre) + (154 x \$4) + (\$100 wire) + (2 x 3 x 6 hr x \$15/hr) + (\$30 clips) = \$1,500.

**Nylon-line deterrent @ \$650**

Triangular shaped nylon will cost \$0.20 per metre and steel posts (\$4 each) and support wire (200 metre @ \$30) to suspend the nylon line across the paddy every 2 metre along the length of the paddy. Installation will require 2 people for 4hr @ \$15 per hr. Total cost is (500 metre x \$0.2 per metre) + (100 posts x \$4) + \$30 wire + (2 x \$15 per hr x 4 hr) = \$650.

**Other equipment @ \$230****Packing shed @ \$10,000**

A shed sized 9.2 metre x 7.5 metre x 3 metre with concrete floor and power will cost \$10,000.

**Cool room @ \$5,000**

A cool room sized at 3 metre x 4 metre x 3 metre with 4°C storage temperature will cost approximately \$5,000.

**(b) VARIABLE COSTS****Corms for direct planting @ \$240**

Assume 2,000 corms are required @ 20g each x \$6 per kg = \$240.

**Nursery raised seedling transplants @ \$2,400**

Assume plant spacing at 2 plants per square metre (2,000 plants) and seedling production costs are \$1.20 each. Total cost is 2,000 x \$1.20 = \$2,400.

**Planting 2,000 corms directly into paddy @ \$75**

Planting rate for corms is 400/hr x 5 hr @ \$15 per hr = \$75

**Transplanting seedlings @ \$120**

Planting rate for seedlings is 250/hr x 8hr @ \$15 per hr = \$120

**Irrigation water @ \$100**

Application rate of 1 Megalitres for the 1,000 square metre

**Fertiliser @ \$250-\$600**

Application of inorganic fertiliser using Super phosphate, Urea and Muriate of Potash will cost \$250, alternatively organic fertiliser such as commercial preparations of composted fish and seaweed extract may cost \$600.

**Hand-weeding @ \$120**

It could take 8 hours to weed and this may be required once during the season so long as a mulch is also used. Total cost is 8 hr x \$15 per hr = \$120.

**Mulching @ \$300**

Use 5 round straw bales (600 kg) and unroll in paddy with a tractor and then spread manually. Total cost is (5 rolls x \$26) + (2 hr on tractor x \$40) + (6 x hr manual spreading @ \$15 per hr) = \$300.

**Herbicide @ \$70****Brush-cutter @ \$60**

Use for 3 hours @ \$15 per hr plus running costs of \$15 = \$60

**Burn stems @ \$15****Manual harvest @ \$15,000**

Manual harvesting using a garden fork and a screen will cover 1 square metre per hour @ \$15 per hr = \$15,000.

**Water-suction harvester @ \$1,280**

Harvest rate is up to 25m<sup>2</sup>/hr and requires 2 people to operate and running costs are \$2 per hr. Total cost is 40 hr harvest x (2 x people @ \$15 per hr) + (\$2 per hr x 40 hr.) = \$1,280

**Modified potato-harvester @ \$1,275**

Harvest rate is 60 square metre per hour, requires 2 operators and a driver, and running costs are \$40 per hr for tractor and \$5 per hr for machine. Total cost is 17 hr harvest x (2 people @ \$15 per hr) + (\$45 per hr x 17 hr) = \$1,275.

**Excavation harvester @ \$2,400**

Harvest rate is 40 square metres per hour, requires 3 operators and running costs are \$40 per hr, plus approximately 3 hours for preparation and cleanup. Total cost is 25 hr harvest x (3 people @ \$15 per hr) + (25 hr x \$40 per hr) + (3 people x 6 hr @ \$15 per hr) = \$2,400.

**Grading @ \$2,000**

Assume total crop is 2 ton and grading operations require four people to operate the grader and electricity cost is \$20. Grading time is (33 hr @ \$15 x 4) + \$20 = \$2,000

**Packaging @ \$1,500**

Assume 50% of crop (1 ton) is packed in 4 kg boxes @ \$2 each (250 boxes) and 50% is packed in 200 g bags @ \$0.10 each (5,000 bags), plus labour to pack @ \$500. Total cost is (250 boxes x \$2) + (5,000 bags x \$0.10) + \$500 labour = \$1,500.

**Packing shed registration @ \$150**

An annual fee of \$150 charged by the Local Government to ensure the packing shed complies with the state food handling regulations

**Transport @ \$800**

Assume a total of 2 ton of corms is transported in chiller trucks @ 4°C @ \$200/500 kg load.

**Maintenance and repairs @ \$280****Sundries @ \$1,500**

[Includes 15 irrigations at 1 hr each @ \$15 per hr, soil nutrient testing and other small cost activities.

**Vehicle @ \$2,400**

Running costs associated with vehicle.

**Agents Fees**

Marketing agents fees as a percentage of yield

## Appendix 2.

Contact details for key growers groups, institutes and individuals engaged with the Chinese waterchestnut crop.

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