Growing root crops on Atolls

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We are grateful to Mr Uatea Vave, Director of Agriculture, Tuvalu, for providing the foreword for this manual.

Finally, we acknowledge the contribution of all those whose names are not mentioned but who have been with us over the course of this work.

1 ACIAR – Australian Centre for International Agricultural Research; FAO – Food and Agricultural Organization of the United Nations; SPC – Pacific Community.

FOREWORD

It gives me great pleasure to introduce this manual, Growing root crops on atolls. To provide a foreword to such an important document is indeed a momentous task for me as Director of Agriculture for Tuvalu on behalf of the atoll nations of the Pacific. Agriculture is both our livelihood and the mainstay for all the people of the Pacific, especially atoll communities.

Food security, as echoed by many, is everybody's business. Families can become panicked and worried that they will not have sufficient, or any, food to feed themselves. Many atoll countries rely on cereals such as rice and white flour as sources of energy in their diets. It is time that we on atolls strive to replace these foods with home-grown root crops. This manual is launched at the right time, giving growers guidelines on how to properly grow root crops in atoll environments.

I take this opportunity to thank the technical staff of SPC, ACIAR and FAO for supporting the research in Kiribati, Tuvalu and Marshall Islands, which generated much of the information that has gone into producing this manual. Last but not least, I also thank the scientists from Kiribati, Tuvalu and Marshall Islands, who actually did the work on the ground, for their dedicated efforts.

I am confident that this manual will make a difference in root crop production on atolls and consequently to the food security of our people.

Faafetai lava

Uatea Vave
Director Agriculture
Tuvalu

1. INTRODUCTION

The atoll countries of the Pacific Ocean, such as Kiribati, Tuvalu and Marshall Islands, are home to probably the most economically and environmentally vulnerable people on this earth. They currently face significant nutrition insecurity and their greatest challenge is to produce enough good-quality food for their people.

Food production on atolls is influenced by many factors including: (i) saltwater intrusion in low-lying areas; (ii) both flooding and drought; (iii) limited availability of arable land (most is of very poor quality); (iv) urbanisation and lifestyle changes; (v) declining outer island populations; and (vi) poor access to local and export markets. Climate change and climate variability are expected to continue to intensify the effects of these factors, with increasing air temperatures putting stress on crops and trees, and saltwater intrusion and flooding further reducing the area of land available for farming.

For atoll communities, subsistence food gathering and production from fishing and farming are the main sources of both food and income. Commonly farmed crops and trees include coconut, breadfruit, pandanus, banana, and root crops such as swamp taro, ground taro, sweet potato, cassava and yam. Most food crops are produced on farms that are small (much less than an acre) and communally owned. There is little local livestock production, although many families raise pigs and chickens for domestic consumption. Copra is the major agricultural export, but production is limited.

Producing food crops on atoll islands requires perseverance. The porous and alkaline soils have limited fertility and support only a narrow range of crops. Increasing soil fertility to support production of more good-quality food and reduce nutrition insecurity is a common challenge for Pacific atoll countries, with the main constraint being lack of appropriate technology.

Development and use of technologies to increase food crop production will improve both local food security and nutritional security for atoll populations. This manual provides guidelines for growing four root crops in atoll conditions: sweet potato, taro, cassava and yam.

1.1 KEY CHALLENGES FOR ATOLL AGRICULTURE

As small, isolated islands, atoll countries are especially vulnerable to the impacts of climate change and sea level-rise, and to natural disasters such as cyclones and droughts. They have very poor soils, low biodiversity and poor-quality water. They also depend heavily on fossil fuel and have problems with waste management.

The capacity of these countries to adapt to climate change and other stressors is low. They generally have weak technical, financial and institutional capacity. They also lack adequate data for planning and decision-making.

Despite these challenges, atoll countries are committed to achieving food and nutrition security through adopting climate-smart agriculture practices based on soil health principles and improved technology.

2. ATOLL SOILS

Good crop growth on atolls is seriously constrained by the general infertility of the soils, which are unsuited to intensive agriculture. The extremely sandy texture of the soil promotes rapid drainage, low water-holding capacity, and little cation exchange capacity.[1]

The chemical properties of atoll soils have not been studied in detail. However, research to date shows that these soils are lacking in nutrients including nitrogen (N), phosphorus (P) and exchangeable potassium (K), and micronutrients such as copper (Cu), iron (Fe), manganese (Mn), boron (B) and zinc (Zn). (Phosphorus may be high in some places because of accumulation of bird guano, but crop growth still sometimes shows P deficiency.) This manual covers the effects of N, P, K and Fe deficiencies for each of the crop described and potential remedies.

Nitrogen is a component of amino acids and proteins, which are important as enzymes that catalyse chemical reactions in plant cells. It is also a component of nucleic acids in deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), which store and transmit genetic information.

Phosphorus, like nitrogen, is a component of nucleic acids. It is also a component of adenosine triphosphate (ATP), an important compound that is involved in energy transfer, powering metabolic activity within plant cells. In addition, phosphorus is a component of phospholipids in membranes that form the outer boundary of living tissues.

Potassium is the most abundant cation in plant tissues. It is required for maintaining plant turgidity, cell extension, and opening the pores in leaves for gas exchange. Potassium is also needed to provide the appropriate cellular environment for protein synthesis.

Iron is a component of proteins involved in oxidation-reduction reactions important for photosynthesis and other plant metabolic processes.

Soils that show these nutrient deficiencies, together with rapid drainage and low cation exchange capacity, require fertilisers to be added in small frequent doses. However, most atoll countries have policies regulating the application of inorganic sources of nutrients.

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1 A measure of the ability of soil to store and release nutrients such as calcium, magnesium, potassium, ammonium, hydrogen and sodium.

2.1 SOIL MANAGEMENT FOR ROOT CROP CULTIVATION ON ATOLLS

Good crop growth on atolls is seriously constrained by the general infertility of the soils, which are unsuited to intensive agriculture. The extremely sandy texture of the soil promotes rapid drainage, low water-holding capacity, and little cation exchange capacity.[2]

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Soil management on atolls should be implemented in two phases: (i) increase the soil depth to allow proper root development; and (ii) apply compost to supply crop nutrient requirements.

How to increase soil depth on atolls

The soil depth can be increased by:

- mounding soil on top of the surface (ridging);
- increasing soil depth down to the subsoil by applying compost down to 30–40 cm and mixing it well in the trenches or planting holes.

In a year with normal rainfall, or in a wet year, mounding will be useful, but if there is a drought, then increasing soil depth down to the subsoil by applying compost will give better results.

Type of compost

Simply applying compost may not meet the nutrient requirements of crops on atoll soils with many deficiencies. The compost must target the nutrients that are lacking. This means developing one or more compost 'recipes' or mixtures that include materials with high levels of the limiting nutrients (N, P, K, Fe, Cu, Mn, B and Zn), as shown in Table 1.

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2 A measure of the ability of soil to store and release nutrients such as calcium, magnesium, potassium, ammonium, hydrogen and sodium.

Table 1. Soil nutrients supplied by different compost ingredients ('best bets') (Source: Deans et al. 2018)

Nutrient	Compost ingredients (best bets)
N	sea cucumbers; fish meal; green leaves (chaya, drumstick, purslane, *Vigna*); manure; vegetable scraps
P	manure; ash (coconut husk, shell); green leaves (*Sida*, chaya, drumstick)
K	ash (coconut husk, shell); seaweed (not seagrass); green leaves (purslane, *Pisonia*); manure
Cu	ash (coconut husk, shell); manure; green leaves (purslane)
Mn	manure; ash (coconut husk, shell); green leaves (*Pisonia*, *Vigna*, castor weed)
Fe	manure; fish meal; ash; algae, seaweed; green leaves (purslane, *Vigna*, chaya); *rusty cans*
Zn	manure; ash (coconut husk, shell); fish meal; green leaves (purslane, hedge panax, *Sida*)
B	ash, algae and seaweed

Organic matter can help bind and stabilise soil particles in some weak soil structures. Microscopic fibres from decomposed plants, as well as the living filaments of soil fungi, can bind mineral particles together into aggregates. Larger pieces of partially decomposed plant material act as aggregates themselves, holding water and nutrients inside and allowing free drainage around them. Even after plant material is completely decomposed, there are organic compounds, such as tannins, that decay more slowly and help to bind soil particles together.

Soil fertility management

Soil fertility refers to the ability of a soil to support plant growth. It is a product of

- the soil's physical structure, which determines aeration, water-holding capacity and root penetration, and
- its chemical fertility, which determines its ability to supply essential nutrients to the plant.

Both the physical and chemical characteristics of soil tend to deteriorate as a result of the cultivation of crops and removal of harvested product. The fertility of atoll soils can be maintained by incorporating organic matter such as crop residue, animal manure and compost, and growing and incorporating green manure crops such as Mucuna pruriens and Vigna marina.

Caution is needed when adding animal manure to soil. It should be dehydrated or well-composted to kill any weed seeds it contains. If well-aged manure is not available, crops may require more weeding.

The physical and chemical characteristics of soil affect, and are affected by, the soil biology. A healthy soil has a balanced population of bacteria, fungi and tiny animals, which have direct and indirect effects on plant health. While soil biology is often overlooked, many problems associated with soil deterioration and soil-borne diseases are in fact linked to an imbalance in soil organisms. Preserving soil structure and organic matter levels is the best way to ensure a healthy soil ecosystem on atolls.

3 ROOT CROPS FOR ATOLLS

3.1 SWEET POTATO

Sweet potato (*Ipomoea batatas* (L.) Lam.) is a nutritious food crop that grows throughout the Pacific Islands including in atoll countries. The edible roots, or tubers (Fig. 1) may have white, red, purple, yellow or orange flesh. The orange-fleshed varieties have a higher sugar content and lower dry matter.

3.1.1 Land preparation and cultivation

Sweet potatoes grow best in high rainfall areas (1500 to 2500 mm/year). Higher rainfall may cause excessive vine and leaf growth at the expense of tubers. The crop grows well in a variety of well-drained soils from sandy to loamy soils but does not tolerate shade.

Tubers develop well in deep soil, which can be provided by either raising the beds or deepening the soil by digging trenches. Good drainage is very important. Shallow soil is likely to produce small, misshapen tubers. The soil should also have a good supply of nutrients, for example, from digging in mature compost. Fresh manure or fertilisers high in nitrogen (such as pelleted chicken manure) should not be used as they will result in more vine growth and no tubers.

Figure 1. Foliage and tubers of sweet potato

The topsoil should be turned over and compacted soil below should be loosened to provide a good tilth for forming the ridges or trenches and a soft, uniform medium for root growth. A shovel, or rotovator (if available), can be used. Loosening the soil increases the oxygen content, which favours the development of the microorganisms that decompose organic matter. Good land cultivation also helps control weeds.

After cultivation, trenches can be dug to 40 cm and compost mixed into the soil (15% compost or 1 shovel of compost per hill). Mounds, 30–40 cm high, can then be formed for planting, or planting may be done on the flat after the trenches are filled in and levelled (Fig. 2). Trenches are usually between 90 and 120 cm apart.

3.1.2 Planting materials

Vine or stem cuttings are normally used to plant sweet potatoes. Tubers can also be used.

Use of stem cuttings

Stem cuttings are taken from the crop before or just after tuber harvest. It is important to select ‘clean’ planting material that is free of insects, soil, and any symptoms of nutrient deficiency, viruses or fungal diseases. The apical, or tip part of the vine is best. This part is less likely to carry sweet potato weevils and fungi, and has been found to establish more quickly than middle or lower stem parts. If the vines are long, two to three further cuttings can be taken. Cuttings should be 20–40 cm long with 5–8 nodes. The number of nodes is more important than cutting length (Fig. 3).

Use of tubers

When there are not enough healthy vines available, tubers can be used to plant the next crop.

Healthy tubers should be selected from high-yielding plants (Fig. 3). The tubers should be planted close together in a seedbed separate from other sweet potato crops and covered with about 3–5 cm of soil, with the bed then mulched to keep in moisture. When the sprouts have grown long enough, they are cut near the base and planted directly in the field. To provide more cuttings, removing the tips of the sprouts when they are about 20 cm long will promote branching.

When yields begin to fall because of pests and diseases (after 4 to 5 years), clean tissue-culture plantlets should be used to start a clean, higher-yielding cycle of production.

3.1.3 Varieties

Several varieties/accessions are currently grown on the atolls:

Kiribati: PNG, Hawaii, PRAP, Banaba and an unknown; and introduced recently IB/PH/03, IB/PNG/29 (may be the same as PNG), and IB/US/18

Tuvalu: PNG, Hawaii, IB/PHL/003, 'pateta magalo kena' (Funafuti-white) and 'pateta kula' Funafuti red.

Marshall Islands: IB/PR/15, IB/US/12, IB/US/23, and IB/PNG/29 (locally called PNG)

The most popular variety is PNG, which grows well in all countries.

3.1.4 Planting

Sweet potato grows best in a season with both plenty of sunshine and enough water, either from rainfall or irrigation, to maintain soil moisture. With appropriate management, sweet potato can be grown throughout the year in many Pacific Islands.

Because sweet potato has a short growing season of between 90 and 120 days, it is suited to a multiple crop system, with planting time depending on the mix of crops and their requirements. Sweet potato can tolerate relatively low fertility and may be planted after more demanding crops, including yam, taro, chili and other vegetables.

Sweet potato can be planted in several ways:

- In **single mounds**, 40 cm wide and 40 cm high, made from soil mixed with compost. Two cuttings, about 30 cm long, are inserted in each mound. A stick can be used to make the planting hole.
- On a **ridge** 40 cm wide and 40 cm high, with growers deciding the length of the ridge. Single cuttings are planted along the ridge at spacings of 30 cm. Ridges are spaced about 1 m apart.
- In **single planting holes**, 40 cm x 40 cm x 40 cm, filled with a mixture of soil and compost and planted with two cuttings.
- In **trenches**, 40 cm wide and 40 cm deep, filled with a mix of soil and compost and then levelled with the surrounding soil. Trenches should be 1 m apart. Single cuttings are planted along the trench at spaces of 30 cm.

Usually, a third to two-thirds of the cutting is buried in the mound or trench, with at least 2–3 nodes, but up to about 8 nodes placed under the soil.

Some growers plant two cuttings at each station, but there is little evidence that this improves yield. Some reports suggest that single cuttings produce a higher number of large storage roots..

3.1.5 Crop management

Water and irrigation

Sweet potato is known as a relatively drought-tolerant crop. It is most commonly grown under suitable rainfall conditions, or with irrigation in seasons where enough irrigation water is available for other crops as well.

Sweet potato crops perform best when the soil is constantly moist. Moist conditions are required after planting until the root system is well developed. Plants can then tolerate brief dry spells and they recover well when the soil is again moist. However, long spells of dry conditions restrict the development of roots and limit photosynthetic ability, producing a stunted crop with tubers likely to be shorter or misshapen.

High soil temperatures, which can occur in dry conditions, may damage root development.

On atolls, maintaining soil organic matter is probably the most important practice for managing the water supply. Organic matter in the soil helps it to hold more water and stay moist for longer. Applying plant mulches to the surface of the soil also helps to reduce surface evaporation and keep the soil temperature even.

Figure 2. (left to right) Mounds formed after mixing in compost; compost applied to trenches; single mounds formed after mixing in compost; and planting holes after applying compost to a depth of about 40 cm.

Where irrigation is available, atoll (sandy) soils require frequent irrigation or more organic matter content. Light-textured soils require less water to wet them through but are more prone to leaching and run-off. Crops need much more water in clear, hot and/or windy weather than in still, overcast conditions.

Weed control

Early-season weed control is critical. Growers should plan a total weed control programme in the first two months before the crop canopy closes. On atolls, weeding should be done with a hoe or by hand.

Vine lifting

Many varieties of sweet potato have long vines that trail over the soil surface. When vine stems come in contact with moist soil, roots may grow from the nodes and small tubers may also form at these nodes. These tubers are unmarketable but they take up crop water and nutrients, reducing the yield of marketable tubers. To prevent this waste, vines should be lifted to break roots growing at the nodes and dry them out. Vines should not be turned over because leaves in contact with the soil may rot.

Lifting is usually done once or twice during the crop season. For crops planted on the flat (in single planting holes and trenches), at the first lifting, soil should be mounded around the base of each plant (Fig. 4). Growers should regularly check whether roots are forming from vine nodes and decide if they need to invest time and labour in vine lifting.

Figure 3. Cuttings and tubers for planting materials.

Vine harvesting

Sweet potato vines can be used as feed for small livestock such as pigs, with vines being harvested several times in the second half of the growing season. However, this practice is likely to reduce the yield of storage roots, with the effects depending on the quantity of vines taken, crop variety, soil fertility and weather. Interested growers can experiment with sections of their crop to examine how much vine harvesting is possible while still giving good tuber yield.

Vine harvesting usually starts 50 days after planting or when the beds are covered by vines. Two or three of the longest vines per plant can be taken, leaving about 15-cm-long vines. Vines may then be harvested in the same way every 10–15 days.

3.1.6 Nutrient deficiencies and plant disorders

Nutritional disorders

Soil nutrient deficiencies reduce crop growth rates and yield. The problem can be treated by increasing the supply of the missing nutrients. However, accurate assessment of nutritional deficiencies and diagnosis of the resulting disorders are important because supplying more nutrients than the crop requires is costly and has no benefits.

Deficiencies of macronutrients, particularly N, P and K, are often associated with decreased fertility, especially after sequential cropping. There may be low natural abundance of macronutrients in the soil, or the soil conditions may mean they are insoluble.

Figure 4. Lifting sweet potato vines

The most common nutrient disorders on atolls are described below.

Nitrogen (N)

Nitrogen deficiency is very common, especially on sandy soils, soils with little organic matter, and any soils that have been repeatedly cropped without replacing nitrogen.

Symptoms. Plants that lack N grow slowly and have small, pale green, dull leaves. Red pigmentation increases on the petioles (leaf stalks) and veins of young leaves and may be more easily seen on the leaf underside. Older leaves may die early, usually turning yellow before wilting and drying (Fig. 5). Nitrogen-deficient plants grow slowly and have small, pale green, dull leaves. In many cultivars, red pigmentation is increased on the petioles and veins of young leaves; this may be more visible on the underside of the leaf. The oldest leaves may die prematurely as their nitrogen is remobilized for new growth. They usually turn uniformly yellow before wilting and drying (Fig 5).

Figure 5. (left) Nitrogen deficiency shows in leaf, which is smaller, paler and duller than the healthy leaf; and (right) yellowing, wilting and drying of oldest leaves. (Photos adopted from O'Sullivan et al. 1997)

Phosphorus (P)

Phosphorus compounds in the soil have low solubility, which means only a small proportion of P is available to plants and it is often the most limiting nutrient for plant growth. Many plants, including sweet potato, form a symbiotic association with root-infecting fungi (known as mycorrhizae), which increases their ability to extract P from the soil.

Symptoms

P deficiency can reduce plant growth considerably before symptoms become obvious. Growers may first notice a darker than normal colour and poor growth rate. In many cultivars, the first noticeable symptom is red-brown or purple pigmentation on older leaves. As these leaves start to die, they begin to yellow unevenly from scattered spots, the tip, or one half of the leaf (Fig. 6). Yellow and orange hues combined with the purple pigmentation may give the appearance of autumn colours.

Figure 6. (left) Symptoms of phosphorus deficiency include development of red-brown or purple pigmentation of leaves. (right) Uneven yellowing develops as the oldest leaves die. (Photo from O'Sullivan et al. 1997)

Potassium (K)

Sandy soils are often deficient in K. Root crops, including sweet potato, remove much more K from the soil in comparison to cereal or pulse crops. A sweet potato crop that produces 15 tonnes/hectare removes around 80 kg/ha of K. Removing the vines as well results in a further loss of 30–50 kg/ha. K deficiency is common in soils where there has been continuous cropping without any addition of K.

Symptoms

Symptoms often become visible when the crop is a few months old and tuber development places increasing demand on the supply of K. The first signs may show on mature leaves, with light green chlorosis between the leaf veins. The oldest leaves yellow, particularly around the edges and between the main veins (Fig. 7). The yellow tissue dies, turning brown and brittle.

Figure 7. With potassium deficiency, older leaves become yellow, particularly between leaf veins. (O'Sullivan et al. 1997).

Because iron becomes less soluble with increasingly alkaline soils (that is, as pH increases above 7), iron deficiency is common in atoll soil. It may also be a secondary symptom of other disorders, such as calcium deficiency and heavy metal toxicity.

Symptoms

Symptoms of iron deficiency are obvious. Young leaves are yellow or almost white, with green veins standing out in contrast. If the deficiency is severe, the young leaves wilt and the tip and axillary buds may die (Fig. 8).

Figure 8. With iron deficiency, young leaves become yellow (left) then almost white (middle); and (right) in severe cases, young leaves wilt and die. (Photos centre and right from O'Sullivan et al. 1997)

Correcting nutrient deficiencies

For atoll soils, where use of inorganic sources of nutrients is discouraged, the best measure for correcting nutrition disorders is to use targeted compost or add any organic matter that is available.

3.1.7 Controlling pests and diseases

Insect pests and diseases can severely restrict sweet potato production, reducing both the yield and quality of tubers. Though atolls experience fewer pest problems, sweet potato weevil and leaf scab have been observed in Pacific Island countries.

Sweet potato weevil

Sweet potato weevil (*Cylas formicarius*) is regarded as the most important pest of sweet potato (Fig. 9). Infestation may be worse during dry seasons.

Damage

Adult weevils feed on the buds, leaves, vines and tubers. More severe damage is caused by the larvae, which tunnel into mature stems and tubers, leaving small punctures on the surface and tunnels filled with frass. Stems thicken, dry and crack, leaving them open to secondary infection by bacteria and fungi. Infested tubers are unfit for human or animal consumption, even if most of the tuber is undamaged. Terpines produced by the damaged tissue give the flesh an unpleasant smell and bitter taste. The effects of weevil damage increase during storage.

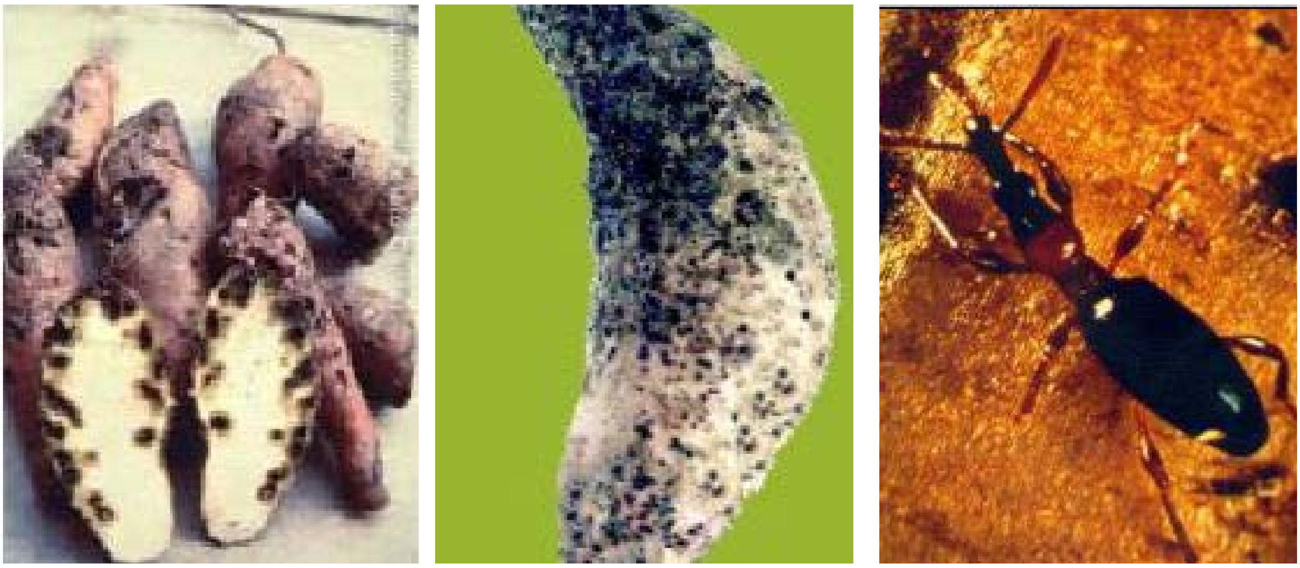

Figure 9. (left) Tubers damaged by sweet potato weevil; (right) an adult weevil. (Photos from O'Sullivan et al. 2012)

Leaf scab

Leaf scab, caused by a fungus called *Elsinoe batatas,* is the most severe fungal disease of sweet potato in South East Asia and the Pacific. Infestation at an early stage of crop growth severely reduces the yield of marketable roots.

Symptoms

The initial symptoms appear as tiny spots or lesions on the leaves and stem. These spots may be circular, elliptical or elongate, and yellow to reddish brown in colour. The spots may be sunken at first, but they become raised and scabby as they spread and join together. The leaf veins on the underside are most commonly infected. When infection occurs on expanded leaves, there is no leaf deformity, but when newly formed leaves are infected, they become distorted. The tissue stops growing and leaves are cup-shaped and shrivelled (Fig. 10).

Figure 10. (left and centre) Symptoms of leaf scab on sweet potato, with tiny spots or lesions on leaves and stems; (right) and leaves that have become cupped and shrivelled. (Photos from O'Sullivan et al. 2012)

Cultural control

The following cultural methods are useful for controlling or reducing pest and disease damage of sweet potato crops:

- Choose cultivars with resistance or tolerance to pests and diseases.
- Use clean planting materials, that is, vine cuttings that are free of soil, insects, insect eggs or insects, and disease symptoms. It is good practice to set up a separate nursery for producing planting material to ensure a supply of cleaner roots or cuttings.
- Practise good field hygiene. Remove all crop residues for use in compost or livestock feed, and all weed species to reduce the build-up of pests and diseases.
- Rotate crops to also avoid build-up of pests and diseases. Sweet potato can be planted before or after vegetables or cereals.
- Mounding up soil around the base of plants reduces weeds and protects roots from weevil infestation.
- Mulching with available materials can reduce weevil populations and weeds.
- Prompt harvesting is useful in managing sweet potato weevils, which build up when harvesting is delayed, especially in dry periods.

3.1.8 Harvesting

Sweet potato tubers may be harvested all at once or in stages. A single harvest is common for commercial growers, while semi-commercial and subsistence growers harvest in stages, or selectively. In this type of harvesting, growers take larger tubers, leaving the small ones to grow further, or take only enough tubers to meet household needs.

Crops planted at different intervals may be harvested in sequence to provide a regular supply of tubers for marketing over a longer time.

3.2 TARO

Taro (*Colocasia esculenta* (L.) Schott) is a staple root crop in tropical areas including Pacific Island countries. While there are eight recognised variants of common taro, only two are usually cultivated. Most of the taro grown in the Pacific is *C. esculenta* (L.) Schott var. *esculenta* (also known as 'dasheen' taro) which has a large central corm. *C. esculenta* (L.) Schott var. *antiquorum* is often preferred in places where taro is grown primarily for leaves because it has a central corm with several relatively large 'cormels' surrounding it. Colocasia taro is susceptible to some pests and diseases including taro leaf blight, plant leaf hoppers, caterpillars and mites.

Corms are harvested 8–12 months after planting (Fig. 11). They have a relatively short storage life of around two weeks post harvest.

Taro grows in areas ranging from sea level to elevations up to 1800 m with daily average temperatures of 21–27°C and annual rainfall of 2500 mm. In dry areas, it is usually planted with a wide spacing of 1 m x 1 m, at 10,000 plants/ha. In wetland areas, spacing is closer at 45 cm x 45 cm or around 49,000 plants/ha.

Figure 11. (left) Taro plants and (right) harvested tubers.

3.2.1 Land preparation and cultivation

The best way to prepare land for taro cultivation on atolls is to dig a trench to 40 cm depth and mix soil with compost at ratio of 1:4 to 1:2, or 2 shovels of compost per planting hole. The trench or planting hole is then backfilled before planting.

Trenches should be about 1 m apart with plant spacing along the trench of 50–90 cm. Taro cultivation on atolls should include intercropping to provide some pest and disease protection, although sole cropping rather than mixed cropping can be done.

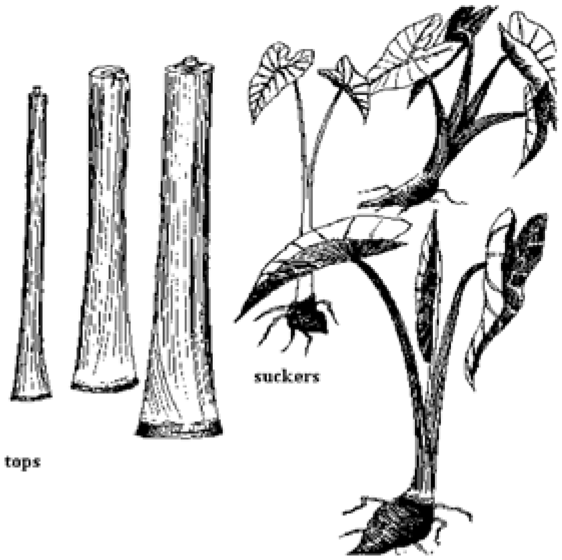

Figure 12. Taro planting material – taro tops and suckers. Source: University of Queensland http://www.uq.edu.au/_School_Science_Lessons/TaroProj.html

3.2.2 Planting material

Taro is propagated vegetatively, and headsetts (sometimes called tops) or large suckers are the best planting material (Fig. 12). These contain the apical bud and have rapid early growth and a high rate of survival. Small, unmarketable corms resulting from the main plant in the previous crop, and small pieces cut from large corms can also be used as planting material. cut into small pieces can also be used as planting materials.

Varieties

There are not many varieties of taro grown on atolls but those available do well.

Kiribati*:* Because of the taro beetle, taro is being promoted in the outer islands. There are three local red, green and white-stemmed cultivars and newly introduced accessions – BC/PNG/13, BC/SM/80 and BC/SM/152. An evaluation in Tab North showed BC/SM/80 was the best variety.

Tuvalu: Taro uli (Fiji), taro kula, taro kena and Manua are the common varieties grown in Tuvalu.

Marshall Islands: The two most commonly cultivated varieties are a red-stemmed variety and a green-stemmed variety.

3.2.3 Planting

Trenches or planting holes are prepared before planting taro setts or suckers to a depth of 30–40 cm using a digging stick or spade (Fig. 13).

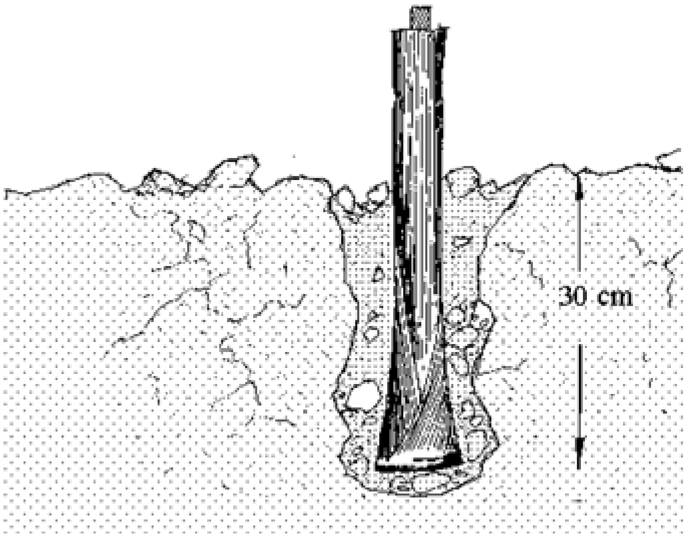

Figure 13. Taro suckers planted to the bottom of the planting hole. Source: University of Queensland http://www.uq.edu.au/_School_Science_Lessons/TaroProj.html

3.2.4 Water management

As taro is prone to drought, irrigation may be essential for production. It requires a good supply of water up to 20 to 25 weeks. Even a two-week drought may affect yield. Prolonged dry conditions will restrict root development and limit photosynthetic ability, resulting in a stunted crop.

When taro cultivation depends on rainfall, timing of planting is critical. The crop must be planted at the start of the rainy season, which has to last long enough for the crop to mature (6–9 months).

On atolls, it is essential to maintain soil organic matter to make best use of the water supplied by rainfall.

3.2.5 Weeding

In the first three months of the crop, weeds should be controlled. On atolls, this is usually done using hand tools. It is important to keep tools to the surface to avoid damaging the taro roots, which are very shallow. To protect young corms, soil can be earthed up around the plant base during weeding. Weeding is not needed after the crop canopy closes.

3.2.6 Nutritional disorders

Nitrogen (N)

Symptoms

Taro plants deficient in N have stunted roots, main shoots, and suckers. Older leaves show yellowing, with all leaves turning yellow as the deficiency progresses (Fig. 14). Early death of older leaves may result in fewer active leaf blades, which reduces growth and crop yield.

Figure 14. Taro leaves showing effects of nitrogen deficiency.

Phosphorus

Phosphorus, like nitrogen, is a component of nucleic acids. It is also a component of adenosine triphosphate (ATP), an important compound that is involved in energy transfer, powering metabolic activity within plant cells. In addition, P is a component of phospholipids in membranes that form the outer boundary of living tissues.

Symptoms: Phosphorus deficient taro plants have stunted root and shoot growth. Older leaf blades may appear darker green due to greater retardation of leaf expansion relative to chlorophyll (green pigment) reduction. In some cultivars, phosphorus deficiency is characterized by light-coloured dots on the surface of leaf blades. As the deficiency progresses, areas of the leaf margins begin to yellow and turn brown

Figure 15. (left) Signs of phosphorus deficiency in taro plants, with older leaves appearing darker green, and (right) some showing light-coloured dots on the leaf surface. (From Miyasaka et al. 2002)

Potassium (K)

Symptoms

Taro that is deficient in K shows slower growth, tends to wilt, has smaller leaves, and has apparent scorching between the veins or around the edges of the leaf (Fig. 16) Iron is a component of proteins involved in oxidation reduction reactions important for photosynthesis and metabolism.

Iron (Fe)

Figure 16. Symptoms of potassium deficiency in taro starting with scorching at leaf edges, which then moves in between the veins.

Symptoms

Taro that lacks iron initially shows yellowing between the veins of younger leaf blades (Fig. 17). As the deficiency progresses, younger leaves become bleached. Lateral root formation is also depressed.

Treatment

Figure 17. Iron deficiency symptoms, with (left) younger taro leaf blades showing yellowing between veins and (right) becoming white when the deficiency is severe. (From Miyasaka et al. 2002)

Deficiencies can be corrected by using targeted compost, green manure crops such as *Vigna marina*, and animal manures.

3.2.7 Pests and diseases

Taro production in the Pacific region, including in atoll islands, is currently under the stranglehold of one pest – **taro beetle** – and one disease – **taro leaf blight**. Both are serious threats to the taro industry.

Taro beetle

Adult taro beetles damage the underground corms by chewing and burrowing into them, creating tunnels (Fig. 18). These beetles create large cavities, which allow secondary rots to develop, resulting in low-quality corms for consumption.

Figure 18. (left) Damage to corms caused by taro beetle, and (right) an adult taro beetle. (Photos from PestNet Pacific Pests and Pathogens Factsheets: Taro Papuana Beetle (030), 2017)

Control measures

Avoid moving taro corms, planting material and other taro beetle host plants from taro beetle-infested areas to non-infested areas. Numerous efforts have been made to develop effective control measures for the taro beetle. These include:

cultural control, using crop rotation and clean planting material (free from soil, grubs and beetles), and destroying breeding sites beside taro gardens;

biological control. The fungus, *Metarhizium*, works under experimental conditions, but has not yet been recommended for farmers. A virus has been tried without success.

Taro leaf blight

Taro leaf blight (TLB) is caused by a fungus called *Phytophthora*. The first sign of the disease is a small circular speck, brown on the upper leaf surface and water-soaked below. Infection often begins on the lobes where water droplets accumulate. The circle of spores begins to enlarge and become irregular in shape and a dark brown with yellow margins (Fig. 19). The initial spots give rise to secondary

Figure 19. Effects of taro leaf blight (left) showing the spreading of spores, and (right) spots of taro leaf blight at the margin and inside the leaf blade. (Photos from PestNet Pacific Pests and Pathogens Factsheets: Taro leaf blight (014), 2017)

infection and most of the leaf blade is colonised rapidly.

Control measures

Cultural methods can be tried, but they are often not effective. They include:

- making new gardens at a distance from old ones
- regularly cutting off infected leaves, and
- harvesting when the leaves are dry; otherwise, spores may infect the ends of the leaf stalks when they are cut as ‘tops’ for the next crop.

TLB-resistant varieties of taro are now available following successful breeding programmes in Papua New Guinea and Samoa. These can be obtained from the Pacific Community’s Centre for Pacific Crops and Trees (SPC CePaCT) in Suva.

3.2.8 Harvesting

Taro planted on dryland takes from 5 to 12 months to be ready for harvesting, with the length of time depending on the cultivar and seasonal conditions. Signs of readiness for harvest include a decline in the height of the plants and general leaf yellowing.

Harvesting is usually done by hand, even in more mechanised systems. Hand tools are used to loosen the soil around the corm, which is then pulled up by grabbing the base of the stalk.

3.3. CASSAVA

Cassava was introduced to the Pacific more recently than other root crops. It is easy to grow and prepare and is popular for both human consumption and for livestock fodder. The leaves are also edible.

Cassava grows best when rainfall is around 1000–1500 mm annually. Too much rain can reduce tuber growth. The plant is tolerant of drought and can be grown in areas with annual rainfall of around 500 mm, though yields will be lower. It can grow in relatively infertile soils and is often used as a final crop in rotations before land is left to fallow. Cassava competes well with weeds but is sensitive to shade (Fig. 20).


Figure 20. (left) Cassava plants and (right) tubers.

3.3.1 Land preparation and cultivation

The best way to prepare land for growing cassava is to dig a trench and fill it with a mixture of compost and soil. Trenches should be 1 m apart with plant spacing of 50 cm along the trench (Fig. 21).


Figure 21. (left) Trenches with compost applied, and (right) after planting cassava.

3.3.2 Planting materials

Cassava is propagated using stem cuttings taken from strong, healthy plants that have already produced tubers. After harvest, selected stems should be stored in bundles in a cool dry area for at least 10 days before planting. Cuttings are only made at the time of planting. Each cutting should be 20 to 30 centimetres long with 4 to 6 growth buds. Most stems provide 4 or 5 cuttings.

Varieties

In all three atoll islands, white and yellow-fleshed varieties of cassava are grown. These varieties were introduced in the 1980s.

3.3.3 Planting

Cuttings are planted on mounds/ridges or in trenches by placing them either straight or slanting, leaving 2 or 3 buds above ground, or burying them horizontally (Fig. 22) and pressing the soil around them. Planting should be done when the soil is quite wet, after the beginning of the rainy season.

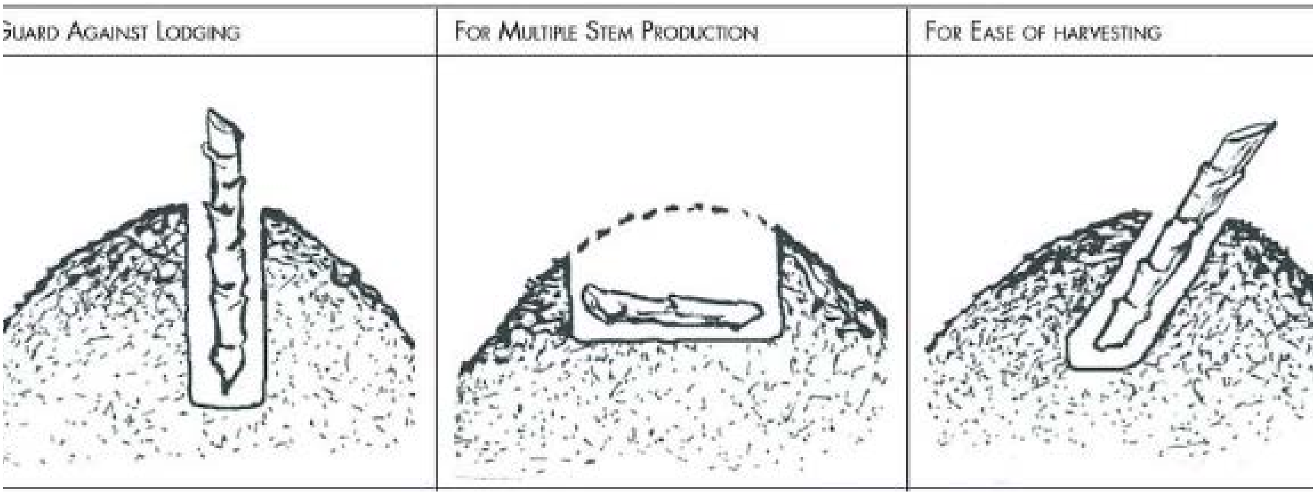

Figure 22. Three ways to plant cassava. (Diagram from Amponsah et al. 2017)

Rows should be spaced 1 to 1.5 m apart, with 1 m between each plant along the row. This spacing gives a density of 7000–10,000 plants/ha. Planting at the right density results in good yields and reduces weeds, requiring less cultivation.

3.3.4 Weeding

Weeding should be done 3 or 4 weeks after planting when the cassava plants are around 20–25 cm high. A second weeding can be done 1–2 months later. The plants can be earthed up at the same time to help tuber formation and stop them blowing over in windy conditions. No further weeding should be necessary. However, the plants may need re-mounding after rain, with a hoe used to break up hardened soil to ensure water and air reaches the roots.

3.3.5 Nutrition disorders

Nitrogen (N) deficiency

N deficiency reduces plant growth. In some cultivars, there may be uniform yellowing of leaves, first of lower leaves then of all leaves (Fig. 23).

Figure 23. Nitrogen deficiency symptoms in cassava, showing uniform yellowing of leaves. (Photos from Alvarez et al. 2012)

Phosphorus (P) deficiency

P deficiency reduces plant growth, resulting in small leaves and thin stems. In severe conditions, lower leaves yellow and wither before dropping off (Fig. 24).

Figure 24. Symptoms of phosphorus deficiency in cassava, with yellowing and eventual loss of lower leaves.

Potassium (K) deficiency

K deficiency also reduces plant growth and results in smaller leaves. In severe conditions, symptoms include purple spotting, yellowing and necrosis of tips and margins of lower leaves, and necrosis and fine cracks in stems (Fig. 25).

Figure 25. Cassava leaf showing symptoms of potassium deficiency. (Photo from Asher et al. 1980)

Iron (Fe) deficiency

Symptoms of Fe deficiency include uniform yellowing of upper leaves and petioles, which whiten under severe conditions, and reduced plant growth with young leaves being small though not deformed (Fig. 26).

Figure 26. Iron deficiency symptoms in cassava.

Control

Nutrient deficiencies can be controlled by applying targeted compost, green manure crops, animal manure or any organic waste.

3.3.6 Pests and diseases

On atolls, there are no major pests of cassava except possibly rodents (rats) and pigs.

3.3.7 Harvesting

Depending on the variety, cassava can be harvested for food 6 months after planting (early varieties), or after 10 months (late varieties). At harvest time (between 6–12 months), mature cassava tubers weigh from 1 to 2 kg, depending on the variety.

Cassava is usually harvested by hand. The roots are pulled out of the ground, then removed from the base of the plant by hand. At the same time, cuttings for the next crop are chosen. The cuttings must not be allowed to dry out before planting.

3.3.8 Storage

Cassava roots begin to spoil as soon as they are pulled out. They keep longer when left in the ground as long as the soil is not too wet. Harvested cassava can be peeled and frozen.

3.4 YAMS

Yams (genus *Dioscorea*) are a high-value food. They are easily grown and mature quickly in the right soil conditions. Unlike most other tropical root crops, yams have good keeping qualities and may be harvested well before eating.

Most varieties of yams grow best in rainfall of >1500 mm/year and require a minimum 6-month growing season with well-distributed rainfall. Yams do not tolerate poorly drained soils or waterlogging. The best soils for growing yams are sandy clay loams. However, they can be cultivated on most soil types if the planting holes are properly dug and filled with organic material.

Yams are mildly drought tolerant but do not compete well with weeds for soil nutrients. They should be staked to improve yield and reduce weed competition and the incidence of anthracnose disease. They tolerate shade in the early stages during establishment but require full sun for good yield (Fig. 27).

Figure 27. (left) Dioscorea alata, (centre) D. rotundata and (right) D. alata tubers.

3.4.1 Land preparation

All grass, brush and trees should be cleared from the land and then the soil should be tilled with hand tools (shovel and spade), or a rotovator if available.

Planting holes, 30 cm x 30 cm x 50 cm, should be filled with a mixture of rotted organic matter (compost) and soil at a ratio of 1:4 to 1:2. One yam sett is planted in each hole (Fig. 28).

Figure 28. (left) Preparation of land for planting yams, (centre) planting hole, and (right) early crop stages.

3.4.2 Planting material

On atolls, yams can be propagated in two ways.

1. **Tubers**: This is the most important method of propagation in the field. Tubers used for planting should be selected from the previous crop. They should be healthy and disease free. The planting material is called a 'sett' and the size of each sett should be between 400 and 500 g. Setts can be pre-germinated in moist sawdust or coconut coir.

Three types of setts (400–500g) can be obtained from a whole tuber (Fig. 29):

- Head setts – these are the best yam setts to plant because this is the location of the eye, which gives rise to the new plants
- Middle setts
- Tail setts

Whole tubers can also be planted.

2. **Tissue culture**, which is used to produce 'clean' plantlets (disease-free).

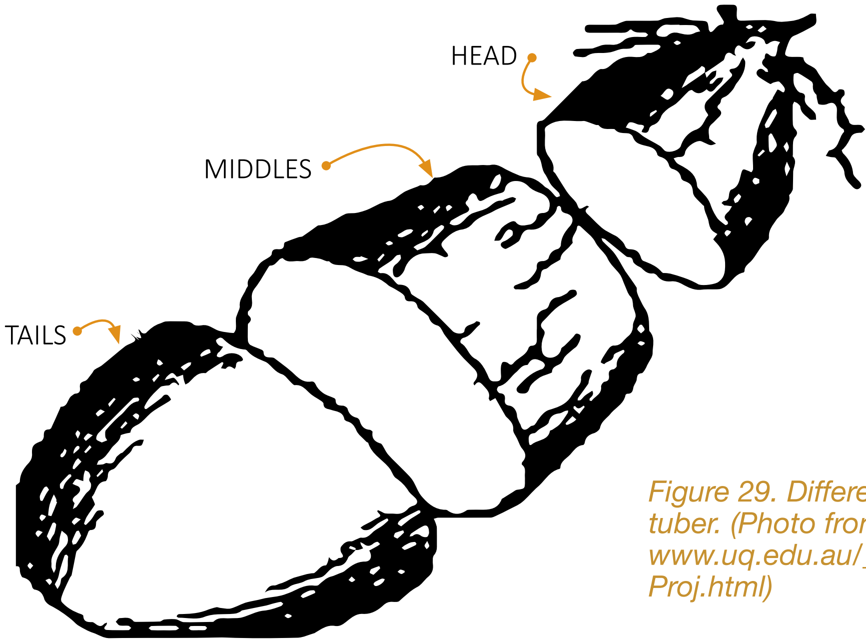

Figure 29. Different yam setts cut from the mother tuber. (Photo from University of Queensland http://www.uq.edu.au/_School_Science_Lessons/Yam-Proj.html)

Pre-germinating the yam setts

In Tonga, a traditional pre-germination method called 'fakamao' is used. After the yam is cut into setts, an 'umu' pit is dug and a stick is placed in the middle of the pit. The umu pit is lined with dried banana leaves and then the planting material (setts) is arranged in the pit. Every few layers are covered with dried banana leaves (Fig. 30). This process is repeated until all the planting material is in the umu pit. Then the pit is covered with soil. After a day, the stick is removed, which allows hot air to escape from the pit. The heat disinfects the planting material. The pit is left closed until the setts all germinate. This reduces the time taken for a field of yam to germinate. With this method, a whole field will germinate in a week or two.

Figure 30. Various steps in Tonga's traditional 'fakamao' process for pre-germinating yam setts.

Varieties

Dioscorea rotundata is recommended for Kiribati, Tuvalu and Marshall Islands as this yam variety is better adapted to atoll conditions. However, with good organic matter management, *D. alata* can also be grown.

3.4.3 Planting

Because of the nutrient limitations of atoll soils, the best planting method is to prepare planting holes as described above (Section 3.4.1). One sett is planted per hole. It should be placed just below the soil surface (about 5 cm) with soil then mounded over the hole. Spacing should be 1 m between rows and 1 m within rows.

3.4.4 Staking

Yams must be staked to expose the massive leaf canopy to full sunlight throughout its growth (Fig. 31).

A wire trellis can be strung between two strong posts and each stem trailed along a string towards the wire support. More simply, tree branches can be cut and thrown over the yam mound. When the yam setts emerge, they climb over the branches.

Figure 31. Different methods for staking yams.

3.4.5 Weeds

Controlling weeds for the first 6–8 weeks after planting is important. Weeding should be done regularly using push or pull hoes or by hand. Yam crops should not be weeded when wet as this may result in anthracnose infestation.

3.4.6 Nutritional disorders

Nitrogen (N)

N is needed in large amounts by plants but is normally scarce in soil minerals. Most of the air we breathe is N gas, but in this form it is not usable by plants. A small number of microbes have the ability to transform this N into usable forms (biological N fixation). Most traditional agriculture depends on biological N fixation by *Rhizobium* bacteria, which live in the root nodules of leguminous plants. N fixation requires a lot of energy and the legume supplies energy to the bacteria in return for N.

Symptoms

The primary symptom of N deficiency is a dull, light-green foliage colour. The colour may be uniform, but there is often a slightly darker green colour on and around the main veins of the leaf (Fig. 32). Mature leaves may be smaller.

Figure 32. Symptoms of nitrogen deficiency in yam, showing leaves with a dull light-green colour and darker green along veins. (Photos from O'Sullivan 2010)

Phosphorus (P)

Plants need P in much smaller quantities than N, but the P in soils is often very tightly bound and difficult for plants to take up. On atolls, P may be adsorbed by calcium carbonate or precipitated as calcium phosphate.

Symptoms

Moderate P deficiency causes reduced growth but there are no apparent symptoms. Leaves may be darker green than in healthy plants. Tuber yield may be adversely affected before symptoms are visible.

With more severe P deficiency, leaves show specific symptoms. There may be shorter internodes and leaves may curl downwards. They may be light green to yellow or may develop bleached white patches between the veins (Fig. 33).

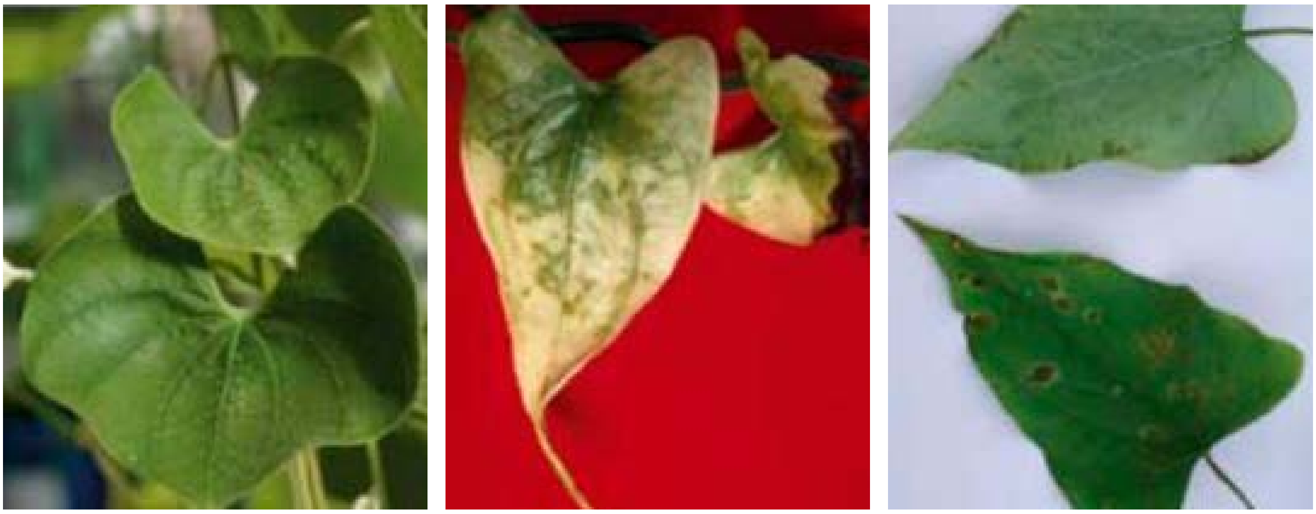

Figure 33. Yam leaves showing symptoms of phosphorus deficiency. (Photos from O'Sullivan 2010)

Potassium (K)

On atolls, K deficiency occurs commonly because of low K levels in the soil and low cation exchange capacity (CEC). A low CEC means low availability of K and poor ability to retain added K. Plants need about as much K as N.

Symptoms

K-deficient crops are generally a lighter shade of green than healthy crops, but specific symptoms may not be present. Young mature leaves usually show chlorosis (yellowing) symptoms most distinctly.

Premature senescence of the oldest leaves is usually characteristic of K deficiency, but in yams, this may not be evident until tuber filling begins. At this stage, the lowest leaves may rapidly develop a light-brown necrosis that spreads from the tips and margins of leaf blades (Fig. 34).

Figure 34. Yam leaves showing potassium deficiency. (Photos from O'Sullivan 2010)

Iron (Fe)

Fe is usually limiting on atolls. Deficiencies often occur in soils with high pH, such as those formed on coral limestone. Symptoms of Fe deficiency are very common on atoll and coastal soils affected by lime.

Symptoms

With Fe deficiency, the young leaves become chlorotic – initially yellowish-green with darker green veins. Young mature leaves may be the first to show symptoms, generally displaying a network of greener veins on a pale leaf (Fig. 35). This vein pattern tends to be more distinct on *D. alata* and *D. esculenta* than on *D. rotundata.*

Figure 35. Yam leaves showing symptoms of iron deficiency (Photos from O'Sullivan 2010)

Control

The best control is to ensure that plenty of organic matter is mixed into the planting holes or trenches. Targeted compost, green manure crops, and animal manure should be used.

3.4.7 Pests and diseases

In yam crops, the major disease problem is anthracnose, *Colletotrichum gloeosporioides* (Penz.). Anthracnose is normally seen as small black spots between the leaf veins. Some infections join together to form massive lesions (Fig. 36).

Figure 36. Symptoms of anthracnose in yam. (Photos from SPC Pest Advisory Leaflet No. 12, 2002)

Control

Anthracnose can be managed using several cultural practices:

1. Encourage healthy plants by ensuring adequate levels of nutrients.
2. Sanitise the field by raking and removing fallen leaves prior to cultivation to reduce the source of inoculum (spores of the fungus).
3. Practise crop rotation.
4. Intercrop with corn. The corn crop helps to move the spores up and away from the yam leaves, reducing the infection rate.
5. Use windbreaks on the windward side of the crop.
6. Inspect the field continuously and rogue out infected plants, especially on the windward side of the field.

3.4.8 Harvesting

Yams mature between 9 and 10 months after planting. Signs of maturity are yellowing of the leaves and natural dieback of the vines. After the vines have been removed, the tubers are lifted using hand forks or with a digging spade, with care taken to do as little damage as possible to the tubers. They should be stored in a cool storage shed to cure well.

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