PHYSIOLOGICAL AND GROWTH RESPONSES OF SELECTED SWEET POTATO (*Ipomoea batatas* (L.) Lam.) CULTIVARS TO WATER STRESS

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ABSTRACT

Drought is one of the most serious environmental problems affecting sweet potato (*Ipomoea batatas* (L.) Lam.) growth and yield in many tropical countries including Highland Papua of Eastern Indonesia, where it is grown as a staple crop under rainfed conditions. Some genotypes survive during drought, while many others fail. This condition regularly devastates sweet potato growth and threatens the lives of highland Papuan people. On the other hand, research into the effects of drought and on the growth, yield, and water relations of sweet potato remains limited. A series of pot and field trials therefore was conducted to identify the drought tolerance of sweet potato cultivars available in Australia. The influence of soil water regimes on the physiology, growth, and yield of sweet potato was studied to determine the critical soil water levels that sweet potato could tolerate and produce acceptable yields. The influence of nutrient supply (N and K) on water use efficiency in sweet potato was also studied. A grafting trial was carried out to examine the nature of the physiological signal between shoot and root in relation to transpiration efficiency and yield responses in sweet potato.

The cultivars Lole and Hawaii showed more strongly developed drought resistant characters than all of the other cultivars. They have better water use efficiency, maintain higher plant water status under drought stress by delaying wilting, and lower percentage decrease in leaf water potential indicating their greater tolerance to water stress at the stage of vegetative growth.

Field trials were conducted to determine tuber yields from the same 15 sweet potato cultivars under well-watered conditions. The Lole and Hawaii cultivars produced low

tuber yields, whereas the Beerwah Gold and Wanmun cultivars produced the greatest yields when not water stressed.

The Lole cultivar representing the vegetative tolerant and Wanmun cv representing the susceptible genotypes were grown in a glasshouse to observe the degree to which sweet potato cultivars could withstand water stress conditions and still produce good tuber yields. The Wanmun cultivar, which grew and produced good yields under well-watered conditions, was strongly affected by water stress. On the other hand, the Lole cultivar showed more drought tolerance, indicated by greater plant water status, including leaf water potential and relative water contents. At maturity, tuber sucrose contents increased while the starch contents decreased. Under drought conditions, cv Lole tubers had higher sucrose and lower starch contents than cv Wanmun. Tuber yields were greater in cv Wanmun when not stressed; Lole on the other hand produced marketable tuber size when water was restricted to ≥ 40% of soil field capacity. The overall results suggested greater drought tolerance of the Lole cultivar.

Results of a study of the influence of nitrogen and potassium on water stress and productivity showed that a greater nitrogen supply resulted in greater shoot dry weight, leaf weight, and leaf area. Increasing the soil nitrogen content beyond 100 kg per ha reduced tuber yields, due to greater top growth and inefficient carbon translocation for tuber development. Low soil nitrogen contents (20 kg of N/ha), on the other hand, lowered the biomass production, reducing tuber formation and development. Potassium had a significant effect in increasing tuber yields when nitrogen supply was optimal. Although cv Wanmun consistently produced greater tuber yields than cv Lole under well-watered conditions, the Lole cultivar supplied with 100 kg of N/ha and 160 kg of

K/ha produced greater tuber yields under water stress. The lower transpiration under higher soil potassium contents suggest that potassium plays an important role in improving water use efficiency.

Grafting was conducted with the aim of producing plants that embody cv Lole's tolerance to drought and cv Wanmun's high tuber yields. The results showed that growth and physiological aspects of the Lole and Wanmun cultivars and their grafted combinations decreased with water stress. Wanmun scions when grafted onto Lole rootstocks grew very poorly, however, Lole scions grafted onto Wanmun rootstocks grew well and produced higher tuber yields than the parent plants, especially under water stressed conditions. Therefore, cv Wanmun and cv Lole are recommended to be independently propagated under good rainfall and drought condition, respectively, and combinations of drought tolerant cv Lole scions grafted onto good storage root capacity of cv Wanmun rootstocks improved tuber yields under water stress condition.

Productivity of sweet potato, as measured by tuber production, was reduced by soil water stress. Under well-watered conditions, cv Wanmun (drought sensitive) produced high tuber yields. Nitrogen and potassium at optimal application levels increased yields of both drought sensitive and tolerant cultivars under both well watered and water stressed conditions. Under drought conditions, cv Lole (drought tolerant) produced good tuber yields, and Lole scions grafted onto Wanmun rootstocks produced even better tuber yields.

The interactions between genotype and environmental constraints, including drought, require further study to produce sweet potato cultivars with high tuber yield potentials that are well suited to different local conditions.

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GLOSSARY AND ABBREVIATIONS

Abbreviation	**Term**	**Definition**
ABA	Abscisic acid	Hormone involved in regulating seed germination, inducing storage protein synthesis, and modulating water stress (Hopkins, 1999).
	Chlorosis	Yellowing of the leaves due to loss or reduced development of chlorophyll (Raven *et al*., 1999).
	Drought	Duration without rain, which is sufficient to cause damage to plants, and to reduce plant growth and economic yield (Jones *et al*., 1981).
	Drought resistance	The ability of plants to obtain and retain water as well as to metabolise during low water potential in the tissue or the ability of a plant to grow satisfactorily when exposed to periods of water stress (Singh *et al*., 1972). A range of mechanisms whereby plants can withstand periods of dry weather (Jones *et al*., 1981).
	Drought escape	The ability of plants to complete their life cycle and produce yields before a water deficit occurs late in the growing season (Turner, 1979).
	Drought avoidance	The ability of plants to close stomata rapidly, to have a greater osmotic adjustment, thick cuticles, leaf rolling, and a large root system to avoid drought effects (Kramer, 1980).
	Drought recovery	The ability of plants to recover and continue to grow after a period of severe water stress (Blum, 2000).

	Equilibrium time	Time to reach the water balance between the humidity of the air in the chamber and the water potential of the cell (Larcher, 1995).
HI	Harvest index	An indication of the relative distribution of photosynthates between the storage roots and the remainder of the plants (Kays, 1985), and is determined by measuring the ratio of tuber yield to the total biomass.
LAD	Leaf area duration	Leaf area integrated over time, gives a measure of the longevity of the photosynthetic surface of the plants (Kays, 1985).
LAI	Leaf area index	The area of leaves per unit area of land (Kays, 1985).
	Leaf diffusive resistance	The resistance of a leaf to CO_2 molecules entering intercellular spaces through the stomata (Larcher, 1995).
	Leaf abrasion	Removal of the waxy leaf cuticle by leaf scratching, in order to increase water vapour conductance across the leaf epidermis (Brown and Oosterhuis, 1992).
LHC	Light-harvesting complex	A function for harvesting additional light energy and regulate the input of energy into photosystem I and photosystem II (Hopkins, 1999).
LWP	Leaf water potential	A common physiological measurement used to assess the general water status of a plant. It is defined as a potential energy (joules) per unit mass of water (m^3) with reference to pure water at zero potential (Beadle *et al.*, 1993). A value of zero indicates the absence of water stress, while increasingly negative values illustrate increasing severity of water stress.
	Field capacity	The water content remaining in the soil after saturation, followed by drainage for 48 hours (Lambers, 1998).
	Marketable tubers	Tubers weighing more than120 g / tuber.

MPa	Megapascal	The unit of pressure used to express water potential, 1MPa = 10 bars (Hopkins, 1999).
OA	Osmotic adjustment	The accumulation of dissolved substances, such as sugars, amino acids and ions in plant cells, that help the cells sustain metabolic activities (Hopkins, 1999).
OP	Osmotic potential	A net increase in solute concentration due to metabolic processes triggered by stress (Raven *et al*., 1999).
PWP	Permanent wilting point	The point at which a plant will not recover from wilting after it has been dried and is placed in a water-saturated atmosphere in a chamber.
P_N	Net photosynthesis	The rate of CO_2 uptake per unit of plant mass required for photosynthesis minus the rate at which CO_2 is freed by total plant respiration in light (Larcher, 1995).
RWC	Relative water content	Water status of plant tissue, which is calculated on either a dry or a fresh weight basis (Kramer, 1980).
RC	Reaction centre	A component of the photosystem, which plays a role in gathering light energy (Hopkins, 1999).
SLA	Specific leaf area	The ratio between leaf area and leaf dry mass (Reddy *et al*., 1989).
SLW	Specific leaf weight	The ratio between leaf mass and leaf area (Nobel, 1980).
TP	Turgor pressure	The pressure component in cells arising from the force exerted outwardly against the cell walls by the expanding protoplast (Hopkins, 1999).
WP	Water potential	The chemical potential of water in a system, defined as the sum of the hydrostatic pressure and osmotic pressure (Hopkins, 1999).

WUE	Water use efficiency	Ratio of dry matter produced by a plant to the amount of water used in transpiration (Atwell *et al*., 1999).

CHAPTER 1

GENERAL INTRODUCTION

1.1 INTRODUCTION TO THE RESEARCH APPROACH

More than 70% of available land in tropical environments is under rain-fed agriculture (Prakash and Ramachandran, 2000). Because water is the main limiting factor in this area, and rainfall is variable in both space and time, drought is common. Drought alters and modifies the physiology, anatomy, and morphology of plants, affects plant function, limits plant growth, and reduces the productivity of the land (Boyer, 1982).

Drought causes plant water deficits that reduce cell turgor and cell enlargement, closes stomata thus reducing the amount of productive foliage, decreases the rate of photosynthesis per unit of leaf area, and shortens the vegetative growth period (Kramer, 1980; Van Loon, 1981; Bradford and Hsiao, 1982).

Almost 76% of the sweet potato (*Ipomoea batatas* (L.) Lam.) crops cultivated in Asian and Pacific regions are in drought-prone areas (Indira and Kabeerathumma, 1988). As a result, crop productivity remains low in drought-affected and insufficiently irrigated areas (Sinha *et al*., 1985). Sweet potato crops in Papua New Guinea and Indonesia, for example, produce an average of only 4 and 10 t/ha, respectively, compared to those in China, Japan and South Korea of 19, 21, and 24 t/ha, respectively (International Potato Centre, 1998). China is the world's largest sweet potato producer and accounts for 80% of total production (Scott, 1992; International Potato Centre, 1998).

In the highland areas of Papua (formerly Irian Jaya), Eastern Indonesia, drought and frost are the major problems for sweet potato production (Schneider, *et. al*., 1993; Ballard, 1999). Drought and frost occur yearly and devastate crops, threatening the lives of the people in the area. Due to the effect of *El Niño*, prolonged and severe drought occurred in 1997. As a consequence, many crops including sweet potato died (Prain and Widyastuti, 1998; Ballard, 1999), and many people of Papua suffered from starvation to the point of widespread deaths throughout the region.

Sweet potato is considered as a drought tolerant crop (Constantin *et al*., 1974; Hahn and Hozyo, 1984), but it is also sensitive to water deficit stress (Ekanayake and Collins, 2004). Water, therefore plays an important role in sweet potato growth and yield. Sweet potato requires a constant water supply throughout the growing season to produce high yields (Newell, 1991). Water deficits reduce leaf water potential and total water use, and subsequently reduce stomatal conductance, leaf area, root mass, tuber development, and total plant mass (Sivan, *et al.,* 1996).

Excessive moisture, on the other hand, inhibits storage root (tuber) initiation and development in early growth, and causes decay of storage roots in later growth stages (Collins, 1995). At the same time, uneven watering will cause tuber growth cracks and diminish crop quality (Peet, 2000). Improvement of plant productivity under water stress needs an understanding of physiological mechanisms by which water stress affects plant growth. To date, there have been few studies of the water relations of sweet potato.

1.2 OBJECTIVES OF THE THESIS

The general objectives of the present study were to identify sweet potato cultivars, which are tolerant to drought and give a high tuber yield. Such information will help determine desirable characters of sweet potato cultivars that provide tolerance to drought conditions and will be very useful to plant physiologists and breeders.

Specific objectives of the present study were:

1. Identification of drought tolerant cultivars

- To identify the responses of 15 sweet potato cultivars to drought conditions.

2. Responses of sweet potato to water stress

- To observe the physiological basis of water stress in drought tolerant and susceptible sweet potato cultivars.
- To assess the vegetative growth and yield of selected sweet potato cultivars in relation to the degree of soil water stress.

3. Responses of sweet potato to nutrient applications

- To observe the effect of nitrogen and potassium in improving water use efficiency in selected sweet potato cultivars.

4. Responses of sweet potato to grafting

- To observe the physiological aspects of rootstocks and scions from both drought tolerant and susceptible sweet potato cultivars on water use efficiency.

1.3 THE SWEET POTATO

1.3.1 Introduction

Sweet potato is the second most important tropical root crop after cassava (Peters and Wheatley, 1997). It plays an important role as an excellent source of energy, vitamins A, B, and C, calcium, and iron (Hill *et al*., 1984; Woolfe, 1992). Sweet potato is grown mostly for its edible storage roots (Kuo and Chen, 1992). Young sweet potato leaves that are rich in protein, are commonly consumed by Asian people as a green vegetable (Villarreal *et al*., 1985; Valenzuela *et al*., 2000).

Sweet potato is the main source of carbohydrate intake in many tropical countries (O'Hair, 1990 and International Potato Centre, 1998). It is the primary food source for the highlanders of Papua, Eastern Indonesia, where it accounts for nearly 100% of the people's diet (Ruinard, 1969; Schneider *et al*. 1993). However, the crop (particularly physiology) has been almost neglected in terms of scientific research. Only in the last decade has an effort been made to realize its full potential for industrial products (International Potato Centre, 1998).

1.3.2 Origin, distribution, and botany

Sweet potato originated in central or northwest South America (Yen, 1982; Huaman, 1997; Peet, 2000). At present, it is cultivated in tropical, subtropical, and temperate regions in latitudes between 40^0N and 40^oS, and from sea level to elevations of about 2000 m (Huaman, 1997; Peet, 2000). There are about 5000 cultivars present in New Guinea, therefore this area is considered as the secondary centre for sweet potato diversity (Yen, 1974).

Sweet potato is a member of the Convolvulaceae family and is more commonly grown as an annual than a perennial crop (Onwueme and Charles, 1994; Norman *et al*., 1995). It is a dicotyledonous, herbaceous plant (Duke, 1983; Hahn and Hozyo, 1984; Schultheis and Wilson, 2000) that can be propagated using tuber roots, stem cuttings, and seeds; vine cuttings are most commonly used for sweet potato propagation (Onwueme and Charles, 1994; Norman *et al*., 1995; Huaman, 1997).

Some sweet potato cultivars produce flowers (monoecious), and others do not flower (Duke, 1983; Huaman, 1997; Schultheis and Wilson, 2000). It is a self-compatible species. Seeds are formed only when cross-compatible types are grown together. Self-sterility and cross-incompatibility in sweet potato are both common (Purseglove, 1968 in Norman *et al*., 1995). The chromosome number in sweet potato is 90, indicating a hexaploid plant with a basic chromosome number of 15 (Huaman, 1997; Schultheis and Wilson, 2000).

The plant habit is vine-system; twining and cylindrical stems expand rapidly on the ground and increase under shading (Norman *et al*., 1995). The leaves may be rounded, reniform (kidney-shaped), cordate (heart-shaped), triangular, hastate (trilobular) and lobed moderately or deeply (Huaman, 1992). Leaves are usually horizontal, prostrate (Brown, 1992), and highly variable in their morphology. They are spirally and alternately arranged on the stem. Some cultivars show some variation in leaf shape on the same plant (Huaman, 1997).

The root system in sweet potato consists of fibrous roots that absorb nutrients and water, and storage roots that hold photosynthetic products, predominantly starches and sugars

(Huaman, 1997). As the plants mature, thick pencil roots with some lignification (and other roots that have no lignification) become fleshy and thicken and are called storage roots or tubers (Huaman, 1997). Tuber masses vary widely depending on cultivar and environmental conditions (Martin, 1988; Goswami *et al*., 1995; Anselmo *et al*. 1998). The yield can be quite variable. Martin (1988) observed that the yields of sweet potato can reach 4.36 kg/plant, but yields of only 1.63 kg / plant are more common in the Papuan highlands (Apaseray *et al.*, 2001).

1.3.3 Ecophysiology

Sweet potato is grown over a broad range of environments and cultural practices and is commonly found in low-input agriculture systems (Prakash, 1994). Genetic and environmental factors determine crop growth and yield. Consequently, different crop genotypes may perform differently under diverse environmental conditions. Biophysical factors such as soils, pests and diseases, and other environmental variables, including temperature, light intensity, and soil moisture affect physiological responses, growth, and yield. Certain ecological ranges are required for sweet potato to produce maximum yields.

Sweet potato requires a moist sandy loam soil with good drainage and pH between 5.6 and 6.6 (Martin, 1988). Warm days and nights are the optimal conditions for sweet potato growth and development (McCraw, 2000). It is a warm weather crop and the best temperatures for growth and yield are above 24 ^{o}C; growth is severely retarded at minimum temperatures below 10 ^{o}C (Onwueme and Charles, 1994). Sweet potato grows best under relatively high light intensity, shading therefore should be avoided (Onwueme and Charles, 1994). It requires a short day-length of 11 hours or less to stimulate tuber formation, while long days tend to favour vine growth at the expense of the root tubers (Onwueme and Charles, 1994).

Sweet potato is highly sensitive to excessive rainfall and to deficits in soil moisture. The crop requires at least 500 mm of rainfall during growing season with optimum levels at 750 – 1000 mm (Onwueme and Charles, 1994). Water supply has to be maintained during the first 40 days after planting, and during the tuber formation stage at 7 to 9 weeks after planting (Valenzuela *et al.*, 2000). Maintaining soil moisture above the wilting point during the whole season is essential for the growth and development of storage roots. The yield of storage roots is known to decrease under water deficit stress below 20% of soil water availability (Indira and Kabeerathumma, 1988). Cultivars differ in their response to water deficit conditions (Indira, 1989). Due to its intolerance of a limited water supply, the production of sweet potato crops in drought-prone semi-arid regions has not been reliable (Yen, 1982).

The photosynthetic pathway of sweet potato is similar to that of C_3 plants (Kays, 1985). During the early growth period, the net photosynthesis rate (P_N) is highest. It declines at the end of growth periods as the sink attains its maximum size (Bhagsari and Harmon, 1982). The net photosynthesis rate in sweet potato is not consistent in different seasons, nor at different growth periods in the same seasons, due to the interaction of P_N with the environment during the plant growth period (Bhagsari and Harmon, 1982). The rate of photosynthesis in individual leaves of sweet potato is affected by leaf age, and young fully expanded leaves tend to have higher photosynthetic rates (Tsuno and Fujise, 1965 in Kays, 1985). The maximum rate of photosynthesis is in the range between 18 and 22 mg CO_2 $dm^{-2}hr^{-1}$, but varies widely between cultivars and experimental conditions

(Kays, 1985). Leaf carbohydrate concentrations decline after storage roots begin to develop (Naka and Tamaki, 1957 in Kays, 1985).

Common leaf chlorophyll concentrations lie between 7.6 and 10.6 mg/g leaf dry mass (Bhagsari and Harmon, 1982). The density of stomata varies among cultivars from 47 to 87 per mm^2 on the adaxial leaves and from 163 to 253 per mm^2 on the abaxial leaf surface (Bhagsari and Harmon, 1982). The optimal leaf area index (the ratio of photosynthetic leaf area to covered ground area) is between 3 and 4, however it varies among sweet potato cultivars (Kays, 1985).

1.4 ROLE OF WATER IN PLANTS

1.4.1 Physiological functions

Water is important to the basic functions of living cells, as it plays a vital role in all physiological processes, and contributes between 60 and 95% of the fresh mass of tissues and organs (Monneveux and Belhassen, 1996). Water is required in vast quantities as the major substance in plant cells (Lambers *et al*., 1998). At a cellular level, water is the major medium for transporting metabolites through cells. At the whole plant level, water is the medium for transporting the raw materials of carbohydrates, nutrients, and hormones required for growth and development (Lambers *et al*., 1998). Water is also an essential medium in biochemical processes and is involved as a reactant in several processes including photosynthesis (Nonami and Boyer, 1989; Monneveux and Belhassen, 1996).

Water also drives the transfer of sap containing nutrients from roots to leaves, it induces mechanical and physiological functions including structural integrity of cells, tissues, and the turgidity and rigidity of plant cells (Nonami and Boyer, 1989; Monneveux and Belhassen, 1996). Due to their high concentrations of solutes, plant cells exert a positive pressure (turgor) against their cell wall, which is the basic support mechanism in plants. When plants lose turgor as a consequence of drying conditions in the root zone, they are no longer able to carry out physiological functions such as cell expansion and photosynthesis (Lambers *et al*., 1998).

Water is quantitatively the most abundant substance transported in the vascular tissue called phloem (Taiz and Zeiger, 1991). Water also drives the translocation of photoassimilate through phloem. Sucrose is a common dissolve substance that transported in sieve tube of phloem. Other organic solutes that move in phloem are nitrogen in the form of amino acids and amides, especially glutamate and aspartate but are usually lower than sucrose, almost all of the endogenous plant hormones (auxin, cytokinin, gibberellin), nucleotide phosphates and enzymes, several inorganic solutes including potassium, magnesium, phosphate, and chloride (Taiz and Zeiger, 1991; Hopkins, 1995).

The movement of water within the plant occurs by diffusion from cell to cell along a water potential gradient (short distance transport), and by conduction through the xylem (long distance transport). The movement of water through the vascular system is controlled largely by xylem properties, such as conducting area (cross-sectional area of the transporting vessels) and flow resistances, the plant physiological state (e.g. degree of stomatal opening), and the environmental conditions (Larcher, 1995).

Under water deficits, plants slow down their biological activities (Mullet and Whitsitt, 1996). When a severe water deficit continues, there is marked reduction in the rate of photosynthesis which can damage biological functioning, and cause the plant to die (Levitt, 1972; Kramer, 1980; Monneveux and Belhassen, 1996). However, the responses of plants to water deficits may vary greatly, depending on species and stress severity (Mullet and Whitsitt, 1996).

1.4.2 Plant water status

Plant water status affects plant growth and yield through the extension of leaf and root growth (Beadle *et al*., 1993). Plant water status is assessed by several major parameters such as leaf water potential (LWP) and leaf relative water content (RWC) (Blum, 2000).

Leaf water potential is defined as the potential energy (joules) per unit mass of water (m^3) with reference to pure water at zero potential (Beadle *et al*., 1993). Leaf relative water content is the water status of plant tissue, calculated on either a dry or a fresh weight basis (Kramer, 1980). Leaf water potential has negative values, due to less potential energy being available for plant tissue than pure water (Beadle *et al*., 1993). Water potential can be measured by a pressure chamber and thermocouple psychrometer. The pressure chamber is simple and suited for field studies, while the psychrometer is best used in the laboratory (Beadle *et al*., 1993). It is still unresolved whether leaf water potential or relative water content has the greater effect on the physiological activity.

Siddique *et al*. (2000) proposed leaf water potential as a reliable parameter for quantifying plant water stress. However, relative water content was considered as the appropriate measurement of plant water status in terms of the physiological consequence of cellular water deficit (Sinclair and Ludlow, 1985). It also represents variations in water potential (WP), turgor potential (TP) and osmotic adjustment (OA) (Blum, 2000). This is because osmotic adjustment is a powerful mechanism for conserving cellular hydration under drought stress, and relative water content expresses the effect of osmotic adjustment in this respect. Osmotic adjustment is the capacity to adjust when the plant experiences water stress, and it is not an inherited trait (Ludlow and Muchow, 1990). It results from the accumulation of solutes within cells, which lowers the osmotic potential (OP) and helps maintain turgor of both shoots and roots as plants experience water stress (Ludlow and Muchow, 1990).

Genotypes may vary in their relative water content while having the same water potential due to a difference in osmotic adjustment (Blum, 2000). Expressing high relative water content as a favourable plant water status in the field can be maintained by three mechanisms:

- The capability to sustain high water potential by deep soil moisture extraction;
- The capacity for osmotic adjustment which allows maintaining relative water content and turgor potential to lower water potential;
- Stomata closing in response to leaf desiccation and/or a transported hormonal signal that is produced in the root, in response to root desiccation (Blum, 2000).

Variations in plant size could affect the variation of relative water content among genotypes. Under limited soil moisture, plant water status can be affected by the rate of leaf canopy development and leaf area index (LAI). Larger plants are likely to express lower relative water contents and use more water than smaller plants after a given time (Blum, 2000).

Leaves must acquire an appropriate amount of water as they grow (Eguchi *et al*., 1998), and leaf area growth is reduced under water deficits (Alves and Setter, 2000). Leaf water status is controlled by stomata through the balance between water loss and carbon gain (Beadle *et al*., 1993). Stomata close when the leaf cells reach zero turgor, or when a plant or leaf exhausts the water available for transpiration (Schulze, 1986).

Leaf water potential has been reported by Ike and Thurtell (1981) to decrease in cassava and sweet potato under drought stress: in cassava, leaf water potential above – 0.5 MPa was independent of stomatal resistance, but increased with decreasing potential; leaf wilting occurred at leaf water potentials of less than – 0.9 MPa. Ghuman and Lal (1983) reported leaf water potentials in unirrigated sweet potato at – 0.96 MPa, compared to –0.36 MPa in cassava. Under higher leaf water potential, the tuber growth rate of sweet potato was higher, and it appeared to be affected by leaf transpiration through the water balance of the whole plant (Eguchi *et al*., 1998). In sunflower, leaf water potential decreased in response to soil dehydration both in drought sensitive and tolerant genotypes (Cellier *et al*., 1998); but decreases in leaf water potential and wilting were delayed in drought tolerant genotypes compared with sensitive ones.

1.4.3 Water uptake by plants

Efficient water uptake by plants is an important determinant of drought resistance. Water uptake depends on root size (length or mass), root activity and its spatial distribution (Huang and Gao, 2000). About 70% of available water at the soil-root zone can be used for vegetative growth. It is recommended that when soil had dried to about 50% of plant available water, it is the time to irrigate any plant (Atwell *et al*., 1999).

Maintenance of water uptake by roots is an important mechanism in maintaining plant turgor and canopy transpiration. Efficiency of water uptake depends on the root system and extensive, dense root systems are considered to be more efficient (Beadle *et al*., 1993).

1.5 MECHANISMS OF DROUGHT RESISTANCE

Drought can be defined as any period without rain which is sufficient to cause damage to plants, and to reduce plant growth and economic yield (Swindale and Bidinger, 1981; Jones *et al*., 1981). Drought occurs when water potentials in the rhizosphere are sufficiently negative to reduce water availability to sub-optimal levels for plant growth and development (Lu *et al*., 2000). Drought can be permanent, seasonal, and unpredictable (Kramer, 1980).

Whole plants respond to drought through morphological, physiological, and metabolic modifications occurring in plant organs (Cellier *et al*., 1998). A number of plant functions may be impaired by water stresses that reduce cell turgor, close stomata, and reduce cell enlargement, thereby reducing leaf area and the rate of photosynthesis per unit of leaf area (Kramer, 1980). Stomatal closure is among the negative effects of water stress in the restriction of carbon fixation (Kaiser, 1987). However, a variety of plants species may continue growing under low available water conditions and still maintain photosynthesis activity (Fischer and Turner, 1978).

“Drought resistance” is the general term used to cover a range of mechanisms whereby plants can withstand periods of dry weather (Jones *et al*., 1981). Drought resistance is the ability of plants to obtain and retain water as well as to metabolise during periods of low water potential in their tissues (Singh *et al*., 1972). Strong drought resistance is often associated with the maintenance of higher leaf water potential, non-stomatal control of transpiration, and high leaf permeability (Blum *et al*., 1983).

The ability of a plant to grow satisfactorily when exposed to periods of water stress is also called drought resistance (Singh *et al.*, 1972). Aspects of drought resistance that are considered important in sweet potato breeding programs are: the effect of short periods of water stress on productivity and on tuber quality; survival and recovery of plants after water stress; and water use efficiency (Van Loon, 1981). Four mechanisms of drought resistance are used by plants to endure the period of insufficient water (Levitt, 1972; Turner, 1979; Ekanayake, 1997) are discussed bellow:

- drought escape,
- drought avoidance,
- drought tolerance, and
- drought recovery

1.5.1 Drought escape

In drought escape, plants are able to complete their life cycle mainly through mechanisms to ensure early maturity and can produce their yields before susceptible stages of water deficit occur late in the growing season (Turner, 1979; Kramer, 1980). Therefore, it is important to match the pattern of plant development to the growing season and to the availability of soil moisture in relation to the evaporative and plant demands (Van Oosterom *et al*., 1995; Passioura, 1996). In millet (*Pennisetum glaucum*) for instance, early maturity is a common escape mechanism for post-flowering drought stress. On the other hand, the escape mechanism also appears for certain genotypes under late flowering drought stress (Van Oosterom *et al*., 1995).

1.5.2 Drought avoidance

A drought avoidance strategy is achieved through osmotic adjustment, rapid closure of stomata, presence thick cuticles, leaf rolling, and the performance of a large root system (Levitt, 1972; Kramer, 1980). Strategies for drought avoidance or moisture conservation have been successful for some crops under prolonged water stress caused by low soil moisture (Bouwkamp, 1989).

In tobacco, which has been shown by Riga and Vartanian (1999) to be highly drought resistant, plant turgor in the first phase of water deficit is maintained by osmotic adjustment and is associated with a steep increase in stomatal resistance from a threshold deficit. During drought stress, osmotic adjustment can play an important role in sustaining several processes such as turgor potential, cell expansion, and stomatal conductance (Turner, 1986). An increased root to shoot ratio may also result from a relatively greater loss of shoot than root mass as a drought avoidance strategy (Levitt, 1972; Jones *et al*., 1981).

1.5.3 Drought tolerance

Drought tolerance refers to the potential of cultivars to yield well under drought stress conditions. It is considered to be a major component of yield stability (Beekman and Bouma, 1986), and can be classified into two types related to tissue water potential:

drought tolerance at high tissue water potential, by maintaining a high water status during rainfall deficit; and drought tolerance at low tissue water potential, through the plant's ability to endure rainfall deficits and tolerate low tissue water potentials (Jones, *et al*., 1981).

Drought tolerance with high tissue water potential involves the maintenance of water uptake by increasing rooting and hydraulic conductance, and reducing water loss in epidermal conductance, radiation absorption and evaporative surface. At low tissue water potential, drought tolerance can be assessed on turgor maintenance, such as solute accumulation, increased cell elasticity, decreased cell size and desiccation tolerance, such as protoplasmic resistance and rapid resumption of photosynthesis activity (Levitt, 1972; Turner 1979; and Jones *et al*., 1981).

Drought tolerance mechanisms are shown by relatively high root densities under short term stress caused by low soil moisture (Bouwkamp, 1989). Despite abrupt falls in leaf water potential and relative water content at the second dry period, cell membranes in tobacco increase its stability, resulting in prolonged plant recovery upon rehydration after severe soil desiccation for 2 months (Riga and Vartanian, 1999). This indicates a drought tolerance strategy operating in tobacco at low tissue water potential.

1.5.4 Drought recovery

The potential for recovery after a period of severe drought stress is often referred to as survival, and is a very common phenomenon in plants (Blum, 2000). This phenomenon can be used to estimate drought tolerance (Beekman and Bouma, 1986). Plant recovery from desiccation in agricultural crops is primarily a function of the capacity for maintaining relative water content during desiccation (Blum, 2000).

Late maturing potato varieties tend to recover better than earlier varieties (Beekman and Bouma, 1986), hence their yields are relatively high under dry conditions. This is due to their potency in continuing tuber growth after the water supply is restored (Beekman and Bouma, 1986). Therefore, the maintenance of relative water content during stress is also related to the potential capacity of the tested genotypes for survival and recovery (Blum, 2000).

Abscisic acid (ABA) may have a role in assisting plants to recover from drought stress that is mediated by its effect on the maintenance of the plant's relative water content (Blum, 2000, Alves and Setter, 2000). Recovery capacity, which is independent of the maintenance of plant water status, has rarely been explored and should be evaluated by the degree of recovery of different genotypes when all are desiccated to the same low relative water content (Blum, 2000).

1.6 EFFECT OF DROUGHT ON PLANT GROWTH AND DEVELOPMENT

1.6.1 Effect of drought on photosynthesis

Drought stress affects photosynthesis in two ways (Hopkins, 1999). First, stomata are closed cutting off access of the CO_2 supply into chloroplasts. Second, cellular water potential is lowered, reducing the structural integrity of the photosynthetic organ. The opening and closing of the stomata also depend on the ambient humidity (Mansfield and Atkinson, 1990). Under low ambient humidity, or high temperature as a dry air mass moves into the environment, plants close their stomata to reduce their leaf water loss, and to enhance the rate at which water can be resupplied by the roots (Hopkins, 1999).

Water influences mechanical and physiological functions in plants by affecting the structural integrity of cells and the turgidity and rigidity of tissues. As the solute concentration increases due to water stress, the integrity of membranes and protein is affected. This condition may lead to shrinkage of the protoplast volume, which may induce structural and metabolic dysfunctions (Hopkins, 1999).

1.6.2 Leaf area and canopy development

Leaves are the source of dry matter production through photosynthesis (Kuo and Chen, 1992). Leaf growth and expansion are genetically controlled and modified by environmental conditions including water supply. In sweet potato, water stress causes a slow growth and reduces leaf mass and area significantly during establishment (Holwerda and Ekanayake, 1991). In herbaceous plants, leaf elongation ceases at a water potential of –0.3 MPa before stomatal closure (Kriedeman, 1986), and leaf enlargement is restored after watering (Cornish and Zeevart, 1984). In cassava, a decrease in soil water potential causes rapid stomatal closure and decreases leaf area growth, which is accompanied by the synthesis and accumulation of abscisic acid at an early phase of a water deficit (Alves and Setter, 2000). Abscisic acid promotes developmental changes that help plants cope with water deficits, and increases in plant organs during drought (Zeevaart and Creelman, 1988). In sweet potato, when the leaf water potential decreased to –1.0 MPa under moisture stress, leaf diffusive resistance was affected, and as a consequence, leaf area and leaf production also decreased (Suja and Nayar, 1996).

1.6.3 Root growth and tuber development

Information on root behaviour associated with drought tolerance is important for understanding drought tolerance mechanisms. Under drought conditions, biomass development in cowpea was reduced but its root growth was greater than in normally watered plants (Evenari *et al*., 1977). On the other hand, drought induced a significant reduction in the number of developed lateral roots, and in the total length and root dry matter produced by drought sensitive beans and peas (Stanislaw *et al*., 1997). Drought resistant cultivars of bean and pea demonstrated greater dimensions in the root system than the above ground part (Stanislaw *et al*., 1997). In cassava, the most critical periods of water stress occurred in the first 6 months of plant growth, and reduced the storage root yield by about 60% (Oliveira *et al*., 1982 in Ghuman and Lal, 1983). Roots and storage roots of sweet potato were affected when the leaf water potential fell below – 1.0 MPa (Suja and Nayar, 1996).

1.7 DROUGHT TOLERANCE MECHANISMS

Many plants have developed mechanisms to adapt to extreme conditions to ensure their survival (Cornish and Zeevart, 1984; Collin, 2001). These mechanisms are related to genetic factors and provide a metabolically effective and efficient mechanism for drought stress alleviation (Cornish and Zeevart, 1984). Adaptation refers to genetic modifications in structure or function that increase the vigour of the organism in the adverse environment (Hopkins, 1999). Collin (2001) also described adaptation as a heritable modification in physiological or developmental attributes that improves the fitness of an organism to the conditions of its environment.

Adaptation is driven by climatic, edaphic, or biotic constraints (Collin, 2001). Water acts as a key element in plant distribution patterns and many morphological traits are conditioned by water availability, directly or indirectly; adaptation, therefore, is a key element in the survival of the plant communities (Collin, 2001).

1.7.1 Morphology and anatomy

Mechanisms of morphological and physiological adaptation have been proposed to explain the tolerance of some plant species to drought (Begg and Turner, 1976; Kramer, 1983; Ludlow, 1989). They include structural and anatomical characters such as a reduction of leaf size, leaf rolling, dense leaf pubescence or hairiness of leaves, deeply developing stomata, accumulation of mucilage and other secondary metabolites in the mesophyll, and increases in mesophyll compactness (Ludlow, 1989 and Beadle *et al.*, 1993). Plants adjust to water stress through changes in the shoot to root ratio, growth rate, and water use efficiency which may be accompanied by changes in water relation properties such as water potential and relative water content that prompt the closure of stomata (Beadle *et al.*, 1993). In a sorghum cultivar (cv Gadambalia), drought tolerance is associated with higher water extraction efficiency, fewer nodal roots per plant, fewer late metaxylem vessels per nodal root, a smaller leaf area, and a well developed sclerenchyma (Salih *et al.*, 1999). Extensive and deep rooting, for instance, often has been emphasised in relation to drought resistance (Hurd, 1974; Marcum *et al.*, 1995) in particular in that rice and millet are intolerant of dry periods. Millets that were not able to recover from drought stress, and rice that performed poorly in drought conditions, had a shallow root system (Karyudi, 2001; Hirasawa, 2001). However, Ray *et al*. (1972) suggested that a small-rooted plant may use limited water more efficiently.

Several sweet potato cultivars have been classified as drought tolerant because they possess a deep fibrous root system, and are able, therefore, to extract water from deep in the soil as water availability from the top layers decreases (Hammet *et al*., 1982; Martin, 1988; Bouwkamp, 1989; Taufatofua, 1994; Prakash, 1994; and Lin *et al*., 1996). Furthermore, their leaves have less surface area and lower transpiration rates, hence they can maintain its cellular integrity during water stress (Garner *et al*., 1992).

1.7.2 Physiology

A number of plants have developed strategies to allow photosynthesis to proceed under severe water deficits. A common strategy is lowering cell osmotic potential by means of accumulation of net solutes to maintain cellular turgor (Morgan, 1984). This mechanism results in the maintenance of stomatal opening, photosynthesis, and leaf and root growth (Morgan, 1984). It is evident in millet accessions that could maintain turgor pressure with high osmo-regulative capacity, lower values of leaf water potential at full turgor, and reduced of osmotic potential that were not related to plant height, inflorescence shape, stem thickness, number of tillers, and dry matter production (Karyudi, 2001).

Stomata close to reduce transpiration and regulate leaf water potential when a plant or leaf depletes the available water and the leaf cells approach zero turgor (Turner, 1975; Mansfield and Davies, 1981; Schulze, 1986). However, stomata can remain open even in wilted leaves, and may close in plants in dry soil at positive turgor in a progressive rather than in a threshold manner (Schulze, 1986).

Plants also adjust to water stress through changing their growth rates and water use efficiency which may be accompanied by changes in water relation properties such as water potential, relative water content that prompt the close of stomata, and diurnal patterns of stomatal conductance (Beadle *et al*., 1993).

In sweet potato, drought tolerant genotypes such as Indian accession numbers 4, 25, 69, 72 normally had low contents of inorganic phosphate in the leaves, high cuticular wax, and higher specific leaf weight, leaf pubescence, higher stomatal diffusive resistance, and high desiccation tolerance, while accessions 1, 17 and 21 also had higher relative water content when grown under water stress conditions (Indira, 1989; Suja and Nayar, 1996).

1.8 IMPLICATIONS OF PLANT RESPONSES IN IMPROVING WATER USE EFFICIENCY

1.8.1 Plant propagation strategies

Breeding for specific and suboptimal environments (such as water deficits) involves an understanding of yield-determining processes (Blum *et al*., 1983). Drought tolerance and high root storage yield is often a desirable trait for selection criterion in breeding programs (Martin, 1988). In an attempt to combine superior characters, sexual breeding is an unlikely choice in sweet potato because the physiology of the sweet potato flower is extremely complex and produces incompatibilities that restrict pollination mechanisms (Onwueme and Charles, 1994).

Grafting is an asexual propagation technique, which can be used to combine the desirable characters of the root and vegetative parts of different plants. In reciprocal grafts between the related species of *Ipomoea batatas* and *Ipomoea trivida*, which does not form tubers, the rate of photosynthesis was greater in grafts with larger tubers than in grafts of smaller tubers (Hozyo and Park, 1971 in Ravi and Indira, 1999).

A source is an organ or tissue that produces assimilates required for metabolism and growth, a sink on the other hand is a net importer or consumer of photo-assimilates (Hopkins, 1999). Grafted sweet potato plants with strong sinks, as reported by Kuo and Chen (1992), showed greater storage root yields than those with weak sink strengths, irrespective of source potential. On the other hand, grafts with a weak sink increased specific leaf mass, and vice versa. It was concluded that the sink, rather than source capacity, determined the storage root yield (Ko *et al*., 1992, in Ravi and Indira, 1999). However, there have not been any reports on grafting trials for improving water use efficiency in sweet potato.

1.8.2 Nutrient application

Nitrogen (N) and potassium (K) are two key nutrients involved in dry matter partitioning in sweet potato (Marti and Mills, 2002). Nitrogen is an essential component for photosynthesis, for the synthesis of chlorophyll and proteins (O'Sullivan *et al*., 1997) and in cell division and enlargement (Russel and Russel, 1973). Nitrogen is required in certain amounts to promote shoot development and provide assimilates for growth of storage roots (Kays, 1985), as heavier N applications alone promote shoot growth and depress root growth (Onwueme, 1978). N fertilization increases leaf area duration (LAD), which in turn increase tuber yields (Bourke, 1985).

Potassium is also a very important nutrient for sweet potato production, as it influences cell division, tuberous root initiation and thickening, photosynthesis, the translocation of sugars and mineral nutrients, and enzyme activity (George *et al*., 2002). Potassium has been shown to influence tuber number and yield by increasing the proportion of dry matter diverted to tubers (Bourke, 1985; George *et al*., 2002). The application of K at 300 kg ha^{-1} was found to produce very high yields due to increased root to shoot ratio, however the extent of the increase differed with genotypes (George *et al*., 2002).

Nitrogen and potassium are reported to be capable of improving water use efficiency in various crops (Sivan *et al*., 1996; Morris *et al.*, 1998). Because nitrogen applications increase crop growth and yields at certain rates, there were some indications that decreased nitrogen supply led to increased stomatal conductance, higher transpiration per unit leaf area due to stomatal opening, hence lower water use efficiency (Morris *et al.*, 1998; Kelm *et al*., 2000). Decreasing water use efficiency under N stress in sweet potato, however, was found to be due to lower total plant dry matter production rather than to increased total water transpiration per plant (Kelm *et al*., 2000). Under drought conditions, however, higher yields in maize can be achieved by supplemental nitrogen, primarily because of a more vigorous root system (Morris *et al*., 1998).

Potassium also plays a role in osmoregulation and stomatal movement (Beringer and Nothdurft, 1985; Hsiao and Lauchli, 1986; Marschner, 1995). In barley, the application of K increased leaf water content and improved turgor maintenance during drought (Losch *et al*., 1992). The dominant role of potassium in the opening and closing of the stomata regulate the transpiration of water and the penetration of atmospheric carbon dioxide into the leaf tissue (Sangakkara *et al*., 2000). Plants well supplied with potassium will quickly close their stomata preventing excessive water loss by the plant (Sivan, *et al*., 1996).

1.9 NATURE OF THE PRESENT RESEARCH

1.9.1 Research materials

The initial trials discussed in Chapter 2 used 15 cultivars of sweet potato obtained from the University of Queensland to identify drought tolerant and susceptible cultivars; they included 1 Queensland, 2 Hawaii, and 12 Papua-New Guinea cultivars (Table 1.1).

Table 1.1 The country of origin of the sweet potato cultivars used in the drought tolerance screening trials.

No.	Genotypes	Country of origin
1	Beerwah Gold	Australia
2	Hawaii	Hawaii
3	Lole	Hawaii
4	Markham	Papua New Guinea
5	Mariken	Papua New Guinea
6	Wanmun	Papua New Guinea
7	NG7570	Papua New Guinea
8	LO323	Papua New Guinea
9	L3	Papua New Guinea
10	L11	Papua New Guinea
11	L18	Papua New Guinea
12	L46	Papua New Guinea
13	L49	Papua New Guinea
14	L131	Papua New Guinea
15	L135	Papua New Guinea

Two cultivars, Lole and Wanmun, representing drought tolerant and susceptible cultivars, respectively, were selected for subsequent experiments. In another trial (Chapter 3), the effects of soil water regimes on the growth and yield of Lole and Wanmun cultivars were observed, and another experiment (Chapter 4) examined the effects of nitrogen and potassium applications on plant water use efficiency in the Lole and Wanmun cultivars grown under non-limiting water and water stressed conditions. A fourth experiment (Chapter 5) studied the growth responses of grafted sweet potato cultivars, using a Lole scion and a Wanmun rootstock, and vice versa, under two different soil water constrains.

1.9.2 Experimental sites and climatic conditions

The experimental studies were conducted in the laboratories, glasshouse, shadehouse and field plots of the School of Marine and Tropical Biology, James Cook University, Townsville, Queensland, Australia between November 2000 and May 2004.

1.9.3 Statistical analyses

All the numerical data were analyzed by analyses of variance using the Statistical Package for Social Scientists (SPSS 11.0 for Windows) at 5% ($p < 0.05$) level of significance. When the treatments were significant, post hoc comparisons of all treatment combinations were performed using Bonferroni's and Duncan Multiple Range Test methods. Some data are presented in this thesis using the Microsoft Excel Package. Correlation analyses were used to examine the relationships between some parameters.

Summary statistical data are provided in the text that follows, and details of the statistical tests are given in Appendices 1-5. Where data in figures or tables that are presented Appendices are referred to, they are indicated by "A" in the figure or table number (e.g. Figure A2.1 is Figure 1 of Appendix 2).

1.10 PAPERS PRODUCED DURING THE COURSE OF THE STUDY

- Saraswati, P., Johnston, M., Coventry, R. and Holtum, J. 2001. Growth, yield and water relations of selected sweet potato genotypes grown under drought stress conditions. Second Annual Conference of James Cook University, School of Tropical Biology, Biology and Zoology of North Queensland (BZoNQ), Townsville, 11-12 August 2001.

- Saraswati, P., Johnston, M., Coventry, R. and Holtum, J. 2004. Identification of drought tolerant sweet potato (*Ipomoea batatas* (L) Lam.) cultivars. Fourth International Crop Science Congress, Brisbane, 26 September – 1 October 2004.

- Saraswati, P., Johnston, M., Coventry, R. and Holtum, J. 2004. Grafting to improve water use efficiency in sweet potato genotypes. Fifth Annual Conference of James Cook University's Biology and Zoology of North Queensland (BZoNQ), Cairns, 6 – 7 November 2004.

- Saraswati, P. 2005. The physiological aspects and yield of sweet potato (*Ipomoea batatas* (L) Lam.) under water stress conditions. Seventh New Guinea Biological Conference. Jayapura, Papua, 16-18 June 2005.

CHAPTER 2

IDENTIFICATION OF DROUGHT TOLERANT SWEET POTATO CULTIVARS

2.1 INTRODUCTION

Plant growth is controlled by environmental factors and genetic potential. Among the environmental factors, drought is widely reported to affect the growth and productivity of many crops. Plant growth and yields are strongly affected by soil water conditions. Limited soil water availability has been widely reported to reduce many crop yields, and the tolerance of plants to drought conditions is not only species dependent but also cultivar dependent (Allison *et al.*, 1981; Martin, 1988). The responses of plants to drought, however, vary greatly depending on the species and the severity of the stress (Mullet and Whitsitt, 1996). In sweet potato, for example, the Vardaman cultivar is classified as drought tolerant due to its low transpiration losses; under water stress, this cultivar has a strong capacity to maintain cellular integrity (Newell, 1991). Lower transpiration sustains the normal plant water status by minimizing the decrease of leaf water potential and soil water depletion; this protects leaf tissues from turgor loss and desiccation (El-Sharkawy and Cock, 1984; Cock *et al*., 1985).

Since drought may impair a number of plant physiological functions, selection for drought tolerant cultivars is an important strategy in reducing the impacts of plant water deficit (Newell, 1991). Ludlow and Muchow (1990) suggested a similar approach to improving plant performance in water-limited conditions by the identification and selection of traits that contribute to drought avoidance, drought tolerance, or water use efficiency.

Sweet potato is regarded as a drought tolerant crop (Jones, 1961; Constantin *et al*., 1974; Hahn and Hozyo, 1984). On the contrary, sweet potato cannot tolerate dry conditions at the time of initial of planting and in its early growth stages including vine development and storage root initiation (Indira and Kabeerathumma, 1988; Martin, 1988). It can tolerate some drought near the end of its life cycle, but it can hardly be thought of as a drought tolerant crop (Martin, 1988) as it requires a continuous water supply throughout the growing season to produce abundant tuber yields of good quality (Newell *et al*., 1994).

Different sweet potato cultivars may respond differently to limited soil water availability. Selection for drought tolerant cultivars is therefore considered to be a research priority, especially considering the fact that sweet potato is the main staple food for people in many tropical areas. In the highlands of Papua, Eastern Indonesia, drought, such as that of the 1997 *El Niño* event, can have a devastating effect on food security and people's livelihoods when their sweet potato crop is destroyed. Securing a reliable food supply is therefore important in environments with intermittent and life-threatening drought.

Although drought tolerance is considered an important component of yield stability (Beekman and Bouma, 1986) and has been investigated in other crop species, only little information is currently available on the physiological aspects of water relations in sweet potato. Therefore, a pot trial was carried out to identify the drought tolerant cultivars from a range of 15 cultivars available for study by observing their morphological growth and water relations in a short-term glasshouse trial. A field trial was also conducted in the Genetic Garden of the School of Marine and Tropical

Biology, James Cook University, Townsville, in order to determine yield responses of the same cultivars when the water supply was not limited.

2.2 MATERIALS AND METHODS

2.2.1 Experimental sites and climatic conditions

A pot experiment (Experiment 1a) was conducted in a glasshouse on the Douglas Campus, James Cook University, North Queensland, Australia, from November to December 2000. The experiment was repeated in another glasshouse from February to March 2001 (Experiment 1b). Daily maximum and minimum temperatures and relative humidity information for Townsville over the period of the experiments were obtained from the Commonwealth of Australia, Bureau of Meteorology.

2.2.2 Glasshouse trials

2.2.2.1 Experimental design

The trials used 15 cultivars of sweet potato obtained from the University of Queensland (Table 1.1). A factorial experiment with a randomised complete design consisted of water stressed and non-limiting water treatments for the15 cultivars listed in Table 2.1. Each treatment was replicated 3 times (in Experiment 1a: 27 November to 18 December 2000) and 4 times (in Experiment 1b: 11 February to 13 March 2001) and the experiment consisted of 90 and 120 pots for experiment 1a and 1b, respectively. Pot locations were randomised every week, thus each pot had the same chance to occupy any specific location on the glasshouse benches during the experiment.

2.2.2.2 Research procedures

The trials consisted of:

- 90 pots (Experiment 1a) and 120 pots (Experiment 1b) of 5 L volume, which accommodated 4.5 kg of soil per pot.
- The fertile sandy soil consisted of a mixture of commercial loam, sand, mill mud, bagasse, chicken manure, and coal ash, sieved to less than 2 mm particle-size, and had a pH of 6.8.

The soil was air dried for several weeks; soil samples were collected and dried daily until they indicated a constant weight. The amount of water required to bring the soil in the pots to field capacity was calculated using the gravimetric method of Topp (1993), following the procedure set out in Appendix A1.1. The calculation of the amount of water needed to bring 1 kg of air dried soil to field capacity was calculated. In the pots containing 4.5 kg of potting mix, the water content per pot was 1,620 mL at 100% field capacity.

Tip cuttings of each cultivar, 25 cm long, were planted directly in each pot in experiment 1a and 1 b. The basal ends of the cuttings were placed in water for 2 days before planting. The cuttings were planted into the soil which had been watered to field capacity and maintained at field capacity for 2 weeks to allow the establishment of the cutting before imposing the water stress treatment. Each cultivar was replicated 3 and 4 times in experiment 1a and 1b, respectively. The plants were watered to saturation before water was withheld permanently. While water stress was induced by withholding water in the water stressed treatment and the pots allowed to dry gradually due to evaporation, the unstressed plants were watered to field capacity every second day. In

Experiments 1a and 1b, 45 and 60 pots respectively were used to determine the amount of water remaining in the pots of the stressed plants at wilting point, and another 45 and 60 pots for Experiments 1a and 1b, respectively were watered normally.

Wilting is the most common symptom of water stress in plants. When the plant wilts, its turgor approaches zero and the cells begin to collapse. Permanent wilting point (PWP) is the point at which a plant will not recover from wilting when it is placed in a water-saturated atmosphere in a chamber. To determine permanent wilting point, plants that were still wilting in the evening were tested by putting the pots into a smaller plastic bag (to prevent water entering the soil) which was then put into a larger plastic bag, which had previously been sealed with some water in the bottom of it. When the plants did not recover from wilting, it indicated that plants were in the state of permanent wilting point (Fig. 2.1).

Figure 2.1a Double bag technique used to determine the permanent wilting point in sweet potato cultivars.

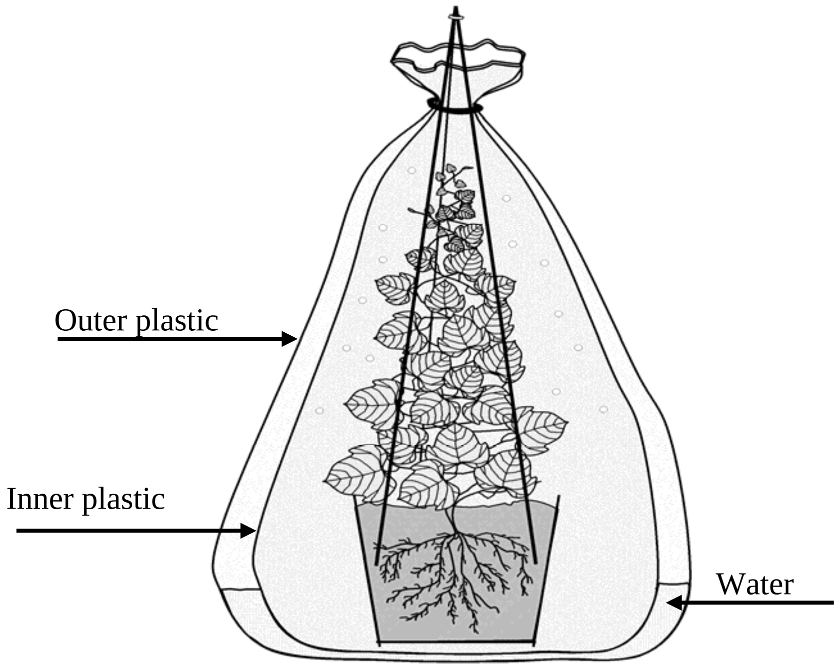


Figure 2.1b Cross-section through the double bag technique used to determine permanent wilting point at sweet potatoes.

The water content of samples of the growing medium at permanent wilting point was also determined using the gravimetric method (Appendix A1.1).

2.2.2.3 Experimental variables

The following plant growth parameters were measured:

Plant growth and tuber yields

- The main stem length (cm/plant) was measured from directly above the ground surface to the growing tip.
- Internode diameter (mm/plant) and internode length (cm/plant) were measured between the 7th and 10th nodes from the tip at three weeks after planting.
- The number of leaves on each plant was recorded at 2, 3 and 4 weeks after planting.

After the plants had permanently wilted, they were destructively sampled and the following parameters were measured using the methods in Appendix A1. 3.1 and were recorded:

- Fresh and dry shoot mass,
- Root weight (only in Experiment 1b).
- Tuber weight
- Leaf area per plant.
- Specific leaf area per plant.
- Leaf dry matter content.

Plant water relations

- Transpiration.

  The method of measuring transpiration is presented in Appendix A1.3.4. Transpiration was recorded as daily losses of weight of the pots and plants, and observations began 7 days after planting when the plants were well established. The measurements were continued until the plants reached permanent wilting point.

- Leaf water potential

  Leaf water potential was measured using young fully expanded leaves of 4 plants for each cultivar in a pressure chamber. The measurements were carried out between 09.00 am and 14.00 pm (Appendix A1.3.4).

2.2.3 Field trial with non-limiting water

2.2.3.1 Experimental design

A well watered field experiment was conducted over the period November 2000 to March 2001 in the Genetic Garden of the School of Marine and Tropical Biology, James Cook University (Fig. 2.2). The total rainfall over the experimental period was 906 mm and it fell on 68 raindays. These water additions were supplemented by watering the plants by a fixed sprinkler system every second day when there was no rain.

Figure 2.2 Sweet potato cultivars grown under non-limiting water conditions in the Genetic Garden of the School of Marine and Tropical Biology, James Cook University, Townsville. Photograph taken on 30 January 2001.

A randomised complete block design was used in the experiment. Each cultivar was randomly allocated in each block. The plot size was 12 m x 8 m, consisting of 6 rows that were 100 cm apart, representing 6 replications with plant spacings of 75 cm along each row.

2.2.3.2 Experimental procedure

The land that had not grown sweet potato previously was cultivated by a tractor–drawn rotary hoe and any remaining plants and stones were removed. The area was then lightly cultivated by hand using a hoe, and soil mounds up to 30 cm high were formed. After watering the site daily for 15 days, vine-tip cuttings 25 cm long were planted with a single cutting in the moist soil of each mound. An organic fertiliser (Australian fertilizer product) with the composition of 3% N, 3% P, 4.5% K, 0.1% Fe, 0.06% Mn, 0.03% Zn) was applied in the soil at 10 g/m^2 (100 kg/ha) one day before planting, and again at 4 and 8 weeks after planting.

Weeds were removed manually. Irrigation was applied using overhead sprinklers during the first month of crop establishment. Plants were irrigated once a day for the first month. During tuber formation and bulking in the following months until harvest stage, the plants were irrigated twice a week, depending on the rainfall. Two months after planting, the morphological characters of the leaf and vine were recorded using the descriptive system of Huaman (1992). Leaf and node measurements were carried out on the eight nodes from the shoot tip.

2.2.3.3 Experimental variables

At harvest, and after drying at 40 ^{o}C, the following plant biomass and root tuber data were collected:

- Total fresh and dry weights of the above ground biomass. All plants were cut off at ground level and their leaves and vines were separated and weighed.
- Fresh and dry tuber weights per plant. Marketable tubers (tubers weighing more than 120 g/tuber) were separated from the smaller, unmarketable tubers.

- Tuber numbers per plant.

2.2.3.4 Statistical analyses

Plant growth response data were analysed using an analysis of variance of the Statistical Package for Social Scientists (SPSS 10.0 for Windows) at a 5% ($p < 0.05$) significance level. When the effects of various treatments were significant, post hoc comparisons were carried out using Bonferroni's method.

2.3 RESULTS AND DISCUSSION

2.3.1 Weather conditions

For Experiment 1a, daily minimum and maximum air temperatures, and relative humidity were recorded from November to December 2000 (Fig. 2.3). The maximum and minimum temperatures inside the glasshouse were also recorded. The maximum temperature was approximately 6 ^{0}C higher than the outside glasshouse, whereas the minimum temperatures were relatively similar. For Experiment 1b, similar temperatures occurred over the experimental period (February to March 2001) (Fig. 2.4).

The plants were grown under non-limiting water conditions in the field in the Genetic Garden between 28 November 2000 and 30 March 2001. Prior to the field experiment starting, 345 mm of rain had fallen marking the early onset of the wet season; it was sufficient to support the initial plant growth. The amount of rainfall declined in December 2000 into 219 mm and to 58 mm in January 2001. During the periods when there was no rain, the plants were watered by using a fixed sprinkler system. In February 2001, the rainfall increased to 236 mm, and supported tuberous roots development. The rainfall declined into 58 mm in March 2001 as the tubers matured.

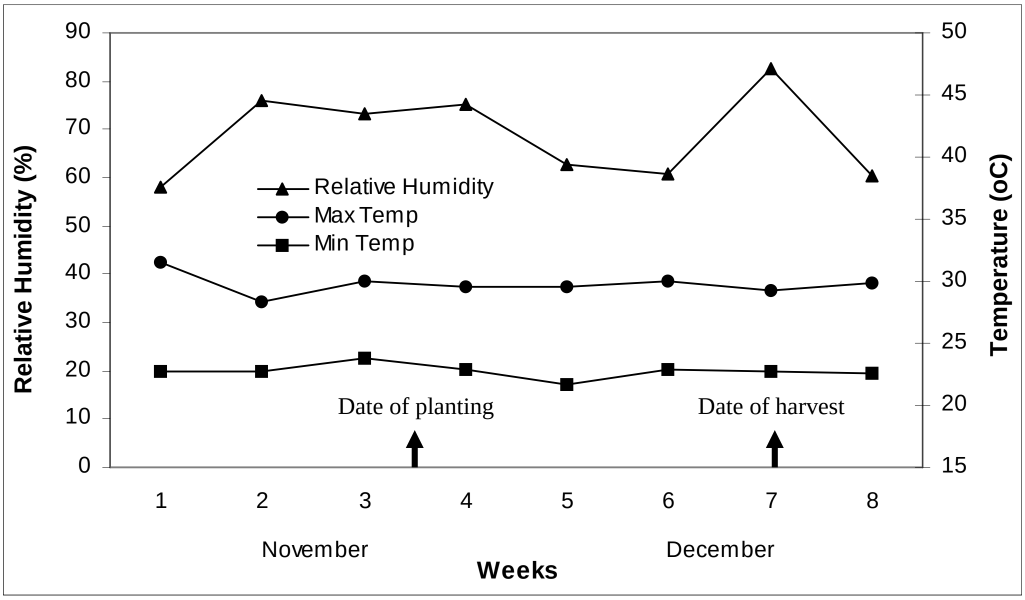


Figure 2.3 Experiment 1a: Weekly mean maximum and minimum air temperatures (^{o}C), and relative humidity measured at 3.00 pm (%) at Townsville area, from November to December 2000. Source: Bureau of Meteorology, Australia.

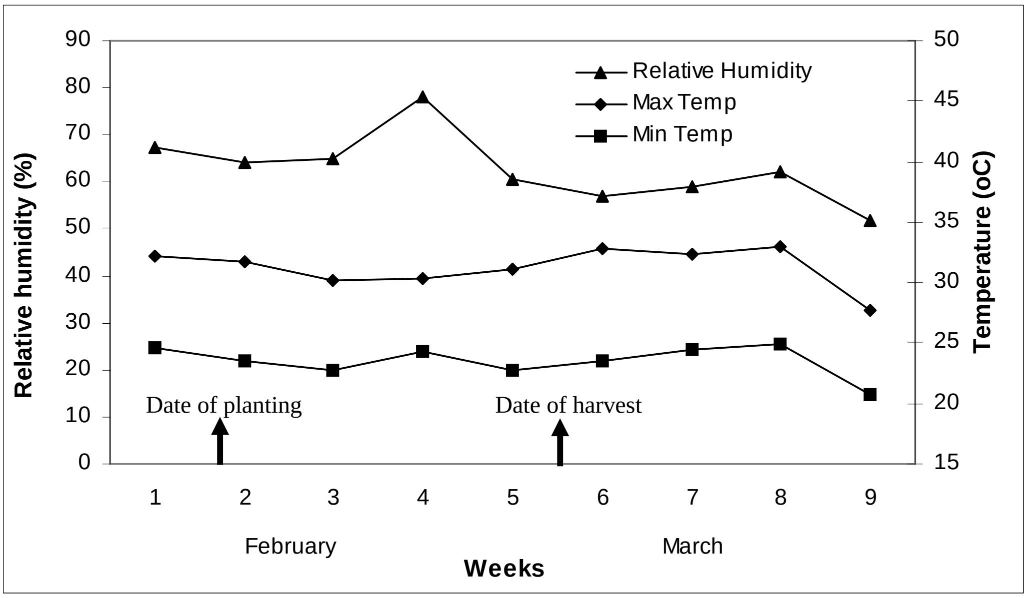


Figure 2.4 Experiment 1b: Weekly mean maximum and minimum air temperatures, and relative humidity at Townsville area, from February to March 2001. Source: Bureau of Meteorology, Australia.

The optimal temperature requirement for sweet potato growth is 24 ^{0}C (Kay, 1973). During Experiment 1a, heavy rain and wind damaged part of the glasshouse roof and the experiment was terminated in December 2000 after water had penetrated into some of the drying experimental units. The experiment was repeated (Experiment 1b) in February and March 2001 and warm temperatures and low relative humidity promoted rapid growth while moisture was not limiting (Fig. 2.4).

2.3.2 Shadehouse Trial

2.3.2.1 Plant growth and morpho-physiological characters

Effects of water stress on plant growth including main stem length, fresh and dry shoot mass, leaf area, internode length and diameter, fresh and dry masses of roots, and morpho-physiology, including specific leaf area and the leaf dry matter, of the 15 sweet potato cultivars are summarized in Table 2.1.

In general, the imposed water stress had a significant effect on all of the growth parameters measured except for the internode length. The interactions between water stress and cultivars were also significant, except for the main stem length, total dry biomass in Experiment 1a, and dry root mass in Experiment 1b. This suggests that the general responses of the cultivars to the water treatments were similar, and that it was just the magnitude of the responses that changed between cultivars.

Table 2.1 Summary of the effects of soil water, cultivars, and their interactions with plant growth parameters.

Plant parameters	Effects of		
	Water	Cultivar	Interaction
• **Main stem length**			
-Experiment 1a	*	*	ns
-Experiment 1b	*	*	*
• **Dry total biomass**			
-Experiment 1a	*	*	ns
-Experiment 1b	*	*	*
• **Dry leaf mass**			
-Experiment 1a	*	*	*
-Experiment 1b	*	*	*
• **Leaf area**			
-Experiment 1a	*	*	*
-Experiment 1b	*	*	*
• **Internode length**#)	ns	*	*
• **Internode diameter**#)	*	*	*
• **Fresh root mass**#)	*	*	ns
• **Dry root mass**#)	*	*	ns
• **Leaf dry matter content**#)	*	*	*
• **Specific leaf area**#)	*	*	*
• **Soil water content under the water stressed plants**			
-Experiment 1a	N/A	*at 11, 13, 15, 17, 19 21, 23 DAP	N/A
-Experiment 1b	N/A	* at 7, 9, 17, 21 DAP	N/A
• **Transpiration of the well watered plants**			
-Experiment 1a	N/A	*at 11, 13, 15, 17, 19, 21 DAP	N/A
-Experiment 1b	N/A	*at 7, 9, 11, 13, 17, 19 DAP	N/A
• **Leaf water potential**	*	ns	ns

ns (no significant effect); * $p < 0.05$);
observed only in Experiment 1 b; DAP = days after planting; N/A = not available

2.3.2.1.1 Main stem length

Water stress significantly reduced stem length in the 15 sweet potato cultivars tested (Table 2.1, Fig. 2.5 and Table A2: 19-20). The effect of the water stress and cultivar interaction was only significant in Experiment 1b.

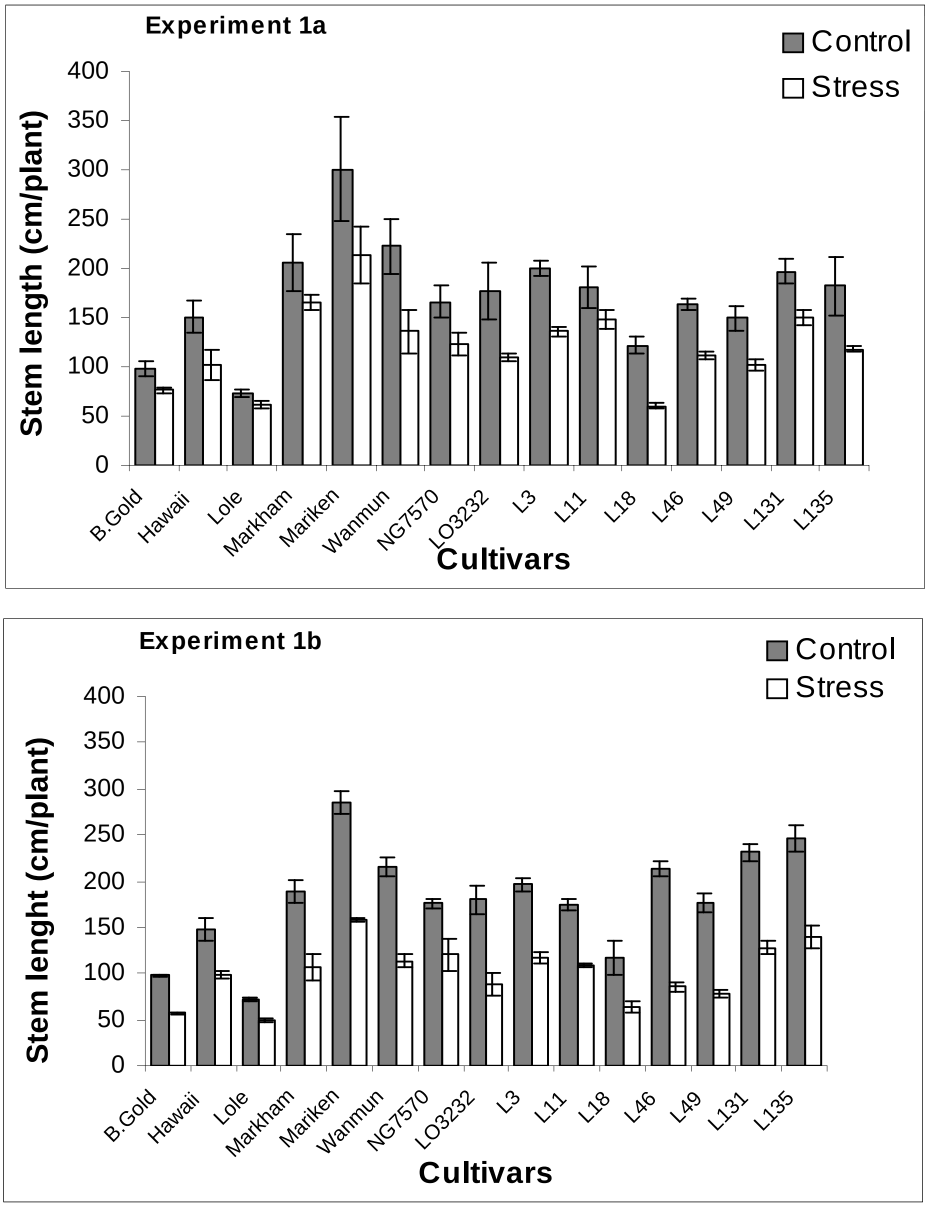


Figure 2.5 The length of main stem of 15 sweet potato cultivars as affected by soil water conditions. The control relates to the field trial in which water was non-limiting, the stressed conditions relate to the glasshouse trials of Experiments 1a and 1b in which water was withheld until permanent wilting point was achieved. Error bars represent standard errors of means with 3 and 4 replications in experiment 1a and 1b, respectively.

(a) Experiment 1a (27 November – 18 December 2000) terminated after 3 weeks of growth because of a leaking glasshouse roof.

(b) Experiment 1b (11 February to 12 March 2001) after 4 weeks of growth.

The vine branching habit was different among cultivars, although none of them had a twinning habit: cvv Lole and L18 had more branches than all of the others, and cv Lole had the smallest main stem diameter. The length of the main stem grew significantly more slowly in the water-stressed cultivars (Fig. 2.5). The reduction of the main stem length from well watered to water stressed conditions in Experiment 1a varied between 60% in cultivar L46 and 31% in the Lole and NG7570 cultivars (Fig. 2.5 a). In Experiment 1b, the reduction varied between 46% in cv L18 and 16% in cv Lole (Fig. 2.5 b). The reduction of stem length in Experiment 1b showed similar pattern to that of Experiment 1a.

Stem length was measured periodically from week 2 to week 4 after planting. The length of the main stem in all cultivars under well watered and water stressed conditions increased from 2 weeks to 4 weeks after planting (Fig. 2.6). While growth of the stem length under water stress conditions was slower, a significantly greater increase was recorded in stem lengths grown under well watered conditions. Under well watered conditions, cv Mariken recorded the longest stem growth in both Experiments 1a and 1b. The Lole cultivar grew very slowly during the first 2 weeks after planting.

The length of the main stem of all the cultivars declined under water stress. According to Taiz and Zieger (2002), the same physiological processes that limit leaf growth during stress might affect stem growth. Although cv Lole had the shortest stem, its stem length reduction under water stress was less than that of the other cultivars, except for cv NG7570.

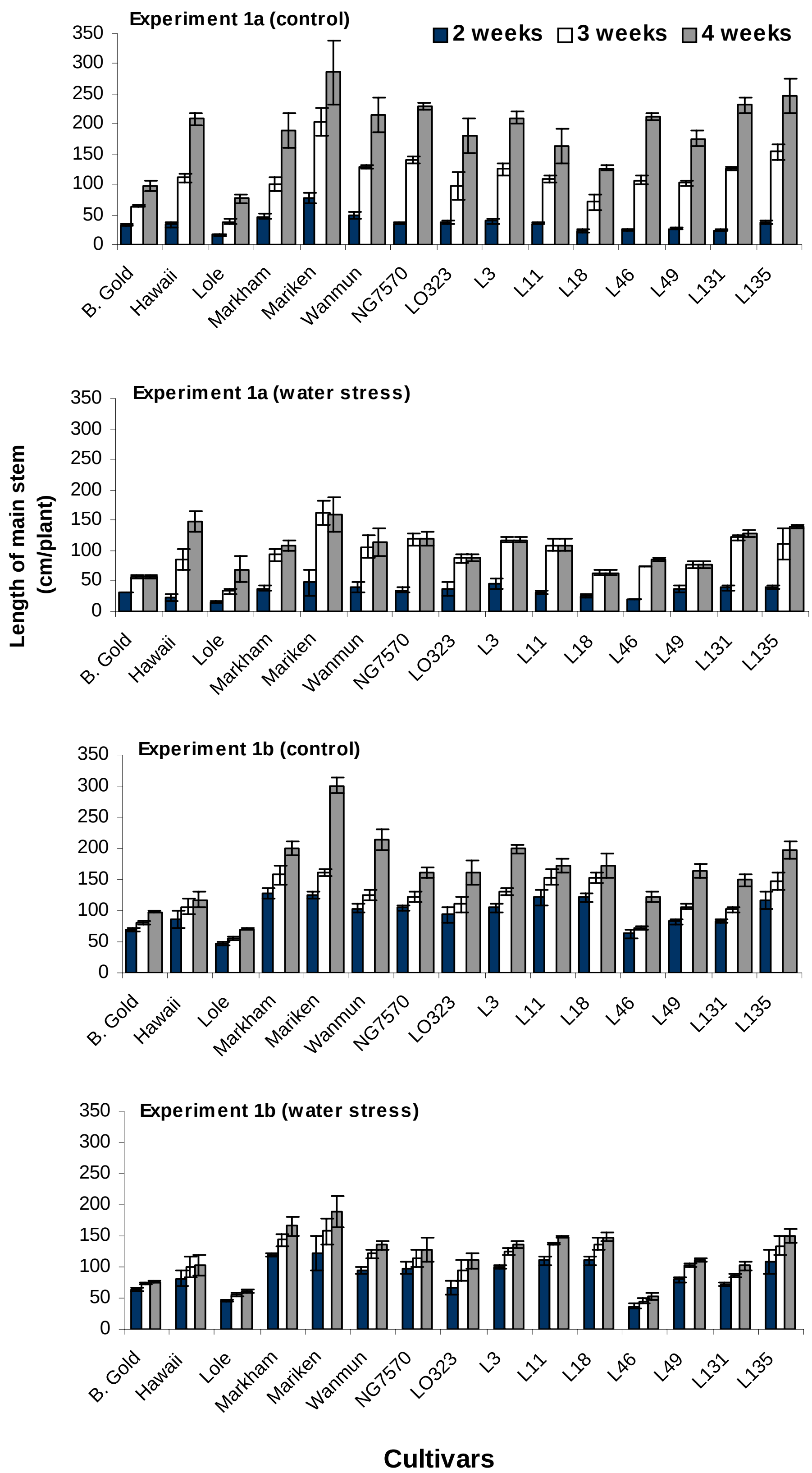


Figure 2.6 The length of main stem of 15 sweet potato cultivars affected by soil water conditions recorded at 2, 3, and 4 weeks after planting from the Experiment 1a and 1b.

2.3.2.1.2 Internode length and diameter

Internode length was not affected by the applied soil water stress, but it varied significantly among the cultivars (Table 2.1). The interaction effect between soil water regimes and cultivars however was statistically significant (Table 2.1 and Table A2: 27). Under well-watered conditions, cv Mariken produced the greatest internode length, followed by cvv Markham, L11, and LO323 (Table 2.2). The cultivars with the shortest internode lengths were cvv Lole and L18. When water was withheld, the internode length of several cultivars declined. The Mariken cultivar produced the highest internode length under water stress, followed by cvv Markham, L11, and LO323. However, cv L46 had the greatest percentage of internode length reduction, followed by cvv Wanmun, NG7570, LO323, and L18. The internode length of some cultivars, including Hawaii, Lole, L3, and L135, remained constant when water was withheld.

Water stress significantly decreased the internode diameter in all cultivars (Tables 2.1, 2.2 and Table A2: 28). Internode diameter was slightly reduced in cv Lole (12%), whereas cultivars LO323, L49, and L131 produced the greatest reduction 30-45% (Table 2.2). The reduction of internode diameter under water stress agrees with the findings of Kirnak *et all* (2001) who observed that water stress in egg plants *(Solanum melongena)* reduced both stem length by 46% and internode diameter by 51% when grown under water stress equivalent to 40% of the soil's field capacity.

Cultivars Lole and L135 appear to have some drought tolerance, as their internode diameters were least affected by water stress compared to their growth under well watered conditions.

Table 2.2 Internode length (cm) and diameter (mm) of sweet potato cultivars as affected by soil water condition 3 weeks after planting in Experiment 1b.

Cultivar	Internode length (cm)			Internode diameter (mm)		
	Control plant	Water stressed plant	Stress as % of control	Control plant	Water stressed plant	Stress as % of control
B. Gold	3.6	3.5	97.2	3.8	2.9	76.3
Hawaii	5.8	5.8	100.0	2.5	2.0	80.0
Lole	2.5	2.5	100.0	2.8	2.5	89.3
Markham	7.7	7.6	98.7	3.4	3.0	88.2
Mariken	9.0	8.9	98.9	3.0	2.3	76.7
Wanmun	5.6	5.3	94.6	3.5	3.0	85.7
NG7570	6.3	6.0	95.2	2.3	2.0	87.0
LO323	7.1	6.8	95.8	2.9	2.0	69.0
L3	6.8	6.8	100.0	3.9	3.0	77.0
L11	7.2	7.0	97.2	3.7	2.8	75.7
L18	2.5	2.4	96.0	3.8	3.2	84.2
L46	5.4	5.0	92.6	3.8	3.1	81.6
L49	5.0	4.9	98.0	5.1	3.4	66.7
L131	6.1	5.9	96.7	3.0	2.0	66.7
L135	5.0	5.0	100.0	2.7	2.4	88.9

A significant difference between pairs of columns is presented in Table A2: 9-10.

2.3.2.1.3 Dry biomass

Water stress significantly reduced dry biomass in Experiments 1a and 1b, and the response was varied among the 15 sweet potato cultivars (Table 2.1 and Table A2: 21-22). The interactions also indicated that the cultivars tested responded differently to soil water conditions (Fig. 2.7).

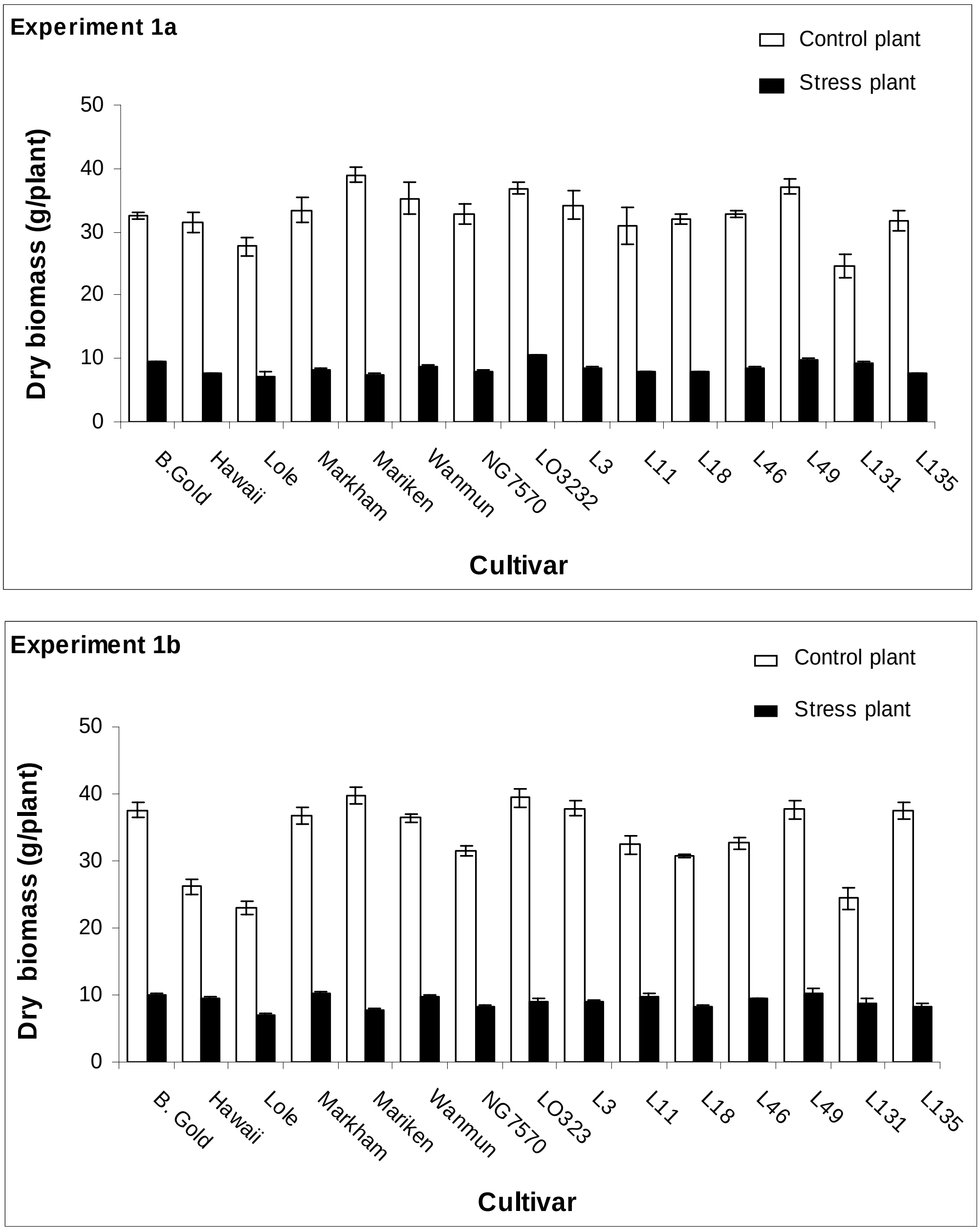


Figure 2.7 Total dry plant biomass (sum of dry shoots and dry roots) of 15 sweet potato cultivars affected by soil water conditions (Experiments 1a and 1b).

Water stress reduced the average dry biomass (31-46 %) with respect to that produced by plants under the non-limiting water regime. Under water stress conditions, the total plant dry masses of cvv Beerwah Gold and L3 were reduced by 31% and 59% compared to the well watered control (Fig. 2.7, Table A2: 3-4). The Lole and Hawaii cultivars produced the lowest percentage reduction in dry biomass.

2.3.2.1.4 Dry leaf mass

Water stress significantly reduced dry leaf masses of the 15 cultivars tested (Tables 2.1 and A2: 23-24). The interaction effect between water treatments and cultivars was significant in experiment 1b.

Table 2.3 Dry leaf masses (g/plant) of sweet potato cultivars as affected by soil water condition in Experiment 1a. The control plants were grown in the field under non-limiting water conditions.

	Dry leaf mass (g/plant)		
Cultivar	**Control plants**	**Water stressed plants**	**Stress as % of control**
Beerwah Gold	11.1	3.0	27.0
Hawaii	15.5	3.0	19.4
Lole	12.4	4.8	38.7
Markham	13.6	2.6	19.1
Mariken	13.6	2.2	16.2
Wanmun	12.7	2.9	22.8
NG7570	13.5	2.5	18.5
LO323	13.3	3.2	24.1
L3	11.5	2.2	19.1
L11	13.6	2.1	15.4
L18	13.5	2.4	17.8
L46	13.8	3.7	26.8
L49	10.7	2.4	22.4
L131	11.8	3.5	29.7
L135	11.2	2.3	20.5

A significant difference among the cultivars is presented in Table A2: 5.

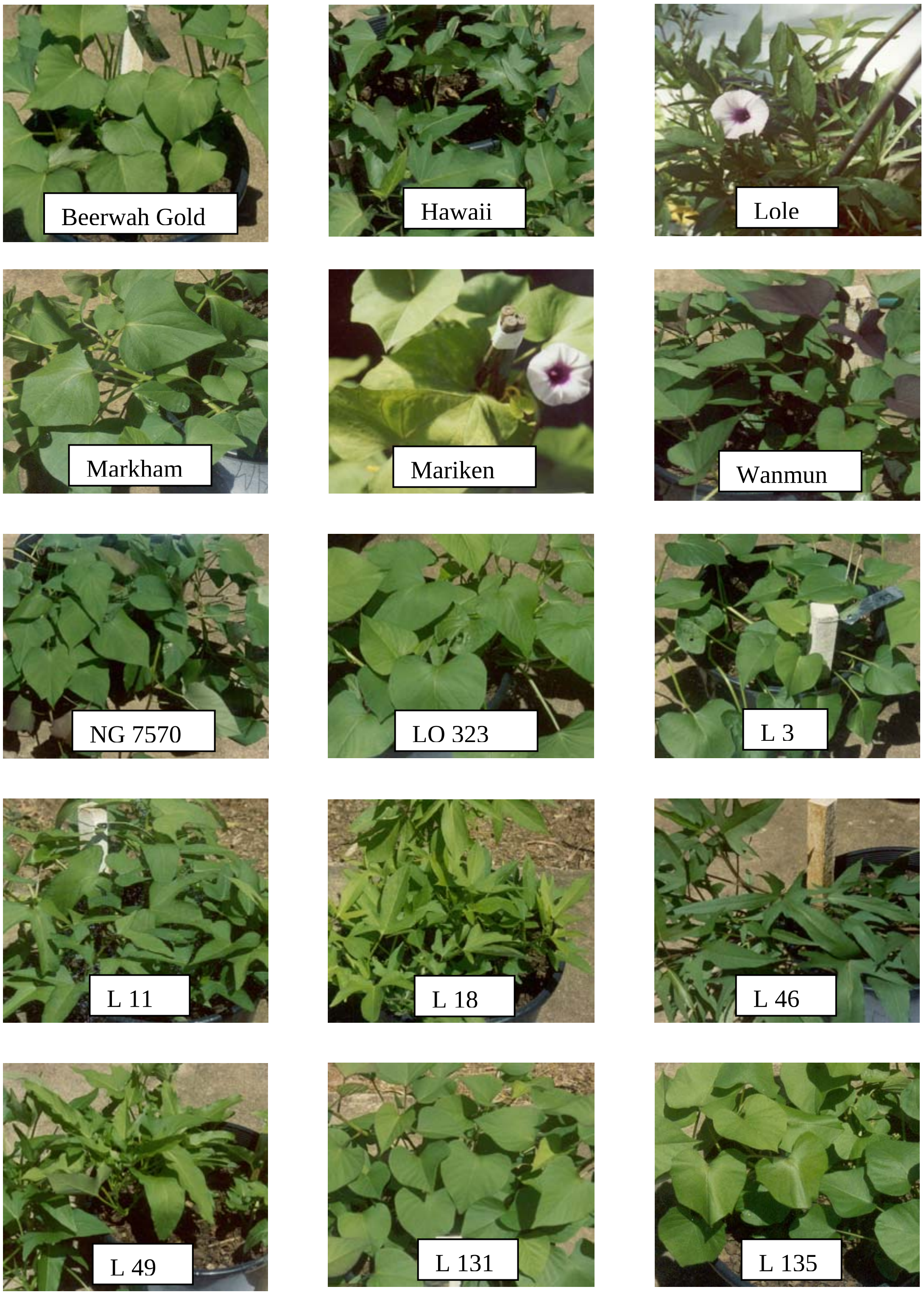


Figure 2.8 Leaf morphological characters of 15 sweet potato cultivars studied.

Table 2.4 Dry leaf mass (g) of sweet potato cultivars as affected by soil water conditions in Experiment 1b. The control plants were grown in the field under non-limiting water conditions.

Cultivar	Dry leaf mass (g/plant)		
	Control plants	Water stressed plants	Stress as % of control
Beerwah Gold	12.6	4.3	34.1
Hawaii	9.4	2.9	30.9
Lole	9.2	3.4	37.0
Markham	11.8	3.9	33.1
Mariken	11.1	2.6	23.4
Wanmun	12.1	2.9	24.0
NG7570	11.8	2.6	22.0
LO323	13.2	4.1	31.1
L3	12.8	2.9	22.7
L11	10.5	3.3	31.4
L18	12.1	2.6	21.5
L46	12.0	3.9	32.5
L49	12.1	3.4	28.1
L131	10.0	3.7	37.0
L135	12.0	3.6	30.0

A significant difference between pairs of columns is presented in Table A2: 6.

Leaf mass declined significantly under the water stress condition in Experiments 1a and 1b (Tables 2.3 and 2.4). The leaf masses of cvv Lole and L131 were least affected by water stress, and the most affected were cvv L18, NG7570, L3, LO323, L3, Mariken and Wanmun.

The leaf mass data suggest that cultivars Lole, Hawaii and L131 have some drought tolerance, as they were less affected by the water stress compared to their growth under well watered conditions. On the other hand, the cultivars Mariken and L18 appear to be sensitive to water stress as their leaf masses were reduced the most by the imposed water stress.

2.3.2.1.5 Root masses

Root masses were recorded only in Experiment 1b. Water stress significantly reduced the root fresh and dry masses of the roots of all of the sweet potato cultivars studied. There were no significant interactions between cultivar and soil water treatments (Tables 2.1, 2.5, and A2: 29-30).

This suggests that root growth was severely affected by water stress. Under well watered and stressed conditions, the greatest fresh root mass was produced by cv Mariken, whereas the lowest fresh root mass was produced by cvv Lole, L18, and L11. The greatest dry root mass, on the other hand was from cv Markham and the lowest was from cv L135 (Table 2.5).

Table 2.5 Fresh and dry masses of roots of sweet potato cultivars (g) as affected by soil water condition in Experiment 1b.

Cultivar	Fresh root mass (g)			Dry root mass (g)		
	Control plant	Water stressed plant	Stress as % of control	Control plant	Water stressed plant	Stress as % of control
B. Gold	93.9	8.7	9.3	4.6	1.4	30.4
Hawaii	71.3	6.9	9.7	3.6	1.1	30.6
Lole	63.9	6.2	9.7	3.4	1.1	32.4
Markham	90.9	8.5	9.3	5.5	1.7	30.9
Mariken	100.7	12.2	12.1	4.4	1.0	22.7
Wanmun	85.3	7.2	8.4	4.4	1.2	27.3
NG7570	75.4	6.7	8.9	3.9	1.2	30.8
LO323	99.6	11.6	11.6	3.7	1.2	32.4
L3	95.8	8.5	8.9	4.3	1.4	32.6
L11	69.2	6.3	9.1	4.8	1.2	25.0
L18	66.7	5.8	8.7	3.5	1.2	34.3
L46	76.4	6.8	8.9	4.4	1.4	31.8
L49	87.7	8.4	9.6	5.0	1.4	28.0
L131	75.3	5.9	7.8	4.5	1.3	28.9
L135	79.8	7.0	8.8	3.5	0.6	17.1

A significant difference between pairs of columns is presented in Table A2: 11-12.

The mass of fresh and dry roots did not vary consistently across all of the 15 cultivars studied. In terms of the reduction in dry root mass when grown under water stress, cultivar L18 appears to have the most drought tolerance, while cultivars L135 and Mariken were the most sensitive to water stress as their dry root masses were reduced the most under such conditions. The decline in root mass under water stress is probably a result of the loss of turgor in expanded cells (Kirnak *et al*., 2001).

2.3.2.2 Leaf shape and area

The shapes and sizes of leaves vary widely among sweet potato cultivars (Bhagsari and Brown, 1986; Huaman, 1997). The general leaf shapes of sweet potato cultivars are shown in Figure 2.9.

Leaf shape

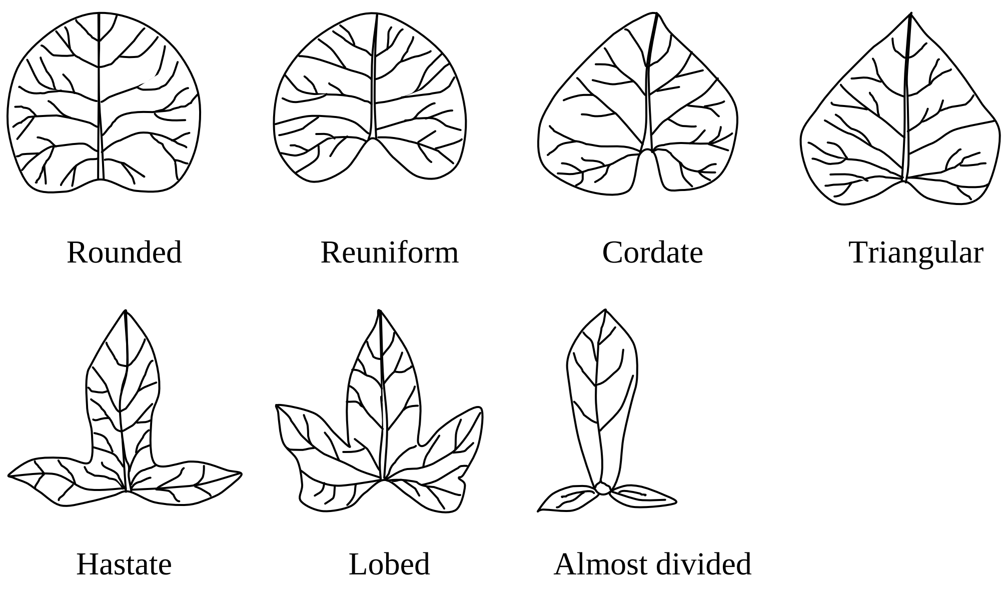


Figure 2.9 The general leaf shapes of sweet potato cultivars (Huaman, 1997).

Of the 15 sweet potato cultivars of the present study, the leaf shapes of 8 were cordate (Beerwah Gold, LO323, Markham, Mariken, L131, L135, NG7570, L3 cultivars with triangular and semi-elliptic leaf types), 2 (L 46 and L 49) were hastate, 3 (L 11, L 18, Hawaii) were lobed, 1 (Lole) was deeply lobed and almost divided, and 1 cultivar (Wanmun) was triangular and cordate.

The leaf sizes among the 15 cultivars were variable. Some cultivars such as Lole, L18, L11, L46, L46, and Hawaii were characterized by smaller leaves with lanceolate lamina and deep lobes resulting in reduced leaf area. Low transpiration and efficient growth under water stressed conditions are often attributed to this important plant parameter (Taiz and Zieger, 2002).

The cultivars of the present study producing the greatest leaf area under well-watered conditions were NG7570, Beerwah Gold, and LO323, whereas cvv Hawaii, Markham, NG7570, LO323, and L46 had the greatest leaf area under the water stressed conditions. There was a significant reduction in the leaf area of all the 15 cultivars due to water stress (Tables 2.1 and 2.6, and Table A2: 25-26).

Table 2.6 Leaf area of sweet potato cultivars (cm^2 / plant) as affected by soil water conditions in Experiment 1a and 1b.

Cultivar	Leaf area (cm^2/plant)					
	Experiment 1a			Experiment 1b		
	Control plant	Water stressed plants	Stress as % of control	Control plants	Water stressed plants	Stress as % of control
B. Gold	3914.7	691.0	17.5	3890.8	771.2	19.8
Hawaii	2894.7	1108.2	38.3	3216.1	838.8	26.1
Lole	2105.8	875.6	41.6	2113.6	755.9	35.8
Markham	3551.5	1047.3	29.5	3716.4	888.5	23.9
Mariken	3403.7	786.8	23.1	3523.9	770.5	21.9
Wanmun	3481.0	889.3	25.5	3488.9	823.4	23.6
NG7570	4012.5	955.3	23.8	4065.0	867.8	21.3
LO323	3914.7	880.0	22.5	4160.3	851.3	20.5
L3	3741.4	846.5	22.6	3870.9	817.7	21.1
L11	3072.4	815.4	26.5	3682.3	819.4	22.3
L18	3349.7	740.8	22.1	3609.0	761.9	21.1
L46	2962.4	757.4	25.6	3809.1	841.9	22.1
L49	3556.5	739.1	20.8	2972.3	814.1	27.4
L131	2358.1	896.3	38.0	2347.9	823.8	35.1
L135	2621.2	868.7	33.1	2773.3	797.9	28.8

A significant difference between pairs of columns is presented in Table A2: 7-8.

The leaf area data suggest that cultivars Lole, Hawaii, and L131 have some drought tolerance, as their leaf area was least affected by water stress compared to their growth under well watered conditions. On the other hand the cultivar Beerwah Gold appears to be the most sensitive to water stress as its leaf area was reduced the most under such conditions. The leaf area of sugar beet (*Beta vulgaris* L.) was reported to be reduced by 84% under drought conditions (Abdollahian-Noghabi and Froud-William, 1998), and this is comparable with the reduction in leaf area observed in the present sweet potato trial (Table 2.6).

2.3.2.3 Leaf dry matter content and specific leaf area

Leaf dry matter and specific leaf area, determined according to the methods set out in Appendix A1.3.1, varied significantly among the 15 sweet potato cultivars studied. Water stress significantly reduced leaf dry matter content and the specific leaf area recorded in Experiment 1b. The interaction between water regimes and cultivars was statistically significant (Tables 2.1 and A2: 31-32).

The Beerwah Gold cultivar recorded greatest leaf dry matter content under the well-watered treatment, followed by cv LO323. In the stressed treatment, cv L131 recorded greatest leaf dry matter, followed by cvv L135 and Lole (Table 2.7). The NG7570 cultivar produced the greatest specific leaf area under both the control and water stressed treatments, while cv Beerwah Gold recorded the lowest specific leaf area under water stress.

Table 2.7 Effect of water stress on leaf dry matter content and specific leaf area of fifteen sweet potato cultivars in Experiment 1b.

Cultivars	Leaf dry matter content (g)		Specific leaf area (cm^2/g)	
	Control plant	Water stressed plant	Control plant	Water stressed plant
Beerwah Gold	0.365	0.144	308.7	180.1
Hawaii	0.275	0.132	344.3	215.4
Lole	0.239	0.173	229.3	227.3
Markham	0.278	0.167	312.2	234.9
Mariken	0.200	0.166	317.1	295.7
Wanmun	0.228	0.168	289.2	286.0
NG7570	0.179	0.152	346.1	340.3
LO323	0.333	0.167	316.0	208.6
L3	0.215	0.167	305.4	294.2
L11	0.228	0.143	354.9	252.8
L18	0.199	0.157	298.0	296.9
L46	0.270	0.171	317.8	219.4
L49	0.246	0.156	245.1	243.5
L131	0.209	0.192	238.1	220.7
L135	0.249	0.184	233.3	225.6

A significant difference between pairs of columns is presented in Table A2: 13-14.

Garnier *et al.* (2001) have shown that leaf dry matter reflects a fundamental trade-off in plant functioning between a rapid production of biomass (in species with high specific leaf area and low leaf dry matter contents), and an efficient conservation of nutrients (in species with low specific leaf area and high leaf dry matter content species). Under the well watered control treatment, the Beerwah Gold cultivar produced the greatest leaf dry matter content, whereas cv L131 produced the highest leaf dry matter content under water stressed conditions. Cultivar NG7570 produced the greatest specific leaf area in both the control and water stressed conditions. During the early vegetative period, on the other hand, cv Lole produced the lowest specific leaf area in the control, thus it had thicker leaves per plant. Thicker leaves means that Lole has an efficient transpiration rate per unit weight of leaves, suited to low water availability conditions (Pugnaire *et al*., 2002).

2.3.2.4 Water relations

Soil water content was recorded for the plants grown under water stressed conditions, while transpiration was recorded for the plants grown under well-watered conditions. To evaluate the plant water status, leaf water potentials were recorded in Experiment 1b.

Effects of water stress on water relations including transpiration and leaf water potential of 15 sweet potato cultivars are summarized in Table 2.1 and Fig. 2.10.

2.3.2.2.1 Soil water content

The water contents of the media in which the plants were grown under water stress conditions was recorded from day 7 after planting. The water losses recorded allow an estimate of transpiration from the stressed plants and are shown in Fig. 2.10.

In the first 7 days after withholding water, the amount of water in the soil remained high, indicating that the physiological function had not yet been affected, as the plants were still small, and had not used much water at that stage. However, as the soil water was further depleted, transpiration rates rapidly decreased between 7 and 21 days after planting. Transpiration then remained low and was almost constant; the leaves progressively wilted and reached permanent wilting point. According to Leopold (1964), as the soil water availability declines, leaf cells loose their turgor; this affects the leaf photosynthesis due to stomatal closure and physical disruption of the leaf cells.

This suggests that water extraction increased when the plant growth progressed particularly under well-watered conditions, as a result of active increases in biomass production and leaf area. These, in turn, increased the transpiration rate and the demand for water for metabolic and physiological functions. The Lole cultivar showed a lower transpiration rate than all other cultivars under both watering regimes (Figs 2.10 and 2.11). Garner *et al*. (1992) found a drought tolerant sweet potato cultivar (cv Vardaman) with a lower transpiration rate than all of the other cultivars that they examined; this was attributed to its capability to maintain cellular integrity during water stress and to conserve water under drought conditions.

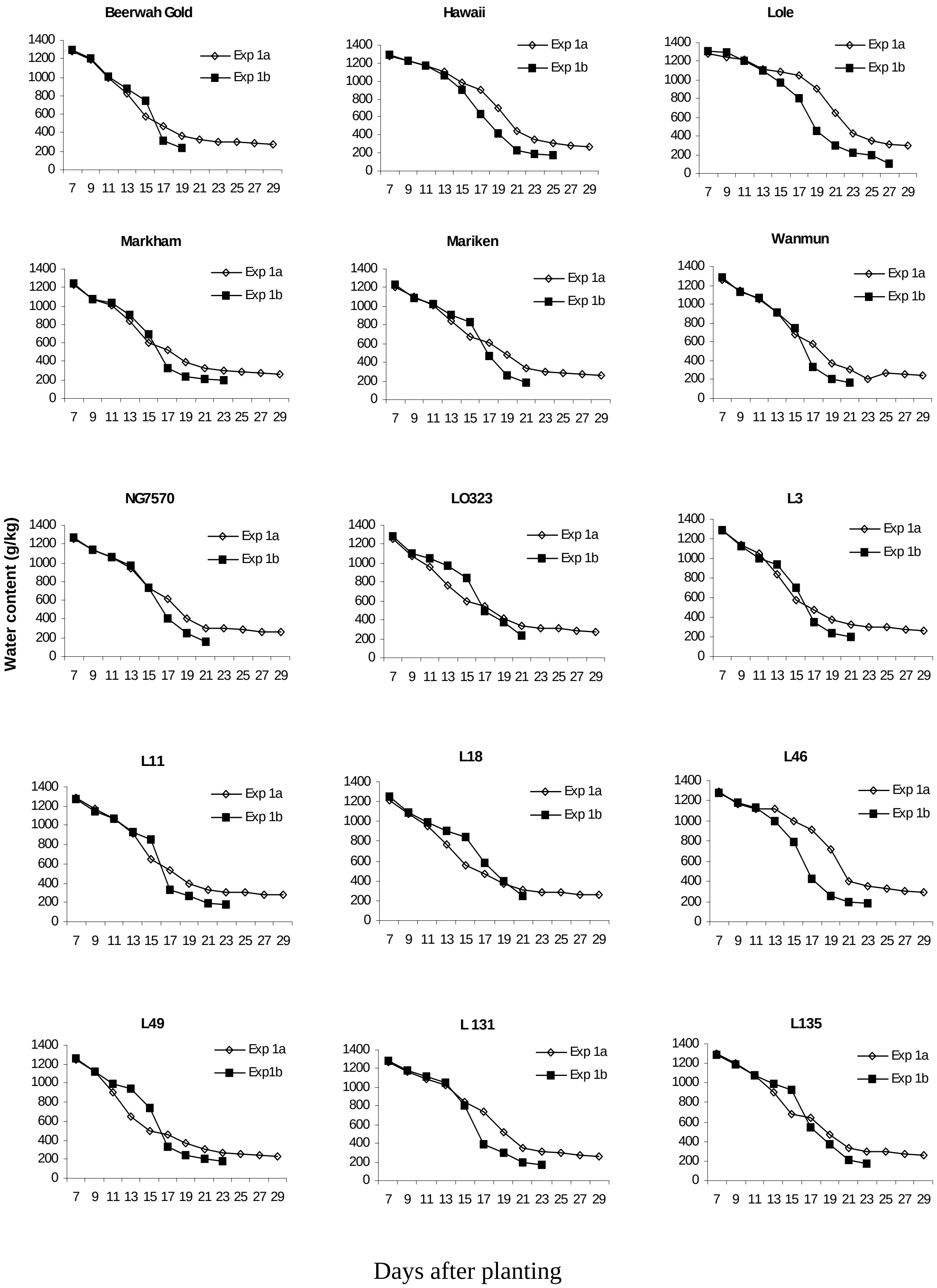


Figure 2.10 Water content (g of water /kg of soil) of the growing media of 15 sweet potato cultivars under water stress conditions, recorded from 7 days after planting until the day on which the plants permanently wilted in Experiments 1a and 1b.

Under well watered conditions, transpiration increased rapidly from the initial growth stage at 7 days to 23 days after planting (Fig. 2.10). On the other hand, transpiration of the water stressed plants declined when soil water availability declined.

Water losses due to transpiration are highly variable across plant species: maximal transpiration rates of 10, 1.0, and 0.1 g of water $dm^{-2}h^{-1}$ have been recorded in hygrophytes, mesophytes, and xerophytes, respectively (Monneveux and Belhassen, 1996). In the present trial, withholding soil water gradually produced a soil moisture stress which reached permanent wilting point. It showed that water availability is crucial in establishing stem cuttings and in supporting subsequent vegetative growth. Lack of water during the early growth stages acted as a growth retardant.

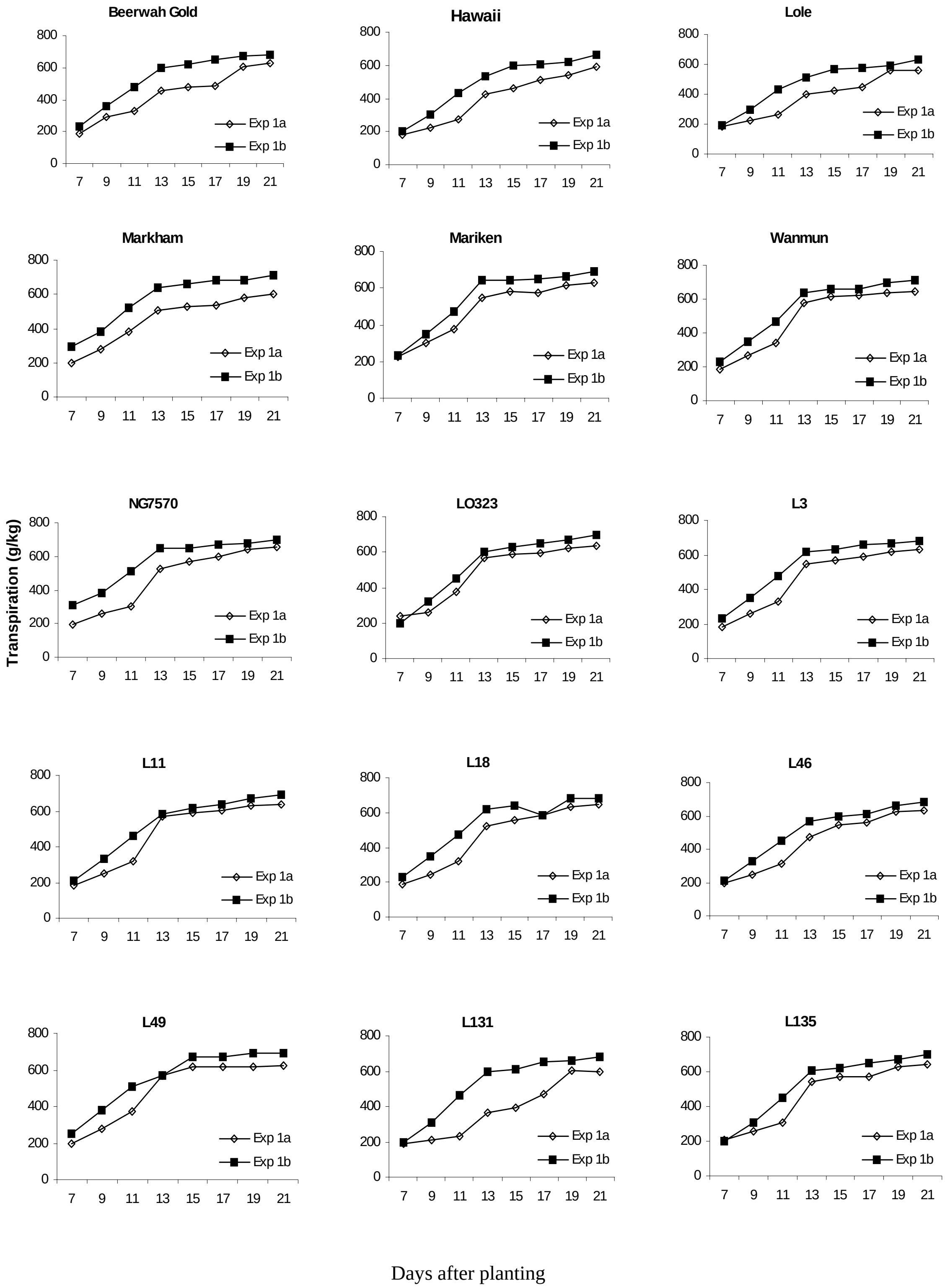


Figure 2.11 Cumulative transpiration (g of water / kg of soil) of 15 sweet potato cultivars recorded from 7 days to 21 days after planting grown under well watered conditions in Experiments 1a and 1b.

Soil water contents at permanent wilting point under the 15 cultivars, and the number of days taken by each cultivar to reach permanent wilting point are presented in Table 2.8. The Beerwah Gold cultivar was severely affected by restricted water and reached permanent wilting point at only 17 days after planting and the soil water content at that time was 240 g of water per 4.5 kg of soil medium (soil moisture content = 14.8%). On the other hand, cvv Hawaii and Lole needed 25 and 27 days, respectively to reach permanent wilting point and the soil moisture content at that time was 170 and 174 g of water per 4.5 kg of soil medium (10.7% and 10.4%, respectively).

Table 2.8 Evaluation of drought tolerance characters of 15 sweet potato cultivars based on the amount of water remaining in the growing media when the plants reached permanent wilting point and the number of days to reach permanent wilting point in the water stressed plants. Data are from Experiment 1b.

Cultivar	Soil water content (g of water/pot)	Soil Moisture Content (%)	Number of days to reach permanent wilting point	Drought tolerance
Lole	170	10.4	27	Good
Hawaii	174	10.7	25	Good
Markham	191	11.8	23	Moderate
L11	181	11.2	23	Moderate
L46	179	11.0	23	Moderate
L49	174	10.7	23	Moderate
L131	173	10.7	23	Moderate
L135	172	10.6	23	Moderate
L18	158	9.8	23	Moderate
Mariken	179	11.0	21	Moderate
Wanmun	163	10.1	21	Moderate
NG7570	163	10.1	21	Moderate
L3	199	12.3	21	Moderate
LO323	239	14.8	21	Poor
Beerwah Gold	240	14.8	19	Poor

A significant difference between pairs of columns is presented in Table A2: 15.

Based on the number of days to reach permanent wilting point and the soil moisture content at that stage (Table 2.8), cvv Lole and Hawaii appeared to be the most drought tolerant cultivars, while the least drought tolerant plants wilted earlier, and retained the highest soil moisture content in the growing media at permanent wilting point.

The number of days to reach permanent wilting point was statistically significant among the cultivars (Table A2: 35). Based on the results of the statistical analysis (Table 2.8), cv Lole had a significantly longer survival period until the onset of permanent wilting, hence was more drought tolerant, than all the other cultivars. On the other hand, however, the Beerwah Gold cultivar had a significantly shorter survival period, and was more drought sensitive, than all of the cultivars except for cvv Mariken, Wanmun, NG7570, LO323, and L3 which had similar drought sensitivities.

2.3.2.4.2 Leaf water potential

Leaf water potential was not statistically significant among the cultivars on the day when the plants reached permanent wilting point, but it was significantly different between plants grown under well watered and water stressed conditions (Fig. 2.12 and Table A2: 36).

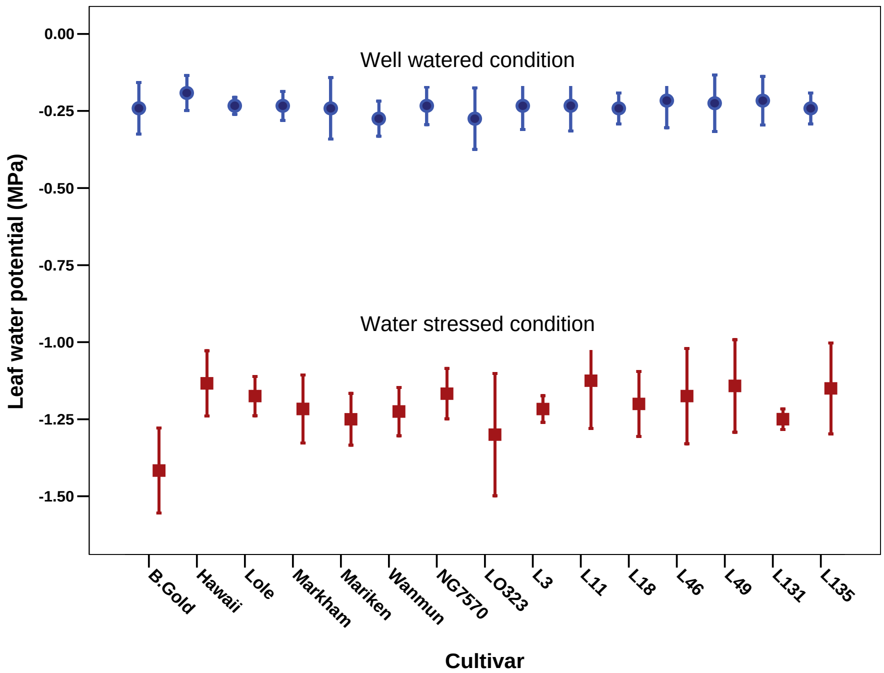


Figure 2.12 Leaf water potential of 15 sweet potato cultivars, grown under well watered and water stressed conditions, at the time that the cultivars reached the permanent wilting point. Vertical bars are standard errors of means (Data are from Experiment 1b).

In the well-watered plants, leaf water potentials ranged between – 0.19 MPa and – 0.28 MPa, and in the stressed plants between –1.13 MPa and –1.42 MPa (Fig. 2.12). The greatest reduction in leaf water potential due to water stress was in the Beerwah Gold cultivar, which reduced from – 0.24 MPa in well watered conditions to –1.42 MPa under water stress.

Plant water potential shows a wide genetic variability, even under unstressed conditions (Monneveux and Belhassen 1996). In the present trial, leaf water potential was not significantly different among cultivars under the well watered regime, but it declined under stressed conditions. The decrease in leaf water potential due to water stress has been widely reported in many crop species including certain genotypes of cowpea, wheat, and mungbean (Walker and Miller, 1986; Siddique *et al*., 2000; Sangakkara *et* *al*., 2000). Siddique *et al.* (2000) found that leaf water potential of wheat decreased from –0.63 MPa in well watered plants to – 2.00 MPa in stressed plants. This was thought to be a response to drought stress: leaf and canopy temperature increased due to increased respiration and decreased transpiration, and affected the photosynthetic rate due to stomatal closure (Siddique *et al.*, 2000).

Transpiration from plants largely depends upon the size of the evaporating areas (leaves, stems) (Monneveux and Belhassen, 1996). In the present study, the sweet potato cultivars with genetically larger leaves and vines showed wilting symptoms earlier than those with smaller leaves and low vine vigour. For example, cvv Lole and Hawaii used less water than the larger, more vigorous cultivars with larger leaves such as Beerwah Gold, LO323, Mariken, Markham, and Wanmun, which therefore had a greater capacity to transpire more rapidly and to exhaust the soil water supply.

2.3.3 Field trials

Sweet potato vines varied morphologically among cultivars (Table 2.9). The internode diameters were very thin to thin (3.5 - 12 mm), and the internode length was very short to intermediate (3.5 - 12 mm; Table 2.9). Leaves of some of the cultivars had sparse tip pubescences, except for cultivar L49, which had a moderate tip pubescence.

Table 2.9 Morphological characteristics of 15 sweet potato cultivars grown in the field under non-limiting water conditions.

Cultivars	**Vine Characters**						
	Leaf shape	**Plant type**	**Petiole length (cm)**	**Internode diameter (mm)**	**Internode length (cm)**	**Mature leaf length (cm)**	**Tip Pubescence**
Beerwah Gold	Cordate	Erect	15	Thin (6)	Very short (3.5)	13	No
Hawaii	Lobed	Erect	8	Thin (5)	Short (6.0)	12	Sparse
Lole	Deep lobed and almost divided	Erect	8	Very thin (3)	Very short (2.5)	12	None
Markham	Triangular	Erect	10	Thin (6)	Intermediate (7.5)	13	Intermediate
Mariken	Cordate	Erect	9	Thin (6)	Long (10.0)	13.5	Sparse
Wanmun	Cordate	Erect	9	Thin (4)	Short (5.5)	13.5	Intermediate
NG7570	Cordate	Erect	9	Thin (5)	Short (6.0)	12	Intermediate
LO323	Cordate	Erect	12	Thin (6)	Intermediate (7.5)	16.5	Sparse
L3	Cordate	Erect	10	Thin (4)	Short (3.5)	13	Sparse
L11	Lobed	Erect	6	Thin (5)	Short (7.0)	14	Sparse
L18	Lobed	Erect	5.5	Thin (5)	Very short (2.5)	12	None
L46	Hastate	Erect	9	Thin (5)	Short (5.5)	15	None
L49	Hastate	Erect	11	Thin (5)	Short (5.0)	14	Moderate
L131	Cordate	Erect	6	Thin (5)	Very short (6.0)	14	None
L135	Cordate	Erect	6	Thin (4)	Short (5.0)	14	None

2.3.3.1 Shoot mass and tuber yield components

Differences among fresh and dry shoot masses, and tuber weights and numbers per plant are summarised in the Table 2.10

Table 2.10 Summary of the effects of different cultivars on the plant growth parameters and tuber yield.

Plant parameters	Effect of cultivars
• Fresh shoot mass	*
• Dry shoot mass	ns
• Total tuber mass	*
• Marketable tuber number	*

ns (no significant); * (significant at $p < 0.05$)

2.3.3.1.1 Fresh shoot mass

Fresh shoot mass was significantly different among the 15 sweet potato cultivars studied but dry shoot mass was not (Table 2.10 and Table A2: 37). The Mariken cultivar had the greatest fresh shoot mass and cv Beerwah Gold the least (Fig. 2.13).

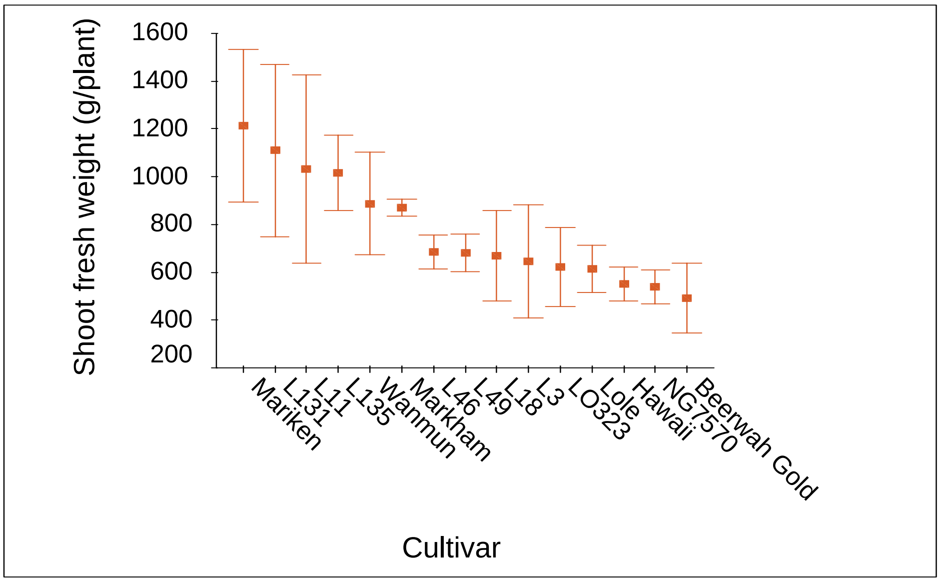


Figure 2.13 Fresh shoot mass of 15 sweet potato cultivars grown under non-water stressed field conditions. Error bars represent standard errors of means with 6 replications.

Beerwah Gold, LO323, and Wanmun were the cultivars that produced the largest leaf areas during vegetative growth (Table 2.6). However, when the plants reached the tuber bulking or maturity stage, the production of young leaves diminished and the total mass of plant leaves declined rapidly as assimilates were diverted from the source (leaves) to the sink (or root storage organs) as the tubers developed. The older leaves turned yellow and dropped at this stage.

According to Bouwkamp (1983), limited leaf growth at the tuber bulking period is related to the mobilization of assimilate from the leaves and results in greater tuber yields. Lower shoot biomasses weight at harvest can be attributed to the senescing leaves which may lose as much as 50% of their fresh weight in the form of soluble organic nitrogen compounds that are transported to the developing sinks in the tubers (Hopkins, 1999).

2.3.3.1.2 Numbers and yield of marketable tubers

Variations in the number of tubers produced by different sweet potato cultivars has been widely reported (Bourke, 1984; Sen *et al*., 1990). The number of marketable tubers (tubers > 120 gram) produced by the unstressed plants in the present study was also significantly influenced by the cultivar, ranging from 2 (cv Hawaii) to 6 (cv Beerwah Gold; Table 2.10, Fig. 2.14 and Tables A2: 15 and 38).

The more drought tolerant cultivars such as Hawaii, Lole, L11, L18, L49, and L135 produced relatively fewer tubers per plant, which is explained by their low (or late) tuber initiation capability as a consequence of genotypic differences.

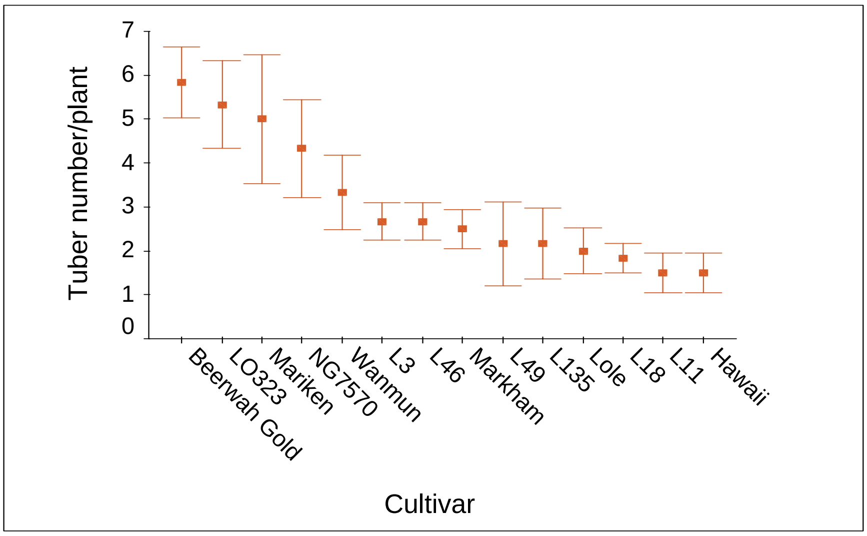


Figure 2.14 The number of marketable tubers produced by 15 sweet potato cultivars grown under non-limiting water conditions in the field. Error bars represent standard errors of means with 6 replications.

The Beerwah Gold cultivar produced the largest tubers under non-limiting water conditions in the field (2.3 kg/plant; Fig. 2.15 and Tables A2: 16 and 39). The lowest tuber masses were produced by the more drought tolerant cultivars, L131, L11, and Lole.

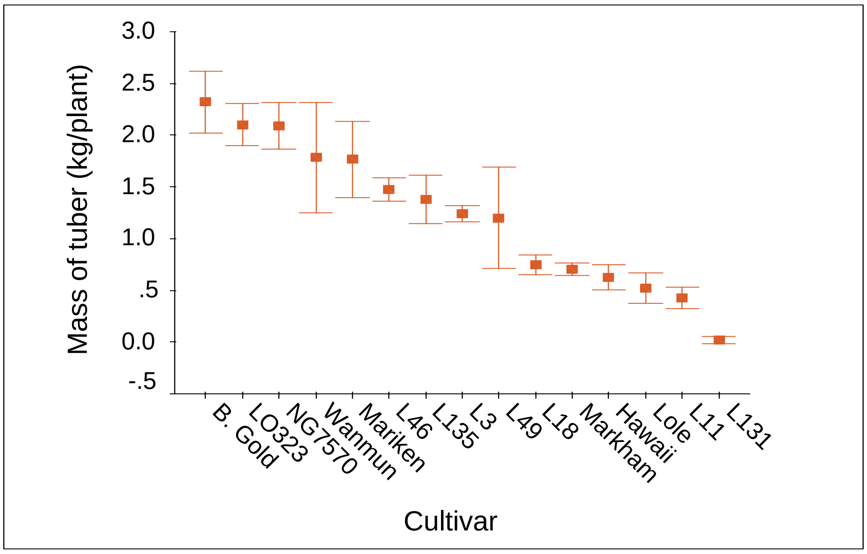


Figure 2.15 Mass of tubers of 15 sweet potato cultivars grown under non-limiting water conditions in the field.

2.4 CONCLUSIONS

Water stress affected plant growth and development differently across the 15 sweet potato cultivars studied. Plant water status and transpiration were significantly and progressively affected as the soil water availability declined. All of the sweet potato cultivars responded to water stress by reducing stem length, internode length and diameter, total biomass, leaf area, and root mass.

Although water stress reduced the length of the main stem in all of the cultivars, the degree of its reduction of stem length varied across genotypes. Cultivars Lole showed less stem length reduction than did the other cultivars. The total plant biomass and leaf mass were also reduced by water stress but cv Lole showed the least reduction of all of the studied cultivars.

Leaf shape and area varied among the cultivars and, under water stress conditions, leaf area declined with cv Lole being the least affected. Internode length and diameter also declined under water stress with all cultivars showing the relatively similar percentage reduction of internode length. Internode diameter was slightly reduced in cv Lole, whereas cultivars, L49, L131 and LO323 showed the greatest reduction under water stress conditions.

Root mass declined under water stress. The smallest root dry mass reduction was in cultivar L18, followed by L3, Lole, LO323, and L46. Leaf dry matter and specific leaf weight varied significantly among the 15 cultivars, and declined under water stress. The Beerwah Gold cultivar recorded greatest leaf dry matter content, followed by LO 323 under the non-limiting water treatment. Under water stressed conditions, cv L131 recorded greatest leaf dry matter content, followed by cvv L135 and Lole. The lowest specific leaf area under well watered conditions were produced by cvv Lole, L131 and L135. The NG7570 cultivar produced the greatest specific leaf area in both the control and water stress treatments, while cv Beerwah Gold produced the lowest specific leaf area under water stressed condition.

Of the 15 cultivars studied, cv Lole was found to be the most drought tolerant on the basis of its assessment on the vegetative plant components and water relations. It showed the smallest percentage of growth reduction compared to other cultivars under water stress.

Leaf water potential was not significantly different among cultivars under both the control and water stressed regimes, but progressively declined under increasing water stress. The Beerwah Gold cultivar, which has larger leaf size, showed a remarkable decrease in leaf water potential in comparison to the other cultivars. Cultivars Lole and Hawaii, which took a longer time to reach permanent wilting point under water stress conditions, had greater leaf water potentials suggesting a better plant water status. They also transpired lower amounts of water than did the several other cultivars. This suggests that they are better adapted to dry conditions than the other cultivars tested.

Under well watered conditions in the field, the cultivars Beerwah Gold, LO323, Mariken, Wanmun, and NG7570 produced significantly higher tuber yields with more marketable tubers per plant than did the other cultivars under non-limiting water conditions. Despite their higher tuber yields, the above ground fresh plant masses were relatively low at harvest time due to assimilate distribution from the leaves to the developing tubers.

Taking into consideration of all the plant parameters listed in Table 2.1, the cultivars have been ranked in decreasing drought tolerance as:

Lole, Hawaii, Markham, L11, L46, L49, L131, L135, L18, Mariken, Wanmun, NG7570, L3, LO323, Beerwah Gold.

Although, the present study has identified some drought resistant cultivars, these plants produced lower tuber yields in terms of numbers of marketable tubers and tuber mass (Table 2.8, Figures 2.14 and 2.15). The Lole and Wanmun cultivars, both from New Guinea, showed marked differences in growth and yield characteristics. Drought tolerance in cv Lole is associated with the lowest percentage reduction in growth, less water consumption, higher leaf water potential, and delayed wilting under imposed drought stress conditions. Hence, cv Lole was selected for further study in the other trials reported in this thesis.

Despite showing strongly developed drought resistant characters, cv Lole produced much lower tuber yields than cv Wanmun; the latter performed very well under well-watered conditions, but it was found to be drought sensitive. Under water stress conditions, the biomass of cv Wanmun was greatly reduced. It also transpired greater amounts of water vapour, produced lower leaf water potential, and wilted earlier under water stress. It was also selected for further study because it is a high yielding cultivar that is commonly grown in Papua New Guinea.

CHAPTER 3

EFFECTS OF SOIL WATER REGIMES ON THE GROWTH, PHYSIOLOGY, AND YIELD OF TWO SWEET POTATO CULTIVARS

3.1 INTRODUCTION

Although sweet potato is considered to be a drought tolerant crop (Constantin *et al*., 1974; Hahn and Hozyo, 1984; Ghuman and Lal, 1983), or a moderately drought tolerant crop (Valenzuela *et al*., 2000; Ekanayake and Collins, 2004), drought is a major environmental constraint for sweet potato production in tropical areas where sweet potato is grown under rain fed conditions (Taufatofua and Fukai, 1996; Anselmo *et al*., 1998). In a previous part of the present study reported in Chapter 2 (above) it was shown that sweet potato severely wilts when the soil water content drops below 20% of the soil field capacity, and that water stress results in growth reduction.

An excess of water, on the other hand, may reduce the oxygen supply to the roots, and subsequently limits respiration, nutrient uptake, and other critical root functions (Hopkins, 1999). The supply of excessive water also inhibits storage root initiation and development in the early growth stages, and causes tuber decay in the later growth stages (Collins, 1995). Uneven watering will also cause tuber growth cracks and reduce yield (Peet, 2000). The water supply, consequently, plays an important role in sweet potato growth and yield.

The aim of the experiment reported in the present chapter was to study the effects of soil water regimes on the growth of two sweet potato cultivars: cv Lole, a drought tolerant plant and cv Wanmun, a drought susceptible sweet potato. Specifically, the experiment aimed to identify the effects of 3 soil water contents (20%, 40%, and 80% of the soil field capacity) on various plant growth parameters.

3.2 EXPERIMENTAL MATERIALS AND METHODS

3.2.1 Experimental location

A pot experiment was conducted in a shadehouse on the Douglas Campus, James Cook University, Townsville, North Queensland, Australia, from 2 August to 29 December 2001.

3.2.2 Experimental materials

The Lole and Wanmun cultivars have different growth and yield characteristics that were discussed in the previous chapter. Despite producing lower tuber yields in the previous field trial under well watered conditions, cv Lole exhibited less growth reduction, less water consumption, higher leaf water potential, and delayed wilting under drought stress conditions, and these were associated with lower leaf area per plant (Fig. 3.1). On the other hand, cv Wanmun, which produced higher tuber yields, was found to be sensitive to water stress: its growth severely declined, and it also transpired a greater amount of water vapour per plant as a consequence of greater leaf area (Fig. 3.1); it was observed to reach permanent wilting point earlier than cv Lole (Table 2.8).

Figure 3.1 The Lole (left) and Wanmun cultivars (right).

3.2.3 Experimental design

The two sweet potato genotypes (cvv Lole and Wanmun) were subjected to three water stress levels that were imposed by maintaining the soil water content at 20%, 40%, and 80% of field capacity. These water contents represent severe water stress (20%), moderate water stress (40%), and no water stress (80%); below 20% of soil field capacity the growth and yield of sweet potato plants decreased and above 80% the sweet potato plants grew poorly as a consequence of poor soil aeration (Ravi and Indira, 1999).

A factorial experiment was used with a complete randomised design and 4 replications. The total number of experimental units was 132 pots with one plant per pot, to allow for destructive sampling of replicated treatments at 1, 2, 3, 4 and 5 months after planting.

3.2.4 Experimental procedures

Twenty-five centimetre long tip cuttings of the two sweet potato cultivars (Lole and Wanmun), were planted into non-draining pots of 10 L volume. To reduce evaporation, the whole of the exterior of the pots and the surface of the growing medium were covered with aluminium foil. To allow the even distribution of water supply throughout the growing medium, a light-texture mixture was used; it consisted of a mixture of equal parts by volume of peat: perlite: vermiculite. The peat was first sun dried to constant moisture.

Field capacity was determined on 10 soil samples using the method of Appendix A1.1, as follows. Each pot was filled with 2.2 kg of the growing medium, and the water required for the pots was found to be 2,052 mL at 80% field capacity, 1,026 mL at 40% field capacity, and 513 mL at 20% field capacity. Osmocote fertilizer (28% N, 1.8% P, and 14% K and micronutrients) was applied at the rate of 1g/plant (Table A 2.1). Each pot was filled with 2.2 kg of soil medium. Plants were treated with 1 g/plant of Osmocote fertilizer every second week from one week after planting for the next 3 months. At the stage of tuber bulking development (3 months after planting), potassium was applied every two weeks as potassium sulphate at a rate of 1 g/plant.

The pots were initially watered to 80% of field capacity for all of the treatments prior to planting. Water was subsequently withheld in the 40% and 20% of field capacity treatments until the soil moisture reached the target field capacity that was determined by weighing the pots regularly. The water contents of the growing media of the Wanmun and Lole cultivars reached 40% of field capacity at 3 and 4 weeks after planting, respectively, and 20% of field capacity at 4 and 5 weeks after planting, respectively. The locations of the pots on the shadehouse benches were re-randomised every week, thus each pot had the same chance to occupy each experimental location.

3.3 EXPERIMENTAL VARIABLES

The detailed methods used to measure plant growth variables are presented in Appendix A1, section 3. Observations were made of the following variables:

- **Plant growth and tuber yields**

Plant height, leaf number and leaf area, above ground biomass, and root mass per plant were recorded monthly by destructive sampling a subset of three pots at monthly intervals from 1 to 5 months after planting (Section 3.2.3). Tuber yields were recorded from 1 to 6 months after planting (Section 3.2.3).

- **Water relations**

Transpiration was recorded as weight losses from the pots (Appendix A1. 3.4) from two weeks after planting until one week before harvesting. Leaf water potential was recorded at 2 and 3 months after planting using a thermocouple psychrometer at three times a day (6.00 am, 12.00 - 2.00 pm, and 6.00 pm) with 3 replications (Appendix A1. 3.4). Leaf relative water content was recorded at 2 and 3 months after planting on 5 replications for each plant (Appendix A1. 3.4).

- **Pigment contents**

Photosynthetic pigments (Appendix A1. 3.2) were determined at 2 and 3 months after planting on 9 replicates per plant using the method described by Wintermans and De Mots (1965).

- **Anatomy**

Stem and leaf samples for anatomical study were collected at 2 months after planting (Appendix A1. 3.2).

- **Starch and sucrose concentrations**

Starch and soluble sugar concentrations of tubers were determined by The Analytical Laboratory, School of Land and Food Sciences University of Queensland (Appendix A1. 3.5).

3.4 STATISTICAL ANALYSES

Analyses of variance based on the factorial experiment with a complete randomised design were conducted for all of the plant growth characters measured. Assessment of the significance of treatments or of combinations of main effects was based on the Duncan Multiple Range Test at the 95% probability level.

3.5 RESULTS AND DISCUSSIONS

3.5.1 Weather conditions

The experiment was conducted from 2 August to 29 December 2001. Daily minimum and maximum air temperatures, rainfall, and relative humidity data were obtained from the Commonwealth of Australia, Bureau of Meteorology, Queensland (Fig. 3.2).

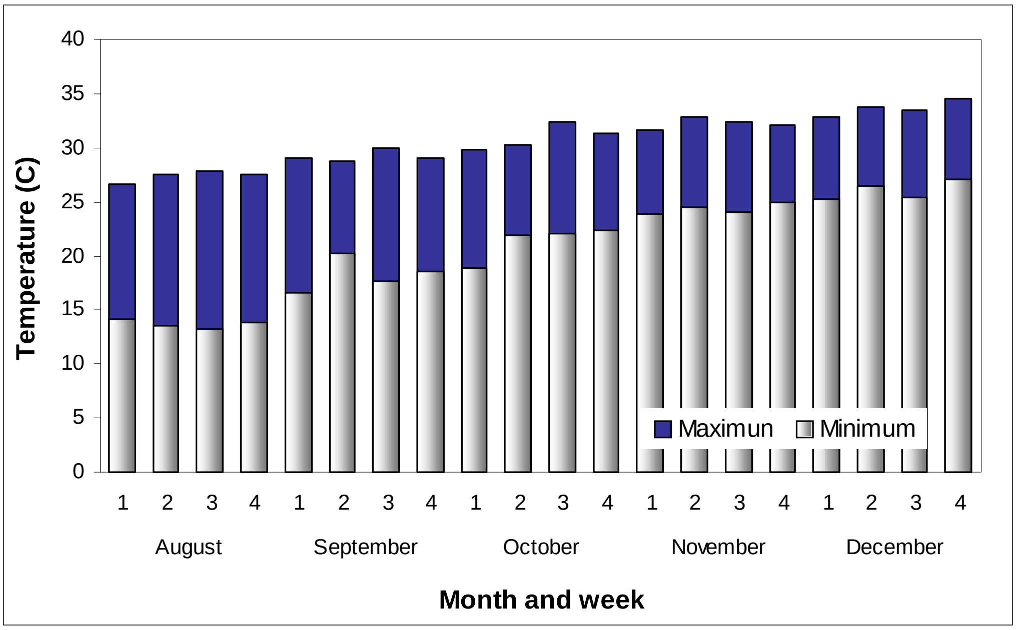


Figure 3.2 Weekly mean maximum and minimum air temperatures (^oC) at Townsville Airport, from 1 August to 31 December 2001. Source: Bureau of Meteorology, Queensland.

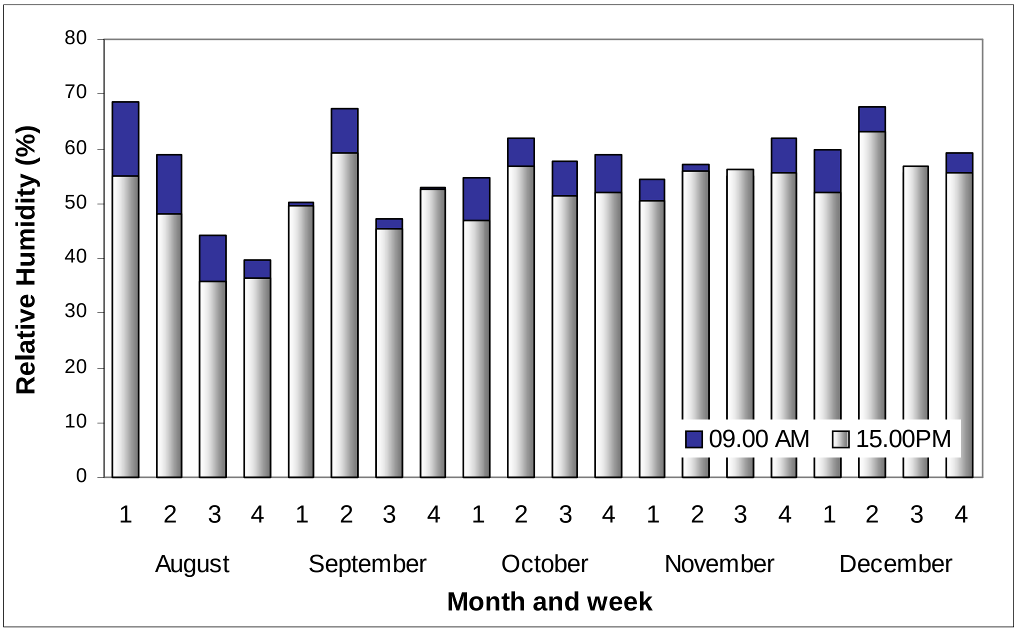


Figure 3.3 Relative humidities at 9.00 am and 3.00 pm at Townsville Airport, from 1 August to 31 December 2001. Source: Bureau of Meteorology, Queensland.

Weekly maximum and minimum air temperatures increased from the first week of August (26.6 and 14.2 ^oC, respectively) at the start of the experiment to the end of

December 2001 (34.6 and 27.1^{o}C, respectively; Fig. 3.2). Mean relative humidity varied from 35% to 67.3% throughout the experiment (Fig. 3.3).

3.5.2 Plant growth characters

Effects of the experimental factors (water levels and cultivars) on the various plant growth parameters are summarized in Table 3.1, and on the water relation parameters in Table 3.9. Other physiological variables including the contents of leaf pigments, tuber starch, and tuber sucrose are summarized in Table 3.11.

Table 3.1 shows that water stress had a significant impact on the growth responses of the Lole and Wanmun cultivars. The effect of interactions between soil water contents and sweet potato cultivars was significant for most of the growth parameters, suggesting that the responses of the cultivars to water stress were different.

Table 3.1 Effects of soil water contents and their interactions on the growth of the Lole and Wanmun cultivars at the indicated number of months after planting.

Plant parameter	Soil water content					Cultivar					Interaction				
Month after planting	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Main stem length	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Branch number	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Fresh shoot biomass	*	*	*	*	*	*	*	*	*	ns	*	*	*	*	*
Dry shoot biomass	*	*	*	*	*	*	*	*	*	*	*	ns	*	*	*
Fresh leaf mass	*	*	*	*	*	*	*	*	*	*	*	*	*	ns	*
Dry leaf mass	*	*	*	*	*	*	*	ns	*	*	*	*	ns	*	*
Leaf area	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Leaf senescence	-	-	-	-	*	-	-	-	-	*	-	-	-	-	*
Fresh root mass	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Dry root mass	*	*	*	*	*	*	*	*	ns	*	*	*	*	ns	*

ns (no significant effect)
* the main effect or interaction was significant ($p < 0.05$)
1, 2, 3, 4, 5 = months after planting
- = no data collected at this stage

3.5.2.1 Main stem length

The responses of the stem length of the Lole and Wanmun cultivars to the different soil water regimes was significant in all the growth stages. Interaction effects between soil water levels and cultivars were also significant (Table 3.1).

The Wanmun cultivar produced stems 3 times longer than those of the cv Lole stems under well-watered conditions, and in the early growth stages (Table 3.2). When grown under the lower soil water contents, the lengths of the cv Wanmun stems were about twice as long as those of cv Lole (Table 3.2).

Table 3.2 Effects of soil water contents (20, 40, and 80% of soil field capacity) on the length of the main stem of the sweet potato cultivars Lole and Wanmun from 1 to 5 months. Number of replicates for each treatment = 4.

	Main stem length (cm/plant) after the indicated number of months since planting				
	1	**2**	**3**	**4**	**5**
Soil water content (fraction of field capacity)					
20 %	45.1c	49.4c	57.6c	57.5c	47.0c
40 %	55.6b	83.5b	89.8b	89.1b	84.0b
80 %	78.7a	105.6a	114.1a	110.5a	106.0a
Cultivars					
Lole	20.1e	34.7e	42.4e	41.6e	39.3e
Wanmun	99.5d	124.3d	131.9d	129.7d	118.7d
Interactions					
Lole x 20%	17.8	20.6	30.7	29.0	28.5
Lole x 40%	20.3	38.8	40.8	40.6	38.5
Lole x 80%	22.3	44.8	55.8	55.5	51.0
Wanmun x 20%	72.5	78.3	84.5	85.5	65.5
Wanmun x 40%	91.0	128.3	138.8	138.0	129.5
Wanmun x 80%	135.1	166.5	172.5	165.5	161.0

Values within a column followed by the same letter symbol are not significantly different ($p < 0.05$). All the interactions are significant ($p < 0.05$).

Stem length in both cultivars increased greatly from 1 to 3 months after planting, but was affected by water stress. In cv Lole, it was reduced by 9.0% and 20.2% from that of the well-watered plants when subjected to water regimes of 40% and 20% soil field capacity at 1 month after planting. In cv Wanmun, the stem length diminished by 32.6% and 46.3% under 40% and 20% soil water regimes, respectively. At the stage of tuber initiation and bulking, which started between 1 and 2 months after planting, stem length reduction was around 50% in both cultivars grown at 20% soil field capacity, and between 13% and 23% in the Lole and Wanmun cultivars, respectively, when grown under 40% of the soil field capacity.

3.5.2.2 Number of branches

The number of branches per plant slightly increased from 1 to 2 months after planting in both cultivars (Fig. 3.4), then increased greatly between 2 and 3 months after planting in cv Lole, with a much less dramatic increase in cv Wanmun; and then remained relatively constant until maturity (Fig. 3.4 and Tables A3: 6-10). However, the number of branches produced under water stress was severely diminished (Fig. 3.4). The production of fewer branches as both sweet potato cultivars approached maturity was attributed to the withering process due to aging and senescence. According to Ravi and Indira (1999), the branching system in sweet potato is influenced by environmental factors such as soil moisture, and the number of branches was found to have increased when irrigation was applied (Ravi and Indira, 1999). Nair and Nair (1995) found that severe competition for light and senescence also reduced the number of branches of mature sweet potato plants.

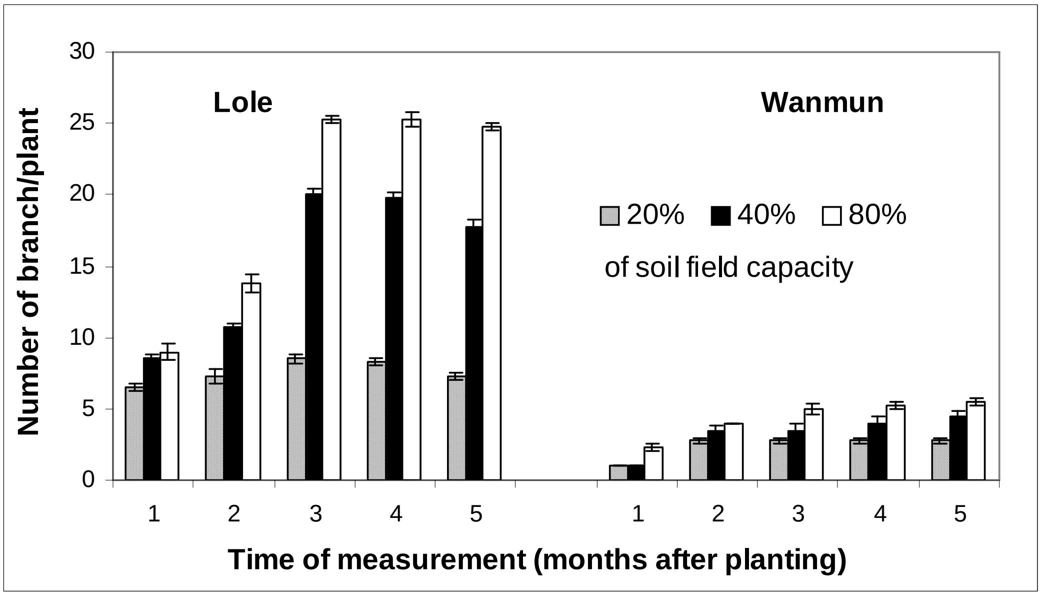


Figure 3.4 Effects of soil water contents (20, 40, and 80% of soil field capacity) on the number of branches in the sweet potato cultivars Lole and Wanmun from 1 to 5 months after planting. Error bars represent standard errors of means with 4 replications.

In summary, then, the number of branches was found to vary with cultivar, but its decline with time was caused by plant aging, environmental factors, and water stress in the Lole and Wanmun cultivars.

3.5.2.3 Fresh and dry shoot mass

Soil water regimes significantly affected fresh and dry shoot masses of sweet potato cultivars during the experimental period. The cultivar Lole produced significantly lower fresh and dry shoot masses compared with cv Wanmun. Interaction effects between soil water contents and cultivars on these variables were all significant (Tables 3.1, 3.3, and A3: 11-20).

Water stress caused a significant reduction in the fresh shoot mass of both the Lole and Wanmun cultivars (Table 3.3). There was no difference between cvv Lole and Wanmun grown under 20% and 40% of soil field capacity at one month after planting, and at this growth stage, the fresh shoot mass of cv Lole grown under both 20% and 40% of soil field capacity decreased by 34% from that of the control (Table 3.3). It shows that at the initial vegetative stage, both of the cultivars were slightly affected by withholding water. On the other hand, cv Lole plants grown under 80% of soil field capacity grew much faster after 1 month than those grown under 20% and 40% of soil field capacity (Table 3.3). Between 2 and 5 months after planting, the fresh biomass reduction in the plants grown under the 20% of soil field capacity was twice the reduction in the corresponding plants grown under 40% of soil field capacity (Table 3.3).

Table 3.3 Effects of soil water contents (20, 40, and 80% of soil field capacity) on the fresh shoot masses of two sweet potato cultivars (Lole and Wanmun) from 1 to 5 months after planting. Number of replicates for each treatment = 4.

	Fresh shoot biomass (g/plant) after the indicated number of months since planting				
	1	**2**	**3**	**4**	**5**
Soil water content (% of field capacity)					
20 %	52.6c	102.1c	119.4c	93.7c	74.4c
40 %	70.5b	228.2b	210.4b	176.2b	147.8b
80 %	134.8a	367.8a	335.5a	274.1a	226.6a
Cultivars					
Lole	48.5e	195.0e	178.0e	161.2e	136.3e
Wanmun	123.5d	270.4d	265.4d	201.6d	162.9d
Interactions					
Lole x 20%	41.2	67.6	91.0	70.1	50.5
Lole x 40%	41.3	200.4	173.7	167.0	142.9
Lole x 80%	63.0	317.0	269.4	246.4	215.7
Wanmun x 20%	64.1	136.5	147.8	117.4	98.3
Wanmun x 40%	99.8	256.0	247.0	185.5	152.8
Wanmun x 80%	206.7	418.6	401.5	301.8	237.5

Values within a column followed by the same letter symbol are not significantly different ($p < 0.05$). All the interactions are significant ($p < 0.05$).

The growth of Lole and Wanmun cultivars was severely affected when grown under 20% of the soil field capacity, with their fresh masses reduced by approximately 70% and 60%, respectively, at maturity. This was attributed to the increasing senescence leaves during the tuber bulking growth stage.

Dry shoot masses of sweet potato grown under low soil water regimes were lower than those produced under the corresponding non-limiting water conditions (Table 3.3). The reduction of dry plant mass under water stress corresponded to the reduction of fresh mass. Dry shoot mass was significantly lower in the stressed plants than in the control plants throughout the growing stages (Table 3.3).

The dry shoot mass of the sweet potatoes increased with time and reached a maximum at 2 months after planting for the plants grown under 40% and 80% of field capacity, and at 3 months after planting for those under 20% of field capacity (Table 3.4). Mukhopadhyay *et al*. (1999) also observed that dry matter accumulation started to gradually increase and attained a maximum at 2 months after planting.

Table 3.4 Effects of soil water contents (20, 40, and 80% soil field capacity) on the dry shoot mass of two sweet potato cultivars (Lole and Wanmun) from 1 to 5 months after planting. Number of replicates for each treatment = 4.

	Dry shoot mass (g/plant) after the indicated number of months since planting				
	1	**2**	**3**	**4**	**5**
Soil water content (% of field capacity)					
20 %	6.5b	11.7c	14.3c	13.0c	7.6c
40 %	7.0b	24.8b	28.0b	21.8b	22.1b
80 %	12.8a	43.3a	48.0a	38.0a	39.8a
Cultivars					
Lole	5.3e	23.8e	27.9e	22.7e	25.1d
Wanmun	12.2d	29.5d	32.4d	25.9d	21.3e
Interactions					
Lole x 20%	4.6	7.6	11.8	11.1	2.3
Lole x 40%	4.6	22.8	27.6	21.7	24.9
Lole x 80%	6.7	41.0	44.2	35.4	48.0
Wanmun x 20%	8.4	15.8	16.9	15.0	12.8
Wanmun x 40%	9.3	26.9	28.4	22.0	19.4
Wanmun x 80%	18.8	45.7	51.7	40.6	31.6

Values within a column followed by the same letter symbol are not significantly different ($p < 0.05$). All the interactions are significant ($p < 0.05$).

Overall, cv Wanmun produced a large dry shoot mass except for the final growth stage when its dry shoot mass was noticeably lower than that of cv Lole (Table 3.4). This was slightly different from the fresh weight results where the fresh shoot weight of cv Wanmun was greater than that of cv Lole (Table 3.4). The difference is attributed to the fact that the mass of fresh shoot was influenced by differences in specific leaf area and fluctuations in the environmental factors such as relative humidity. In general, sweet potato grew rapidly when the plants were in the vegetative growth stage between transplanting and 2 months old; growth declined steadily as the plants entered the maturity stage.

3.5.2.4 Fresh and dry masses of leaves

Fresh and dry leaf masses were significantly affected by the soil water regime and by cultivar (Table 3.1). Interaction effects between cultivars and soil water regimes were statistically significant. However, leaf dry mass and its interactions at 3 months were not statistically significant (Tables 3.1 and A3: 21-30).

Water stress significantly depressed the fresh and dry masses of leaves by approximately 30% - 65% in the Lole and Wanmun cultivars respectively, when grown under both 20% and 40% of soil field capacity (Table 3.5 and 3.6). As the plants approached maturity, leaf fresh mass further declined, more so in the water stressed plants, particularly from 3 months after planting (Tables 3.5 and 3.6).

Table 3.5 Effects of soil water contents (20, 40, and 80% of soil field capacity) on the fresh leaf mass of two sweet potato cultivars (Lole and Wanmun) from 1 to 5 months after planting. Number of replicates for each treatment = 4.

	Fresh leaf mass (g/plant) after the indicated number of months since planting				
	1	**2**	**3**	**4**	**5**
Water contents (% of field capacity)					
20 %	28.8c	53.9c	52.9c	34.1c	23.7c
40 %	37.5b	104.9b	76.0b	62.4b	39.5b
80 %	65.6a	153.3a	107.8a	96.5a	71.5a
Cultivars					
Lole	29.2e	96.9e	69.0e	56.2e	40.3e
Wanmun	58.7d	111.2d	88.7d	72.5d	49.5d
Interactions					
Lole x 20%	25.3	41.7	46.2	27.5	22.7
Lole x 40%	24.8	100.3	66.3	53.5	33.8
Lole x 80%	37.7	148.6	94.6	87.6	64.4
Wanmun x 20%	32.3	66.1	59.6	40.7	24.8
Wanmun x 40%	50.3	109.5	85.7	71.4	45.2
Wanmun x 80%	93.6	158.0	121.0	105.5	78.6

Values within a column followed by the same letter symbol are not significantly different ($p < 0.05$). All the interactions are significant ($p < 0.05$).

Table 3.6 Effects of soil water contents (20, 40, and 80% of soil field capacity) on the dry leaf mass of two sweet potato cultivars (Lole and Wanmun) from 1 month to 5 months after planting. Number of replicates for each treatment = 4.

	Dry leaf mass (g/plant) after the indicated number of months since planting				
	1	**2**	**3**	**4**	**5**
Water contents (% of soil field capacity)					
20 %	4.0b	6.6c	7.0c	3.3c	3.0c
40 %	4.0b	11.5b	11.0b	6.9b	5.2b
80 %	7.1a	16.2a	17.2a	14.0a	14.0a
Cultivars					
Lole	3.6e	10.3e	11.6d	7.5e	6.9e
Wanmun	6.5d	12.6d	11.9d	8.6d	7.9d
Interactions					
Lole x 20%	3.1	4.9	6.9	2.8	2.3
Lole x 40%	3.0	10.9	10.7	6.0	4.9
Lole x 80%	4.8	15.0	17.2	13.7	13.4
Wanmun x 20%	4.9	8.3	7.2	3.7	3.7
Wanmun x 40%	5.1	12.0	11.3	7.8	5.5
Wanmun x 80%	9.3	17.4	17.2	14.4	14.6

Values within a column followed by the same letter symbol are not significantly different ($p < 0.05$). All the interactions are significant ($p < 0.05$).

Approaching maturity, the leaf mass further declined, concomitant with increased leaf senescence (Fig. 3.6), suggesting that dry matter was transferred from the leaves to the storage roots (Nair and Nair 1995). Bhagsari (1990) found that the rate of canopy photosynthesis in sweet potato declined to 50% at the end of the growth period; at this growth stage, the proportion of older leaves in the canopy increases and the photosynthetic rate of individual leave decreases due to the maximum growth rates of the storage roots. Bhagsari (1990) also reported a decline in the dry mass of sweet potato leaves with age from 25 mg $dm^{-2}h^{-1}$ in 20 day-old leaves to about 5 mg $dm^{-2}h^{-1}$ at 40 days and a further slight decrease at 60 days.

3.5.2.5 Leaf area

Decreasing the soil water regimes to 40% and 20% of the field capacity significantly reduced leaf production compared to growth under well watered conditions (Fig. 3.5 and Tables A3: 31-36). Leaf area increased rapidly from 1 month to 2 months after planting, before it slightly declined at 3 months after planting, and then decreased significantly during plant maturation.

Leaf area reduction under water stress has also been reported in many other crop species. For example, leaf area expansion of cassava was markedly reduced by water stress (Connor and Cock, 1981). The inhibition of leaf area growth of cassava found by Alves and Setter (2000) under stress water conditions was attributed to inhibition of both cell expansion and cell division.

Leaf areas of the Lole and Wanmun cultivars were found to increase with the age of the plants and decreased steadily after 3 months (Fig. 3.5). This suggests that leaves as a source of photosynthetic capacity declined with age, and according to Brown (1992) the decline of leaf expansion in sweet potato is likely to be influenced by development of sinks (storage roots) and environmental factors. The young leaves function as a sink and have to compete with the storage roots for carbon when they start developing. The leaves utilise carbon to support their expansion, then the leaf area declines as the aging leaves undergo senescence, which is characterised by a loss of chlorophyll and photosynthetic enzymes (Hopkins, 1999).

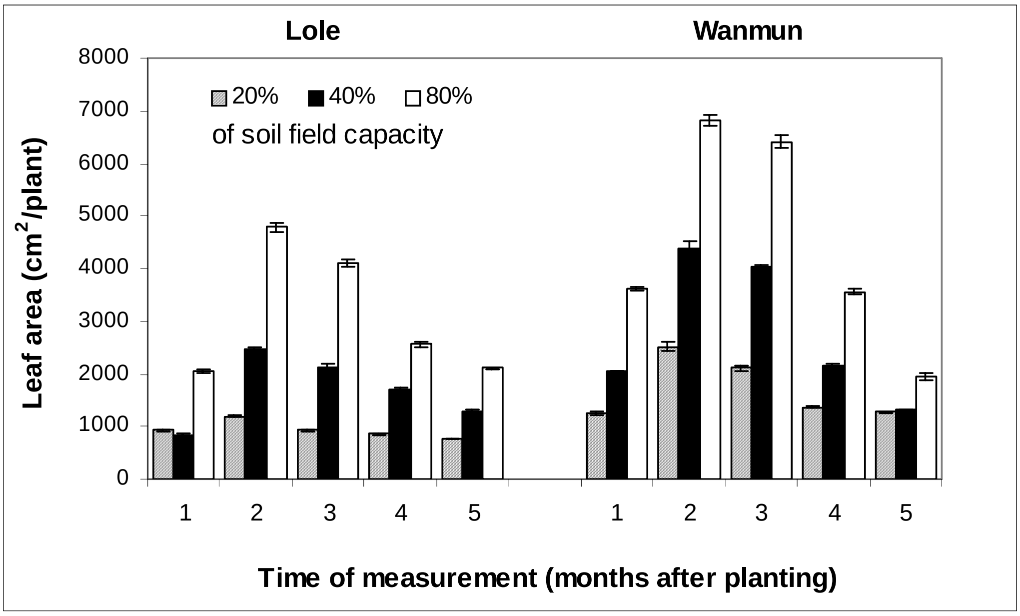


Figure 3.5 Effects of soil water contents (20, 40, and 80% of soil field capacity) on leaf area of two sweet potato cultivars (Lole and Wanmun) from 1 to 5 months after planting. Error bars represent standard errors of means with 4 replications.

Crock *et al*. (1979) and Irikura *et al*. (1979 *in* Connor and Cock, 1981) reported that the sizes of fully expanded cassava leaves declined following the attainment of maximum leaf size at about 4 months after planting. In the present trial, the sweet potato plants produced their maximum leaf area, under all soil water contents at 3 months after planting, before declining as the plants matured, probably because sweet potato has a shorter growing period than cassava. However, Mukhopadhyay *et al*. (1999) observed that the leaf area of sweet potato increased to a maximum gradually from 1 to 4 months after planting then decreased due to leaf senescence. Despite the time difference in the attainment of maximum leaf area (due to different growth environments and cultivars), the present crop showed a similar trend of leaf area expansion and reduction due to leaf senescence toward maturity.

Reduced leaf expansion might benefit plants under conditions of water stress because it leads to a smaller leaf area and reduced transpiration (Hopkins, 1999). However, the consequence of limited water supply is reduced growth (Hopkins, 1999). The occurrence of water deficits in young growing plants would also be expected to cause a reduction in cell turgor which would slow leaf expansion and growth (Hopkins, 1999).

3.5.2.6 Leaf senescence

Differences in the amount of leaf senescence (Appendix A1 3.1) were statistically significant under the different soil water regimes, and cv Lole lost significantly more its leaves than did cv Wanmun (Fig. 3.6; Tables 3.1 and A3: 37).

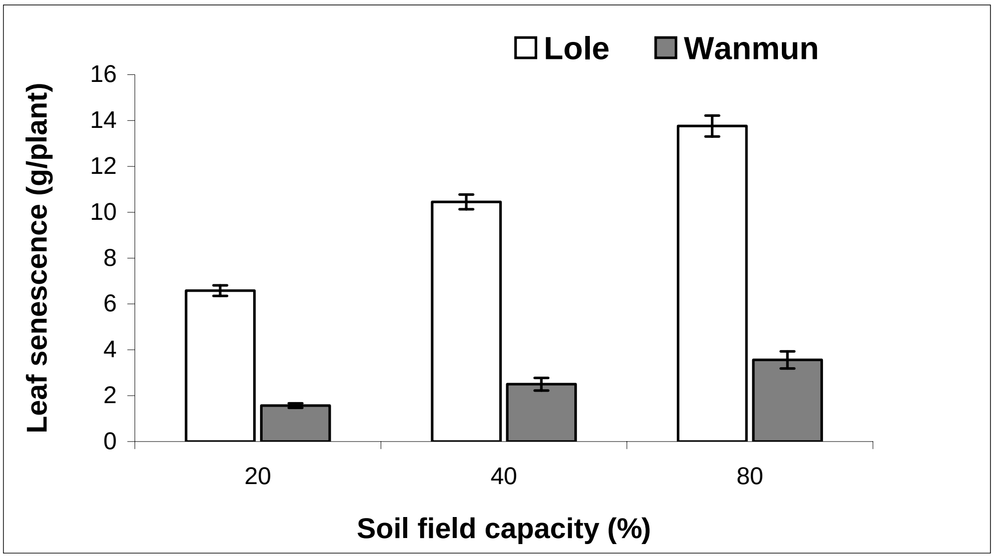


Figure 3.6 Effects of soil water contents (20, 40, and 80% of soil field capacity) on the total leaf senescence of two sweet potato cultivars (Lole and Wanmun) from 1 month to 5 months after planting. Error bars represent standard errors of means with 4 replications.

Compared to cv Wanmun, which lost only 1.57 g leaf dry mass/plant, cv Lole lost about 6.58 g/plant during the entire growing period under 20% of the soil field capacity (Fig. 3.6). At 80% of field capacity, leaf drop in cv Lole accounted for 13.8 g dry mass/plant, which was 4 times more than that of cv Wanmun (3.6 g/plant; Fig. 3.6). This is related to the physiological mechanisms by which the plants limit excessive leaf production to promote tuber development. On the other hand, Leopold (1964) suggested that senescence might offer adaptability to the environmental limitations such as water stress, as it allows the conservation and re-utilization of nutrients from these organs.

In the present trial, leaf senescence was higher under the higher soil water content than at the corresponding lower water levels (Fig. 3.6). This is likely to be a consequence of higher biomass production and leaf turnover under higher available soil water.

Compared to cv Lole, cv Wanmun was likely to maintain its expanded leaves during growth, as was shown by its resistance to dropping leaves. This may be due to different photosynthetic capacities between the different leaves types of both cultivars as found by Hopkins (1999). Senescing leaves may lose as much as 50% of their dry weight, in the form of soluble organic nitrogen compounds that may be exported to developing leaves and other sinks, including tubers (Hopkins, 1999).

Leaf area reduction is an effective mechanism for reducing transpiration during times of limited water availability (Hopkins, 1999). Many plants, subjected to prolonged water stress will respond by accelerated senescence and abscission of the older leaves (Hopkins, 1999). However, to conclude that leaf senescence was the only physiological mechanism to reduce the water consumption by the Lole cultivar needs deeper study.

3.5.2.7 Fresh and dry masses of roots

Both the fresh and dry masses of roots were significantly reduced by water stress (Tables 3.7 3.8, and A3: 38-47). The fresh mass of cv Lole roots was significantly greater than that of cv Wanmun toward the tuber development stage (4 and 5 months after planting). During the initial growth stages under 80% of the soil field capacity, however, cv Wanmun had a greater root mass than cv Lole; but after 3 months (or during the tuber bulking stage), the root mass of cv Wanmun dropped significantly, while the root mass of cv Lole increased (Tables 3.7 and 3.8).

Table 3.7 Effects of soil water contents (20, 40, and 80% of soil field capacity) on the fresh root masses of two sweet potato cultivars (Lole and Wanmun) from 1 to 5 months after planting. Number of replicates for each treatment = 4.

	Fresh root mass (g/plant) after the indicated number of months since planting				
	1	**2**	**3**	**4**	**5**
Soil water contents (% of soil field capacity)					
20 %	13.84b	25.39c	50.34b	41.49b	31.58b
40 %	14.15b	29.49b	47.65b	38.42b	35.75b
80 %	22.51a	65.76a	67.19a	142.93a	101.20a
Cultivars					
Lole	7.32e	47.95d	71.47d	121.35d	89.23d
Wanmun	26.35d	32.48e	38.65e	27.20e	23.12e
Interactions					
Lole x 20%	7.35	18.38	59.08	59.90	41.53
Lole x 40%	6.70	28.20	53.37	49.08	47.93
Lole x 80%	7.90	97.28	101.96	255.07	178.25
Wanmun x 20%	20.33	32.41	41.60	23.08	21.63
Wanmun x 40%	21.60	30.77	41.92	27.75	23.58
Wanmun x 80%	37.13	34.24	32.42	30.77	24.16

Values within a column followed by the same letter symbol are not significantly different ($p < 0.05$). All the interactions are significant ($p < 0.05$).

The fresh and dry masses of roots of cv Lole grown under well-watered conditions was 3 times greater than those of the same cultivar grown under the lower soil water regimes (Tables 3.7 and 3.8).   The root masses of cv Wanmun reached a maximum at one month after planting before declining with the development of tubers.

The root masses of cv Lole grown under 80% of the soil field capacity diminished after 4 months. As the fibrous roots of the Lole cultivar were longer than those of cv Wanmun (Tables 3.7 and 3.8), it grew more deeply into the soil layers in comparison to the roots of cv Wanmun, which were considerably shallower and declined in mass early in the tuber development stage. This indicates that cv Lole has an ability to push its root system into deeper soil layers which provides a useful mechanism for drought avoidance by using deep reservoirs of soil moisture.

Table 3.8 Effects of soil water contents (20, 40, and 80% of soil field capacity) on the dry root masses of two sweet potato cultivars (Lole and Wanmun) from 1 to 5 months after planting. Number of replicates for each treatment = 4.

	Dry root mass (g/plant) after the indicated number of months since planting				
	1	**2**	**3**	**4**	**5**
Soil water content (% of soil field capacity)					
20 %	3.40b	5.75c	5.63c	5.95c	3.81c
40 %	3.45b	7.66b	10.02b	6.98b	6.61b
80 %	4.88a	13.58a	13.34a	17.08a	11.65a
Cultivars					
Lole	2.48e	7.68e	12.14d	14.31d	9.49d
Wanmun	5.33d	10.32d	7.18e	5.70e	5.23e
Interactions					
Lole x 20%	2.46	4.13	5.20	6.00	3.10
Lole x 40%	2.45	7.23	12.50	8.54	7.68
Lole x 80%	2.54	11.68	18.72	28.40	17.71
Wanmun x 20%	4.33	7.38	6.05	5.90	4.53
Wanmun x 40%	4.46	8.10	7.53	5.43	5.55
Wanmun x 80%	7.21	15.48	7.95	5.78	5.60

Values within a column followed by the same letter symbol are not significantly different ($p < 0.05$). All the interactions are significant ($p < 0.05$).

Overall, water stress retarded the growth and development of both sweet potato cultivars, compared with those grown under well-watered conditions by reducing stem length and branch number, leaf area and weight, and root weight.

3.5.3 Water relations

The plant water status was mostly affected by soil water regimes and varied between Lole and Wanmun cultivars (Table 3.9). The only plant growth parameters that were not significantly different between the two cultivars were leaf water potential and relative leaf water content recorded at dawn at 2 months after planting (Table 3.9). No interaction effects were observed in these parameters (Table 3.9).

Table 3.9 Summary of the effects of soil water contents (20, 40, and 80% of soil field capacity) on two sweet potato cultivars (Lole and Wanmun) and their interaction effects on plant water relation parameters.

Plant parameters	Soil water contents	Cultivar	Interaction
• **Transpiration**			
1 month after planting	*	*	*
2 months after planting	*	*	*
3 months after planting	*	*	*
4 months after planting	*	*	*
5 months after planting	*	*	*
• **Leaf water potential**			
2 months after planting			
06.00 am	ns	ns	ns
12.00 - 2.00 pm	*	*	*
6.00 pm	*	*	*
3 months after planting			
6.00 am	*	*	ns
12.00 - 2.00 pm	*	*	*
6.00 pm	*	*	*
• **Relative leaf water content**			
2 months after planting			
6.00 am	*	ns	ns
12.00 - 2.00 pm	*	ns	ns
6.00 pm	*	ns	ns
3 months after planting			
6.00 am	*	*	ns
12.00 – 2.00 pm	*	*	ns
6.00 pm	*	*	ns

ns (no significant effect); * the main effect or interaction was significant ($p < 0.05$)

3.5.3.1 Transpiration

The daily mean transpiration rates of the Lole and Wanmun cultivars were determined from 1 month to 5 months (Table 3.10), and Lole showed significantly less transpiration than Wanmun under all soil water regimes (Table 3.10). The water stressed plants transpired less water compared to the well watered plants of both cultivars (Table 3.10).

The interaction effects between soil water regimes and cultivars were also significant (Tables 3.9, 3.10, and A3: 48-52).

Table 3.10 Effects of soil water contents (20, 40, and 80% of soil field capacity) on the daily transpiration rate (g of water/day) of Lole and Wanmun cultivars.

	Lole (g of water/day)		**Wanmun (g of water/day)**	
1 month after planting				
20% of soil FC	130.25b	B	160.38c	A
40% of soil FC	130.13b	B	180.00b	A
80% of soil FC	210.35a	B	305.35a	A
2 months after planting				
20% of soil FC	167.50c	B	263.89c	A
40% of soil FC	330.53b	B	450.01b	A
80% of soil FC	630.17a	B	815.44a	A
3 months after planting				
20% of soil FC	255.65c	B	337.89c	A
40% of soil FC	487.96b	B	566.94b	A
80% of soil FC	882.47a	B	1021.72a	A
4 months after planting				
20% of soil FC	308.09c	B	335.81c	A
40% of soil FC	534.07b	B	569.14b	A
80% of soil FC	921.82a	B	1013.48a	A
5 months after planting				
20% of soil FC	251.24c	B	316.98c	A
40% of soil FC	416.19b	B	525.16b	A
80% of soil FC	725.96a	B	895.49a	A

Values within a column followed by the same lower case letter symbol, and upper case letter symbols within a row, are not significantly different ($p < 0.05$). All the interactions are significant ($p < 0.05$).

The mean daily transpiration rate sharply increased from 1 month to 3 months after planting, especially in the well-watered plants (Table 3.10). While the rate was constant after 3 months in Wanmun, it slightly increased until 4 months in Lole before it declined slightly (Table 3.10).

The sharp increase in transpiration between 1 and 3 months after planting was attributed to active vegetative growth and rapid tuber development. At this stage, a good water supply was needed to cope with increase in transpiration (Brown, 1992).

3.5.3.2 Leaf water potential

Leaf water potential was affected by water stress, except in the predawn measurements when the leaf water potential values of the Lole and Wanmun cultivars, recorded at 2 and 3 months after planting, were closely similar under all of the soil water contents (Figs 3.7 and 3.8; Table 3.9). Apart from the predawn data, the interactions between soil water levels and cultivars were also significant (Figs 3.7 and 3.8; Tables A3: 53-58 and A3: 81). The significant interaction at 3 months after planting showed that the leaf water potentials of the cultivars responded differently as a result of the different soil water regimes.

There was a daily change in leaf water potentials of the Lole and Wanmun cultivars grown under both well watered and water stressed conditions. Leaf water potential was greatest in the morning, declined during the middle of the day, and recovered during the late afternoon under all soil water contents. However, water stress was found to reduce the diurnal range of the leaf water potential in both cultivars (Fig. 3.7). The decrease in the leaf water potential at midday was greater in cv Wanmun than in cv Lole at both 2 and 3 months after planting (Figs 3.7 and 3.8). As a consequence of the efficiency of its leaf transpiring area, cv Lole was better able to maintain its water relations at midday than could cv Wanmun. The leaf water potential of the Lole cultivar also recovered faster than that of cv Wanmun in the late afternoon which showed that due to its greater plant water status, the Lole cultivar was able to regain its cell turgor faster than could cv Wanmun.

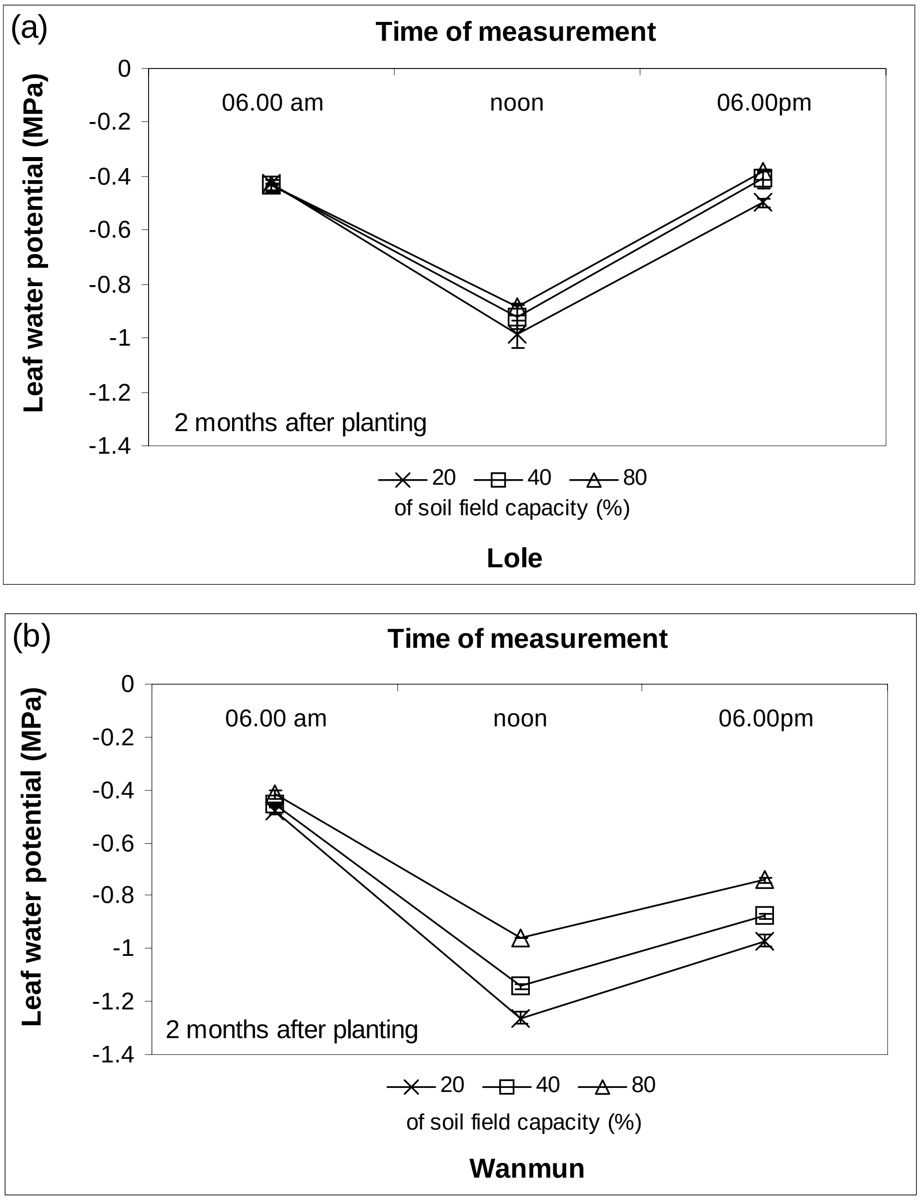


Figure 3.7 Leaf water potential of Lole and Wanmun cultivars, affected by three soil water contents (20, 40, and 80% of soil field capacity) at 2 months after planting. Error bars represent standard errors of means with 3 replications.

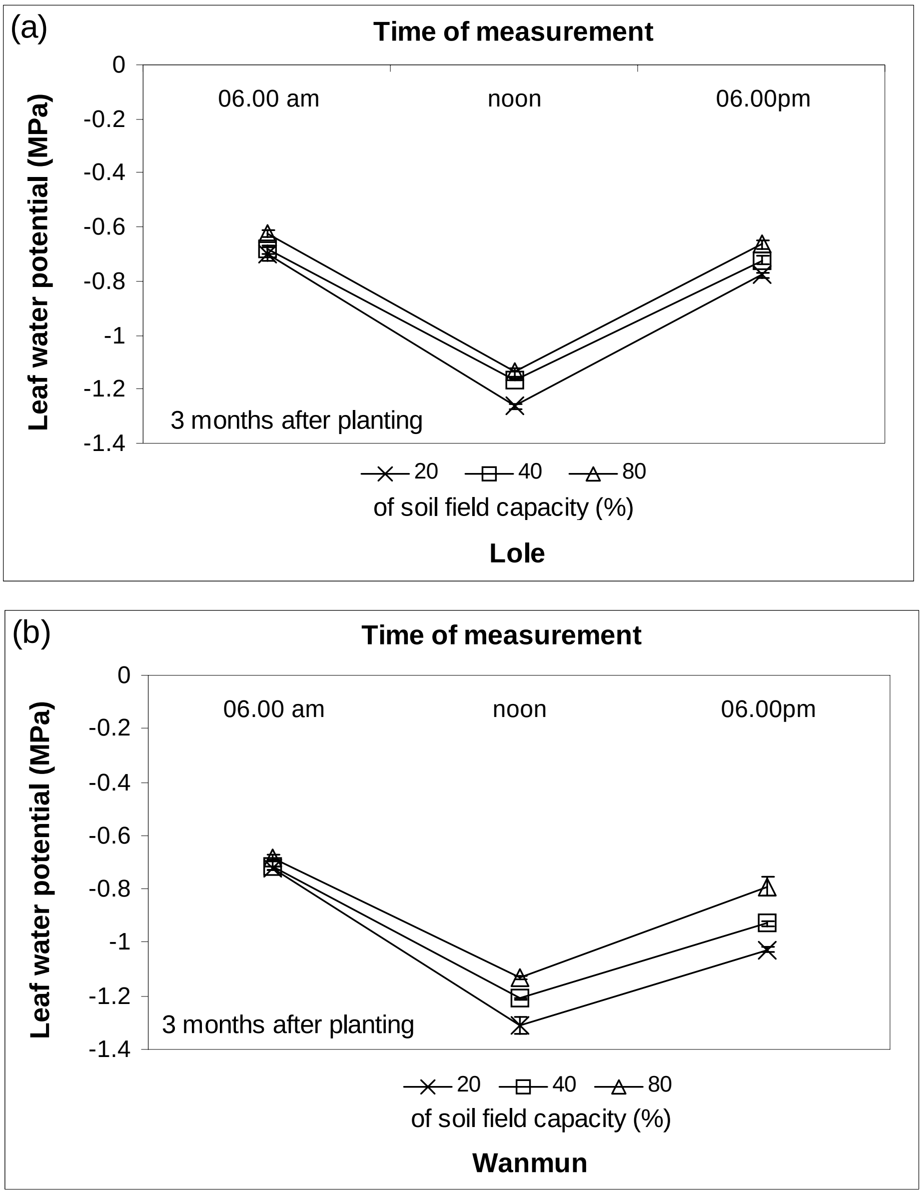


Figure 3.8 Leaf water potential of Lole and Wanmun cultivars, affected by three soil water contents (20, 40, and 80% of soil field capacity) at 3 months after planting. Error bars represent standard errors of means with 3 replications.

Similar results have been found in many crops including wheat and cassava. In wheat, water stress reduced diurnal leaf water potential and leaf osmotic potential in both drought tolerant and drought sensitive genotypes (Sen Gupta *et al*., 1989). Leaf water potential also declined at midday in cassava (- 0.36 MPa) and sweet potato (- 0.96 MPa) (Ghuman and Lal, 1983). Boyer (1982) also found that the diurnal change in leaf water potential was possibly as the result of interactive effects of water supply and maximum atmospheric water demand. Lambers *et al*. (1998) showed that, as the soil dries out, there are parallel decreases in soil water potential and plant water potential, both immediately before dawn (when the water stress is least) and at midday (when the water stress is greatest). As transpiration rates at night are small or near zero, the water potential inside the plant comes into equilibrium with the water potential of the soil in the root zone. Therefore plant water potential values measured just before dawn will provide the highest plant water potential (i.e., smallest negative value) during the day, and therefore will provide a reasonable estimate of the soil water potential (Lambers *et al*., 1998).

Leaf water potential decreased with increasing the stage of plant growth from 2 to 3 months after planting and at all measuring times throughout the day (Figs 3.7 and 3.8). For instance, the predawn leaf water potential declined from –0.4 MPa at 2 months to –0.7 MPa at 3 months after planting in both cultivars; and the leaf water potential of cv Lole was higher than that of cv Wanmun (Figs 3.7 and 3.8).

At 3 months after planting, the predawn leaf water potential was significantly different among soil water levels and cultivars (Fig. 3.7; Table 3.9). The values for cv Lole were similar when grown under 20% and 40% of the soil field capacity (-0.48 M.Pa) at early morning, and were only slightly different from those of plants grown under 80% of the soil field capacity (-0.70 M.Pa).

In general as both cultivars grew, leaf water potential declined as the soil water availability declined. The decline in leaf water potential is probably related to the increasing growth and development of shoots and tubers, leading to increased crop water requirements and consequently to further depletion of the soil water supply. Transpiration was also depressed when the availability of soil water became limited under water stressed conditions and as a result, photosynthesis decreased (Leopold, 1964). Under low leaf water potential, tuber growth rate was also lower, as it appeared to be affected by leaf transpiration (Toshihiko *et al*., 1998).

3.5.3.3 Leaf relative water contents

Tables 3.9, A3: 59-64 and A: 82 show the significance of the effects of soil water stress and cultivars on leaf relative water content. The cultivars alone had no significant effect on the leaf relative water content at 2 months after planting, but they were significant after 3 months (Table 3.9). At both growth stages, there were no interaction effects between water stress and cultivars suggesting that the responses of the cultivars and to water stress were similar (Table 3.9).

Both the Lole and Wanmun cultivars had lower relative leaf water contents in the plants grown under the drier (20% field capacity) than the wetter soil moisture regimes (Fig. 3.9). Water stress caused a significant decrease in the leaf relative water contents in both cultivars. Under 20% and 40% of the soil field capacity, the leaf relative water content of cv Lole measured at 2 months after planting and at 6:00 am declined by 3.9% and 1.4%, respectively, compared to that of the same cultivar grown at 80% soil field capacity (Fig. 3.9). At the same time, however, the relative water content of Wanmun declined by 0.9% and 3.8% when grown under 20% and 40% of soil field capacity, respectively. At midday, the leaf relative water contents decreased further in each cultivar, but they all recovered during the late afternoon, except for those grown under the 20% soil field capacity after 3 months which did not recover much by 6.00 pm (Fig. 3.9).

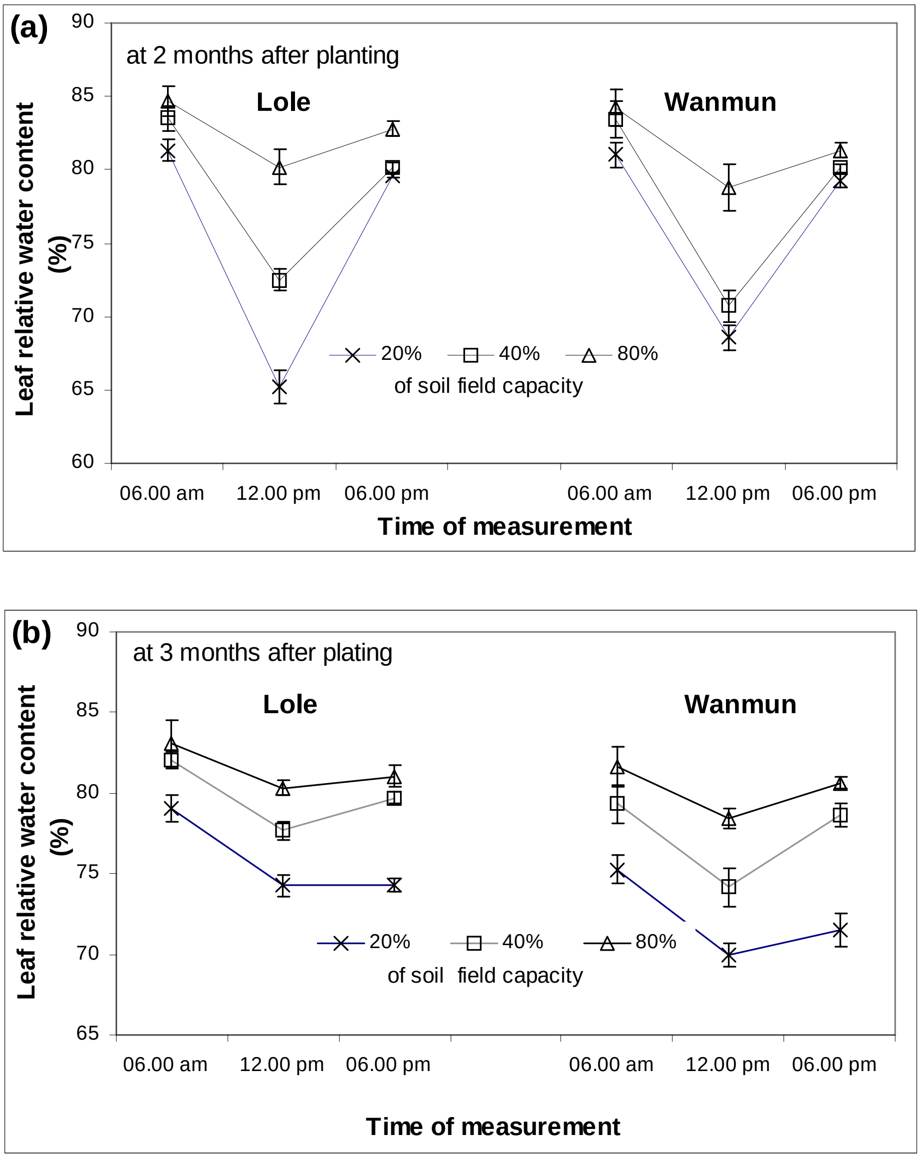


Figure 3.9 Leaf relative water contents of Lole and Wanmun cultivars, affected by three soil water contents (20, 40, and 80% of soil field capacity). Error bars represent standard errors of means with 4 replications.

The Lole cultivar had a significantly higher leaf relative water content than that of cv Wanmun at 3 months after planting. The results suggest that the pattern of reduction in plant water status of the Lole and Wanmun cultivars under water stress were similar in leaf water potential (expressing the energetic status of water inside the leaf cells), and in relative water content (expressing the relative amount of water in the plant tissue). Relative water content was higher in the plants grown under 80% field capacity than in those grown under the lower soil water regimes. It is possible that the finding of Siddique *et al.* (2000), that plants with higher relative water content had higher photosynthetic rates, may also apply to sweet potato.

3.5.4 Pigments, stomatal density, and tuber organic contents

Table 3.11 shows the significance of soil water regimes and cultivars on pigment concentrations, stomatal densities, tuber yield and the organic composition of the tubers.

3.5.4.1 Pigment contents

Water stress produced lower pigment (chlorophyll and carotene) concentrations in both sweet potato cultivars. There was a significant interaction between soil water and cultivar on the chlorophyll concentration in sweet potatoes, and the main effects were also significant (Tables 3.11 and A3: 65-68).

Table 3.11 Effects of soil water contents, cultivars, and their interactions on pigment concentrations, stomatal density, and tuber production.

Plant parameters	Soil water content	Cultivar	Interaction
• **Total chlorophyll**			
2 months after planting	*	*	*
3 months after planting	*	*	*
• **Carotene**			
2 months after planting	*	*	*
3 months after planting	*	*	*
• **Stomatal density**			
Adaxial leaf surface	ns	*	ns
Abaxial leaf surface	ns	*	ns
• **Sucrose and starch in tubers**			
3 months			
- Sucrose concentrations	ns	*	ns
- Starch concentrations	*	*	ns
6 months			
- Sucrose concentrations	ns	*	ns
- Starch concentrations	*	*	ns
• **Tuber yield**			
2 months	*	*	*
3 months	*	*	*
4 months	*	*	*
5 months	*	*	*
• **Tuber number**	*	*	*

ns (no significant effect); * the main effect or interaction was significant ($p < 0.05$)

Total chlorophyll and carotene concentrations of the youngest fully expanded sweet potato leaves decreased with increasing growth stages (Figs 3.10 and 3.11). The Lole cultivar had significantly greater chlorophyll and carotene concentrations than did cv Wanmun, except for those grown under 80% of the soil field capacity at 2 months after planting.

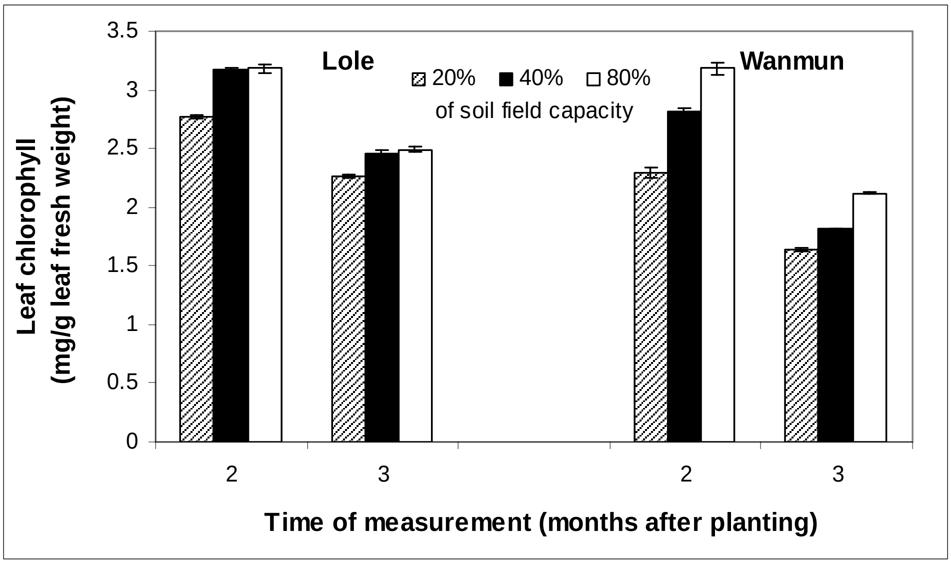


Figure 3.10 The effect of soil water content on the chlorophyll concentrations in the leaves of the Lole and Wanmun sweet potato cultivars at 2 and 3 months after planting. Error bars represent standard errors of means with 4 replications.

The pigment contents significantly reduced as water stresses developed. Total chlorophyll concentration in cv Lole leaves declined by 12.8% and 0.3% on average, in the plants grown under the 20% and 40% soil water regimes, respectively, at 2 months after planting. However, this reduction was slightly lower than that in cv Wanmun (Fig. 3.10).

The total chlorophyll and carotene content of the youngest fully expanded leaves decreased with age (from 2 to 3 months after planting) in both cultivars under all of the soil water regimes. At 3 months after planting, the chlorophyll concentration of cv Lole leaves was reduced by 9.2% and 1.5% in plants grown under 20% and 40% of the soil field capacity compared to that of plants grown under the wettest soil water regime. In comparison with cv Lole, the chlorophyll concentration of cv Wanmun leaves dropped by 23.0% and 14.8% in the increasingly drier soil water regimes. This demonstrates that water stress had less effect on the chlorophyll concentration of cv Lole leaves than on those of the Wanmun cultivar.

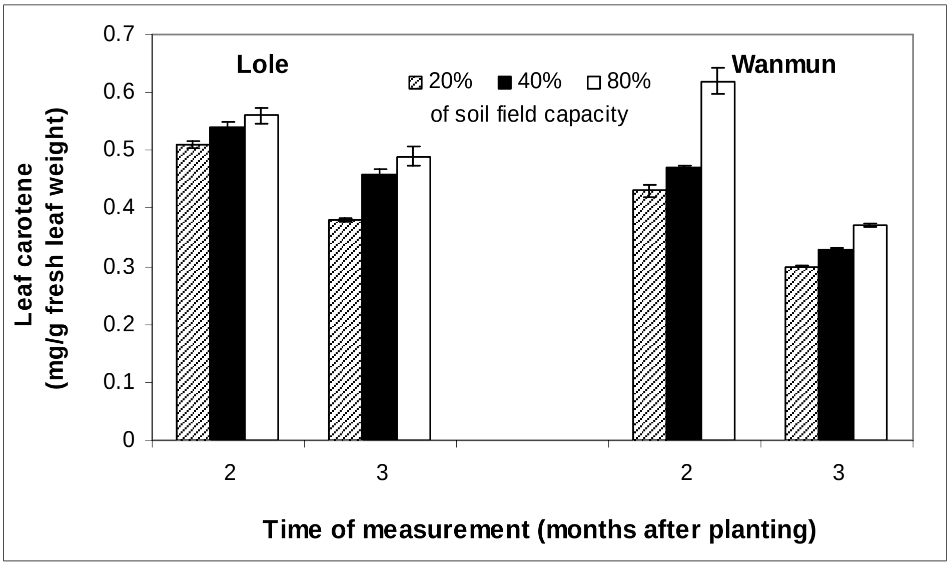


Figure 3.11 The effect of soil water content on the carotene concentration in the leaves of Lole and Wanmun sweet potato cultivars at 2 and 3 months after planting. Error bars represent standard errors of means with 4 replications.

The carotene concentration of sweet potato leaves also diminished under water stress conditions. In plants grown under 80% of the soil field capacity, the carotene concentration of cv Wanmun was much greater than that of cv Lole at 2 months after planting, but this was reversed at 3 months after planting (Fig. 3.11). The Lole cultivar sustained significantly higher carotene concentrations than did cv Wanmun under water stress conditions at both observation times (Fig. 3.11). The cv Lole plants grown under the 20% and 40% of soil water regimes showed a slight reduction in carotene content compared with well watered plants. The carotene content of leaves of cv Wanmun, on the other hand, declined as much as 30% in the plants grown under the drier soil moisture conditions.

Leaf pigments have been widely reported to play an important role as a part of photosynthetic processes in plants. Unsuitable environmental conditions may destroy the photosynthetic pigments, leading to the inhibition of photosynthesis. In many crops, including wheat, mungbean, and eggplants, the chlorophyll contents of leaves is known to decline as a consequence of water stress (Ashraf *et al*., 1994; Kirnak *et al*., 2001; Haider and Paul, 2003). A reduction in chlorophyll concentration had reduced the photosynthesis in *Solanum melongena* (brinjal) (Prakash and Ramachandran, 2000). Limited water supply induced rapid chlorophyll degradation in wheat tillers (Ashraf *et al*., 1994). Parimelazhagan and Francis (1996) suggested that higher leaf chlorophyll concentrations were associated with increased plant vigour and productivity in green gram beans. But Shaw *et al*. (2002) found that there was no indication in sugar beet that leaf chlorophyll measurements could be used as an indicator of genotype differences in the tolerance of drought stress, and that chlorophyll fluorescence remains a more effective method for measuring damage to the photosynthetic apparatus caused by drought stress than the measurement of chlorophyll quantity.

In summary, the pigment contents of the Lole and Wanmun cultivar leaves were found to have diminished with growth from 2 to 3 months after planting. This reduction may be due to differences in season and/or physiological state (Sims and Gamon, 2003). It was suggested by Sanger (1971) that chlorophyll contents of leaves usually decrease in plants with maturity as a consequence of the addition of fibrous material and the breakdown of chlorophyll in leaves.

The present study has shown that the chlorophyll concentration per unit of fresh leaf mass diminished significantly as more severe water stresses were imposed on the sweet potato cultivars (Table 3.11). The chlorophyll-deficient, water stressed sweet potatoes were unable to meet their metabolic requirements and have ultimately disturbed the physiological functioning of the whole plant. The leaves of cv Lole had greater pigment contents than those of the less drought tolerant cv Wanmun. The pigment concentrations also varied with cultivar: even under lower soil water regimes, cv Lole cultivar produced greater leaf pigment concentrations than did cv Wanmun, which also suggests its greater tolerance to water stress.

3.5.4.2 Leaf anatomy (stomatal density)

The Lole and Wanmun cultivars produced 21 and 27 stomata/mm^2, respectively on their adaxial (upper) surfaces when grown under all soil water contents at 2 months after planting. These results were lower than the corresponding stomata number on the abaxial (lower) surface where cv Lole had an average of 43 stomata/mm^2, and Wanmun had 73 stomata/mm^2, again independent of the soil water regime.

An analysis of stomatal density in both the Lole and Wanmun cultivars is presented in Tables 3.11 and A3: 69-70. There was no significant effect of water stress on the stomatal density on the adaxial or abaxial leaf surfaces of either cultivar (Figs 3.12 and 3.13), suggesting that the stomatal density of the sweet potato cultivars was not influenced by soil water stress conditions.

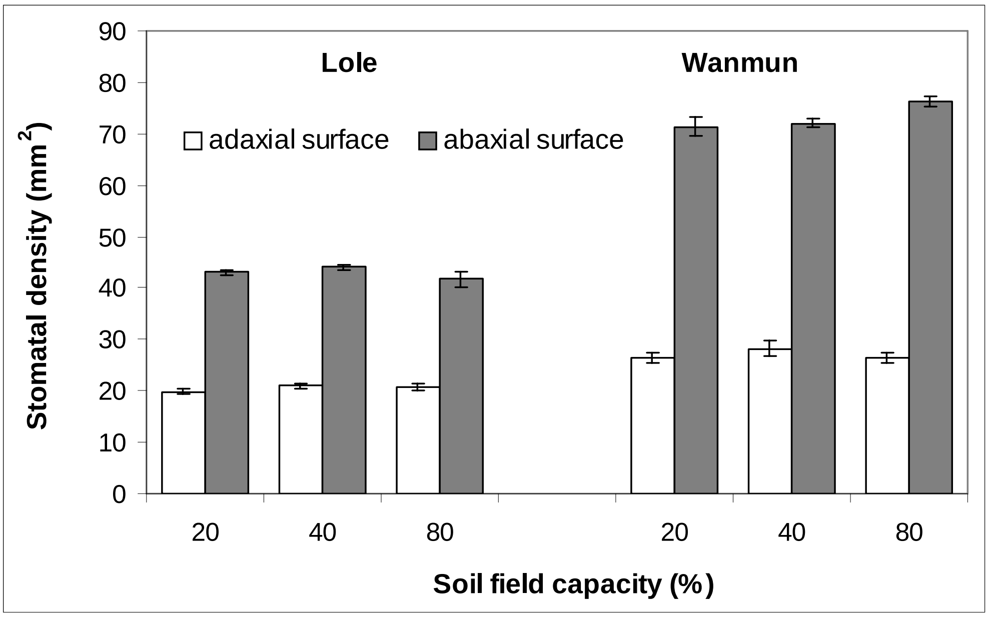


Figure 3.12 The effect of soil water contents (20%, 40%, and 80% soil field capacity) on the stomatal density on adaxial (upper) and abaxial (lower) surfaces of leaves of Lole and Wanmun sweet potato cultivars. Error bars represent standard errors of means with 5 replications.

Greater numbers of stomata on the abaxial leaf surface has been reported from other cultivated crops including the common bean (*Phaseolus vulgaris*) (Medina *et al*., 2002), and is associated with greater gas and water vapour efflux from the leaf surface. Under drier conditions, greater stomatal density, accompanied by greater stomatal opening, may create the risk of excessive evaporation from the leaf. On the other hand, when the stomata close, the gas exchange is limited.

The frequency and distribution of stomata is relatively variable and depends on a number of factors such as species, leaf position, ploidy level, and growth conditions (Hopkins, 1999). The number of stomata on abaxial and adaxial of herbaceous monocotyledons is usually equal, while they are usually greater in the abaxial leaf surfaces of herbaceous dicotyledonous plants (Hopkins, 1999).

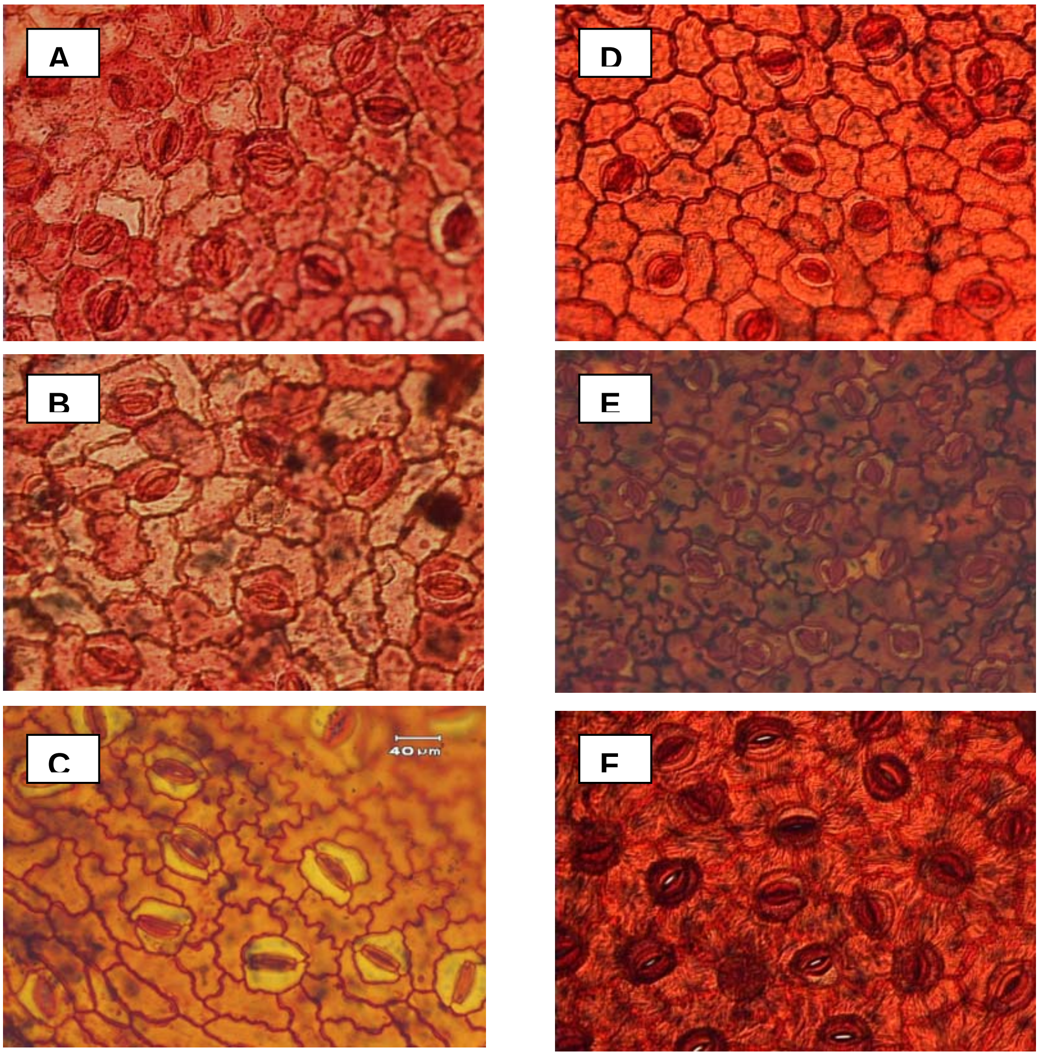


Figure 3.13 Stomata density of the Lole cultivar at 20X of magnification grown under 20% (A), 40% (B), and 80% (C) of soil field capacity, and of the Wanmun cultivar grown under the same conditions 20% (D), 40% (E), and 80% (F) of soil field capacity.

When plants are grown under water stress, their stomatal densities are known to be higher in broad beans (*Vicia faba*), tomato (*Lycopersicon esculentum* cv INCA 9), wheat (*Triticum aestivum*), and maize (*Zea mays)* (Xia, 1990; Sam *et al*., 2000; Hameed *et al*., 2002; HaiQiu *et al*., 2003), and lower in certain grape (*Vitis vinifera*) cultivars (Del Campo *et al*., 2003). Tomato plants with large stomata and high stomatal densities are more prone to water stress (Hinckley, 1973), and lines with low stomatal density were unresponsive to irrigation and in this sense were more tolerant of water stress, their overall yields, however, were low (Buttery *et al*., 1993), as low stomatal density limits the water losses, but also limits the influx of carbon dioxide for photosynthesis. Drought resistant Indian sweet potato accessions 16, 22, 27, 28, 29 and 35 have also been shown to have a low stomatal density (Indira, 1989).

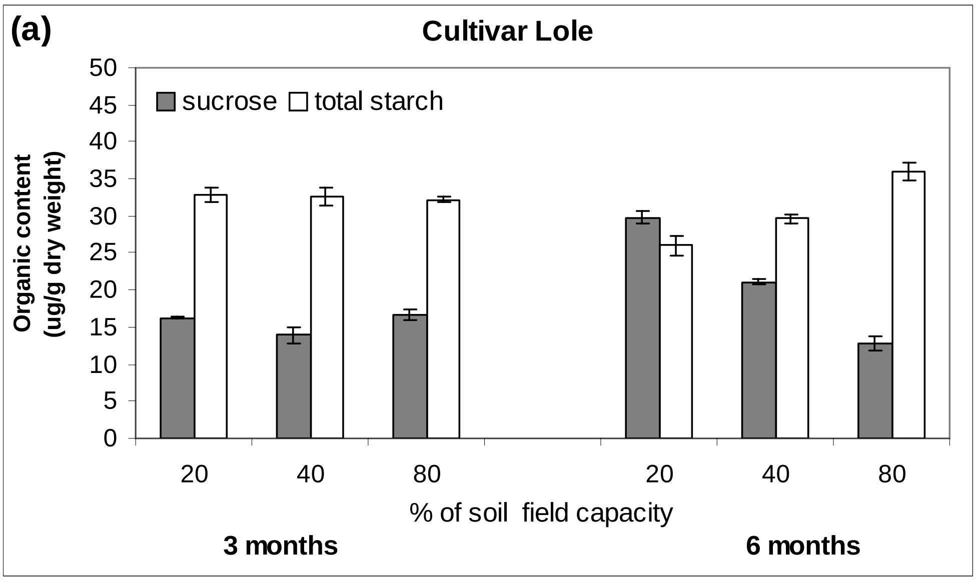
Water stress did not affect stomatal density in either cultivar used in the present study, and the cultivars varied in their responses to water stress conditions. The Wanmun cultivar had significantly greater stomatal density than cv Lole which suggests that fewer stomata in the latter provides a mechanism by which the transpiration of cv Lole was lower, and more water use efficient, than that of cv Wanmun.

3.5.4.3 Tuber starch and sucrose concentrations

The concentration of starch and sucrose in the tubers of Lole and Wanmun at 3 months after planting and at harvest (6 months after planting) are presented in Fig. 3.14, and Tables 3.11 and A3: 71-74.

The results revealed that the concentration of sucrose and starch in the tubers of both Lole and Wanmun cultivars were not significantly affected by the soil water regimes at 3 months after planting; but they increased significantly at harvest (6 months after planting), at which time the sucrose concentration was found to be significantly higher under the water stress conditions in both cultivars.

Geigenberger *et al*. (1999) reported a rise in sucrose concentrations in potato tubers grown under water stress. Increased sucrose contents are often associated with restrictions in starch accumulation and an enhancement of sucrose phosphate synthetase activity, an enzyme that generates sucrose in plant tissue (Rufty and Huber, 1983). Indira and Kabeeratumma (1988) found that the sugar content of sweet potato tubers increased while the starch content decreased with water stress at maturity.



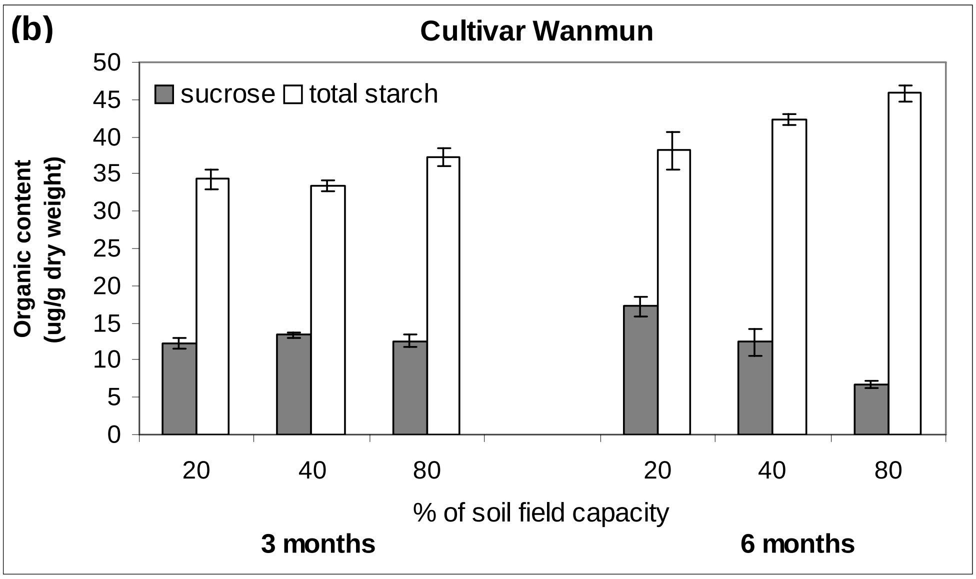


Figure 3.14 The effect of soil water contents on the concentration of sucrose and total starch in the tubers of two sweet potato cultivars at 3 and 6 months after planting. Error bars represent standard errors of means with 3 replications.

The tuber starch concentrations at harvest time of both cultivars used in the present study increased with increasing soil water content. The starch concentration was found to increase in the Lole and Wanmun cultivars under well watered conditions. As growth progressed from 3 months to harvest at 6 months after planting, the starch content declined in cv Lole but increased in cv Wanmun grown under water stress conditions. Concentrations of total starch content may have increased because of the larger tubers developed at 6 months than at 3 months. Hence, it is suggested that the decline of starch content at harvest under water stress conditions in cv Lole was probably related to the enzymes catalysing starch synthesis which are adversely affected, with photosynthate accumulating as sucrose in the tuber. Mukhopadhyay *et al*. (1999) also reported sweet potato tuber starch content gradually increasing to a maximum at harvest time (150 days, or 4 months after planting).

The Lole cultivar had significantly higher tuber sucrose concentrations, but lower starch concentrations than cv Wanmun (Fig. 3.14). The physiological mechanisms behind the increase of sucrose concentration in tubers need deeper study. However, it has been widely reported that, under drought conditions, sucrose concentrations in the leaves of sorghum increased (Premachandra *et al*., 1992). Premachandra *et al*. (1992) reported increased concentrations of soluble sugars and potassium in plant cell sap was associated with their contribution to osmotic potential. Under drought conditions, carbon fixation used primarily for sucrose production is utilised for osmotic adjustments (Jones *et al*., 1980). Plant cells that have greater osmotic potential can sustain their metabolic activity for longer time under the influence of drought conditions (Blum *et al*., 1989). Further study is clearly needed in relation to the sucrose concentration of other plant parts in order to determine if the resistance of cv Lole to water stress can also be attributed to the greater sucrose concentration of the whole plant cell sap.

3.5.5 Tuber yield components

3.5.5.1 Tuber mass

Tuber production was significantly influenced by the available soil water contents (Table 3.11). With decreasing soil water availability, tuber yields decreased, particularly in cv Wanmun (Fig. 3.15; Tables 3.11 and A3: 75-80).

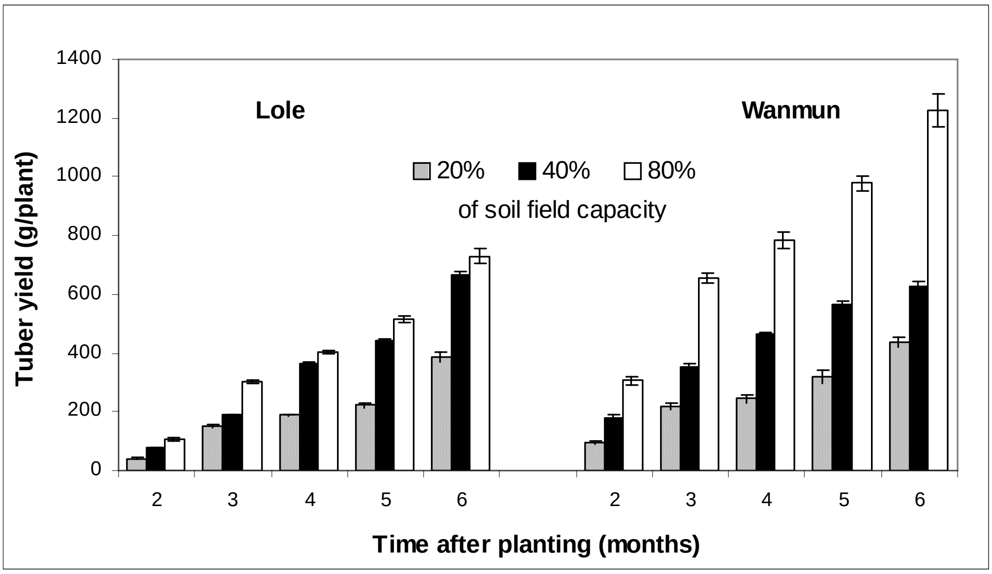


Figure 3.15 The effects of soil water contents (20, 40, and 80% of field capacity) on tuber yields of two sweet potato cultivars (Lole and Wanmun) at different times after planting. Error bars represent standard errors of means with 4 replications.

Tubers started to develop only 1 month after planting and their yields were determined by monthly destructive sampling from 2 to 6 months after planting (Section 3.2.3). When the plants were harvested 1 month after planting, the primary roots of the Lole and Wanmun cultivars had not yet developed into tubers. When the plants were harvested at 2 months after planting, small tubers had started to swell.

The tuber yield of cv Lole at 6 months after planting declined by 62% and 28% when grown under 20% and 40% of soil field capacity, respectively, in comparison to yields produced under 80% of soil field capacity. At the same time, the tuber yield of cv Wanmun also declined by 69% and 41% when grown under 20% and 40% of soil field capacity. At harvest (6 months after planting) the maximum tuber yields per plant were produced by cv Wanmun (1228.5 g per plant) under non-limiting water conditions. Although cv Wanmun produced about twice the mass of tubers/plant than cv Lole under well watered conditions, its tuber production was severely affected by water stress and produced a mass of tubers/plant equivalent to that of cv Lole when both cultivars were grown under 40% of soil field capacity (Fig. 3.15). The ability of cv Lole to sustain tuber production under severe water stress confirms its strong drought tolerance.

3.5.5.2 Tuber numbers

The number of sweet potato tubers produced per plant was significantly affected by soil water stress (Table 3.11). When grown under non-limiting water conditions (80% of soil field capacity), cv Lole produced significantly more tubers than did cv Wanmun (Fig. 3.16; Tables 3.11 and A3: 79), but they were significantly smaller than those produced by either cv Wanmun or cv Lole at 40% field capacity. The interaction between cultivars and soil water regimes was also significant for the numbers of tubers produced per plant (Table 3.11).

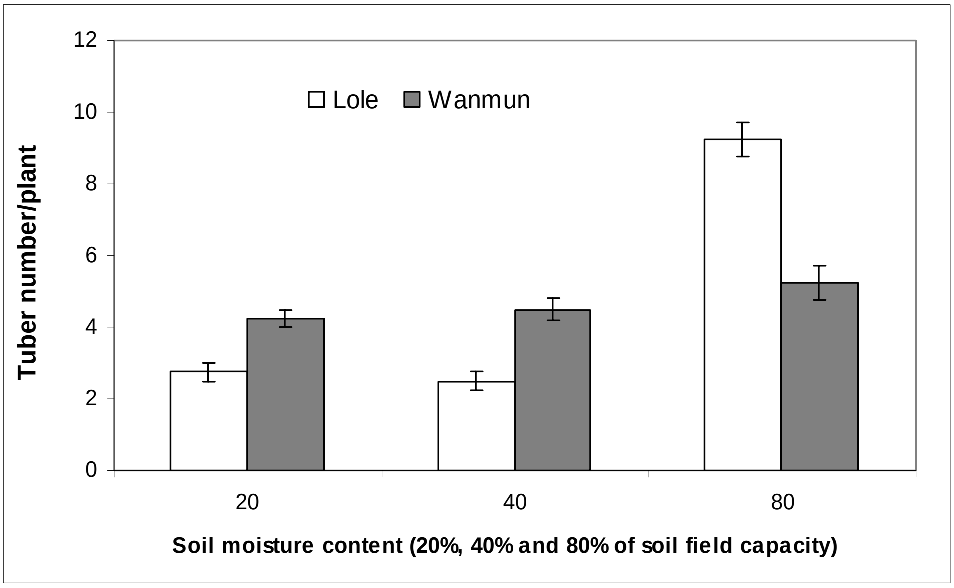


Figure 3.16 The effect of soil water contents (20%, 40%, and 80% of field capacity) on the number of tubers produced per plant by Lole and Wanmun cultivars at harvest time (6 months after planting). Error bars represent standard errors of means with 4 replications.

Increasing water stress (i.e. lower soil water contents) slightly depressed the number of tubers produced by cv Lole. For instance, Lole under the 40% soil water regime produced no more than 2 or 3 tubers per plant. But the number of tubers produced by cv Wanmun (4 - 5) was unaffected by different soil moisture contents (Fig. 3.16). The Lole cultivar grown under 40% of soil field capacity produced comparable masses of marketable tubers (247.5 g/tuber) with those of cv Wanmun grown under 80% of soil field capacity (243.8 g/tuber; Fig. 3.17). However, cv Lole produced a lower total mass of tubers per plant than did cv Wanmun under 80% of soil field capacity.

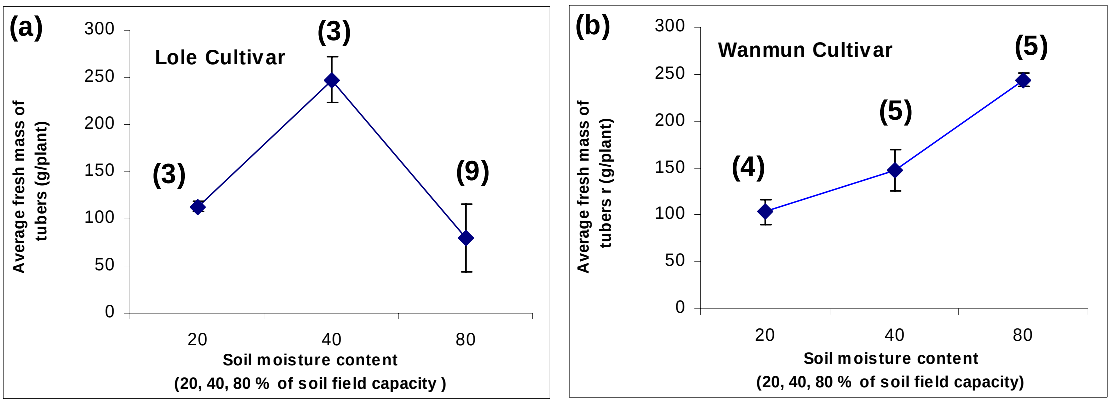


Figure 3.17 The effect of soil water contents (20%, 40%, and 80% of soil field capacity) on tuber size (average fresh mass per tuber) of two sweet potato cultivars. The number in brackets is the average number of tubers produced per plant.

The yield of sweet potato genotypes is known to be highly responsive to environmental conditions (Luh and Moowaw, 1979). The present study has shown that 80% soil field capacity was the most effective water regime in promoting high tuber yields in cv Wanmun, as these conditions produced the maximum tuber yield at the harvest time (6 months after planting) of 1228 g of tubers/plant with a fresh mass of 243.7 g per tuber (Figs 3.15 and 3.17). These yields compare the production of cv Lole at 728 g/plant and a fresh mass of 79.9 g/tubers (Figs 3.15 and 3.17). The greater tuber yield in cv Wanmun was attributed to the earlier onset of tuber formation. It has also been reported that tuber formation in sweet potato may start between 1 and 13 weeks after planting (Ravi and Indira, 1999). Hence, the genotypic differences observed between the studied cultivars, may be a result of differences in the rate of photosynthesis and leaf area (regarded as the source potential), and the number and the mean weight of storage roots (regarded as the sink capacity), both of which have been shown to vary widely among sweet potato cultivars (Ravi and Indira, 1999).

Conversely, cv Lole favoured the lower water regimes and, when grown under non-limiting water conditions, produced greater fibrous root masses per plant and more tubers at the expense of tuber mass per plant (Figs 3.16 and 3.18). As a result, it produced no marketable tubers under the well watered conditions. Tuber initiation in sweet potato was found by Indira and Kabeerathumma (1988) to be reduced by water stress, but water stress during tuber development increased tuber yield over the well watered control, and water stress during tuber maturation produced a slight decrease in tuber yield.

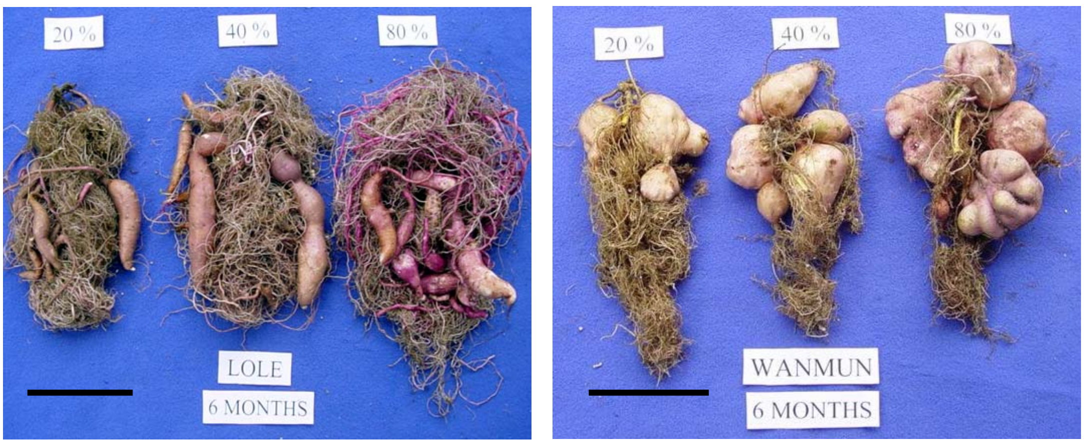


Figure 3.18 Tuber components as affected by different soil water levels in 2 sweet potato cultivars, Lole and Wanmun.

Goswami *et al*. (1995) showed that top growth of sweet potato was promoted over root growth under frequent irrigation, because photosynthesis is utilised primarily for the production of shoot biomass. On the other hand, the fibrous roots of cv Lole were more abundant than tubers when grown under non-limiting water conditions (Fig. 3.18), showing that the level of soil moisture alters the pattern of photosynthetic distribution favouring fibrous root growth.

The detrimental effect of water stress was not equally apparent over all of the sweet potato growth stages (Indira and Kabeerathumma, 1988), nor across the different cultivars. Bourke (1989) found that the number of tuberous roots is reduced when sweet potato is exposed to wet periods between 3 and 10 weeks after planting. Thus, drought has a very strong impact on sweet potato yield during the tuber-bulking phase later in the crop life (Bourke, 1989).

Goswami *et al*. (1995) observed that the sweet potato cultivar V-35, with long and thick tubers, produced higher tuber masses per plant than cv X-47 that yielded greater tuber numbers; the higher yield of cv V-35 was attributed to its high sink efficiency.

In general, sweet potato cultivars performed differently when grown under different soil moisture contents. A high soil water content (80% of field capacity) was found to be suitable for the growth and development of the Wanmun cultivar. The growth and development of cv Lole's tubers were impeded, however, by the high soil water content; and that fibrous roots flourished and small tubers developed at the expense of larger tubers.

On the other hand, the number of tubers produced by cv Wanmun was unaffected by different soil water regimes (Fig. 3.16), possibly because cv Wanmun started tuber growth earlier than did cv Lole. Withholding water (i.e. growing the plants under 40% and 20% of the soil field capacity) during the first 2 weeks from the initial planting had little impact on the formation of tubers in cv Wanmun.

3.5.6 Relationships between leaf area and tuber yield

There was a strong positive correlation between leaf area and tuber yield measured as g / plant at each growth stage of the sweet potatoes (Table 3.12; Fig. 3.19), indicating that leaf area contributed to the final yield of sweet potato tubers. Leaf area determines the capacity of the photosynthetic source to produce carbohydrates and thereby influences the development of the sink (tubers).

Table 3.12 Correlation coefficient (R^2) between leaf area and the total harvested tuber yields (g / plant) from Lole and Wanmun cultivars.

Month after planting	Correlation coefficient (R^2)	
	Lole	**Wanmun**
2	0.71	0.95
3	0.74	0.92
4	0.81	0.93
5	0.75	0.94
6	0.74	0.88

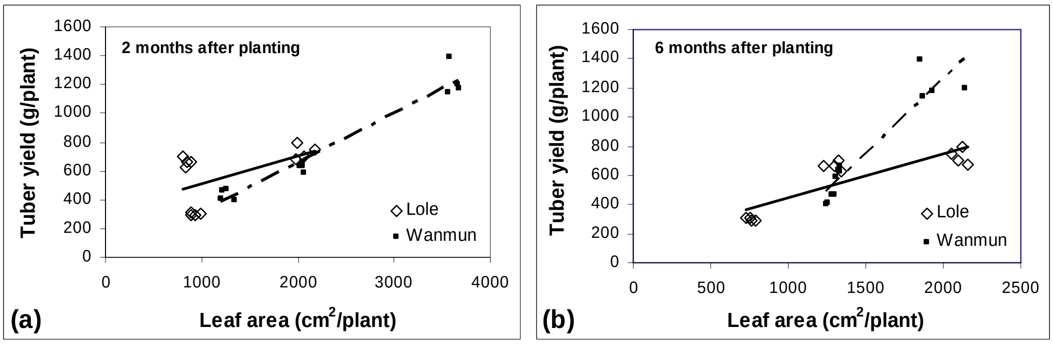


Figure 3.19 Relationships between leaf area and total harvested tuber yield of Lole and Wanmun sweet potato cultivars as affected by soil water contents.
(a) 2 months after planting,
(b) 6 months after planting (at harvest).

Bhagsari (1990) found that genotypic differences in dry matter production and photosynthetic activity of sweet potato (and in their physiological processes and morphological features) often were not correlated with storage root yield. The absence of strong correlations in the present study between total dry matter production and tuber (storage root) yields indicates that physiological and biochemical processes that are not related to the source potential have also affected the harvested tuber yield (Kuo and Chen, 1992). The findings of Spence and Humphries (1972 in Ghuman and Lal 1983) support the results of the present study, in that the storage root yield increased with increasing shoot weight as a consequence of increased photosynthetic surface. However, the yield of storage roots is not only controlled by the source potential but also by the sink strength (Kuo and Chen, 1992).

3.6 Conclusions

As found by Onwueme and Charles (1994), the results of the present study clearly showed that, irrespective of soil water contents, the growth of sweet potato occurs in 3 phases that vary among cultivars and with environmental conditions:

- an initial phase, when the fibrous root grow extensively and the vines grow moderately;
- a middle phase, when the vines grow extensively, tubers are initiated, and leaf area increases remarkably;
- a final phase, when tuber bulking occurs and the growth of the vines, total leaf area, and fibrous roots declines.

Water stress significantly reduced plant biomass (shoot weight, branch number, leaf mass and area, and root mass). Plant biomass was severely affected when sweet potato plants were grown under a strong water stress (20% of soil field capacity). The shoot biomass increased until approximately 3 months after planting, before it declined toward the maturity stage.

The Wanmun cultivar produced significantly higher shoot biomass than did Lole under all levels of soil moisture studied, and its fibrous root (non-tuber) biomass was significantly lower than that of the more drought tolerant cv Lole. Under higher soil water contents, cv Lole tended to produce extensive fibrous roots, while the fibrous roots of cv Wanmun were restricted at the time of tuber development.

The Lole cultivar showed less transpiration than cv Wanmun when grown under all of soil water contents studied; its transpiration rate increased sharply from 1 month to 3 months after planting, and was greater in the well watered plants than in the water stressed plants. Transpiration was relatively constant after 3 months and then declined at harvest stage. The sharp increase in transpiration between 1 month and 3 months after planting was attributed to active vegetative growth and rapid tuber development.

Leaf water potential and leaf relative water content of both cultivars were affected by water stress, especially when transpiration was high at midday. Plants grown under 20% of soil field capacity had the lowest leaf water potentials and leaf relative water contents. A diurnal pattern of leaf water potential and relative water content appeared in all cultivars and under all soil water contents as a result of the water absorption and transpiration patterns of the plants.

Leaf pigments were significantly higher under well watered conditions in both cultivars, but with increasing levels of water stress, leaf pigment concentrations decreased significantly; a similar trend was evident as the plants approached maturity.

The leaf surfaces of cv Wanmun had more stomata than those the drought tolerant Lole cultivar. Stomatal densities were different on the adaxial and abaxial leaf surfaces of both cultivars where the abaxial leaf surface contained a higher number of stomata. Water stress had no significant effect on the stomatal density of either leaf surface of either cultivar.

Tuber compositions were not different in plants grown under the different soil water levels at early plant development stages. At maturity, however, the plants grown under well watered conditions produced tubers with lower sucrose and higher starch concentrations than those grown under lower available soil water conditions. The Lole cultivar tubers had significantly higher sucrose and lower starch concentrations than those of the cv Wanmun tubers. High starch and lower sucrose contents in sweet potato are suitable for industrial products such us flour; on the other hand, however, many people prefer higher sucrose concentrations for fresh food consumption.

The Lole and Wanmun sweet potato cultivars grown under restricted soil water conditions produced low tuber yields. Tuber production was strongly related to the production of plant biomass and the expansion of leaf area. The Wanmun cultivar produced higher yields when grown under 80% of soil field capacity indicating that a large proportion of photosynthate in this cultivar was partitioned to the tuber.

On the other hand, cv Lole plants grown at higher soil water contents produced large numbers of tubers per plant, but most of these were below marketable weight. The more drought tolerant cv Lole plants grown at 40% of the soil field capacity, however, produced masses of marketable tubers that were comparable with the masses of marketable tubers from the more drought sensitive Wanmun plants grown under much wetter soil conditions (80% of the soil field capacity).

In conclusion, different soil water regimes were found to be important in stimulating tuber yields from particular cultivars. However, the optimal soil moisture content depends on the genotype under cultivation. A high yielding cultivar of cv Wanmun required higher soil water regimes to stimulate good tuber yields; on the other hand they reduced the mass of tubers produced by cv Lole. This showed that greater vegetative components accounted for the greater tuber yields with the expense of greater water consumption in cv Wanmun.

CHAPTER 4

EFFECTS OF NITROGEN AND POTASSIUM ON WATER RELATIONS, GROWTH, PHYSIOLOGICAL CHARACTERISTICS, AND YIELD OF SWEET POTATO

4.1 INTRODUCTION

Inadequate soil moisture or water stress, as discussed in the preceding chapters, affects plant physiological functions, biomass production, and tuber yields of sweet potato. Another environmental factor that is known to cause low yields in sweet potato is low soil fertility. Nitrogen (N), phosphorus (P), and potassium (K) are three macronutrients that are essential for the growth of all plants. They are needed to restore soil fertility, but sweet potato has rarely been reported to respond to phosphorus (Norman *et al*., 1995), probably due to its efficiency of phosphorus utilization. The essential elements, however, are not only capable of restoring soil fertility, but they have also been reported to improve osmotic adjustment within plants (Ashraf *et al*., 2001), hence improving their water use efficiencies.

Nitrogen is an essential component for photosynthesis, and the synthesis of chlorophyll and proteins (O'Sullivan, 1997; Satchithanantham and Bandara, 2002). However, a high nitrogen supply may cause abundant growth of sweet potato vines at the expense of storage root development (O'Sullivan, 1997). Responses of sweet potato to nitrogen also depend greatly on genotypic and environmental variations (Hill, 1984; Villagarcia and Collins, 1998).

In tuber crops, the main effect of low soil nitrogen contents under well-watered conditions is to decrease shoot growth, while tuber yields may or may not be reduced (Taufatofua and Fukai, 1996). Depending on soil conditions, nitrogen applications up to certain rates increase crop growth and yield. In one sweet potato study, marketable tuber yields were highest with the application of 100 kg N/ha, and decreased with increasing nitrogen fertilizer rates (Hartemink, *et al*., 2000).

Nitrogen deficiency may lead to increased stomatal conductance and greater transpiration per unit leaf area due to stomatal opening, thereby resulting in decreased water use efficiency (Morris *et al.*, 1998; Kelm *et al*., 2000). In sweet potato, this was probably a consequence of lower total dry matter production rather than increased total water transpiration per plant (Kelm *et al*., 2000). Higher yields in maize, on the other hand, can be achieved by supplemental nitrogen primarily because of its vigorous root system (Morris *et al*., 1998), hence deep root penetration into the soil matrix.

Potassium, an important cation in many physiological and biochemical processes, is required by many plants as much, or even more than nitrogen (Marschner, 1995). The requirement for potassium is higher in sweet potato than in cereals especially in the harvested roots (O'Sullivan *et al*., 1997). Potassium has an important effect on photosynthesis, especially carbohydrate and protein synthesis (Pier and Berkowitz, 1987; Robitaille and Lawrence, 1992), and maintains and regulates cell turgor and stomatal movement (Beringer and Nothdurft, 1985; Hsiao and Lauchli, 1986). Potassium influences plant water status and tends to overcome the effects of soil moisture deficiencies (Marschner, 1995; Jayawardane, 1984; Losch *et al.*, 1992). Plants well supplied with potassium can better regulate their stomatal opening and closing thereby preventing excessive water loss by the plant (Sivan, *et al*., 1996), and providing a drought tolerance mechanism.

In food legumes, potassium has been found to promote root growth under water stress conditions, thereby improving water use efficiency by improving the tolerance of the plant to soil water deficits (Sangakkara *et al*., 2000). Ashraf *et al*. (2001) found that additional amounts of potassium fertilizer did not relieve the effect of water stress on the growth of pearl millet, particularly on shoot mass, relative growth rate, leaf area, net assimilation rate, photosynthetic rate, transpiration rate, stomatal conductance, and water use efficiency, even though the effect of drought stress on those variables was significant. This indicates that there was adequate potassium already in the soil and that it was not limiting millet growth. Considerable osmotic adjustment occurred, however, when pearl millet plants experienced water deficits under a high potassium supply (Ashraf *et al*., 2001).

It is widely known that sweet potato requires high potassium contents in the soil to promote tuber formation and development (Scott and Bouwkamp, 1974; O'Sullivan, 1997, Valenzuela *et al*., 2000). However, the role of potassium in relation to overcoming soil moisture deficits in sweet potato has rarely been reported. As sweet potato is often planted in drought-prone areas, potassium from fertilizers could be expected to have beneficial effects not only increasing tuber yields, but also in improving water use efficiency.

Therefore, an experiment was carried out to study the influence of nitrogen and potassium on water stress and productivity in sweet potato. The trial was conducted by observing the effects of nitrogen and potassium on the growth, yield, and physiological characteristics of two sweet potato cultivars, Lole and Wanmun, grown under different soil water regimes.

4.2 MATERIALS AND METHODS

4.2.1 Experimental location

A pot experiment was conducted from 1 March to 31 July 2004 in a shadehouse at the School of Marine and Tropical Biology, James Cook University, Townsville, Queensland, Australia.

4.2.2 Experimental design

Two sweet potato cultivars (drought-tolerant Lole and drought-sensitive Wanmun) were used as indicator plants and two soil water regimes were applied (30% and 80% of the soil field capacity) with the application of complete and partial nutrients (normal NPK level, a partial nitrogen level, and a partial potassium levels). A water content of 30% of soil field capacity was imposed as a water stress treatment that would still able to support reasonable growth and tuber yields, while another treatment at 80% of the soil field capacity was imposed as a control in which sweet potato would be expected to produce vigorous growth and maximum tuber yields.

In this experimental design, treatments 3 and 6 each consisted of the same 16 nutrient applications and one of them was omitted; the results of the remaining treatment were incorporated in both the nitrogen and potassium experiments. The total number of experimental units was, therefore, 80 pots; each pot held one plant.

Two separate experiments were carried out in complete randomised designs with 4 replications. The first experiment of 48 pots was a nitrogen fertilizer trial with 3 nitrogen levels, 2 soil water levels, and 2 cultivars, and the second of 48 pots was a potassium fertilizer trial with 3 potassium levels, 2 water soil levels, and 2 cultivars. They were run concurrently using 10 L undrained pots containing 11 kg of clean, washed, coarse sand as the growing medium.

Nitrogen and potassium treatments were applied as follows:

- The nitrogen treatments consisted of 20, 100, and 200 kg of N / ha from ammonium nitrate, with a non-limiting potassium supply (160 kg of K/ha)
- The potassium treatments consisted of 16, 80, and 160 kg of K / ha from potassium chloride, with a non-limiting nitrogen supply (200 kg of N/ha).

Combinations of the nutrient treatments were:

1. N20, K160
2. N100, K160
3. N200, K160
4. K16, N200
5. K80, N200
6. K160, N200

The N and K inputs were applied to the pots as 4.35 g, 2.15 g, and 0.29 g NH_4NO_3 per pot which were equivalent to 200 kg N, 100 kg N and 20 kg N/ha, respectively, and as 1.38 g, 0.69 g, and 0.14 g KCl per pot which were equivalent to 160 kg K/ha, 80 kg K/ ha and 16 kg K/ha, respectively.

Other elements were applied as a basal nutrient dressing using the compounds listed in Table 4.1. All of the nutrients were applied in a split dose at 1 week (half from the above dose) and again 6 weeks after planting (the remaining half from the above dose).

Table 4.1 Nutrient application rates, adjusted from Asher *et al*. (2002).

Element	**Nutrient application rate**	**Compound**	**Rate of compound application**	
	(kg/ha)		**(kg/ha)**	**(g/pot)***
N	200	NH_4NO_3	572	4.347
P	30	$NaH_2PO4.2H_2O$	173	1.588
K	160	KCl	161	1.375
Ca	35	$CaCl_2$	98	0.510
Mg	30	$MgCl_2.6H_2O$	250	3.315
S	25	Na_2SO_4	111	0.654
Fe	5	Fe Na EDTA	32.9	0.058
B	2	H_3BO_3	11.4	0.007
Mn	5	$MnCl_2.4H_2O$	16.35	0.014
Zn	4	$ZnCl_2$	8.34	0.004
Cu	3	$CuCl_2.2H_2O$	8.04	0.003
Mo	0.4	$[NH_4]_6 MoO_{24}.4H_2O$	5.15	0.003

* Details of the calculations are set out in Appendix A4.1.

4.2.3 Research procedure

The growing medium was clean, coarse, nutrient-free sand, air dried to constant moisture for several weeks. The sand was passed through a 2 mm sieve, washed to remove fine components, dried and its moisture content determined. The amount of water required to bring the soil in the pots to field capacity was calculated using the gravimetric method described in Appendix A1.1. Based on 11 kg sand, the water content per pot was 2,350 mL at 100% field capacity, 1,880 mL at 80% field capacity and 705 mL at 30% field capacity. The pots and the surface of the growing medium were covered with aluminium foil to minimize evaporation.

Shoot tip cuttings of sweet potato stems, 25 cm long, were made and allowed to stand in water for 2 days. The cuttings were planted into non-draining 10 L pots containing 11 kg of air-dried sand that had been watered to field capacity. Water was then withheld for 1 week until the soil moisture content reached 80% for the control (with non-limiting water conditions), and for 3 weeks until 30% field capacity for the water stressed treatments. The plants were then watered to the nominated percentage of field capacity every second day, based on the weight lost from the pots by transpiration.

To control insects, mostly red spider mite, the plants were sprayed with Garden King Red Spider Miticide, at 5 mL/L water, once every 2 weeks.

4.2.4 Experimental measurements

The plants were harvested 5 months after planting. Each plant was separated into leaf blades, remainder of shoot (vines plus petioles), tubers, and roots. At harvest, tuber fresh weight and total leaf area per plant were recorded. Leaves, vines and roots were dried at 70 ºC and the dry masses were recorded. Other physiological variables calculated included leaf dry matter content and specific leaf weight using the methods set out in Appendix A1.1.3. Chlorophyll and carotene concentrations of leaves were determined at 4 months after planting

To quantify crop water relations, transpiration was recorded as the weight losses from the pots every second day (Appendix A1.3.4) and water use efficiencies were calculated at the end of the experiment (Appendix A1.3.4).

4.2.5 Statistical analysis

Analyses of variance based on factorial experiments in complete randomized designs were conducted to test the significance of each treatment effect and their interactions. The Duncan Multiple Range Test was used to determine whether the effects of the treatments on plant growth parameters were significant.

4.3 RESULTS AND DISCUSSION

4.3.1 Climatic conditions

Daily minimum and maximum air temperature, and relative humidity records were obtained for the period of the experiment from the Commonwealth of Australia, Bureau of Meteorology, Queensland (Figs 4.1 and 4.2). The average maximum weekly temperature declined slightly from 32 ^{o}C in March to 29 ^{o}C in July 2004, whereas the minimum weekly temperature fell from 24 ^{o}C to 19 ^{o}C (Fig. 4.1). Relative humidity was relatively constant between March and July 2004 (Fig. 4.2).

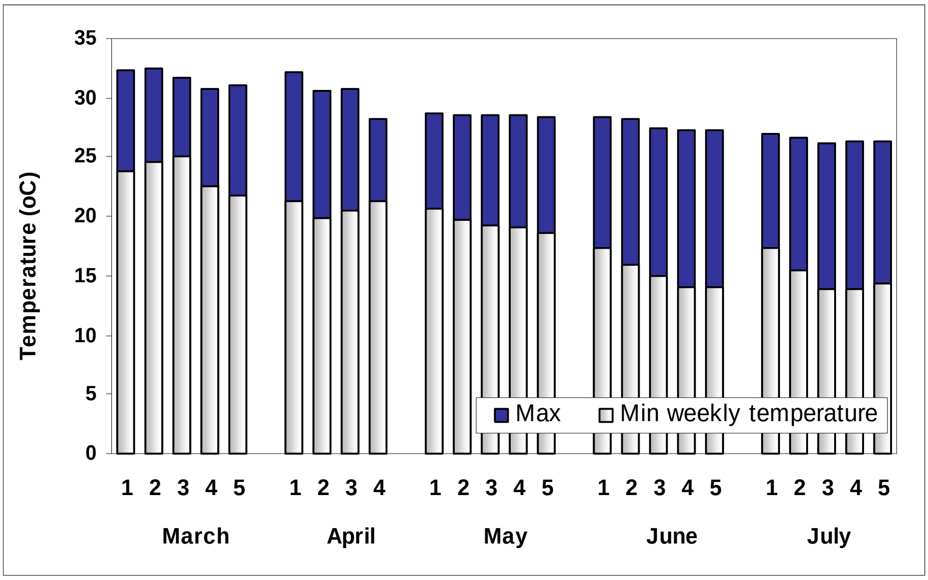


Figure 4.1 Weekly mean daily maximum and minimum air temperatures (°C), at Townsville Airport, from 1 March to 31 July 2004. Source: Commonwealth Bureau of Meteorology, Queensland.

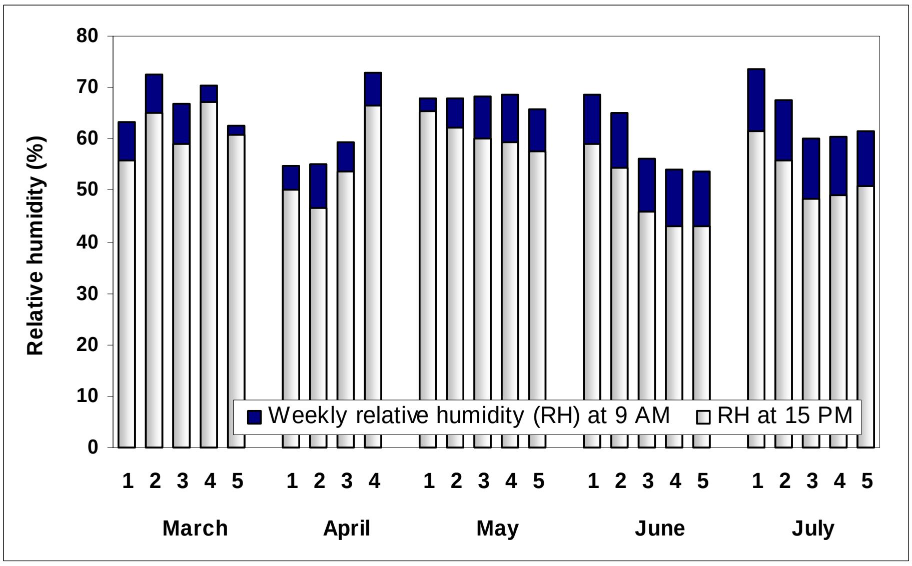


Figure 4.2 Relative humidity at 9.00 am and 3.00 pm at Townsville Airport, from 1 March to 31 July 2004. Source: Commonwealth Bureau of Meteorology, Queensland.

4.3.2 Plant growth characters

The effects of soil water regimes, nutrients, and cultivars on dry shoot mass, leaf mass and area, specific leaf area, and specific leaf weight are summarized in Tables 4.2, A4: 1-8, and A4: 31-32.

In general, soil water regimes and nitrogen levels significantly affected the dry shoot mass, leaf mass, leaf area, and specific leaf weight of the Lole and Wanmun cultivars (Table 4.2). In the nitrogen experiment, there was no significant interaction between soil water regimes and cultivars on the leaf dry mass and leaf area, but there was a significant interaction between cultivars, soil water contents, and nutrients with shoot and leaf dry masses, leaf area, tuber yield, and total chlorophyll. In the potassium experiment, there was a significant interaction between cultivars, soil water contents, and nutrients on leaf area, tuber yield, and total chlorophyll and carotene concentrations. Neither the N nor K experiment showed any significant interactions with cultivars, soil water contents, and nutrients on specific leaf weight, dry root mass, and chlorophyll *a*/*b* ratio.

Table 4.2 Nitrogen, potassium, soil water contents, cultivars, and their interactions on the vegetative growth, yield components, and pigment contents of two sweet potato cultivars.

Plant parameters	The effect of #						
	W	**C**	**T**	**W*C**	**C*T**	**W*T**	**C*W*T**
• **Dry shoot mass**							
N experiment	*	*	*	ns	*	ns	*
K experiment	ns	*	*	*	*	ns	ns
• **Dry leaf mass**							
N experiment	*	*	*	ns	*	*	*
K experiment	*	*	ns	*	*	ns	ns
• **Leaf area**							
N experiment	*	*	*	ns	*	ns	*
K experiment	ns	*	*	*	ns	ns	*
• **Specific leaf weight**							
Effect of N	ns	*	ns	ns	ns	ns	ns
Effect of K	*	*	*	ns	ns	ns	ns
• **Dry root mass**							
Effect of N	*	*	*	ns	ns	ns	ns
Effect of K	*	*	ns	*	ns	ns	ns
• **Tuber yield (fresh mass)**							
Effect of N	*	*	*	*	*	*	*
Effect of K	*	*	*	ns	*	*	*
• **Total chlorophyll**							
Effect of N	*	*	*	*	*	*	*
Effect of K	*	*	*	ns	*	*	*
• **Carotene**							
Effect of N	*	*	*	*	*	*	ns
Effect of K	*	*	*	ns	*	*	*
• **Chlorophyll *a/b* ratio**							
Effect of N	ns	ns	ns	ns	ns	*	ns
Effect of K	*	ns	ns	ns	ns	ns	ns

# ns (no significant effect); * the main effect or interaction is significant ($p < 0.05$)
W = water; C = cultivar; T = nutrient (N for the N experiment, and K for the K experiment)
W*C = interaction between soil water contents and cultivars
C*T = interaction between cultivars and nutrient levels
W*T = interaction between soil water contents and nutrient levels
C*W*T = interaction between soil water contents, cultivars and nutrient levels

4.3.2.1 Dry shoot mass

The effects of nitrogen and potassium on the dry shoot mass of the Lole and Wanmun cultivars grown under two soil water contents (30% and 80% of soil field capacity) are presented in Table 4.2 and Fig. 4.3.

The dry shoot mass of both cultivars was significantly reduced by both water stress and lower N supply (Fig. 4.3, Tables A4: 1 and A4: 31). Under water stress conditions, the dry shoot mass of the Lole and Wanmun cultivars were similarly low (4.7 g/plant) when grown under low soil nitrogen conditions (20 kg N per ha) and increased with soil nitrogen content and soil water availability (Fig. 4.3). The greatest shoot mass under water stress was recorded when the plants were grown at 200 kg N/ha (17.8 and 22.8 g/plant in the Lole and Wanmun cultivars, respectively). Under well-watered and low nitrogen conditions, both of the cultivars had reduced shoot masses (7.7 and 8.5 g/plant, respectively). The greatest shoot dry mass was in cv Wanmun (46.0 g/plant), followed by cv Lole (27.5 g/plant) grown under non-limiting nitrogen (Fig. 4.3); cv Wanmun was more affected by the lower soil nitrogen supply than cv Lole.

Under both well watered and stressed conditions, the dry shoot mass of cv Lole was relatively unaffected by the addition of K to the soil (Fig. 4.3), but the shoot mass of cv Wanmun increased. The effect of potassium on the dry shoot mass was greater when cv Wanmun was grown under well watered than stressed conditions (Fig. 4.3; Tables A4: 2 and A4: 32).

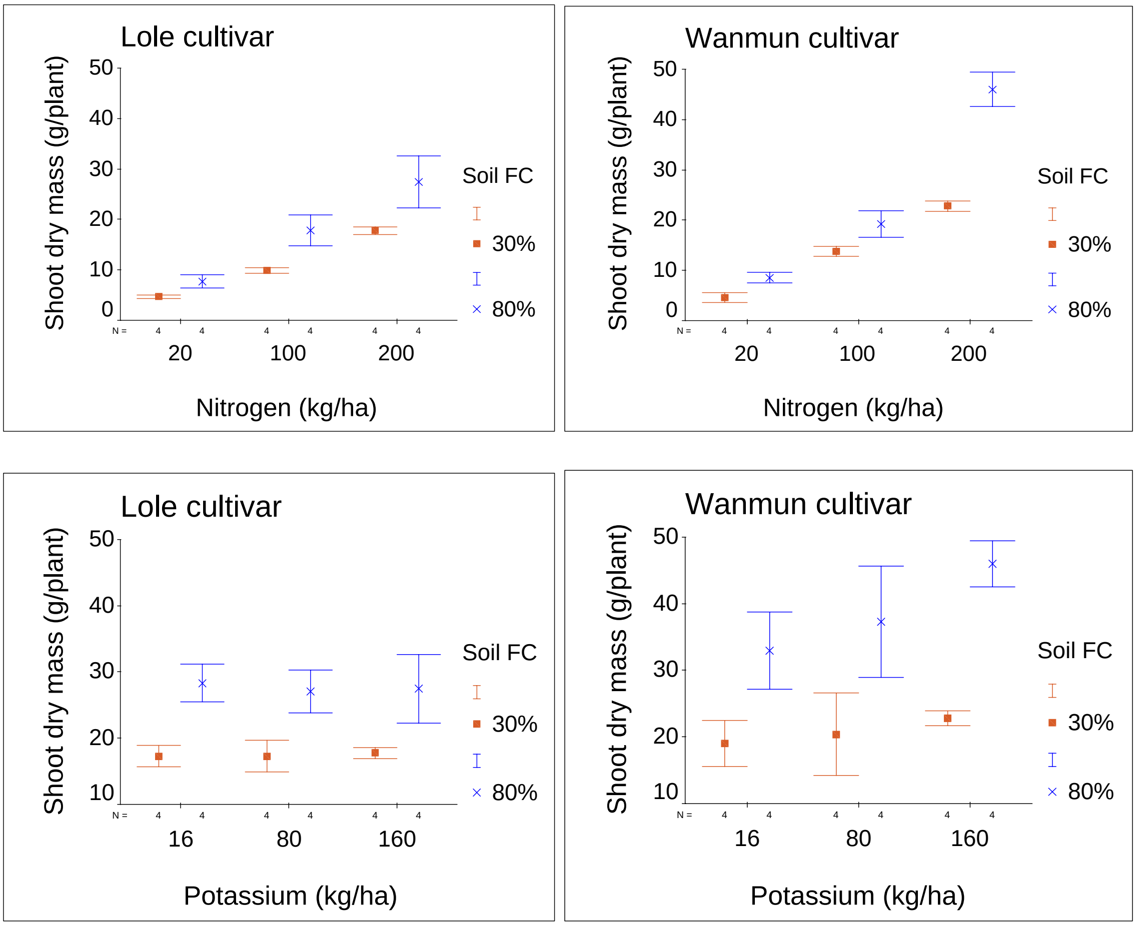


Figure 4.3 The effects of N and K on dry shoot mass of Lole and Wanmun sweet potato cultivars grown under 30% and 80% soil field capacity. Error bars represent standard errors of means with 4 replications. The nitrogen responses are shown for the non-limiting K trial, and the potassium responses for the non-limiting N trial.

The decline in dry shoot mass under water stress and reduced N supply in both cultivars was associated with a decline in leaf mass and area. The plants were stunted when grown under limited N (20 kg N / ha), as a consequence of reduced stem and leaf growth. The leaves of the stunted plants of both cultivars showed chlorosis around the midvein, which turned to yellow and red-purple and developed progressively in the older leaves; the vine colour turned from green to red-purple, which is an indication of the damage caused by reduced chlorophyll production.

Increasing nitrogen levels increased the shoot dry mass of both cultivars grown under both soil water regimes. Regardless of K levels, a greater N supply produced greater shoot growth irrespective of the soil water conditions. Soil potassium contents, on the other hand, had less influence on the shoot dry mass, except in cv Wanmun which increased slightly with increasing soil potassium content, particularly under well watered conditions (Fig. 4.3). This was attributed to the greater biomass produced, requiring a greater potassium uptake from the soil nutrient supply provided by the higher potassium fertilizer inputs.

4.3.2.2 Dry leaf mass

Nitrogen produced a significant increase in the dry leaf mass of both cultivars under both soil water regimes. The well-watered plants produced significantly greater dry leaf masses than the water stressed plants did, and cv Wanmun produced more than cv Lole (Fig. 4.4; Table A4: 3).

Under water stress, the dry leaf masses of both cultivars were reduced compared to that when they grew under well-watered conditions. There was a significant interaction between nitrogen and cultivar, and increasing nitrogen from 20 kg to 200 kg N/ha increased leaf weight from 1.7 g/plant to 9.3 g/plant in cv Lole, and from 1.9 g/plant to 12.3 g/plant in cv Wanmun (Fig. 4.4; Table A4: 31).

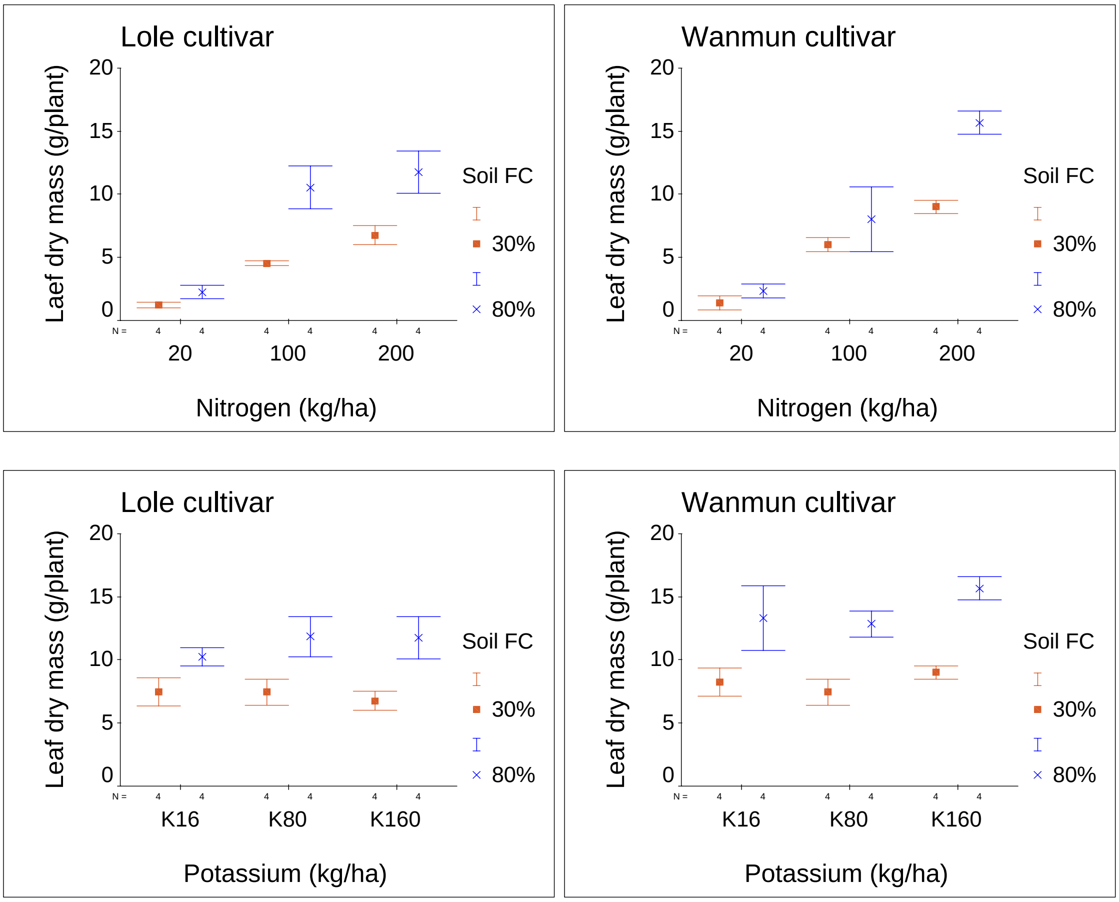


Figure 4.4 The effect of N and K on the dry leaf mass of the Lole and Wanmun sweet potato cultivars grown under 30 and 80% soil field capacity. Error bars represent standard errors of means with 4 replications. (The nitrogen responses are shown for the non-limiting K trial, and the potassium responses for the non-limiting N trial).

Growth responses of sweet potato to nitrogen applications depend greatly on genotypic and environmental variations (Hill, 1984; Villagarcia and Collins, 1998). The results of the present study suggest that a greater soil nitrogen supply promoted the production of leaf mass, while a nitrogen deficiency depressed leaf growth regardless of the presence of sufficient other nutrients. The function of nitrogen is to stimulate leaf number and area (Patil *et al*., 1992; Villagarcia and Collins, 1998). Without adequate soil nitrogen, the rate of plant metabolism is affected due to decreased cell division and elongation (Vasudevan *et al*., 1996). However, a high soil nitrogen supply may cause abundant growth of the sweet potato vines at the expense of their storage roots (O'Sullivan, 1997).

The effect of soil potassium content on dry leaf mass was significantly different between the cultivars (Tables 4.2, A4: 4, and A4: 32), and was greater in plants grown under well watered than water stressed conditions.

Application of the increasing potassium levels did not stimulate increases in leaf mass (Fig. 4.4). This suggests that K was not limiting growth in the present trial whose results agree with those of Ashraf *et al*. (2001) where additional amounts of potassium applied to pearl millet had no effect on shoot mass, relative growth rate, leaf area, net assimilation rate, or photosynthetic rate. On the other hand, a potassium deficiency in aroids reduced leaf size, area and number (Sivan *et al*., 1996). In the presence of adequate potassium, water stress reduced the leaf growth attributes of taro and tannia (Sivan *et al*., 1996), which corresponded with the results of the present study.

4.3.2.3 Leaf area

Nitrogen additions had a significant positive effect on the leaf area of both cultivars under both water regimes (Fig. 4.5; Tables A4: 5 and A4: 31). Bourke (1985) found that nitrogen fertilizer increased leaf number, and as a consequence increased leaf area and growth rates.

On the other hand, potassium additions produced a significant negative response to leaf area in both cultivars under both soil water regimes (Fig. 4.5; Tables A4: 6 and A4:32).

The greater leaf areas produced by lower potassium supply was attributed to the presence of non-limiting nitrogen contents in the soil.

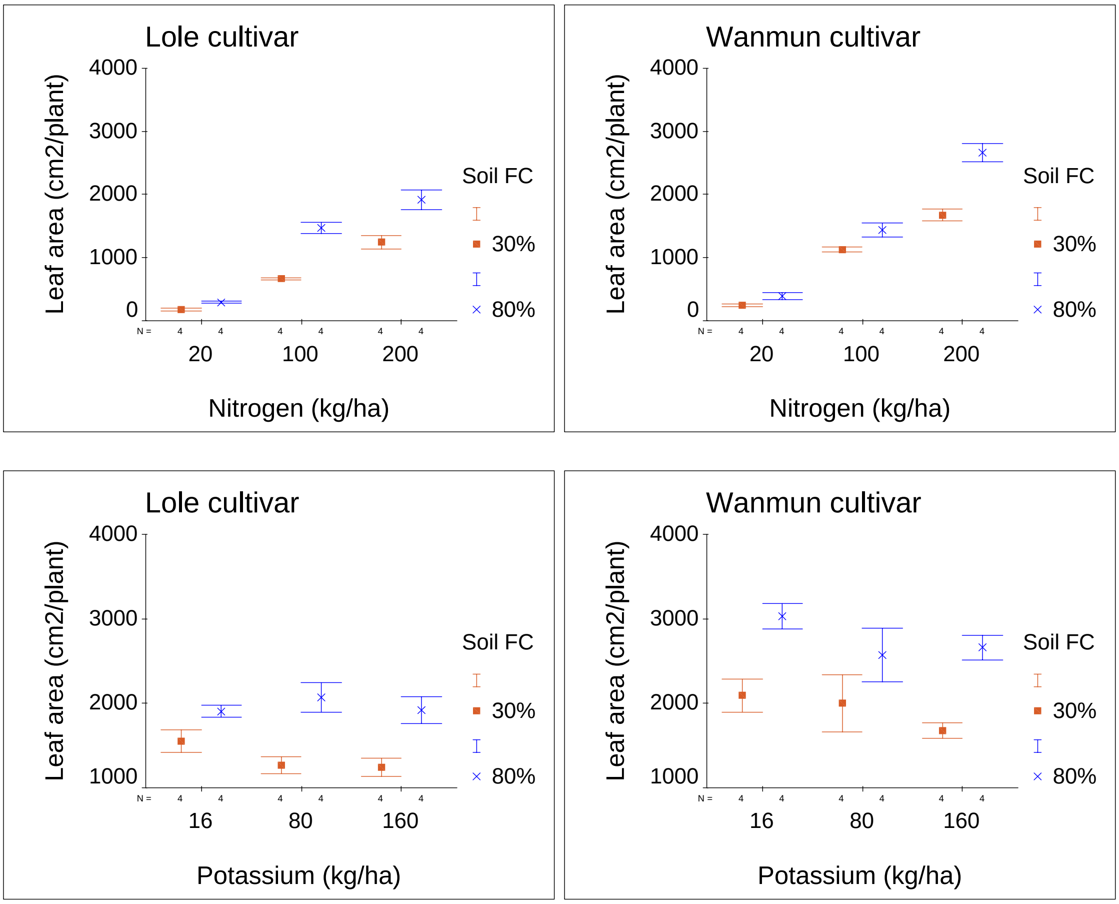


Figure 4.5 The effect of N and K on the leaf area of Lole and Wanmun sweet potato cultivars grown under 30 and 80% soil field capacity. Error bars represent standard errors of means with 4 replications. (The nitrogen responses are shown for the non-limiting K trial, and the potassium responses for the non-limiting N trial).

4.3.2.4 Specific leaf weight

The specific leaf weights (masses) were significantly different between cultivars, however, they were not significantly affected by different soil water regimes in the nitrogen trial. Under water stress, the specific leaf weight of both cultivars declined, but cv Lole produced a significantly greater specific leaf weight than cv Wanmun in the nitrogen and potassium trials (Tables A4: 31, A4: 32). There was also no significant interaction between the treatment effects on the specific leaf mass (Fig. 4.6; Tables 4.2, A4: 7 and A4: 8).

The greatest specific leaf weight for both cultivars was recorded when sweet potato was grown under low nitrogen conditions (20 kg N/ha) and well watered conditions (Fig. 4.6 and Table A4: 31). Nitrogen deficiency resulted in greater specific leaf weight (i.e. heavier leaves per plant) and, conversely, a greater nitrogen supply resulted in lower specific leaf weight. The increase in specific leaf weight under the low nitrogen supply is likely to be the result of a build up of a carbohydrate excess that could not be used in the synthesis of amino acids or other N-containing compounds (Larcher, 1995).

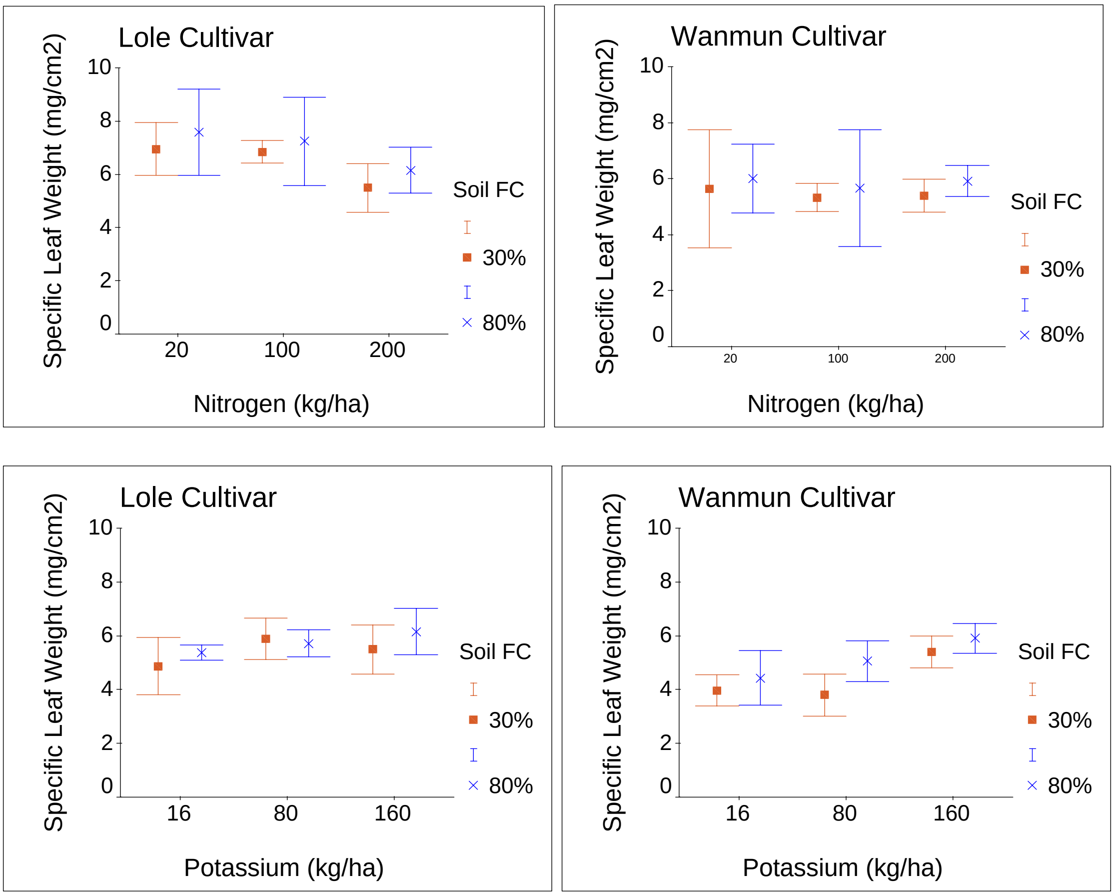


Figure 4.6 The effect of N and K on the specific leaf weight of Lole and Wanmun sweet potato cultivars grown under 30 and 80% of soil field capacity. Error bars represent standard errors of means with 4 replications. (The nitrogen responses are shown for the non-limiting K trial, and the potassium responses for the non-limiting N trial).

Specific leaf weight was significantly higher in cv Lole than in cv Wanmun and was significantly reduced by water stress in both cultivars. The higher rate of potassium (160 kg/ha) significantly increased specific leaf weight of the sweet potato cultivars. There was no significant difference (i.e. no interaction) in the effect of potassium on the specific leaf weight of Lole and Wanmun cultivars, in relation to water stress (Fig. 4.6; Tables 4.2, A4: 8, and A4: 32).

4.3.3 Root growth and tuber yields

The effects of the experimental factors (soil water contents, nutrients, and cultivars) on dry root masses and tuber yields are summarized in Tables 4.2, A4: 9-12, and A4: 33-34. In addition to the effect of K on dry root mass, soil water contents, cultivars, and nutrition levels also significantly affected the dry root masses and tuber yields of the sweet potatoes cultivars (Table 4.2). Most of the interaction effects were not statistically significant for the dry root masses, but were significant for the tuber yields.

4.3.3.1 Dry root mass

Higher soil nitrogen levels produced greater dry root masses under well watered (5.7 g/plant) than water stressed conditions (3.6 g/plant). The Lole cultivar produced greater root masses under well watered conditions (7.9 g/plant) than cv Wanmun (3.4 g/plant). Under water stress, cv Lole also produced greater root dry mass (4.7 g/plant) than cv Wanmun (2.4 g/plant). Greater soil nitrogen similarly produced significantly greater root dry mass (Fig. 4.7; Tables A4: 9 and A4: 33).

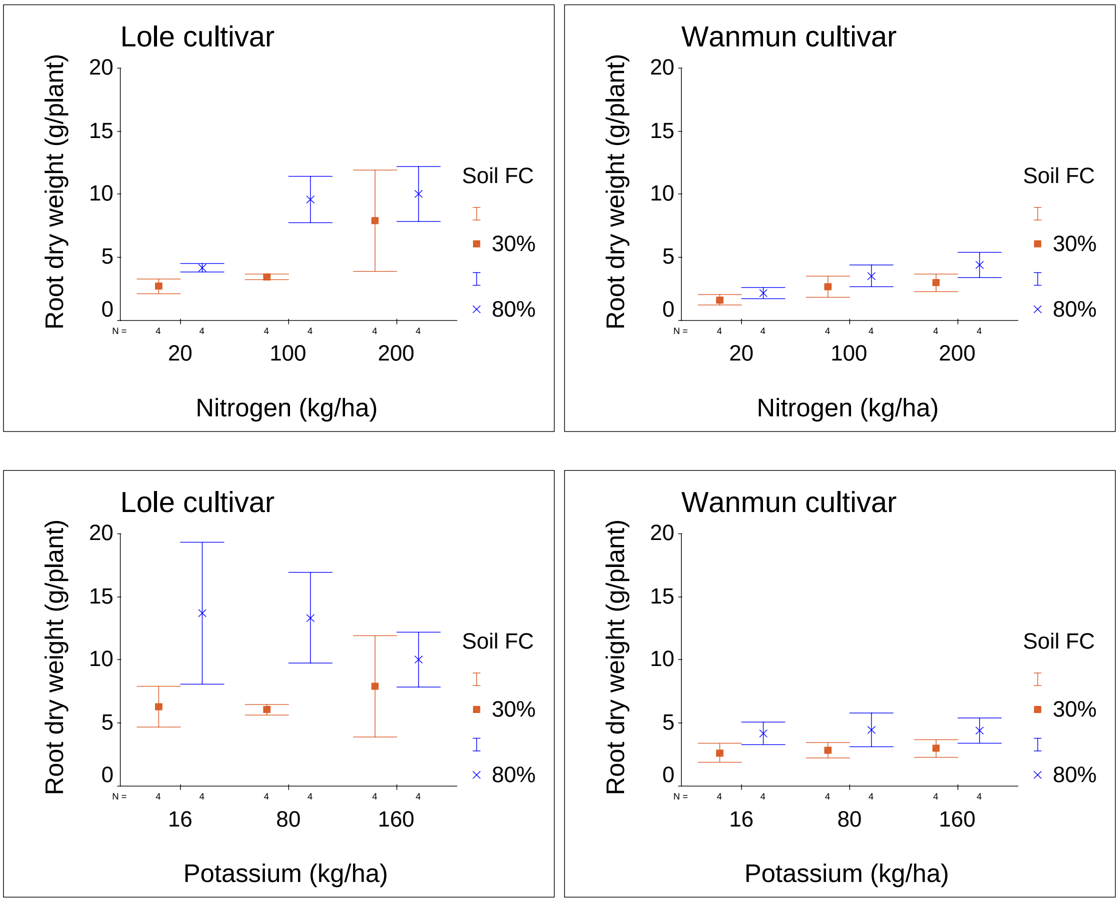


Figure 4.7 The effects of nitrogen and potassium on dry root masses of Lole and Wanmun cultivars grown under 30% and 80% soil field capacity. Error bars represent standard errors of means with 4 replications. (The nitrogen responses are shown for the non-limiting K trial, and the potassium responses for the non-limiting N trial).

The effects of potassium on the dry root mass was greater in plants grown under well watered (8.3 g/plant) than water stressed conditions (4.8 g/plant). The Lole cultivar produced significantly greater root dry mass (12.4 g/plant) than cv Wanmun (4.3 g/plant) under well-watered conditions. Under water stressed conditions, cv Lole produced a much greater dry root mass (6.8 g/plant) than cv Wanmun (2.8 g/plant). Different potassium levels did not significantly affect the root mass of either cultivar (Fig. 4.7; Tables 4.2, A4: 10, A4: 34).

The present study clearly showed that the application of greater amounts of nitrogenous fertilizer, regardless of soil potassium contents, promoted root mass development, while the different application rates of potassium did not produce any response in root growth. According to Taufatofua and Fukai (1996), nitrogen applications increased fibrous root growth in sweet potatoes but had no effect on tuber yield. Related to the nitrogen effect, cv Lole under both soil water regimes produced a greater fibrous root mass than did cv Wanmun. The more abundant fibrous roots in cv Lole benefited the plants as an adaptation mechanism for survival under restricted soil water supply.

4.3.3.2 Tuber yield

Tuber yield was significantly affected by the nutrient addition treatments and their interactions (Tables 4.2 and A4: 11). The effect of nitrogen on tuber yield under well-watered conditions was greater in cv Wanmun (870 g/plant) than in cv Lole (644 g/plant) when supplied with 100 kg of N/ha (Fig. 4.8). Under water stressed conditions, however, the greater nitrogen supplies produced greater tuber yields. Tuber yield was optimal (391 g/plant from cv Wanmun and 411 g/plant from cv Lole) at a nitrogen application of 100 kg/ha (Fig. 4.8; Table A4: 33).

Under water stress conditions, tuber yields increased when potassium application rates were increased, but the yields were much lower than those of the well watered plants when grown in soils with the same level of potassium. Under such conditions, the cultivars produced their greatest yields of tubers (Lole: 426 g/plant; Wanmun: 403 g/plant, respectively) with the application of 200 kg/ha of N and 160 kg of K per ha (Fig. 4.8; Tables A: 33 and 34).

The effects of potassium on tuber yields were significant (Tables 4.2 and A4: 12). Non-limiting water and moderate N applications (160 kg N per ha) produced the greatest yields of 774 g/plant in cv Wanmun and 643 g/plant in cv Lole (Fig. 4.8, Table A: 33). The tuber yields of cv Wanmun declined when the application rate of potassium was reduced to 80 kg of K/ha (Fig. 4.8, Table A: 34). Increasing potassium rate to 80 and 160 kg K/ha increased the tuber yield in cv Lole to 647 g/plant, and 643 g/plant, respectively (Fig. 4.8). Hence, 160 kg/ha of K is needed to ensure optimal tuber yields from cv Wanmun.

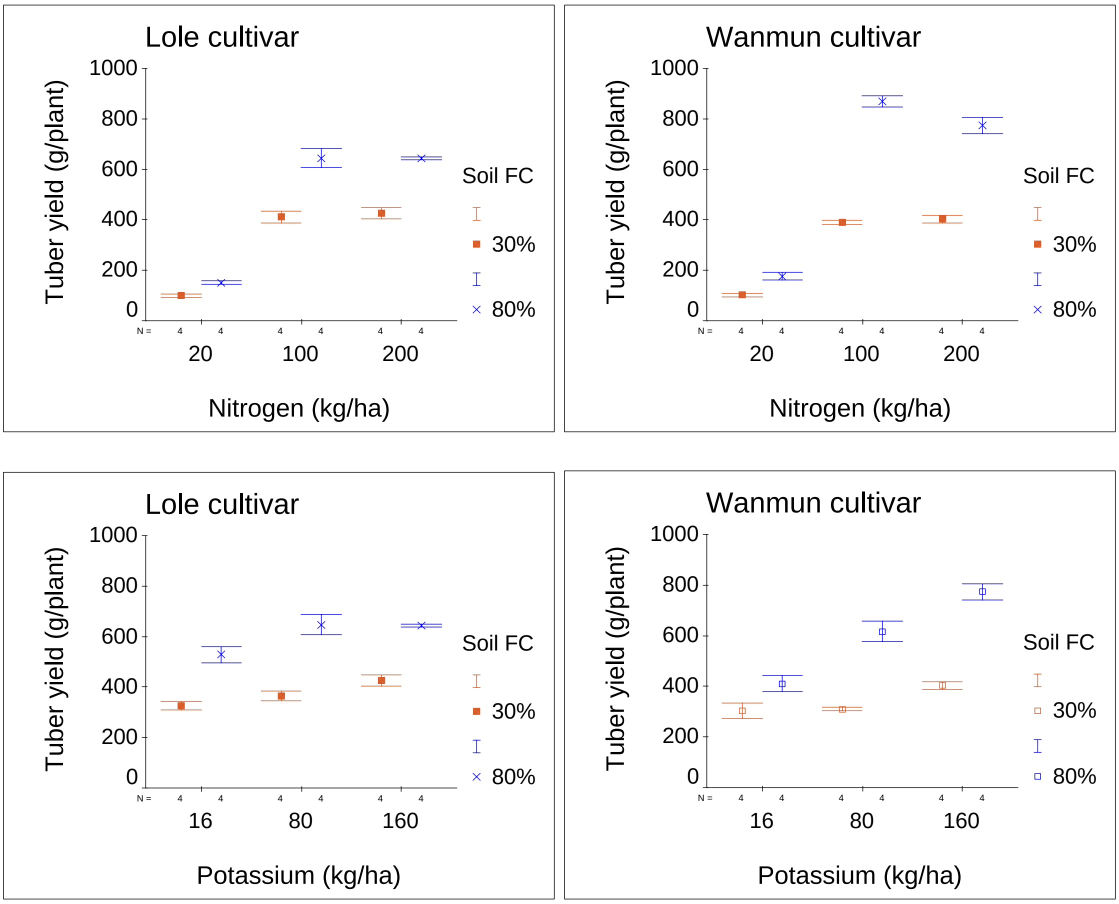


Figure 4.8 The effects of nitrogen and potassium on tuber yields of Lole and Wanmun cultivars grown under 30% and 80% of soil field capacity. Error bars represent standard errors of means with 4 replications. (The nitrogen responses are shown for the non-limiting K trial, and the potassium responses for the non-limiting N trial).

These results show that, although there was a lack of response to potassium in root development in both cultivars and a much smaller response in shoot growth, the potassium content of the soil may limit tuber yield even when no effect is seen in vine growth.

Greater nitrogen applications to infertile growing media promoted the growth of the vegetative parts of the Lole and Wanmun cultivars. The lack of increase in tuber production with soil nitrogen levels greater than 100 kg N/ha may be attributed to the influence of nitrogen on tuber growth and development. Kelm *et al*. (2000) showed that tuber initiation was delayed with high nitrogen supply in 2 sweet potato genotypes. Hartemink *et al*. (2000) also found that nitrogen fertilizer negatively affected tuber yield of sweet potato by promoting vine growth, as was evident in the present trial.

Taufatofua and Fukai (1996) reported faster sweet potato growth and greater tuber yields by increasing the soil nitrogen content under irrigation. They also observed that, in the absence of a nitrogen fertilizer, the yield of tubers was still high, but this was associated with adequate supplies of soil nitrogen. Hence, the responses of sweet potato to applications of nitrogen depend on the cultivar, soil type, and climatic conditions (O'Sullivan *et al*., 1997).

A greater potassium supply promoted greater tuber yields in both cultivars under both water regimes. This result agrees with that of Bourke (1985) who also found that potassium fertilization up to a rate of 375 kg K/ha increased sweet potato tuber yields in the Papua New Guinea highlands. Such a response may be attributed to the role of potassium in starch synthesis, leading to tuber growth and development through the accelerated translocation of photosynthates from leaves to tubers (Mukhopadhyay *et al*., 1992). In *Colocasia*, an increase in both soil nitrogen and potassium contents increased growth and tuber yields, due to the greater assimilate translocation and accumulation rates of the plants grown in enhanced soils (Vasudevan *et al*., 1996). Similarly, George *et al*. (2002) also reported that a yield increase in sweet potato as a result of potassium application, was mainly due to an increase in storage root to shoot ratio, which led to a greater amounts of photosynthetic translocation to the tuber. Higher contents of potassium in the soil, according to Hahn (1977) prevented excessive leaf growth, resulting in higher tuber yield. Wang *et al*. (1995) demonstrated that a decrease of stem and leaf yields, and consequent reduced transpiration, was caused by the application of potassium; the associated increase in overall yield of tubers was consistent with the results of the present experiment where increased levels of soil potassium also reduced the leaf area and increased tuber yields.

The nutrient levels required to produce optimal growth in the present study demonstrate the necessity to apply balance doses of nitrogen and potassium to sweet potato plants. It also demonstrates that the balance of nitrogen and potassium is important in determining tuber yield in sweet potato. Reducing nitrogen inputs to levels below the optimal level (100 kg N/ha) with the addition of potassium had no effect on tuber yields. For this reason, an imbalance of nutrients between nitrogen and potassium should be avoided. On the other hand, tuber yields under water stress conditions increased under greater nitrogen and potassium supplies. This may be attributed to the fact that nitrogen and potassium are essential plant nutrients, which are widely reported for increasing osmotic adjustment of plant cells under drought conditions (Mortlock and Fukai, 1998; Ashraf *et al*., 2001). Hence, a greater nitrogen supply balanced with a greater potassium supply, produced greater tuber yields under water stress conditions. However, the nutrient requirement may depend on the cultivar, soil type, and climatic conditions (O'Sullivan *et al*., 1997; George *et al*., 2002).

4.3.4 Pigment contents

Total chlorophyll and carotene concentrations of the leaves of both cultivars were significantly affected by all of the nitrogen and potassium treatments (Table 4.2). However the chlorophyll *a/b* ratio was affected only by soil water contents, and not by any of the other treatments (Tables 4.2, A4: 13-18, and A4: 35-36).

4.3.4.1 Total chlorophyll

Under well watered conditions, the total chlorophyll concentrations in the youngest fully mature leaves of the Lole and Wanmun cultivars were 1.9 and 1.7 mg/g of fresh leaf, respectively, which were significantly greater than the 1.4 and 1.3 mg/g of fresh leaf, respectively, and were produced under water stressed conditions. The chlorophyll concentrations of the leaves increased with greater soil nitrogen inputs, but responded less strongly to potassium additions to the soil (Fig. 4.9). The greatest total chlorophyll concentrations in Lole and Wanmun cultivar leaves (2.5 and 2.4 mg/g of fresh weight, respectively) developed under the application of 200 kg N/ha (Fig. 4.9; Table A4: 13).

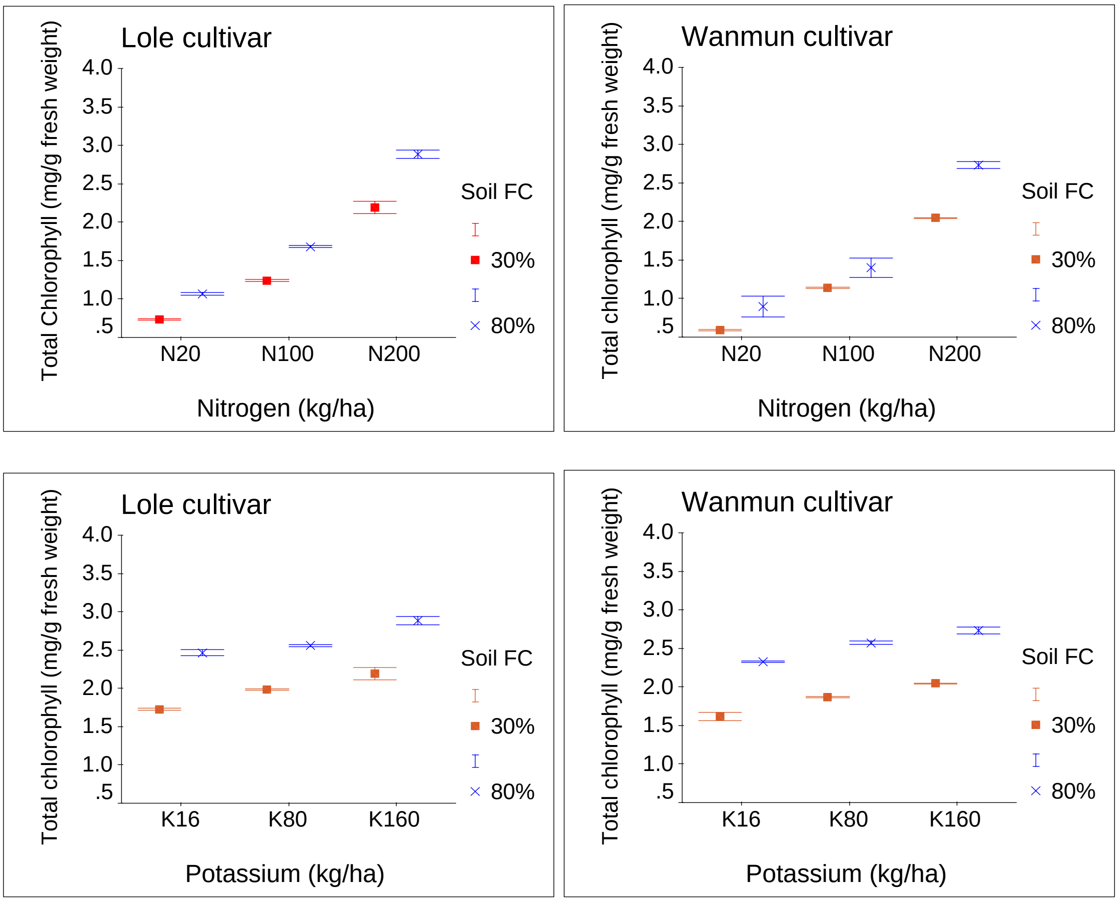


Figure 4.9 The effects of nitrogen and potassium applications to the soil on the total chlorophyll concentration of the leaves of Lole and Wanmun cultivars grown under 30% and 80% of soil field capacity. Error bars represent standard errors of means with 4 replications. (The nitrogen responses are shown for the non-limiting K trial, and the potassium responses for the non-limiting N trial).

From the results of the present study, it is suggested that water deficits and nitrogen inputs consistently reduced the total chlorophyll concentrations of the leaves of both cultivars (Fig. 4.9). The symptoms of chlorophyll reduction could be easily observed from the colours of the leaves. Under nitrogen stress, leaves and petioles turned to yellowish or reddish purple and the symptoms were most severe in the leaves of cv Wanmun (Fig. 4.10). One of the visual symptoms of nitrogen deficiency is the yellowing of the leaves (particularly the older leaves) due to the loss of protein nitrogen from the chloroplasts and hence lower amounts of chlorophyll in the leaves. Under soil nitrogen deficiencies in sugar beet, the decrease in chlorophyll concentration was found to reduce photosynthetic rates (Draycott, 1993), and therefore to reduce overall growth. A similar response was observed in the present experiment in sweet potatoes grown under nitrogen stress.

Figure 4.10 Leaves of Lole cultivar (left) and Wanmun cultivar (right) affected by low nitrogen supply.

The potassium content of the soil was also found to affect the total chlorophyll concentrations in the leaves of both cultivars (Fig. 4.10; Table A4: 14). They were relatively high in plants grown under well watered conditions where increasing potassium levels increased the total chlorophyll concentration; they were greatest in cv Lole (2.9 mg/g fresh weight) than in cv Wanmun (2.7 mg/g fresh weight) in the plants supplied with 200 kg N / ha (Fig. 4.10; Table A4: 35). Under water stress conditions, the highest potassium inputs (160 kg K / ha) also produced high chlorophyll concentrations in the leaves of both cultivars, and their total chlorophyll contents declined as the potassium supply decreased (Fig. 4.10; Table A4: 36). These results conform with the findings of Ashraf *et al*. (2001) that chlorophyll *a* and *b* in certain lines of pearl millet increased with an increasing soil potassium supply.

4.3.4.2 Carotene

The effects of soil nitrogen and potassium contents on the carotene concentrations in the leaves of both cultivars grown under different soil water contents were statistically significant; most of the interaction effects were also significant (Table 4.2).

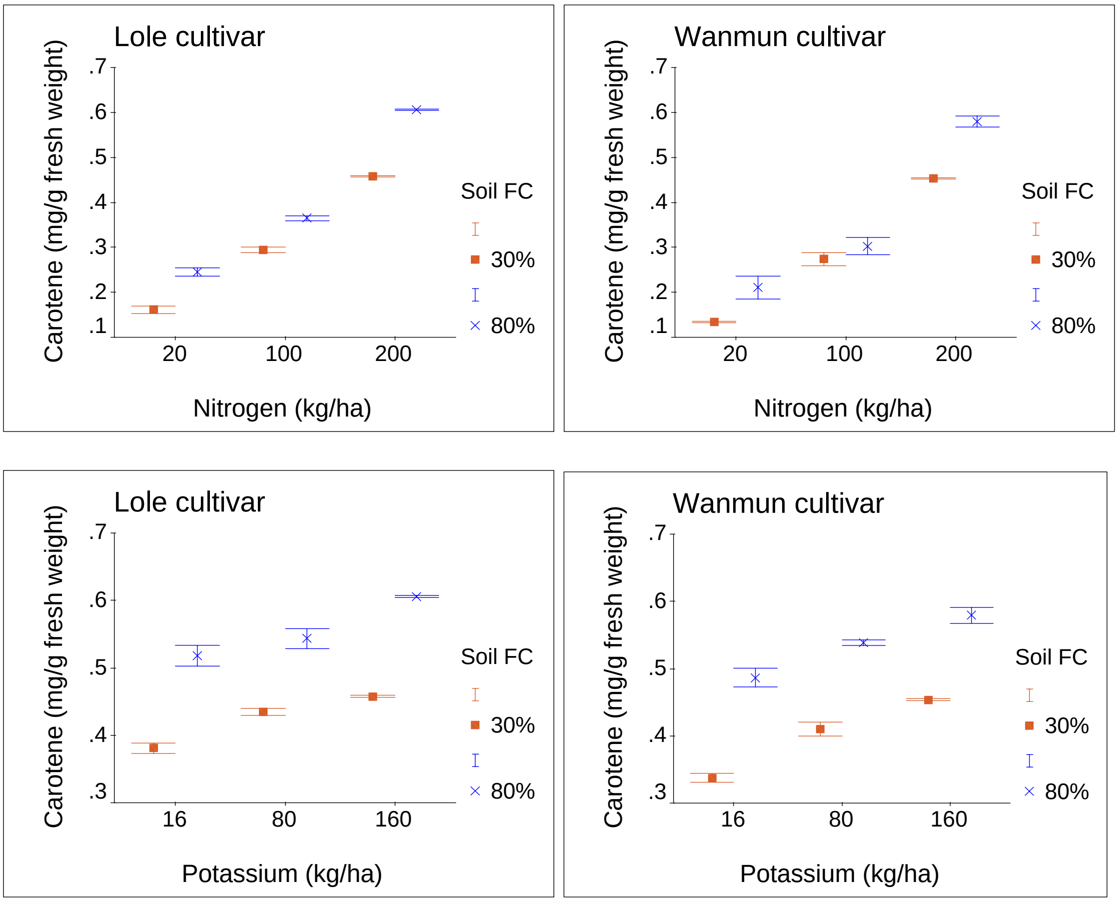


Figure 4.11 The effects of nitrogen and potassium on the carotene concentrations of leaves of the Lole and Wanmun cultivars grown under 30% and 80% of soil field capacity. Error bars represent standard errors of means with 4 replications. (The nitrogen responses are shown for the non-limiting K trial, and the potassium responses for the non-limiting N trial).

When the soil water content was reduced from 80% to 30% soil field capacity, the carotene concentration declined in the leaves of both cultivars (Fig. 4.11). Higher soil nitrogen supplies produced significantly greater carotene concentration in the leaves under both water contents (Fig. 4.11; Tables A4: 15, A4: 35). The highest nitrogen fertilizer input (200 kg N / ha) produced the greatest carotene concentration in the leaves of cultivars Lole and Wanmun (0.61 and 0.58 mg/g of fresh leaf, respectively) under well watered conditions, and 0.46 and 0.45 mg/g of fresh leaf, respectively, under water stress and the same nitrogen input. Low nitrogen inputs (20 kg N / ha) significantly depressed carotene production by cvv Lole and Wanmun under water stress (0.16 and 0.13 mg/g of fresh leaf, respectively), even when the soil water was not limiting (0.25 and 0.21 mg/g of fresh leaf, respectively).

The effect of potassium additions on the carotene concentration of plant leaves was statistically significant (Fig. 4.11; Table A4: 16). Both cultivars produced their highest carotene concentrations (0.61 and 5.79 mg/g of fresh leaf in the Lole and Wanmun cultivars, respectively) when water, nitrogen, and potassium supplies were not limiting. A similar trend was evident in the leaves of the plants grown under water stress conditions in which increased soil potassium contents promoted greater carotene production in the plant leaves, but they never achieved the carotene contents of the well watered plants (Fig. 4.11).

The results of the present study show that total chlorophyll and carotene concentrations of both cultivars responded similarly to the application of nutrients under both soil water regimes. The Lole cultivar consistently produced higher plant pigment contents than did cv Wanmun under water stress, strongly suggesting that the former is well adapted to growth under drought conditions. Similar results were obtained by Kelm *et al*. (2000) who observed that a Tanzanian genotype of sweet potato (the cultivar name was not given) characterized as water stress tolerant, also had high chlorophyll concentrations in its leaves. In addition, George *et al*. (2002) revealed that carotene and anthocyanin contents of sweet potato increased as a result of increased potassium applications to the soil, and that the rate of increase varied with genotype. However it should be noted that, as the different potassium rates did not strongly impact on vine and leaf growth over the growing period, but there was a strong effect of potassium on the leaf pigment content. This suggests that, by the time that the pigment analyses were performed (5 months after planting), the potassium supply had run low and was limiting growth in the soils that had received the lighter K treatments. It is suggested that leaf analysis at such a growth stage does not necessarily reflect limitations to photosynthesis over the whole growing period, because it cannot be assumed that any such differences were present throughout the whole experiment.

4.3.4.3 Chlorophyll a/b ratio

There was no significant effect of nitrogen supply on the chlorophyll *a*/*b* ratio in plant leaves, nor were there significant differences between cultivars (Fig. 4.12; Tables A4: 17, A4: 35).

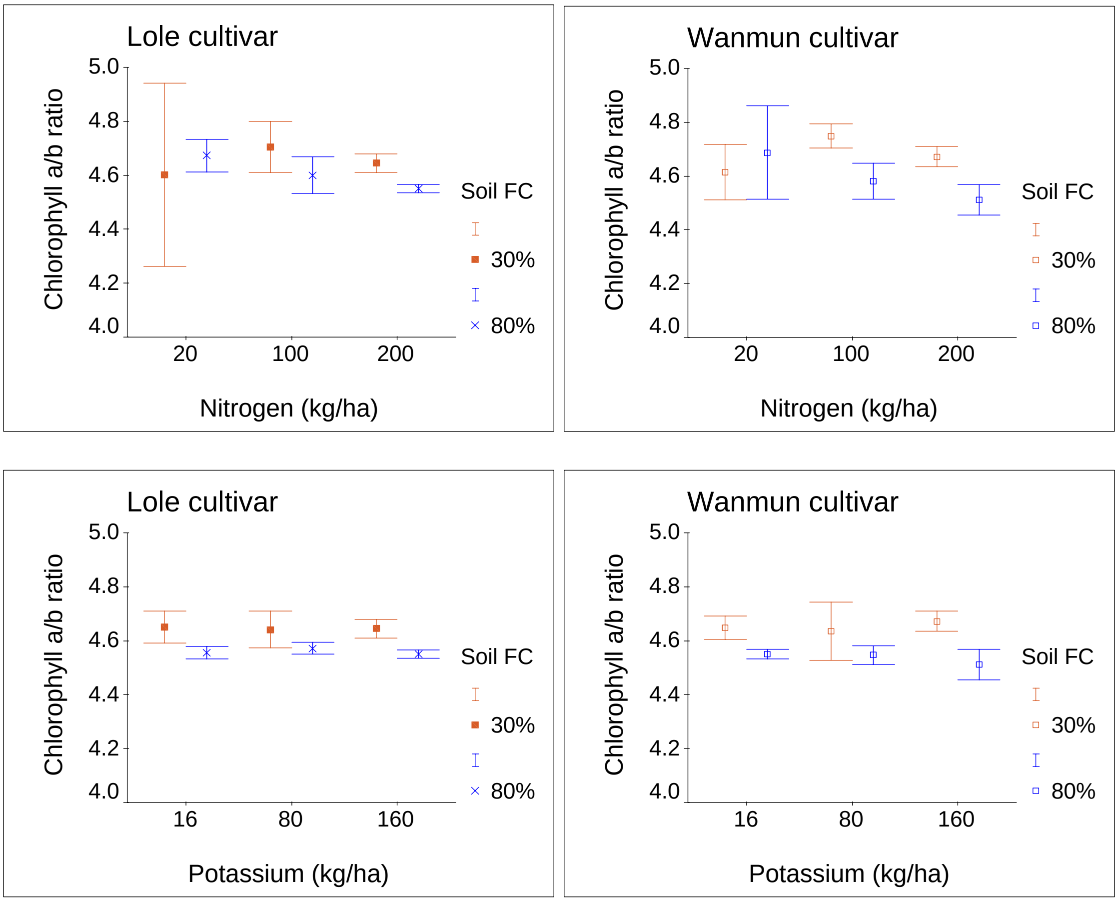


Figure 4.12 The effects of nitrogen and potassium on the chlorophyll *a*/*b* ratio in leaves of Lole and Wanmun cultivars grown under 30% and 80% of soil field capacity. Error bars represent standard errors of means with 4 replications. (The nitrogen responses are shown for the non-limiting K trial, and the potassium responses for the non-limiting N trial).

That the chlorophyll *a*/*b* ratio was not significant in the present trial is attributed to the time of sample collection; all of the leaf results presented in previous sections of this thesis had been collected at 2 and 3 months after planting when the vegetative growth was still active. In the present trial, however, the leaf samples were collected a week before harvesting which was 5 months after planting, and there may have been considerable pigment breakdown in the mature leaves. This explanation is consistent with the findings of Mukhopadhyay *et al*. (1999) who found that the concentration of leaf N in sweet potato was at a maximum during the primary vegetative stage (2 months after planting) and declined gradually towards plant maturity as the pigment concentrations declined, thereby affecting the chlorophyll *a*/*b* ratio of the leaves.

Changing leaf colour from green to yellow indicated the breakdown of chlorophyll at maturity. Atwell *et al*. (1999) found that the common pattern of leaf yellowing varied with nitrogen supply: pale colours developed first in the older leaves of N-deficient plants, and they extended to the younger leaves as the nitrogen deficiency intensified. Although leaf sampling at the harvest stage of the present experiment collected only the youngest fully expanded leaves, it is possible that a loss of chlorophyll may have occurred in the older leaves as a consequence of nutrient translocation into the tubers at this late stage of growth.

The chlorophyll *a*/*b* ratios of the present study showed a small, but not statistically significant trend toward higher values under lower soil nitrogen supplies, possibly suggesting that nitrogen deficiency may have had an influence chlorophyll synthesis.

In the potassium experiment, the effect of potassium on the chlorophyll *a*/*b* ratio was not significant, however there was a significant effect of soil water contents in the present experiment where plants were grown under water stress treatments showed statistically greater chlorophyll *a*/*b* ratios than did those of the well watered treatments (Fig. 4.12; Tables A4: 18, A4: 36). It is possible that chlorophyll synthesis was affected under low potassium supply, indicating that the whole photosynthesis process may also have been affected. This result agrees with that of Sen Gupta *et al*. (1989), who found that photosynthesis was much less inhibited under drought conditions when sweet potato plants were given an enhanced potassium supply. Similar results were obtained by Ashraf *et al*. (2001) who showed increased chlorophyll *a* and *b* concentrations in pearl millet grown under a greater potassium supply and watering regimes that did not affect chlorophyll *a*/*b* ratio. In earlier studies, the chlorophyll *a*/*b* ratio in maize and alfalfa leaves was shown to increase under water stress (Alberte and Thornber, 1977; Estill *et al*., 1991).

Despite no significant effect of potassium on the chlorophyll *a*/*b* ratio in the present trial, water stress was found to produce a significant, slight increase in the chlorophyll *a*/*b* ratio in the leaves of both sweet potato cultivars studied.

4.3.5 Plant water relations

4.3.5.1 Daily transpiration

Daily transpiration losses, recorded as pot mass losses (Section A1. 3.4) throughout both nutrient trials from 1 to 5 months after planting, showed that the transpiration rates of both cultivars were affected by most of the treatments applied (Table 4.3). An interaction effect was also statistically significant, apart from the effects of potassium 1 month after planting and nitrogen 3 months after planting, suggesting that the responses of the cultivars to the soil water content and nutrient supply were similar (Tables 4.3, A4: 19-28, A4: 37-38).

Table 4.3 Effects of soil water content, nitrogen, potassium, and their interactions to the daily transpiration of Lole and Wanmun sweet potato cultivars.

Plant parameters	**The effect of**						
	W	**C**	**T**	**W*C**	**C*T**	**W*T**	**C*W*T**
• **Transpiration**							
1 month after planting							
N experiment	*	*	*	*	ns	*	*
K experiment	*	*	*	*	*	ns	ns
2 months after planting							
N experiment	*	*	*	*	*	*	*
K experiment	*	*	*	ns	*	*	*
3 months after planting							
N experiment	*	*	*	*	*	ns	ns
K experiment	*	*	ns	*	*	*	*
4 months after planting							
N experiment	*	*	*	ns	*	ns	*
K experiment	*	*	ns	*	*	ns	*
5 months after planting							
N experiment	*	*	*	*	*	*	*
K experiment	*	*	*	*	*	*	*
• **Water use efficiency**							
Effect of N	*	ns	*	*	*	ns	ns
Effect of K	ns	*	*	ns	ns	ns	*

ns (no significant effect); * significant ($p < 0.05$)
W = water; C = cultivar; T = nutrient
W*C = interaction between soil water levels and cultivars
C*T = interaction between cultivars and nutrient levels
W*T = interaction between soil water levels and nutrient levels
C*W*T = interaction between soil water levels, cultivars and nutrient levels

The daily transpiration rate of both cultivars rose with nitrogen inputs from 1 month until 4 months after planting before it declined at 5 months after planting (Fig. 4.13). Plants grown under water stress showed significantly lower transpiration rates than those with an adequate water supply. Under both water regimes and high soil nitrogen inputs (200 kg of N / ha), the Wanmun cultivar plants transpired greater amounts of water than did those of cv Lole under the same conditions (Fig. 4.13).

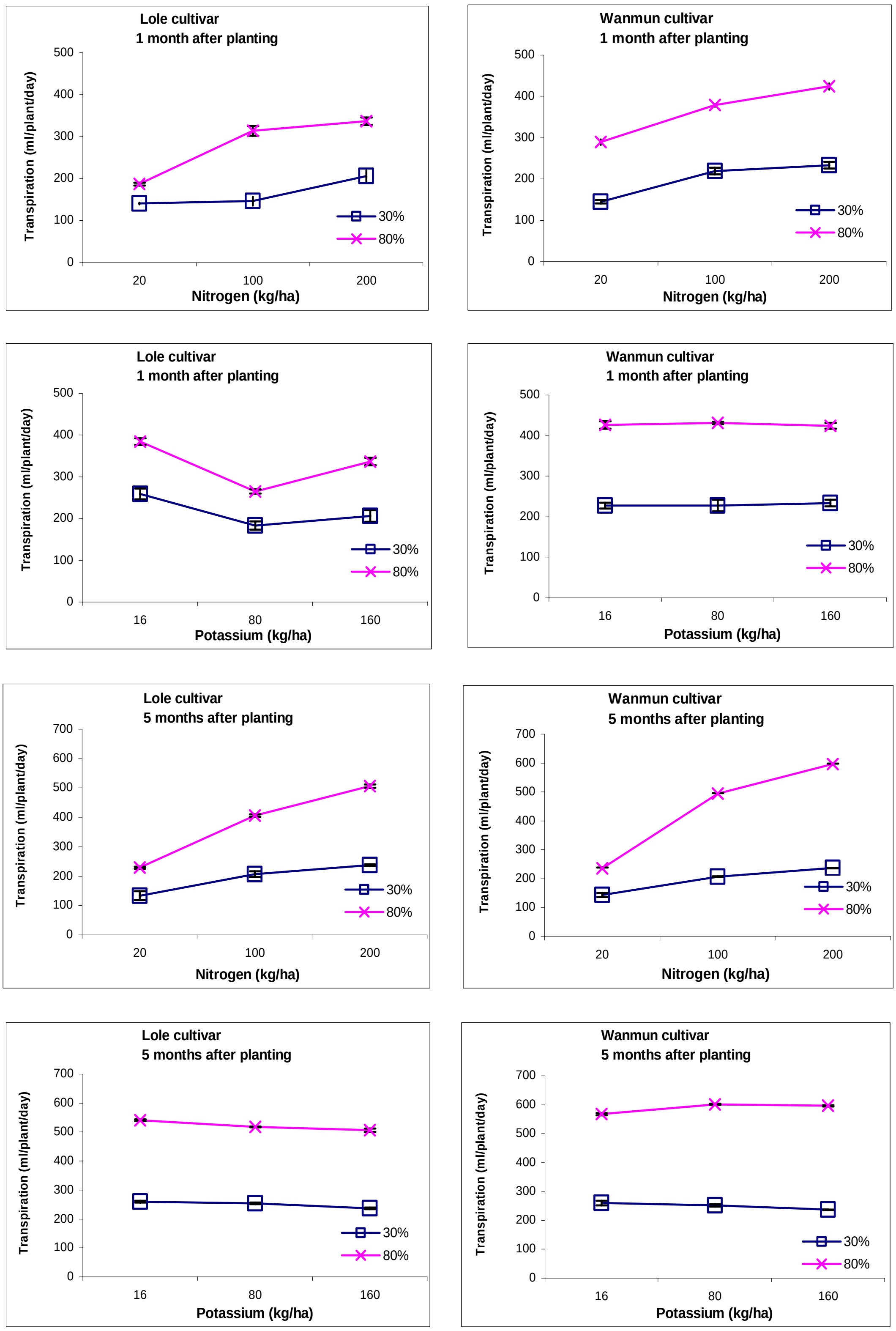


Figure 4.13 Effects of nitrogen (20, 100, and 200 kg of N / ha) and potassium (16, 80, and 160 kg of K / ha) applications on the average daily transpiration of Lole and Wanmun cultivars grown under 30% and 80% of the soil field capacity, at 1and 5 months after planting. Monthly transpiration data are shown in the Appendix (Fig. A4:1).

There was a rapid increase in the transpiration per plant of both cultivars between 1 month and 3 months after planting, particularly in those grown under 80% of the soil field capacity, but only a gradual increase in the plants grown under 30% of the soil field capacity (Figures A4.1; Tables A4: 37 and 38). The rate of average daily transpiration per plant was steady for 4 months after planting, then showed a slight decrease between months 4 and 5 as leaf area declined with tuber development (Sections 2.3.2.2.1, 3.5.3.1, and 5.5.6.3).

The effect of potassium on the mean daily transpiration was also significant; the interactions between the main effects were mostly significant, apart from the main effect interaction recorded at 3 months after planting (Fig. 4.13; Table 4.3). Potassium had less effect than nitrogen on mean daily transpiration of both cultivars grown under both water regimes (Fig. 4.13; Table A4: 19–28).

The dramatic transpiration increase in both cultivars with the higher rates of nitrogen fertilizer matched the concomitant increase on dry matter production discussed above (Section 4.3.2.1). Active vegetative growth and tuber initiation was associated with the transpiration of large amounts of water as a consequence of greater water extraction from the soil, and biomass production in the vegetative parts of the plant, particularly in leaf area. The decrease in transpiration rate as the plants approached maturity is attributed to the decline in vegetative growth and reduction in leaf area with the age of the sweet potato vines (Section 3.5.2); it was also coincident with lower temperatures occurring during the winter season (Fig. 4.1). All of the plants grown under water stress transpired less water as a consequence of their reduced leaf areas (Fig. 4.13).

The plants supplied with low nitrogen transpired less water than the plants grown with a greater nitrogen supply, regardless of soil water regimes (Fig. 4.13). It is widely known that adequate nitrogen is required for optimal plant growth, and the present nutrition trials showed that greater nitrogen supplies promoted vegetative growth increased leaf area in both cultivars of sweet potato, and was associated with greater leaf transpiration. In addition, greater potassium levels not only promoted tuber yields but also have been reported to enhance water use efficiency in some legumes by controlling soil moisture uptake (Sangakkara *et al*., 2000). Greater potassium supply was therefore expected to promote sweet potato growth under low soil water regimes.

The present study showed that the plants grown in the soils with the greater potassium supplies transpired less water than those grown under the lower potassium supply, particularly during the early vegetative stage and rapid tuber bulking stage (Fig. 4.13). The lower amount of water transpired under the higher potassium supplies was attributed to the reduction of leaf area and the development of tubers at these critical stages. Potassium is widely reported to have enhanced plant growth by increasing osmotic adjustments under low soil water regimes, strongly promoting sink capacity for photosynthates in storage organs, and is associated with depressed leaf growth in sweet potato (Hahn, 1977).

Therefore, a good balance of nitrogen and potassium is needed for optimal growth of sweet potato. Nitrogen applications without potassium promoted shoot growth; but low soil nitrogen supplies suppressed overall plant growth. Nitrogen applications with low soil potassium contents depressed tuber development and increased transpiration as a consequence of the larger leaf area produced. This can all be explained by the fact that nitrogen influenced the yield of tubers by increasing leaf area, which in turn increased photosynthesis, and resulted in enhanced tuber weight. On the other hand, potassium influenced tuber yield by increasing the proportion of dry matter diverted to tuber development, and producing greater tuber numbers per plant (Bourke, 1985).

4.3.5.2 *Water use efficiency*

Soil water regimes and nutrient levels produced statistically significant effects on water use efficiency of both sweet potato cultivars; their interactions were mostly significant showing that the responses to the treatments were similar (Table 4.3).

Water use efficiency is the ratio of dry matter produced (g of total dry biomass) to the amount of water used in transpiration (kg of water applied /plant) during the whole growth period. There were statistically significant differences between the water use efficiency responses of the plants grown under different nitrogen and potassium fertilizer inputs (Figure 4.14, Tables A4: 29-30, A4: 37-38). The Lole cultivar had significantly greater water use efficiency than cv Wanmun at each corresponding fertilizer input level. The greatest water use efficiency of cv Lole was obtained under the supply of 100 kg N / ha which was not statistically different from its water use efficiency under 200 kg N / ha for both cultivars under both water regimes, and it was driven by lower dry matter production. The water use efficiency of both cultivars was significantly greater under the low soil water treatments in the nitrogen experiment and, although not significantly significant, tended to be higher in low soil water treatments in the potassium experiment (Fig. 4.14).

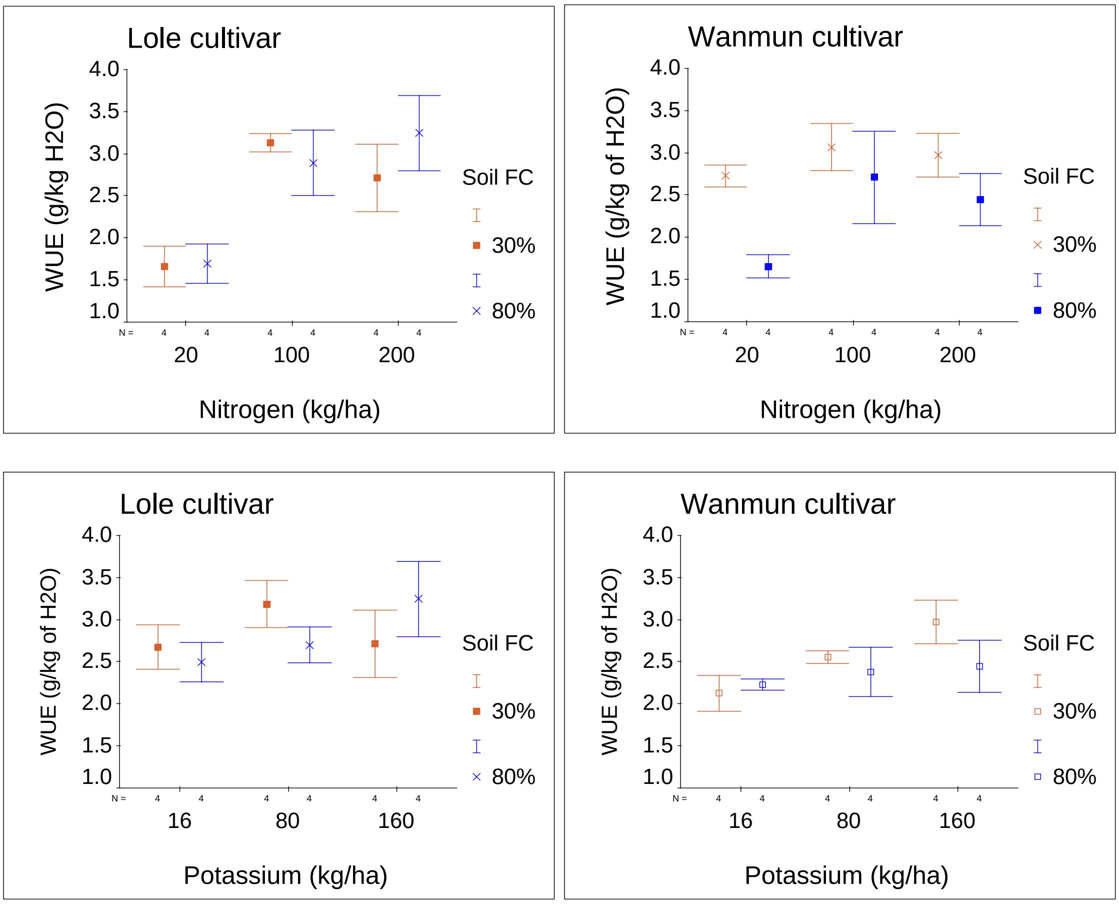


Figure 4.14 Effects of nitrogen and potassium inputs on the water use efficiency (WUE) of Lole and Wanmun cultivars grown under 30 and 80% of the soil field capacity (Soil FC).

The lowest water use efficiency was produced by plants growing under low nutrient inputs (Fig. 4.14), and was a consequence of poor growth and low transpiration rates.

Plant water use efficiency increased as the potassium supply also increased (Fig. 4.14; Table A4: 38). Under well-watered conditions, plant growth under the addition of 160 kg K per ha produced high water use efficiency in both cultivars (Fig. 4.14). This suggests that potassium has a beneficial effect in improving water use efficiency in sweet potatoes. Similarly the water use efficiency increased under water stress conditions when greater amounts of potassium were supplied to both cultivars (Fig. 4.14).

The overall effect of nitrogen and potassium soil nutrients on water use efficiency showed that optimal soil nitrogen contents (100 kg N/ha), with high potassium applications (160 kg K/ha), increased water use efficiency in both cultivars under both soil water regimes. Potassium at this rate particularly contributed to improved water use efficiency under water stress conditions.

4.4 CONCLUSIONS

The supply of nitrogen and potassium fertilizers at 100 kg N / ha and 160 kg K / ha produced the highest tuber yields under both well watered and water stressed conditions. A higher nitrogen supply in the soil produced greater shoot mass, leaf mass, leaf area, and specific leaf weight, but increasing soil nitrogen availability beyond 100 kg N / ha reduced tuber yields. This suggests that the amount of nitrogen is important in regulating the balance between vegetative and tuber growth.

The lack of nitrogen, on the other hand, resulted in stunted growth and affected the overall plant growth and tuber yield. It also resulted in lower chlorophyll production that affected the overall photosynthetic process and plant metabolism. Greater potassium availability enhanced tuber yields when the soil was also supplied with basal amounts of the other plant nutrients; the potassium applications increased tuber yield but did not enhance growth of the vegetative parts of the sweet potato.

Low nitrogen and potassium supplies in the soil reduced plant growth and yields that are both characteristics of poor water use efficiency. The significance of greater water use efficiency of cv Lole under water stressed conditions was attributed to its relatively low transpiration rates.

The Wanmun cultivar consistently produced a greater mass of tubers than cv Lole under well watered conditions. When the soil water content was restricted, however, cv Lole supplied with 100 kg N / ha and 160 kg K / ha produced its greatest tuber mass.

The sweet potato cultivars Lole and Wanmun, grown under 30% of the soil field capacity, consistently produced stunted plants and low tuber yields. The extent of the reduction of growth and yields varied between the drought tolerant Lole and drought sensitive Wanmun cultivars. The growth and yields of cv Lole were less affected by water stress than were those of cv Wanmun. Despite cv Wanmun produced greater dry shoot mass and tuber yield, cv Lole produced greater dry root mass and more fibrous roots. The latter is associated with mechanisms for drought adaptation under field conditions (O'Toole and Chang, 1979, Holwerda and Ekanayake, 1991), while greater shoot mass in cv Wanmun resulted in greater transpiration per plant (Kirnak *et al*., 2001, Saraswati *et al*., 2004). However under water stress conditions, cv Wanmun produced lower tuber yields than did cv Lole.

The mean rate of daily transpiration was higher in the well watered plants than in those under water stress. The Wanmun cultivar sustained significantly greater transpiration than cv Lole, and the highest transpiration rates coincided with the combination of a high nitrogen and low potassium applications through their influence on leaf growth and leaf area development. A low nitrogen supply with high potassium applications, on the other hand, resulted in lower transpiration rates and low tuber yields because of an overall reduction in growth.

Thus, the use of 100 kg N / ha and 160 kg K / ha, applied as ammonium nitrate and potassium chloride respectively, was found to be the best combination of nutrients to sustain sweet potato growth under well watered and water stressed conditions encountered in the present experiment.

CHAPTER 5

GRAFTING TO IMPROVE WATER USE EFFICIENCY IN SWEET POTATO GENOTYPES

5.1 INTRODUCTION

Drought is a serious constraint to agricultural production; even in normally well watered regions, occasional droughts have a devastating effect on local food production. Drought tolerance is often a desirable trait or selection criterion in plant breeding programs. Breeding for specific suboptimal environments (such as nutrient or water deficits) involves a deep understanding of the yield-determining process (Blum *et al*., 1983). Hence, an understanding of the morphological and physiological traits that contribute to drought tolerance can greatly assist plant breeders.

Sweet potato is commonly propagated by vegetative methods, such as vine cuttings rather than using tuber sprouts, to reduce the impact of soil borne diseases (Onwueme and Charles, 1994). Sexual breeding strategies, on the other hand, have not been very effective (Prakash, 1994), as incompatibility or sterility is common in the sweet potato (Reynoso *et al*., 1997). Traditionally, farmers have selected seedlings from natural (segregating) populations, for specific traits. Also the use of polycross seeds have been used to a limited degree and still have potential for breeding programs.

Sexual breeding is long-term job requiring a lot of resources and has often been unsuccessful for sweet potato. Grafting may offer a short term solution by combining the desirable characteristics of different cultivars into one plant. If successful, the grafted plants open up possibilities for enhanced sweet potato production in drought-prone areas.

Grafting is an asexual propagation technique, which can be used to combine the desirable characters of the root and vegetative parts of different plants. The grafting method has been used in sweet potato to screen the yield potential and relative sink strength (Kuo and Chen, 1992). However, there is a lack of information in relation to the effect of grafting on transpiration, sink capacity, tuber production and water use efficiency.

Various studies reported in the earlier chapters of this thesis indicated that the Wanmun and Lole sweet potato cultivars differ in their responses to water stress. The Wanmun cultivar produced higher tuber yields but was very susceptible to water stress, the Lole cultivar, however, had a lower tuber yield but was more drought tolerant as a consequence of its smaller leaf area, fewer stomata per leaf, higher leaf water potential, and higher relative water content than cv Wanmun. Therefore, cv Lole offers more efficient mechanisms for conserving water.

A grafting experiment was carried out in an attempt to obtain sweet potato plants that embodied cv Lole's tolerance to drought and cv Wanmun's high tuber yields. The study also examined the nature of the root and shoot factors influencing growth and yield responses to water stress. The study was also aimed to at identifying the physiological traits contributing to drought tolerance in cv Lole. The compatibility of grafted plants and their growth and yield performance, anatomy, and physiology under water stress conditions were also addressed.

5.2 EXPERIMENTAL MATERIALS AND METHODS

5.2.1 Experimental location

The experiments were carried out from 1 December 2003 to 30 April 2004, in a shadehouse of the School of Marine and Tropical Biology, James Cook University, Townsville.

5.2.2 Research preparation

Pots of 10 L volume without drainage holes were used to accommodate 11 kg of growing medium similar to the sand used the nutrition trials (Chapter 4). It was a clean coarse sand that had been washed to remove any soil components, passed through a 2 mm sieve, and air dried to a constant moisture content. The amount of water required to bring the soil in the pots to field capacity was calculated using a gravimetric method (Appendix A1.1).

The grafting technique used stem tips of about 25 cm length of Lole and Wanmun cultivars that were grafted onto the rootstocks of Wanmun and Lole cultivars that had been growing in the pots for 2 months at 80% of soil field capacity (Figs 5.1a, b). The scions and rootstock were cut into keyhole shapes using a hand-operated Omega Grafting Tool distributed by H.T.C. International Pty. Ltd., Victoria, Australia. The grafted unions were covered with a 3 cm length of a plastic drinking straw and held in place with parafilm. The grafted plants were kept humid by spraying them with water regularly for a day, then were kept in a shaded area for one month until the graft union was established and had healed. Very few of the grafts were unsuccessful.

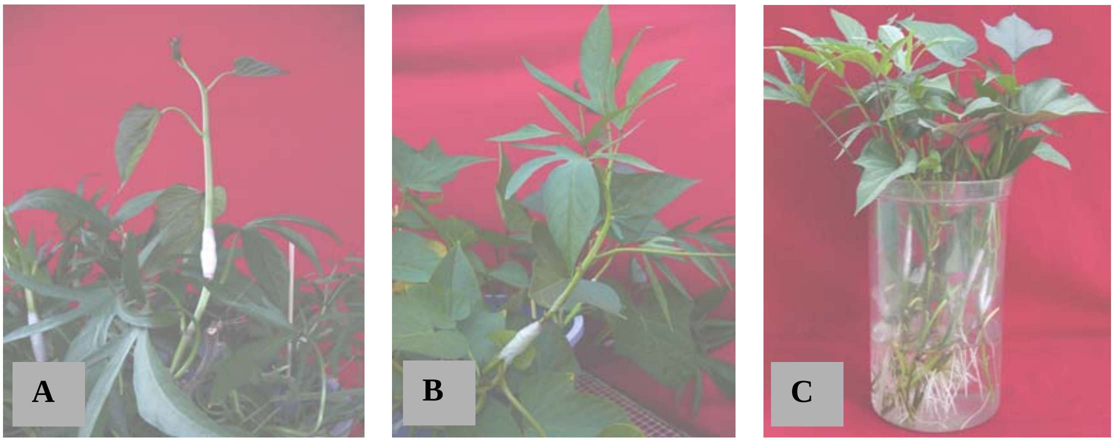


Figure 5.1 Grafted sweet potato cultivars:
(A) the grafted union between Lole rootstock and Wanmun scion one week after grafting;
(B) Wanmun rootstock and Lole scion 4 weeks after grafting;
(C) the grafted cuttings imbibing water for 2 days before planting.

One month after grafting, the tip-grafted shoots were cut from the parent plant at a point 15 cm below the graft union and 15 cm above the union. Cuttings from non-grafted Lole and Wanmun cultivar stems were similarly prepared. The cuttings were kept in water for 2 days until roots appeared from the nodes (Fig. 5.1c) and were then planted into the pots containing the sandy growing medium 11 kg of sand and maintained at 80% of field capacity for 2 days. Water was then withheld until the pots reached the desired treatment water content (30% or 80% of field capacity) after which they were watered every second day to maintain the growing medium at those moisture contents for the rest of the experimental period.

The amount of water applied in any one irrigation given was equal to the quantity lost by evapotranspiration to maintain the targeted soil water contents. The pots and growing media were covered with aluminium foil to reduce evaporative losses to a minimum. Fertilizer requirements were supplied by adding Soluble Osmocote every second week at a rate of 1 g/plant for the first three months. Additional potassium was given as 1 g of potassium sulphate /plant at one week after planting (Appendix A1. 2).

In order to prevent sweet potato scab and insect pest damage, particularly red spider, the plants were sprayed regularly with fungicide (Fungoride) 1 g/1 L of water, and with Red Spider Miticide (Garden King brand: active constituent of 150 g/L Dicofol) at 5 mL of insecticide / 1 L of water.

5.2.3 Experimental design

The experimental design included 4 types of planting materials and 2 soil water treatments in a factorial design using 40 pots in a complete randomised design with 5 replications, as follows.

1. Planting materials, 4 levels:
    a. Non-grafted cv Lole
    b. Non-grafted cv Wanmun
    c. Grafted: Lole rootstock and Wanmun scion
    d. Grafted: Wanmun rootstock and Lole scion
2. Soil water, 2 levels:
    a. 30% of soil field capacity
    b. 80% of soil field capacity
3. Replicates: 5

An additional 64 pots were included to allow for destructive sampling (4 replications) at 1 and 2 months after planting.

5.3 EXPERIMENTAL VARIABLES

Observations were made on the following variables that are described in some detailed in Appendix A1. 3.

5.3.1 Plant growth and tuber yields

Data on shoot biomass, leaf mass, leaf area, root mass, tuber mass, and tuber number were collected. Shoot and root data were collected by destructive sampling at 1 and 2 months after planting. At the end of the experiment (5 months after planting), the plants were harvested and the leaf and total shoot masses determined. Fibrous roots were separated from the tubers and measured separately. These data were used to compute specific leaf weight (mass), water use efficiency, and harvest index with 5 replications.

5.3.2 Water relations

Daily transpiration was recorded as daily pot mass changes from two weeks after planting until one week before harvesting, and each measurement was replicated 5 times.

Leaf water potential was recorded at midday when water stress was at its maximum at 3 months after planting. A pressure chamber was used to measure the water potential of three replicates of the youngest fully expanded leaves from each of the experimental units.

Leaf relative water content was also measured at midday at 3 months after planting in the youngest fully expanded leaf in 5 replications from each of the experimental units (5 leaves per treatment).

Water use efficiency was calculated as the ratio of the total dry biomass that accumulated to the total mass of water used during the growing period.

5.3.3 Leaf pigment contents

The contents of photosynthetic pigments in the plant leaves (chlorophyll *a*, chlorophyll *b*, total chlorophyll, the chlorophyll *a*/*b* ratio, and carotene) were determined using a spectrophotometric method (Wintermans and De Mots, 1965).

5.3.4 Leaf anatomy

Leaf anatomy is strongly related to the gas exchange and loss of water from plants (Hopkins, 1999). In an attempt to determine some of the mechanisms by which the sweet potato copes with water stress, various leaf anatomy characteristics were observed including stomatal density, the lengths of guard cells, and the thicknesses of cuticle waxes. Leaf samples for anatomical study were collected at 4 months after planting and were prepared for study in the Histology Laboratory of the School of Marine and Tropical Biology, James Cook University, Townsville.

5.4 STATISTICAL ANALYSIS

Analyses of variance based on a factorial experiment in a complete randomised design were conducted for all characters measured. The statistical significance of treatments or combinations of main effects were determined using the Duncan Multiple Range Test at the 95% probability level.

5.5 RESULTS AND DISCUSSION

5.5.1 Climatic conditions

Daily minimum and maximum air temperatures, and relative humidity data for the experimental period (December 2003 – April 2004) were obtained from the Commonwealth of Australia, Bureau of Meteorology, Queensland (Figs 5.2 and 5.3). Average minimum and maximum temperatures were relatively constant during the summer wet season from December 2003 to February 2004. The temperature steadily declined from the 2nd week of March and slightly increased in April 2004 (Fig. 5.2). Relative humidity was also fairly constant between December 2003 and February 2004, and after that it gradually declined. The lowest humidity was recorded between the first week and the third week of April 2004 (Fig. 5.3).

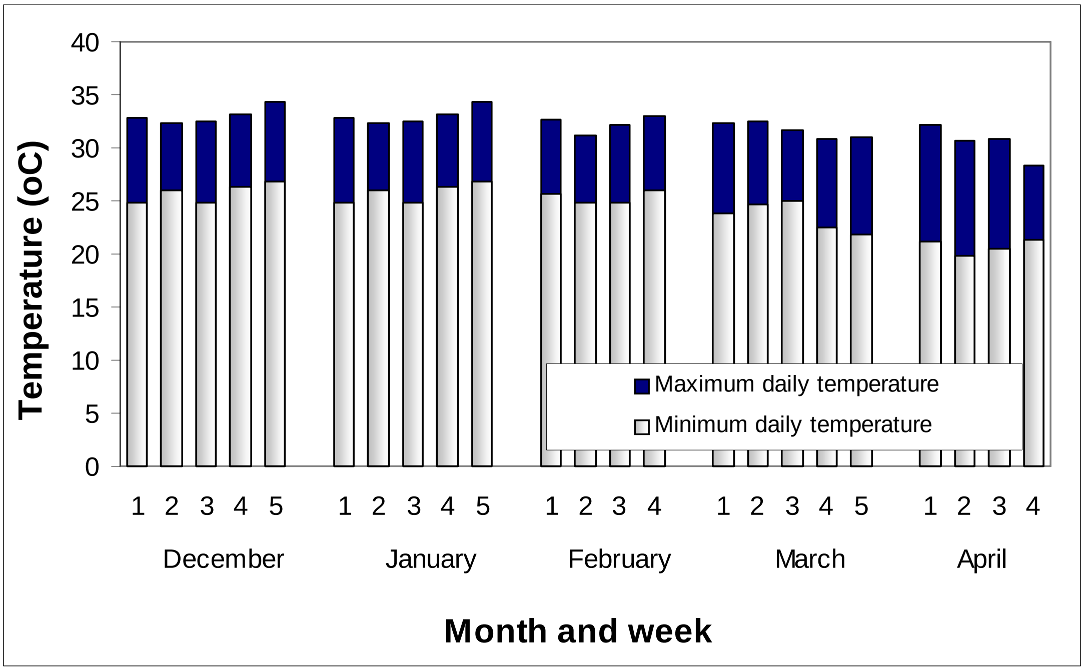


Figure 5.2 Weekly mean maximum and minimum air temperatures (^{o}C), at Townsville Airport, from 1 December 2003 to 30 April 2004. Source: Commonwealth of Australia, Bureau of Meteorology, Queensland.

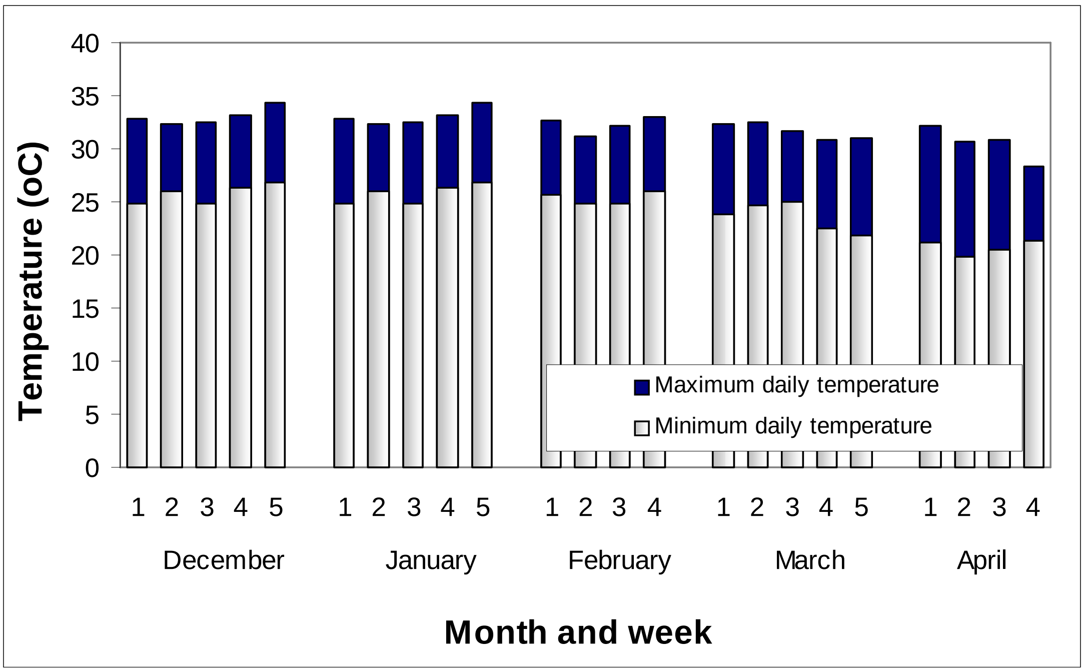


Figure 5.3 Relative humidity of 09.00 am and 15.00 pm at Townsville area, from 1 December to 30 April 2004. Source: Commonwealth of Australia, Bureau of Meteorology, Queensland.

5.5.2 Success of grafting technique

Lole scions grafted onto Wanmun rootstocks were very compatible as indicated by the rapid healing and even formation of calluses at the graft union which was helped by the good fit and the alignment between the grafted sections (Figures 5.4a). Because of its bigger stem diameter, the Wanmun rootstock could easily hold the Lole scion, therefore, the graft union was readily healed. Since the vascular tissues were connected and aligned, the translocation of assimilates, and the flow of water and inorganic nutrients, were not affected. It appeared that the metabolic function was not interrupted in such grafted unions.

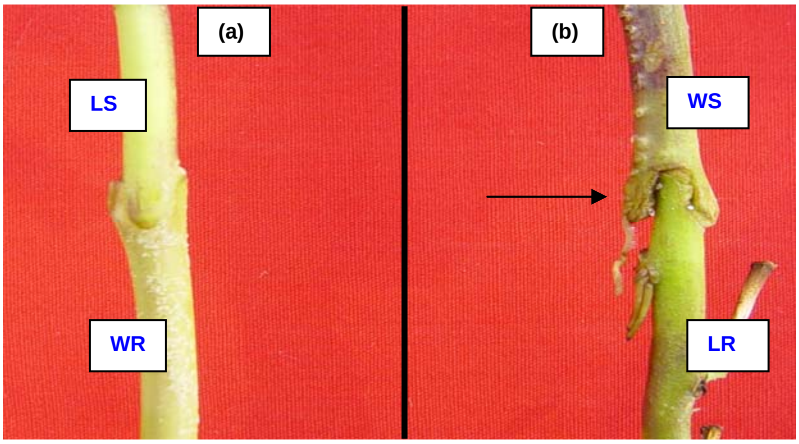


Figure 5.4 The grafted unions of sweet potato cultivars:
(a) a Lole scion (LS) and Wanmun rootstock (WR);
(b) a Wanmun scion (WS) and Lole rootstock (LR).
The arrow points to an area where the phloem of the scion is not well connected to the phloem of the rootstock.

On the other hand, the union of the Wanmun scion grafted onto Lole rootstock was not as good which was a consequence of poor alignment of the stem parts, or lack of mechanical strength in the Lole rootstock of small diameter to hold the Wanmun scion with a large stem diameter (Figs 5.4b).

Figures 5.4b shows that the translocation of sap and its organic contents is disrupted through the grafted union, and this occurred in all such cases where the larger diameter of the Wanmun scion was not strongly connected or attached to the cv Lole rootstock. Andrews and Marquez (1999) suggested that internal symptoms of grafting incompatibility precedes the external symptoms, and the phloem tissues may be more severely affected than xylem tissues. Because the phloem tissue of scion was not well connected to that of the rootstock, the metabolic function of the plant, including transport from the leaves, was interrupted. On the other hand, some of the xylem tissue that translocate water from the root to the leaves was attached across the grafted union. Therefore, some water and nutrient from the roots were able to reach the leaves, and the plant was still able to grow (Hopkins, 1999), despite its ability to translocate photosynthates produced in the leaves through the phloem vessels into the roots being severely impaired.

5.5.3 Plant growth characters

The effects of experimental factors (water contents and the grafted treatments) on fresh and dry shoot biomass, leaf mass and area, fresh and dry root masses, and tuber components are summarised in Table 5.1.

Water stress had a significant effect on the growth of both the grafted and non-grafted sweet potato cultivars (Table 5.1). The interactions between soil water contents and the sweet potato planting materials were significant for most of the variables, apart from the fresh and dry leaf masses at 2 months after planting. This suggests that the response of the plant combinations to the water stress was not similar.

Table 5.1 Effects of soil water contents and their interactions on the growth of Lole and Wanmun, Lole grafted onto Wanmun and Wanmun grafted onto Lole at 1, 2, and 5 months after planting.

Plant parameters	**Significance**								
	Water contents			**Planting material**			**Interaction**		
Time of measurement (months after planting)	**1**	**2**	**5**	**1**	**2**	**5**	**1**	**2**	**5**
Fresh shoot mass	*	*	*	*	*	*	*	*	*
Dry shoot mass	*	*	*	*	*	*	*	*	*
Leaf fresh mass	*	*	*	*	*	*	*	ns	*
Leaf dry mass	*	*	*	*	*	*	*	ns	*
Leaf area	na	na	*	na	na	*	na	na	*
Specific leaf mass	na	na	*	na	na	*	na	na	*
Root fresh mass	*	*	*	*	*	*	*	*	*
Root dry mass	*	*	*	*	*	*	*	*	*
Tuber mass per plant	na	na	*	na	na	*	na	na	*
Tuber number	na	na	*	na	na	*	na	na	*
Average mass of tuber	na	na	*	na	na	*	na	na	*
Harvest index	na	na	*	na	na	*	na	na	ns

ns (no significant effect); * the main effect or interaction of soil water by type of planting material are significant ($p < 0.05$); na: not available

5.5.3.1 Fresh and dry shoot mass

Table 5.2 shows the shoot biomass of non-grafted and grafted sweet potato plants grown under two water contents (30% and 80% soil field capacity). Shoot biomass was affected by soil water regimes, planting material type, and their interactions, recorded from the early plant development (1 month after planting) until harvest stage (5 months after planting) (Tables 5.2 and A5: 1 – 6).

Table 5.2 Effects of soil water content (30 and 80% soil field capacity) on the fresh and dry shoot mass of grafted and non-grafted sweet potato plants sampled at 1, 2, and 5 months after planting. Number of replicates for each treatment = 5.

	Fresh and dry shoot mass (g/plant) after the indicated number of months since planting					
	Fresh shoot mass (g/plant)			**Dry shoot mass (g/plant)**		
Months after planting	**1**	**2**	**5**	**1**	**2**	**5**
Soil water content						
30% field capacity	66.2b	172.3b	235.5b	9.6b	23.6b	12.1b
80% field capacity	105.8a	279.1a	387.2a	17.5a	40.6a	19.4a
Planting material						
Lole (L)	83.8d	222.0e	250.0e	12.5f	31.4e	12.6e
Wanmun (W)	102.2c	251.7c	329.2d	16.7d	35.5c	18.3d
L-W	81.6be	171.8d	208.3f	13.6e	22.8d	11.9e
W-L	76.5e	257.2c	457.8c	11.3c	38.6c	20.2c
Interactions						
30% x Lole	68.6	178.0	213.2	9.4	23.7	8.9
30% x Wanmun	72.6	187.6	240.0	11.0	26.7	15.7
30% x L-W	64.5	135.6	159.8	9.8	16.7	7.9
30% xW-L	59.1	188.0	329.0	8.0	27.3	15.7
80% x Lole	98.9	266.0	286.8	15.7	39.1	16.3
80% x Wanmun	131.8	315.8	418.4	22.3	44.3	20.8
80% x L-W	98.7	208.0	256.8	17.3	28.9	15.9
80% x W-L	93.8	326.4	586.6	14.5	49.9	24.6

Values within a column followed by the same letter symbol were not significantly different ($p < 0.05$).
All the interactions of soil water content by type of planting material were significant ($p < 0.05$).
L-W= Lole scion and Wanmun rootstock; W-L= Wanmun scion and Lole rootstock.

Shoot growth of both the grafted and non-grafted plants declined under water stress. Although the non-grafted Wanmun cultivar and the Wanmun scion grafted onto Lole rootstock produced greater shoot biomass, they showed the greatest decline in production under water stress (40%), compared to that of the non-grafted Lole cultivar and the Lole scion on the Wanmun rootstock, which had a 30% decline in shoot biomass in the water-stressed plants (Table 5.2). The Wanmun scion on Lole rootstock started shoot growth more slowly during the early growth phases than did either the non-grafted plants or those with a cv Lole scion. However, as the experiment progressed, the biomass of the Wanmun scions grafted onto Lole rootstocks increased greatly. They showed biomass production characters intermediate between those of their mother plants (Table 5.2).

5.5.3.2 Fresh and dry leaf mass

Fresh and dry leaf mass was significantly affected by water stress in both cultivars and their grafted combinations (Tables 5.3 and A5: 7-8). The interactions between the main effects were significant.

Fresh and dry leaf mass declined under the imposed water stress, and the greatest decline was evident in the Wanmun cultivar and in the Wanmun scion grafted onto Lole rootstock. The reduction of leaf dry mass followed the same order as the reduction of leaf fresh mass: non-grafted cv Wanmun and the Wanmun scion (46% and 45%, respectively), followed by non-grafted cv Lole and the Lole scion (39% and 29%, respectively). It has been shown above that reduced leaf mass under water stress was associated with the reduction of leaf area and total leaf number (Chapters 2 and 3). It was in accord with the common response to water deficit (Ludlow and Muchow, 1990), of leaf growth reduction and increased senescence.

Table 5.3 Effects of soil water content (30 and 80% soil field capacity) on the fresh and dry leaf mass, and leaf area of grafted and non-grafted sweet potato plants at harvest time (5 months after planting). Number of replicates for each treatment = 5.

	Fresh leaf mass (g/plant)	**Dry leaf mass** (g/plant)	**Leaf area** (cm^2/plant)
Soil water content			
30% field capacity	72.6b	11.8b	1733.2b
80% field capacity	126.4a	19.9a	2324.1a
Planting material			
Lole (L)	65.3e	14.7e	1779.6e
Wanmun (W)	123.0d	16.0d	1993.8d
L-W	57.3f	13.6f	1700.2f
W-L	152.3c	19.1c	2640.9c
Interactions			
30% x Lole	53.2	11.0	1651.6
30% x Wanmun	94.4	11.2	1745.4
30% x L-W	48.3	11.3	1515.6
30% x W-L	94.4	13.5	2020.1
80% x Lole	77.4	18.3	1907.7
80% x Wanmun	151.7	20.8	2242.2
80% x L-W	66.3	15.9	1884.8
80% x W-L	210.2	24.6	3261.7

Values within a column followed by the same letter symbol were not significantly different ($p < 0.05$).
All the interactions of soil water by type of planting material were significant ($p < 0.05$).
L-W= Lole scion and Wanmun rootstock; W-L= Wanmun scion and Lole rootstock.

5.5.3.3 Leaf area

The mean leaf areas of both sweet potato cultivars and their grafted combinations were significantly diminished by water stress and the interactions between the soil water contents and planting materials were also significant (Tables 5.3 and A5: 9). The Wanmun scion grafted onto the Lole rootstock produced the greatest leaf area under both well-watered and stressed conditions, and also showed the largest leaf area reduction under water stress. The reduction in leaf area followed the same sequence of planting materials as the reduction in leaf mass. The reduction of leaf area was the consequence of the reduction of the branch development under water stress (Section

3.5.2.2). However, the graft with large source capacity in terms of leaf area and mass (i.e. Wanmun scion on Lole rootstock) produced the greatest leaf area.

Leaf area is an important trait in contributing to yield since any reduction in leaf area will affect photosynthesis, and therefore tuber yields. Reduced leaf area tends to enhance survival under water stress; however, it can be detrimental to productivity if the leaf area index (the area of leaves per unit area of land) falls below a value of 3 (Ludlow and Muchow, 1990). An excessively large leaf area index can also reduce yield if there is strong shading of the lower leaves (Ravi and Indira, 1999). If sweet potato plants have access to large supplies of soil nitrogen, their growth often becomes vegetative and very little carbon or energy is transported to the roots; consequently, tuber yield can be greatly reduced. Hence, a balance is needed to produce enough leaf area to give a maximum photosynthesis and at the same time trigger the plant to develop a strong sink for the carbohydrate in the tubers. Unlike cereal crops, there is no direct relationship between leaf area (or leaf area index) and tuber yield in sweet potato which complicates interpretations and makes yield prediction difficult, especially as the relationship between leaf area and yield varies considerably among cultivars.

5.5.3.4 Specific leaf weight

Specific leaf weight (mass) was significantly different between the plants grown under different soil water contents, between the parent sweet potato cultivars and their grafted combinations, and their interactions (Fig. 5.5; Table A5: 10).

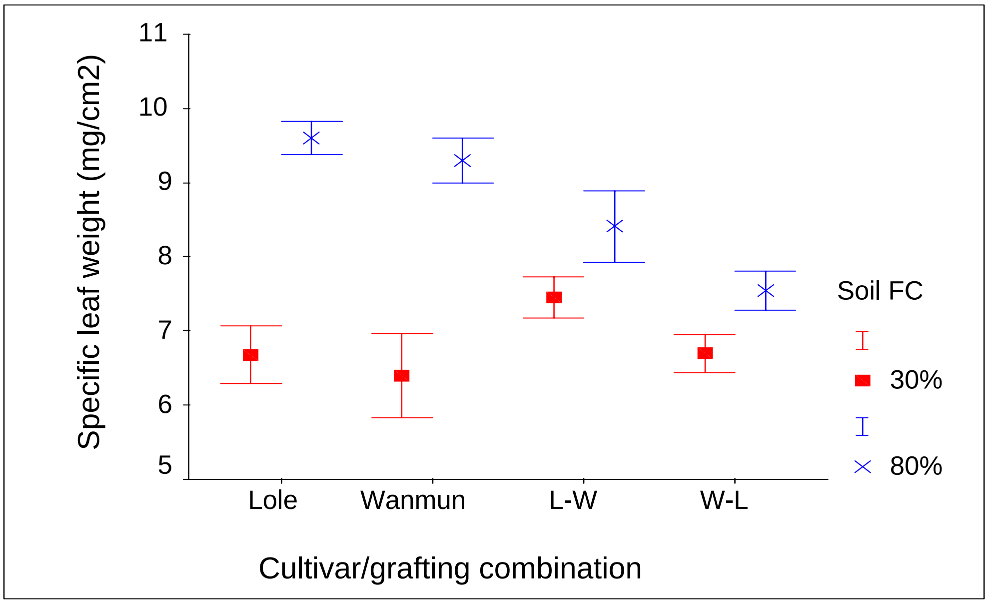


Figure 5.5 Specific leaf weight mass of Lole, Wanmun, Lole scion grafted onto Wanmun rootstock, and Wanmun scion grafted onto Lole rootstock under 30 and 80% soil field capacity (FC).

Under well watered conditions, the non-grafted parent plants produced the largest specific leaf masses which were not statistically different from each other (Fig. 5.5). Specific leaf mass declined when the water stress was imposed. The Lole scion grafted onto Wanmun treatment produced the greatest specific leaf mass under water stressed conditions (Fig. 5.5).

Specific leaf weight is the ratio of leaf mass to the leaf area, is used as a drought tolerance estimate in several crops, and has been considered as a selected trait for breeding programs (Nobel, 1980). Genotypes with a high specific leaf mass have leaves with a small surface area to volume ratio, or thick leaves, which is thought to be an advantage in using water efficiently (Kuo and Chen, 1992; Suja and Nayar, 1996). The experimental results showed that grafted plants growing under well watered conditions did not produce greater specific leaf mass. In contrast, however, the Lole scion grafted onto Wanmun rootstock produced greatest specific leaf mass of the plants grown under water stress. The reduction in the specific leaf mass under water stress is probably due to water loss for the leaf and if great enough this will reduce photosynthesis and eventually lead to wilting of the leaf. The Lole scion on the Wanmun rootstock managed to either extract more moisture from the soil or lose less from its leaves. This shows that grafting plant materials with a strong sink capacity (Wanmun rootstock) and a water use efficient source (Lole scion) resulted in increased specific leaf mass under water stress.

Kuo and Chen (1992) found that sweet potato grafts with a large source (leaves) or a weak sink (tubers), increased the specific leaf mass, whereas grafts with strong sinks decreased specific leaf mass under well watered conditions (AVRDC 1990, in Kuo and Chen, 1992). Sangakkara *et al*. (2000) showed that specific leaf mass was usually higher in plants grown under lower soil moisture contents. The increase in specific leaf mass, according to Kuo and Chen (1992), represents an increase in palisade cell thickness, or leaf thickening, and may indicate the immobilization of material from the leaves. However, higher specific leaf mass attained under water stressed conditions in the present trial was considered to be a beneficial trait in relation to water use efficiency.

5.5.3.5 Fresh and dry root masses

Fresh and dry root masses of all of the planting materials were significantly diminished by water stress. There was a significant difference in the root mass among both the non-grafted and grafted sweet potato plants; the interactions between the main effects were also significant (Tables 5.4 and A5: 11-16).

Table 5.4 Effects of soil water contents (30 and 80% soil field capacity) on the fresh and dry root mass of grafted and non-grafted sweet potato cultivars from 1 to 5 months after planting. Number of replicates for each treatment = 5.

	Fresh and dry root mass (g/plant) after the indicated number of months since planting					
	Fresh root mass (g)			**Dry root mass (g)**		
Time of measurement (months after planting)	**1**	**2**	**5**	**1**	**2**	**5**
Soil water content						
30% field capacity	35.9b	38.3b	55.6b	5.0b	3.9b	7.2b
80% field capacity	52.8a	102.3a	125.2a	9.4a	12.6a	24.0a
Planting material						
Lole (L)	36.1e	63.0e	130.0d	7.5d	10.4c	19.0d
Wanmun (W)	49.0c	34.7f	27.0e	7.2d	5.4e	6.1e
L-W	49.8c	76.7d	42.2e	8.5c	7.7d	4.3e
W-L	42.6d	106.6c	161.8c	5.6e	9.6c	33.0c
Interactions						
30% x Lole	26.4	30.4	72.0	3.7	4.1	10.4
30% x Wanmun	34.9	30.0	30.0	5.9	3.3	4.0
30% x L-W	41.2	36.4	33.4	5.9	2.2	2.3
30%xW-L	41.2	56.2	86.8	4.3	6.1	12.2
80%xLole	45.8	95.6	188.0	11.2	16.6	27.5
80% x Wanmun	63.0	39.4	24.0	8.4	7.5	8.2
80% x L-W	58.4	117.0	52.0	11.1	13.3	6.3
80% x W-L	44.0	157.0	236.8	6.8	13.1	53.8

Values within a column followed by the same letter symbol are not significantly different ($p < 0.05$). All the interactions of soil water by type of planting material are significant ($p < 0.05$).
L-W= Lole scion and Wanmun rootstock; W-L= Wanmun scion and Lole rootstock.

Table 5.4 shows the average root masses of all of the planting materials grown under 30% and 80% of soil field capacity. The root mass increased over the first 2 months after planting in response to active vegetative growth, but then declined as tuber bulking was initiated in the reproductive growth stage. The root mass decline at harvest is a response to the maximization of tuber yields. This pattern was also observed in the nutrition trials reported in the previous chapter of this thesis (Section 4.3.3.1).

The Wanmun cultivar is recognized as a high-yielding sweet potato under well watered conditions (Taufatofua, 1994) and was shown in Section 2.3.3.3 to produce relatively large tubers and few fibrous roots. The Wanmun cultivar, and the Lole scion grafted onto the Wanmun rootstock under well watered conditions, both produced low root masses in comparison with the non-grafted Lole cultivar and with the Wanmun scion grafted onto Lole rootstock (Table 5.4; Sections 3.5.2.7 and 4.3.3.1). On the other hand, the root growth of the Lole scion grafted onto Wanmun rootstock was similar to that of the ungrafted Wanmun cultivar (Table 5.4).

The root mass of the water stressed Wanmun scion grafted onto Lole rootstock had declined by 77% at 5 months after planting. The root mass reduction was greater than that of the Lole scion grafted onto Wanmun, and of the non-grafted cv Lole and cv Wanmun cultivars whose root masses were diminished by the imposed water stress by 63%, 62%, and 51%, respectively.

5.5.4 Tuber components

Tuber yields were reduced significantly by water stress irrespective of the planting material used, and the interactions between the soil water contents and planting materials also had a significant effect on tuber yields (Fig. 5.6; Tables 5.1 and A5: 17-20).

5.5.4.1 Tuber weight

Tuber weight (tuber mass) declined under the imposed water stress. The Wanmun cultivar produced the greatest tuber mass under well watered conditions (708.4 g/plant). Under water stress, however, its tuber mass declined by 63%. The Lole cultivar produced a smaller mass of tubers (640.4 g/plant), but showed less reduction under water stress (49%), and the effect was similar to that of the Lole scion grafted onto Wanmun rootstock (46%). The Wanmun scion grafted onto Lole rootstock produced luxuriant top growth but only a few, small tubers under both soil water regimes; this response might be attributed to the graft incompatibility discussed above (Section 5.5.2).

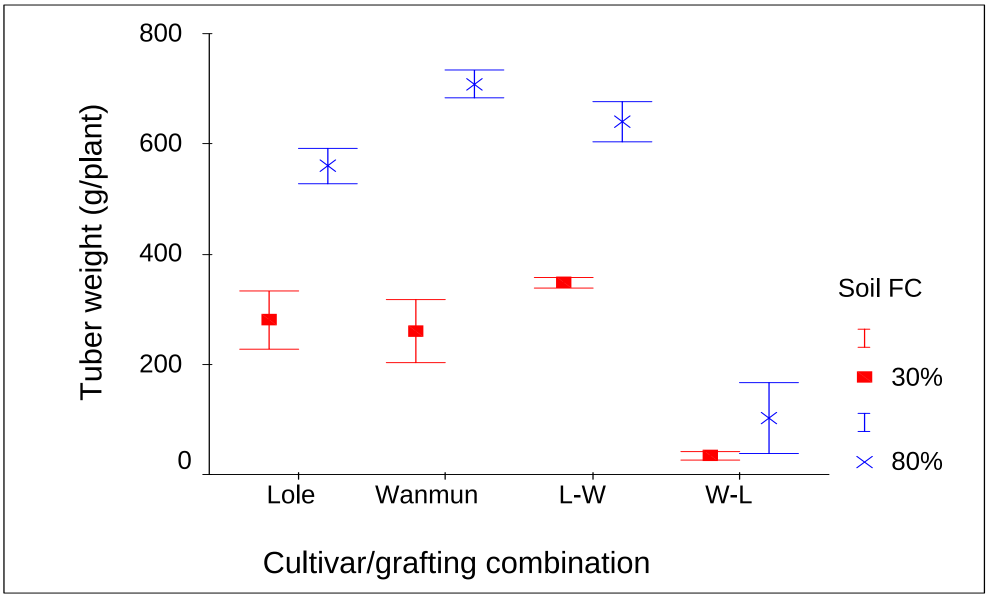


Figure 5.6 Effects of soil water contents (30 and 80% of soil field capacity) on the mass of tubers at harvest of the sweet potato cultivars (Lole, Wanmun) and grafted cultivars (Lole scion on Wanmun rootstock L-W, and Wanmun scion on Lole rootstock W-L). Number of replicates for each treatment = 5.

Under well-watered conditions, this plant only produced 102 g tuber/plant, or less than one sixth of that of the Lole scion grafted onto Wanmun rootstock (640.4 g/plant). The fibrous root system of the Wanmun scion grafted onto Lole rootstock was extensive and penetrated deeply into the soil, similarly to that of the non-grafted Lole cultivar grown under well watered conditions. These results show that the root growth of the Lole cultivar reduced the tuber storage sink capacity, and may have affected partitioning of assimilates into storage roots and it is also possible that hormonal differences may have affected source allocation to sinks (fibrous roots vs storage roots) both in Lole especially in the Wanmun scion on Lole rootstock (W-L) (with the poor graft).

Under water stress, the Lole scion grafted onto Wanmun rootstock produced slightly higher tuber yields than did the non-grafted cv Wanmun (348 and 260 g/plant, respectively). Under similar conditions, the Wanmun scion grafted onto Lole rootstock produced only 34 g of tuber/plant, which much lower than the tuber yield of the non-grafted cv Lole (280.4 g/plant). According to Kuo and Chen (1992), both source potential (leaves) and sink strength (tubers) play a vital role in regulating the yields of sweet potato. The results of the present study have confirmed that sink strength, more than source potential, affects photosynthesis and translocation. The sink thereby controls dry matter production and the development of storage roots, as was also found by Kuo and Chen (1992).

5.5.4.2 Tuber numbers

The Lole cultivar produced significantly higher tuber numbers under well watered conditions than under water stress (10 / plant and 2 / plant, respectively), and the larger number of tubers was at the expense of lower masses per tuber (Figs 5.7 and 5.8). The water stress did not greatly affect the number of tubers produced by cv Wanmun or the Lole scion grafted onto the Wanmun rootstock (3 tubers / plant compared with 4 tubers / plant when grown under well watered conditions). It was suggested by Kuo and Chen (1992) that grafts with strong sinks (storage roots) will produce greater tuber yields than those with weak sink strength irrespective of the source (leaves) potential. On the other hand, the Wanmun scion grafted onto Lole rootstock produced abundant fibrous roots and few tubers, possibly as a result of grafting incompatibilities, in that, of the 4 grafted plants (Wanmun scion onto Lole rootstock), only 2 plants produced tubers which were smaller than those of the original non-grafted cv Lole. Kuo and Chen (1992) suggested that the ability of clones to develop storage roots in early or late maturity was determined by their sinks, not by their sources, as was also indicated by the present experiment.

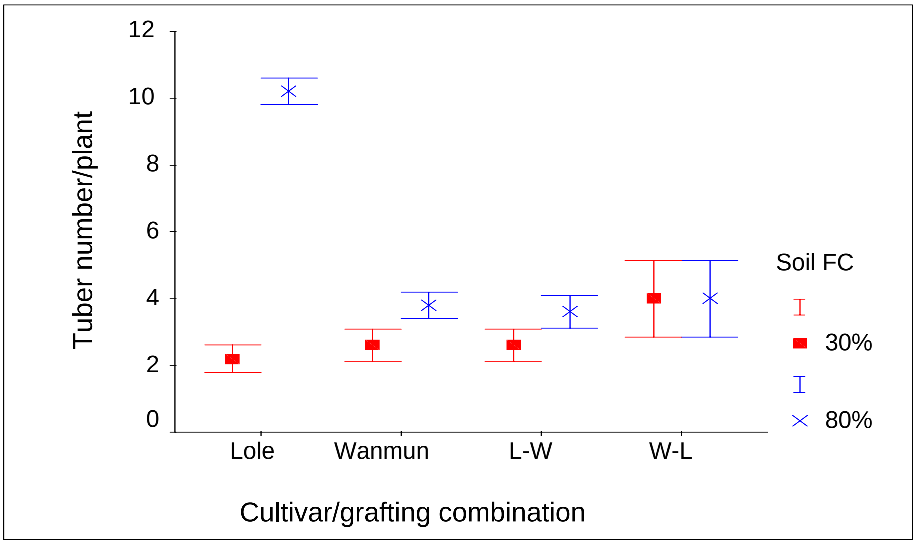


Figure 5.7 Effects of soil water contents (30 and 80% of soil field capacity) on the number of tubers at harvest for the sweet potato cultivars (Lole, Wanmun) and grafted cultivars (Lole scion on Wanmun rootstock L-W, and Wanmun scion on Lole rootstock W-L). Number of replicates for each treatment = 5.

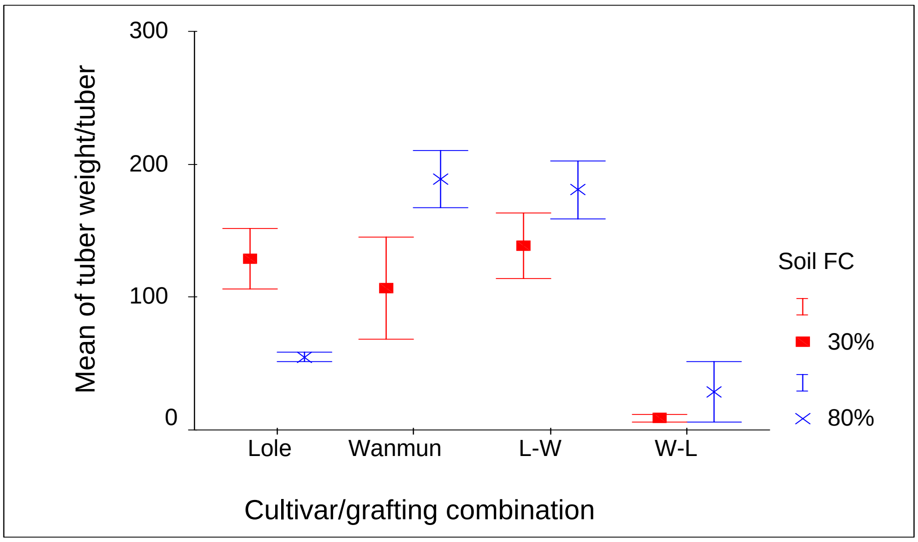


Figure 5.8 Effects of soil water contents (30 and 80% of soil field capacity) and the sweet potato cultivars (Lole, Wanmun) and grafted cultivars (Lole scion on Wanmun rootstock L-W, and Wanmun scion on Lole rootstock W-L) on the average mass of tuber at harvest time. Number of replicates for each treatment = 5.

There is a general association between tuber mass and tuber number in many crops, in that high tuber numbers are likely to relate to low individual tuber masses (Norman *et al*., 1995). The highest mean tuber mass produced in the present study under well watered conditions was from the non-grafted cv Wanmun (188.6 g/tuber) followed by the Lole scion grafted onto Wanmun rootstock (180.6 g/tuber), non-grafted cv Lole (55 g/tuber), and the Wanmun scion grafted onto Lole rootstock (29 g/tuber). Under water stress conditions, however, the Lole scion grafted onto Wanmun rootstock, and cv Lole produced the greatest tuber mass (139 g/tuber and 129 g/tuber, respectively). The Wanmun cultivar and the Wanmun scion grafted onto Lole rootstock produced somewhat lower tuber yields (106.7 g/tuber and 8.8 g/tuber, respectively). Previous results (Section 3.5.5.2) showed that cv Lole, grown under water stress, produced a comparable mean mass per tuber with that of cv Wanmun grown under well watered conditions.

The Wanmun cultivar and the Lole scion grafted onto Wanmun rootstock started tuber growth early in the maturity stage under well watered conditions. This also helped to determine their potential in maximising tuber yield compared with faster than the other sweet potato planting materials.

5.5.4.3 Harvest index

Harvest index, an indicator of the relative distribution of carbon, was significantly affected by soil water contents and grafting (Tables 5.1 and A5: 20). Under well watered conditions (80% of soil field capacity), the harvest index was greatest for the Lole scion grafted onto Wanmun rootstock, followed by cv Wanmun, then cv Lole (Fig. 5.9). The same pattern was observed with the plants grown under water stress (30% of field capacity), but the water stress reduced the harvest index. The higher harvest index indices were attributed to the greater distribution of assimilates into the tubers and resulted in greater tuber production. The Wanmun scion grafted onto Lole rootstock produced the lowest harvest index as a consequence hormonal differences, which may have affected source allocation to sinks (fibrous roots vs storage roots).

These results, like the tuber growth responses, are consistent with those of Kuo and Chen (1992) who found that sweet potato grafts with a strong sink (storage roots) produced a greater yield of storage roots than those with weak sink strength, irrespective of the source potential (leaves). The reciprocal graft treatment also showed that the ability of clones to develop storage roots early or late was determined by their sinks, not by their sources (Hozyo *et al*., 1971 in Kuo and Chen, 1992). Kuo and Chen (1992) also showed that grafts with a large source and weak sink produced an intermediate content of total dry matter and storage root yield.

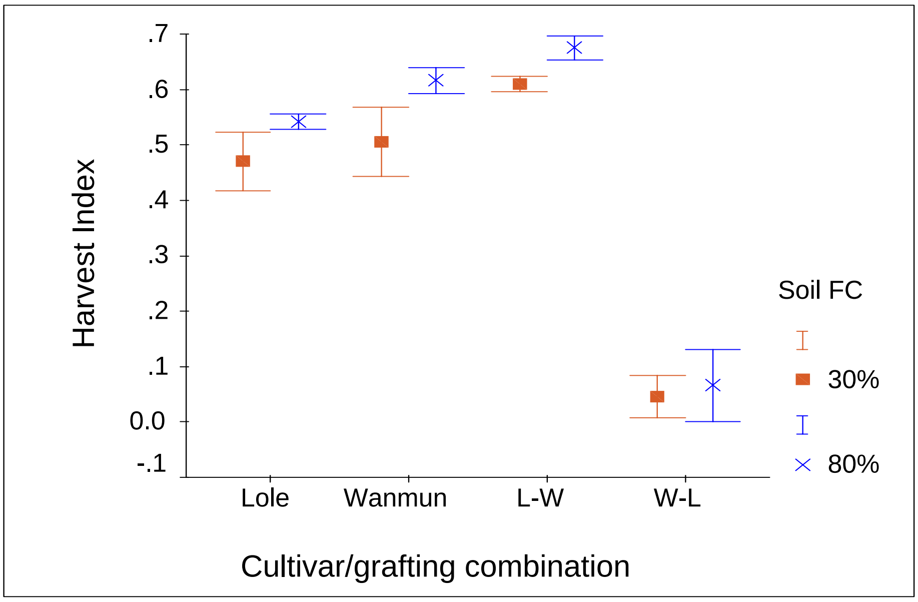


Figure 5.9 Effects of soil water contents (30 and 80% of soil field capacity) on the harvest index of the sweet potato cultivars (Lole, Wanmun) and grafted cultivars (Lole scion on Wanmun rootstock L-W, and Wanmun scion on Lole rootstock W-L). Number of replicates for each treatment = 5.

The high harvest index of the Lole scion grafted onto Wanmun rootstock, according to Kuo and Chen (1992), indicates high efficiency in storage root formation. It is implied, then, that efficient carbon mobilization to the storage roots from the leaves rather than larger source leaf area is critical for the development of high harvest index in sweet potato.

5.5.5 Physiological traits

Table 5.5 shows the effects of soil water contents on the physiological traits of the sweet potato cultivars Lole, Wanmun, and their grafted combinations.

The main effects and interactions were mostly significant (Table 5.5). Significant interactions indicate that the cultivars and grafting combinations responded differently to different soil water contents for that parameter. The interactions between soil water contents and the grafted and the non-grafted plants was not significant for chlorophyll *b*, chlorophyll *a*/*b* ratio, and plant water relations. Stomatal density was not affected by different soil water contents, however it was significantly different among cultivars. Interactions between soil water contents and the grafted and non-grafted plants were also not significant for stomatal density, indicating that the cultivars and their grafted combinations responded similarly to the different soil water contents sustained throughout the experimental period.

Table 5.5 The significance of soil water contents on the physiological aspects of sweet potato cultivars Lole, Wanmun, Lole grafted onto Wanmun, and Wanmun grafted onto Lole and their interactions, grown at 30% and 80% of soil field capacity.

Plant parameters	**Significance**		
	Soil water content	**Planting material**	**Interaction**
Leaf pigments			
Chlorophyll *a*	*	*	*
Chlorophyll *b*	*	*	ns
Carotene	*	*	*
Total chlorophyll (*a*+*b*)	*	*	*
Chlorophyll *a*/*b* ratio	*	*	ns
Anatomy			
Stomatal density	ns	*	ns
Length of guard cell	*	*	ns
Cuticle thickness	*	*	ns
Plant water relations			
Leaf water potential	*	*	ns
Leaf relative water content	*	*	ns
Water use:			
1st month of growth	*	*	*
2nd month of growth	*	*	*
3rd month of growth	*	*	ns
4th month of growth	*	*	*
5th month of growth	*	*	ns
Water use efficiency	*	*	*

ns (not significant); * the main effect or interaction was significant ($p < 0.05$)

5.5.5.1 Leaf pigments

Soil water contents had a significant effect on the pigment contents of the two cultivars, their grafted combinations, and their interactions (Tables 5.5 and A5: 21 –25).

Table 5.6 Effects of soil water contents (30 and 80% of soil field capacity) on the leaf pigment content on the sweet potato cultivars Lole, Wanmun, and their grafted combinations, at 3 months after planting. Number of replicates for each treatment = 6.

	Leaf pigment content (mg / g leaf fresh mass)				
	Chlorophyll *a*	**Chlorophyll *b***	**Chlorophyll *a*/*b* ratio**	**Total chlorophyll (*a* + *b*)**	**Carotene**
Water content					
30% field capacity	1.8b	0.5d	0.4b	2.3b	3.7a
80% field capacity	2.3a	0.7a	0.5a	3.0a	3.5b
Cultivar					
Lole (L)	2.2c	0.6b	0.5c	2.8c	3.8c
Wanmun (W)	1.9d	0.5c	0.4d	2.4d	3.9c
Lole-Wanmun	2.1c	0.6b	0.5c	2.7cd	3.5d
Wanmun-Lole	2.0bc	0.6b	0.5c	2.7cd	3.2e
Interactions					
30% x Lole	1.7	0.4	0.4	2.2	4.1
30% x Wanmun	1.7	0.4	0.4	2.1	3.9
30% x L-W	1.9	0.5	0.4	2.4	3.7
30% x W-L	1.9	0.6	0.4	2.5	3.5
80% x Lole	2.7	0.7	0.6	3.4	3.7
80% x Wanmun	2.2	0.6	0.5	2.8	3.9
80% x L-W	2.3	0.7	0.5	3.0	3.5
80% x W-L	2.2	0.7	0.5	2.8	3.1

Values within a column followed by the same letter symbol are not significantly different ($p < 0.05$). All the interactions of soil water by type of planting material are significant ($p < 0.05$).

In general, the pigment contents (chlorophyll *a*, chlorophyll *b*, total chlorophyll (*a* + *b*), and carotene) declined in the plants grown under water stress. The chlorophyll *a*/*b* ratio, on the other hand, was significantly higher under water stress and varied among the grafted and non-grafted sweet potatoes (Table 5.6). The results are consistent with the previous results that the pigment content declined under water stress (Sections 3.5.4.1, and 4.3.4)**.**

5.5.5.1.1 Chlorophyll a and b

Under well watered conditions, chlorophyll *a* content per unit of leaf fresh mass was significantly higher in both the non-grafted cv Lole and Lole scion grafted onto Wanmun rootstock plants compared with that of cv Wanmun (Table 5.6). Under water stressed conditions, however, both of the grafted plants had greater chlorophyll *a* contents than their non-grafted parents (Table 5.6). Chlorophyll *b* contents were not significantly different between cv Lole and the two grafted combinations, but cv Wanmun leaves, on the other hand, had a significantly lower chlorophyll *b* content than all of the others (Table 5.6).

5.5.5.1.2 Total chlorophyll

Under well watered conditions the total chlorophyll (*a* + *b*) concentration was significantly higher in cv Lole and in the Lole scion grafted onto Wanmun rootstock, but it was higher in both of the grafted plant combinations grown under water stress (Table 5.6).

Chlorophyll plays an important role as a structural component in photosynthesis. High chlorophyll contents indicate better organization of the light harvesting complex in the thylakoid membranes (Dahlin, 1988), and low chlorophyll contents may cause a reduction of light absorption by leaves (Evans, 1996).

5.5.5.1.3 Chlorophyll *a*/*b* ratio

The decrease of chlorophyll concentrations in leaves under water stress was associated with an increase in the chlorophyll *a*/*b* ratio with respect to well-watered sweet potato plants. Under water stressed conditions, cv Wanmun produced the greatest chlorophyll *a*/*b* ratio in its leaves, followed by cv Lole, and the Lole scion grafted onto Wanmun rootstock. The Wanmun scion grafted onto Lole rootstock produced the lowest chlorophyll *a*/*b* ratio, under both the water-stressed and well watered conditions. The chlorophyll *a*/*b* ratio is an index for determining the photosynthetic efficiency in that chlorophyll *a* is present in the reaction centre and chlorophyll *b* is only present in the light-harvesting complex (Nordenkampf and Lechner, 1988). A high chlorophyll *a*/*b* ratio also indicates that the ratio between photosystem I and II contents changes in stressed leaves (Anderson, 1986), and this indicates a poor physiological status of the plants. Alberte and Thornber (1977) found that the ratio of chlorophyll *a*/*b* under water stress increased and reduced photosynthetic unit sizes both in mesophyll and bundle sheath chloroplast of maize (*Zea mays* L.). Water stress also decreased chlorophyll a and b contents but increased chlorophyll *a*/*b* ratio of wheat (*Triticum aestivum* L.) cultivars (Haider and Paul, 2003). Under water stress conditions, cv Wanmun had greatest ratio of chlorophyll *a*/*b* ratio, followed by cv Lole, and then both of the grafted plants.

5.5.5.1.4 Carotene

Under water stressed conditions, the Lole and Wanmun cultivars produced greater carotene contents in their leaves than when grown that under well watered conditions. The Lole cultivar produced greater carotene than cv Wanmun under water stress, and the result was reversed under well watered conditions (Table 5.6).

The role of carotene in photosynthesis is in light harvesting and photoprotection (Hopkins, 1999). Carotenoids absorb and transfer light energy to chlorophyll *a*, and are used in photosynthesis (Devlin and Witham, 1983). It is suggested that, as the water stress was imposed in the present experiment, that the leaf pigment contents including the carotenoids declined, and such a change is usually associated with a decrease in photosynthesis and growth, however the present results showed a greater carotene under water stress conditions.

It is possible that the carotenoid concentration of leaves may increase under water stress to protect the system by minimising photoinhibition, but this was not obvious from the present analysis of the total carotenoid concentrations of sweet potato leaves. An analysis of the pool sizes of the different carotenoids would be needed to verify if the carotenoids are protecting the plants against photoinhibition under water stress.

5.5.5.2 Leaf anatomy

5.5.5.2.1 Stomatal density

Previous results (Section 3.5.4.2) showed that stomatal density was not affected by water stress, but was significantly different between cvv Lole and Wanmun on both the adaxial (upper) and abaxial (lower) leaf surfaces and under both the well-watered and stressed conditions (Fig. 5.10; Tables 5.5 and A5: 26-27). The densities of stomata on the leaves of the grafted plants were similar to those of the parent scion, which was attributed to the maintenance of leaf morphology characters after grafting (Fig. 5.10).

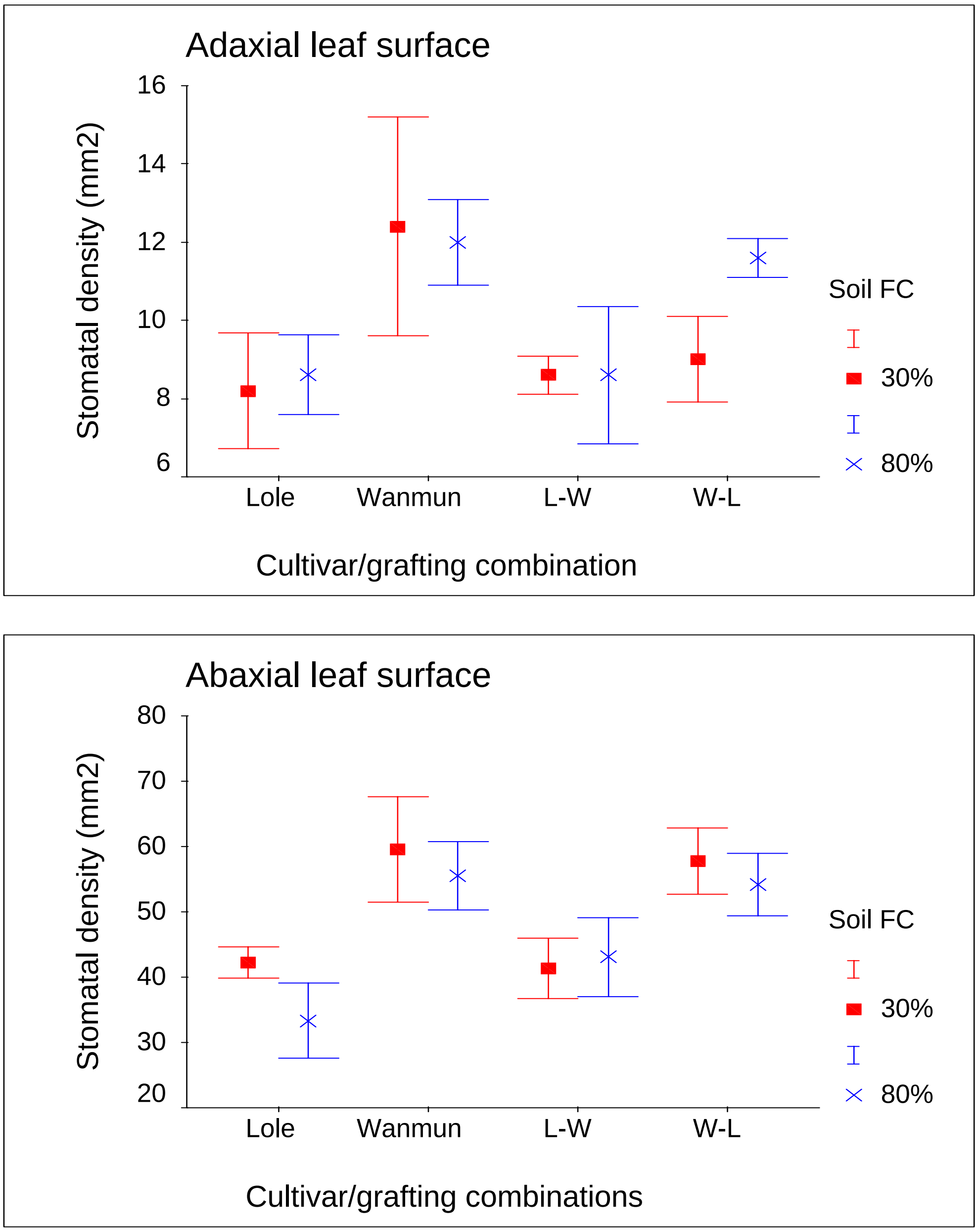


Figure 5.10 Effects of soil water contents (30 and 80% of soil field capacity) on the stomatal density of (a) the adaxial and (b) abaxial leaf surfaces of the sweet potato cultivars (Lole, Wanmun) and grafted cultivars (Lole scion on Wanmun rootstock L-W, and Wanmun scion on Lole rootstock W-L). Number of replicates for each treatment = 10.

5.5.5.2.2 Lengths of guard cells

The lengths of guard cells (the cells that control the functioning of the stomatal pores; Hopkins, 1999) were significantly shortened by soil water stress (Fig. 5.11; Tables 5.5

and A5: 28), but the interactions among the main effects were not statistically significant.

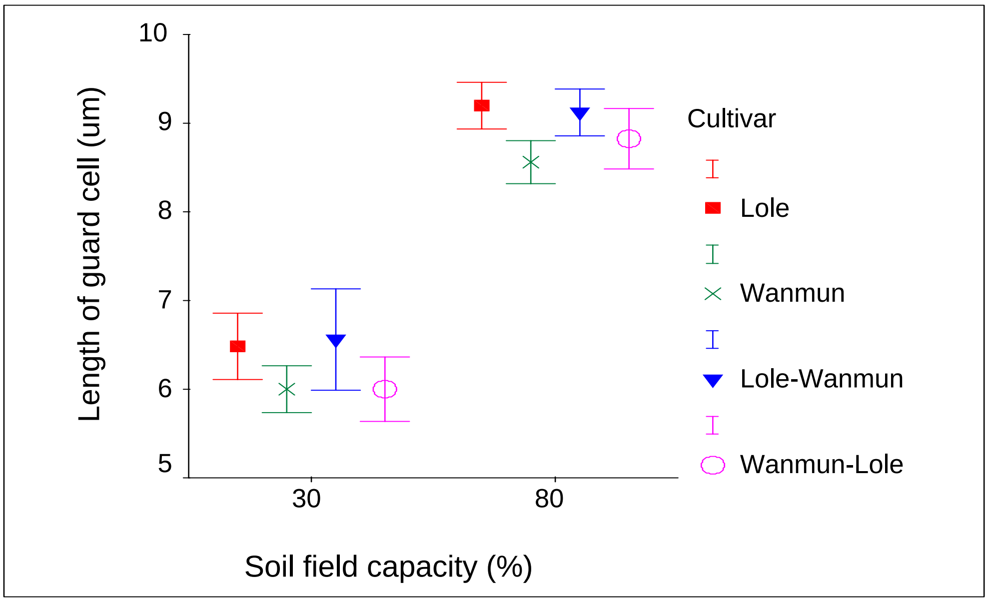


Figure 5.11 Effects of soil water contents (30 and 80% soil field capacity) on the lengths of guard cells of the sweet potato cultivars (Lole, Wanmun) and grafted cultivars (Lole scion on Wanmun rootstock L-W, and Wanmun scion on Lole rootstock W-L). Number of replicates for each treatment = 10.

The opening and closing of the stomatal pores is related to the osmotic pressure of the guard cell contents (Taiz and Zeiger, 2002). More sugar molecules in the guard cell (under well watered conditions), create a greater tendency for water to enter the guard cells. Hence, the longer guard cells produce greater stomatal pore openings, allowing more water to escape from the leaf surface under well watered conditions.

5.5.5.2.3 Cuticular thickness

The cuticle is the outer surface of the leaves of vascular plants, which is covered with a multi-layered wax deposit (Hopkins, 1999) which is part of a plant's defence mechanism to protect it from desiccation (Zobayed *et al*., 2000). While stomata contribute to 90-95% of the water lost from the leaf surface to the atmosphere, transpiration through the cuticle contributes only 5-10%, depending on the cuticle thickness (Hopkins, 1999). Thicker cuticles are characteristic of plants growing in full sun or dry habitat (Hopkins, 1999).

There was no real difference in cuticular thickness between cultivars. It decreased in all of the sweet potato plants studied under water stress (Fig. 5.11; Tables 5.5 and A5: 29). However, the interactions between soil water contents and the grafting treatments were not significant.

Higher stomatal numbers and thinner cuticular wax are important leaf characters thought to be responsible for the high water transpiration rates found in cv Wanmun (Section 3.5.4.2). The smaller leaf areas of cv Lole and of the Lole scion, combined with their thicker cuticular waxes, gave better control of transpiration, hence, reduced water loss and increased drought tolerance.

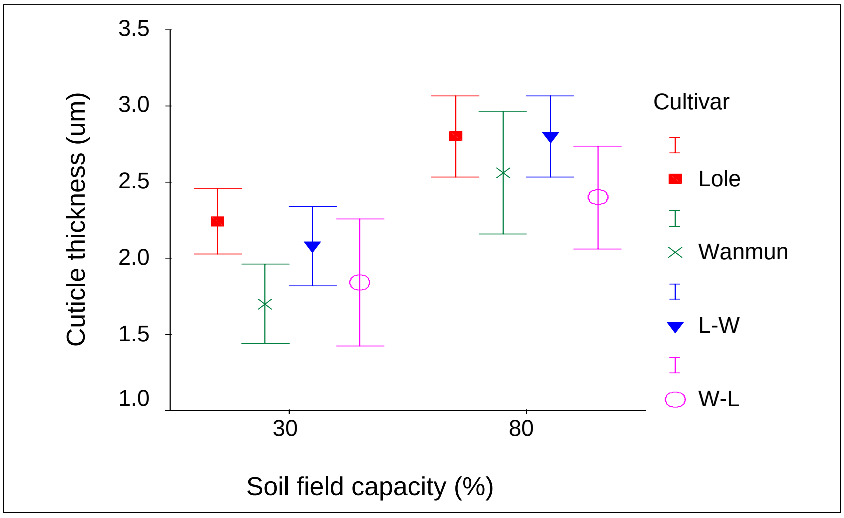


Figure 5.12 The leaf cuticle thickness of Lole, Wanmun, Lole scion grafted onto Wanmun rootstock, and Wanmun scion grafted onto Lole rootstock grown at 30% and 80% soil field capacity.

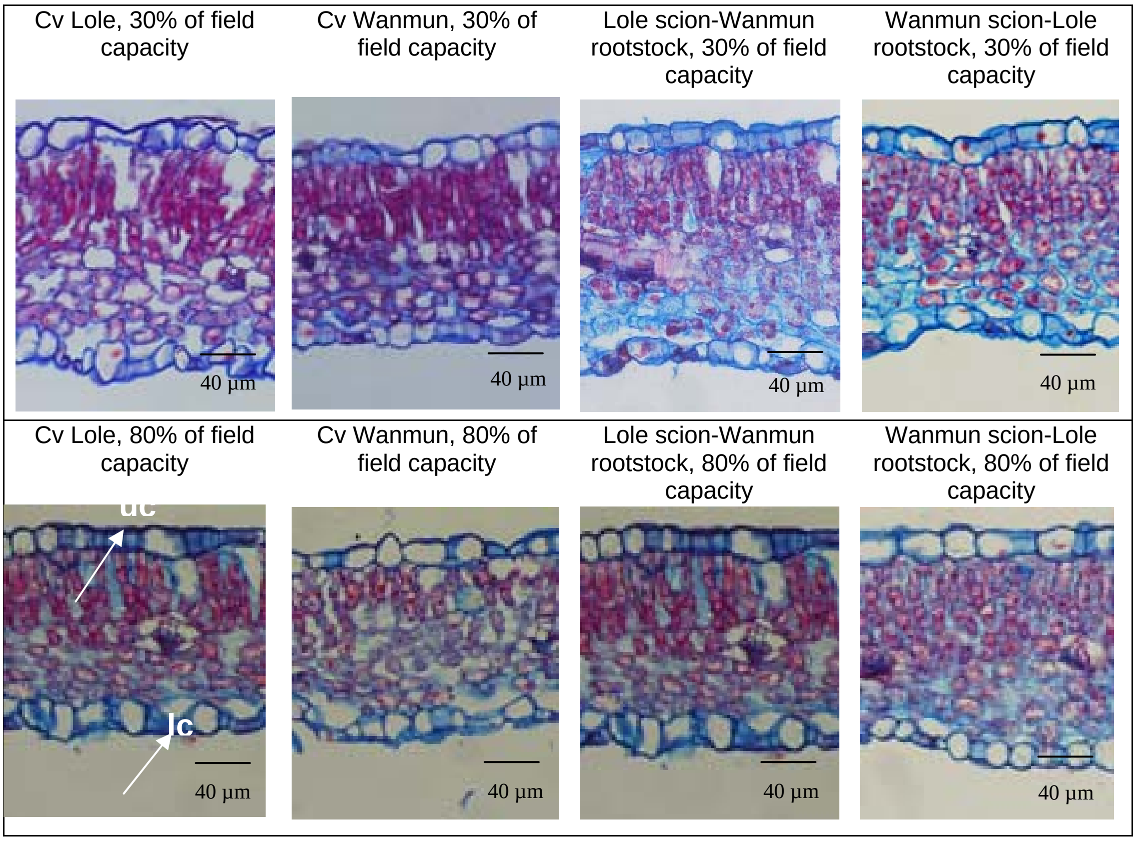


Figure 5.13 The structure of sweet potato leaves in cross-section. leaves of cv Lole (L), cv Wanmun (W), Lole scion grafted onto Wanmun (LW), and Wanmun scion grafted onto Lole root (WL) were grown under 30% and 80% of soil field capacity and sampled 4 months after planting. All of the leaf sections are orientated with their adaxial (upper) leaf surfaces towards the top of the page. The upper and lower cuticular waxes are indicated by arrows.

5.5.6 Plant water relations

5.5.6.1 Leaf water potential

Sweet potato plants subjected to water stress had significantly lower leaf water potential compared to those grown under well watered conditions, but the interactions between soil water contents and the cultivars and their grafting combinations were not significant (Fig. 5.14; Tables 5.5 and A5: 30).

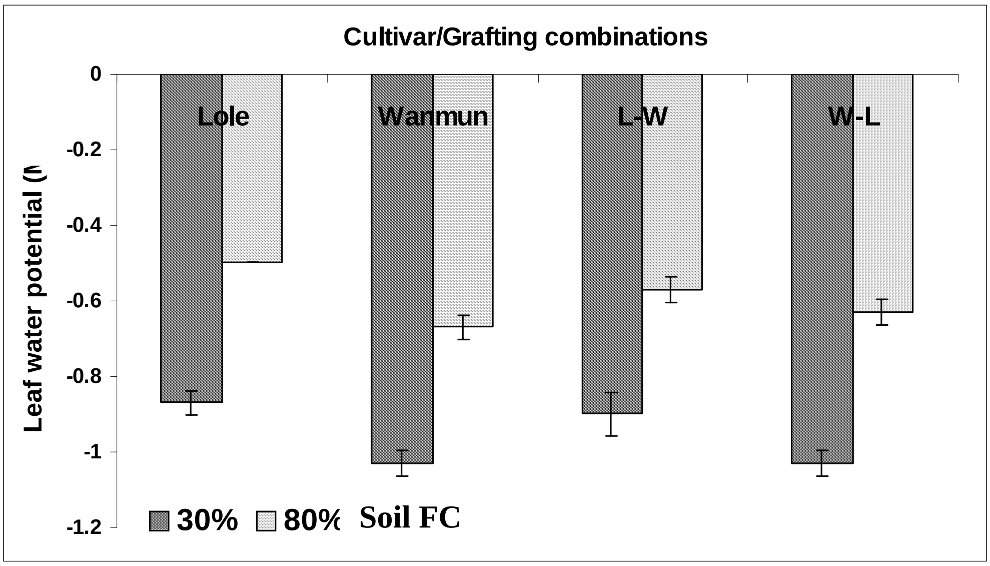


Figure 5.14 Effects of soil water contents (30 and 80% of soil field capacity) on the leaf water potential of the sweet potato cultivars (Lole, Wanmun) and grafted cultivars (Lole scion on Wanmun rootstock L-W, and Wanmun scion on Lole rootstock W-L) at 3 months after planting. Number of replicates for each treatment = 3.

The mean leaf water potential of the grafted and non-grafted plants was –0.59 MPa under well-watered conditions, which was significantly higher than –0.94 MPa in the water stressed plants (Fig. 5.14). It is evident that cv Lole and the Lole scion grafted onto Wanmun rootstock were more efficient than cv Wanmun in maintaining their leaf water potentials. During the day when temperatures and transpiration were high, cv Lole had more turgid leaves demonstrating the capacity of this cultivar to reduce transpiration from the leaf surface. As a result, cv Lole and the Lole scion regulated water use more efficiently, and had a less negative leaf water potential, than did the cv Wanmun and Wanmun scion with large leaf areas and high leaf surface transpiration.

5.5.6.2 Leaf relative water content

Leaf water potential and leaf relative water content are physiological variables, which are commonly used as indicators of plant water status. The ability to maintain leaf water potential and leaf relative water content indicate a strong drought tolerance characteristic that is needed to maintain yields under water stress conditions.

The relative water content of sweet potato leaf tissue grown under well watered conditions was significantly higher than that of all of the plants grown under water stress, but there were no interactions among the main effects (Fig. 5.15; Tables 5.5 and A5: 31).

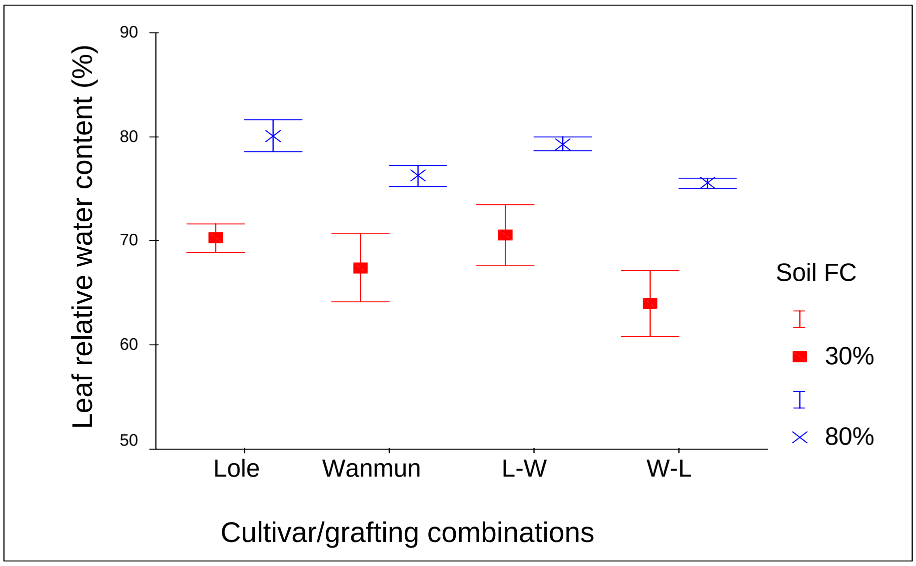


Figure 5.15 Effects of soil water contents (30 and 80% of soil field capacity) on the leaf relative water content of the sweet potato cultivars (Lole, Wanmun) and grafted cultivars (Lole scion on Wanmun rootstock L-W, and Wanmun scion on Lole rootstock W-L) at 3 months after planting. Number of replicates for each treatment = 6.

5.5.6.3 Transpiration

The daily transpiration rate was affected by soil water contents in different cultivars and their grafted combinations throughout the experimental period. Interactions between the two main effects were also significant in the first 2 months after planting (Fig. 5.16; Tables 5.5, A5: 32-36, and A5: 38).

Under well watered conditions, the sweet potato plants transpired an average 476.4 g water/day in the first month of growth, which was more than twice that of the plants under water stress (202.1 g water/day) (Fig. 5.16). At the same time, cv Wanmun and the Wanmun scion had similar transpiration losses that were greater when grown under well watered conditions compared with water stressed conditions (the order of 531 and 217 g water/day, respectively), followed by cv Lole and the Lole scion whose water uses were closely similar under both well watered and water stressed conditions (the order of 474 and 217 g water/day, respectively).

The present experiment has clearly shown that transpiration losses are dependent on signals from the vegetative part of the sweet potato plant, and are independent of a root signal.

Two months after planting, the mean transpiration across all the well watered plants was 62% greater than that of the water stressed plants. The amount of water consumed by the well watered sweet potato plants increased rapidly from the first to the second month after planting, then remained moderately stable (Fig. 5.16); the increased water use was associated with an increase in biomass and initial tuber development.
At 3 months after planting, the sweet potatoes grown under well-watered conditions used an overall mean of 711.4 g of water/day. This was 50% higher than mean mass of water used by the stressed plants (355.3 g water/day). Transpiration in the well watered plants increased dramatically from the initial vegetative growth (1 month after planting) to 3 months after planting as tuber development proceeded.

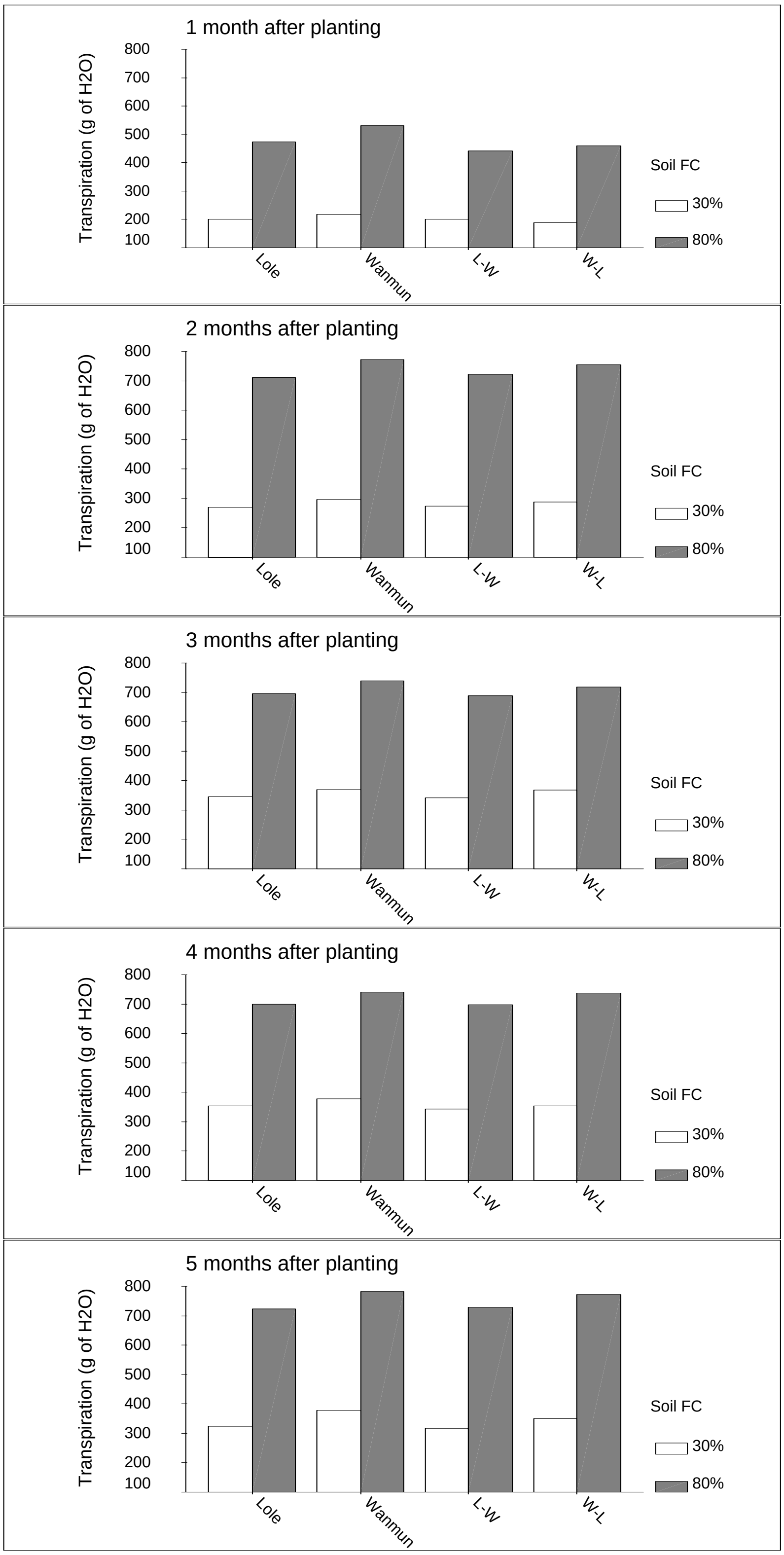


Figure 5.16 The mean rate of daily transpiration of Lole, Wanmun, Lole scion grafted into Wanmun rootstock (L-W), and Wanmun scion grafted onto Lole rootstock (W-L), grown under 30% of soil field capacity and 80% of soil field capacity between 1 month and 5 months after planting.

As the plants approached maturity, their transpiration rates increased slightly and the well-watered plants attained their maximum dry matter production levels; the greater transpiration rates may also have been partly in response to an increase in temperature and a decrease in relative humidity during the experimental period (Figs 5.2 and 5.3). The water lost by the other plants during the reproductive stage is attributed to the decreasing shoot growth and leaf area due to senescence at crop maturity.

Under a good water supply, total dry matter production in the leaves is thought to be related to the proportion of dry matter diverted into tubers (Kuo and Chen, 1992). An efficient transpiration capacity in the leaves combined with a good tuber yield capacity in the sink was expected in cv Wanmun which extracted more water from the soil due to its high water demand for growth and transpiration. As a result, however, tuber production was severely restricted when the water supply was reduced.

Grafting of Lole scions onto Wanmun rootstocks produced a plant that transpired efficiently through the leaves of the Lole scion, and its Wanmun rootstock produced acceptable tuber yields. This grafting combination of sweet potato cultivars shows very promising results: it produced a drought tolerant plant that can still produce satisfactory tuber yields under dry conditions.

5.5.6.4 Water-use efficiency

Water-use efficiency was significantly influenced by the differences in soil water contents on the growth of both the non-grafted and grafted sweet potato plants; interaction effects were also significant (Tables 5.6, A5: 37 - 38). Water use efficiency in plants grown under water stress was ranked in the following decreasing order: Lole scion grafted onto Wanmun rootstock (3.9 g total plant dry mass/kg of water), followed by non-grafted cv Lole (3.7 g/kg water), non-grafted cv Wanmun (3.6 g/kg water), and the Wanmun scion (2.6 g/kg water). Under well-watered conditions, the plants were ranked in water-use efficiency as follows: cv Wanmun (3.5 g/kg of water), followed by cv Lole (3.2 g/kg of water), the Lole scion on Wanmun rootstock (3.0 g/kg of water), and the Wanmun scion on Lole rootstock (2.7 g/kg of water). These results are comparable those with Taufatofua (1994) who recorded that an average water use efficiency of 3 - 4 g/kg for other well watered sweet potato cultivars.

The Wanmun cultivar consumed the greatest amount of water for its growth and development as a consequence of its high biomass production and heavy tuber yields. Crop growth rates were the highest in the early vegetative stage 1 - 2 months after planting, when the plants consumed water most rapidly (Fig. 5.16). Therefore, water stress during this stage is highly detrimental to the sweet potato growth and tuber development. Taufatofua (1994) also found that the effects of water stress were most severe in young plants, and reduced tuber yields more severely in the crops subjected to water stress later in their growth cycle.

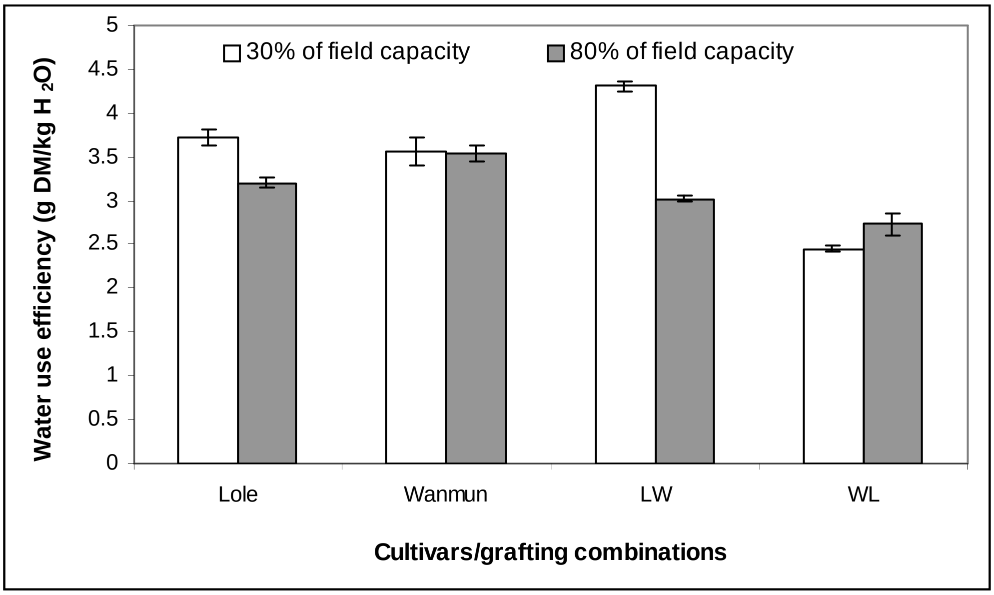


Figure 5.17 Water use efficiency of Lole and Wanmun cultivars, Lole scion grafted onto Wanmun rootstock (L-W), and Wanmun scion grafted onto Lole rootstock (W-L), grown under 30% and 80% of soil field capacity.

5.6 CONCLUSIONS

The application of a severe water stress by reducing the water availability to 30% of soil field capacity, decreased the overall growth and physiological functioning of the non-grafted and grafted sweet potato plants of the present study. Despite producing greater biomass, the shoot mass of the non-grafted cv Wanmun and of the Wanmun scion grafted onto Lole rootstock showed more severe decline under water stress than did that of the non-grafted cv Lole and the Lole scion grafted onto Wanmun rootstock. The reduction of shoot mass under water stress was associated with several factors. First, soil water stress reduced the internal plant water status, which was expressed by decreased leaf water potential, lower leaf relative water content, and reduced leaf pigment content. Second, as a consequence of insufficient water available to plant cells, the leaf mass and leaf area were reduced and this affected the whole biomass gain through reduced radiation interception.

Water stress affected the development of leaf area and mass. Among the planting materials studied, the non-grafted cv Wanmun and Wanmun scion grafted onto Lole rootstock produced the greatest leaf areas and masses, and the highest water transpiration losses, under both soil water regimes, and these growth parameters declined under water stress.

Specific leaf weight was greater in the non-grafted sweet potato cultivars (cv Lole greater than cv Wanmun) under well watered conditions. Under water stress, however, the Lole scion grafted onto Wanmun rootstock had greatest specific leaf weight, while the other plants showed no statistically significant difference from the corresponding values for the well watered plants. This result implies that greater specific leaf weights of cv Lole and the Lole scion are associated with more efficient use of water.

Root masses declined under water stress, and the greatest declines were in cv Lole and in the Wanmun scion grafted onto Lole rootstock, both of which were characterised by abundant fibrous roots. The less fibrous roots of cv Wanmun and of the Lole scion grafted onto Wanmun rootstock favoured heavier tuber yields. The Wanmun cultivar produced the greatest tuber masses under well watered conditions. Under water stress, however, the Lole scion grafted onto Wanmun rootstock produced the greatest tuber mass. This implies that scion and rootstock controlled different aspects of the growth and development of vegetative and reproductive parts of the grafted plants.

The Wanmun cultivar showed poor compatibility when grafted as a scion onto Lole rootstock and produced very few tubers compared with all of the other planting materials, although cv Lole produced the largest number of tubers, but of relatively small size, under well watered conditions. Under water stress, however, the number of tubers declined in all the plants, particularly in cv Lole, but brought about a parallel increase in average tuber mass.

The Lole scion grafted onto Wanmun rootstock produced the greatest harvest index. This implies that the ability of plants to develop storage roots was determined by an efficient top growth (leaves and stems) and a strong sink capacity in an effective root system.

The content of pigments in the sweet potato plants (chlorophyll *a*, *b*, total chlorophyll, carotene concentrations) all diminished under water stress, while the chlorophyll *a*/*b* ratio increased, which implied that physiological functions were affected by the imposed stress. Both grafted sweet potato plants produced only slightly lower chlorophyll *a*/*b* ratios in both soil water regimes than did the non-grafted plants, indicating a similarity of physiological function between the vegetative parts of the grafted and non-grafted plants.

Stomatal density was not affected by water stress. However cv Lole, and the Lole scion grafted onto Wanmun rootstock had lower stomatal densities in comparison to the non-grafted Wanmun cultivar and the Wanmun scion grafted onto Lole rootstock. This suggests that cv Lole and the Lole scion had a mechanism to regulate the efflux of water efficiently from the leaf surface of the sweet potato. The stomatal guard cells were longer and the leaf cuticle waxes were thicker in all of the plants grown under well watered compared with water stress conditions.

An important finding presented in this chapter is that grafting did not change the characteristics of the vegetative parts of the cultivars, nor the functioning of the sink in the storage root. A strong sink was shown to improve tuber yield, and plant shoots that conserved plant moisture, combined by grafting with a strong sink, produced good tuber yields under water stress conditions.

The results show that the leaves of the Lole and Wanmun cultivars varied in their morphologies and structural anatomies. The leaves of the grafted plants had similar characters to those of the parent of the scion. The characteristically small leaves of cv Lole and the Lole scion reduced water loss at the whole-plant level; their anatomical features (lower stomatal density and thicker cuticle wax) helped to reduce leaf transpiration and thus improved crop water-use efficiency in comparison to the cv Wanmun and the Wanmun scion grafted onto Lole rootstock.

Leaf water potential and relative water content declined under water stress in all of the studied plants. The non-grafted Wanmun cultivar and Wanmun scion grafted onto Lole rootstock had strongly negative leaf water potential, a lower percentage of relative water content, and high transpiration, all of which are associated with greater water losses and lower water-use efficiency as a consequence of larger leaf areas and related anatomical features.

Water use increased rapidly during the early stages of vegetative growth but became constant towards plant maturity. As the consequence of biomass reduction at maturity, water use by all of the studied plants was lower during the entire growth period under water stress.

Under water stress, the Lole cultivar and the Lole scion grafted onto Wanmun rootstock had high water-use efficiencies. On the other hand, the Wanmun cultivar had the greatest water-use efficiency under well watered conditions. The results suggest that the ability of plants to develop storage roots under water stress was determined by an efficient transpiration capacity in the source (leaves) and a strong sink capacity in the roots.

In general, the ability of sweet potato genotypes to partition carbon into the tubers is important in determining storage root yields. Likewise, selection for greater leaf transpiration efficiency is a useful criterion in coping with water deficit problems. Therefore, combining the cultivar traits by grafting an efficient leaf transpiring organ onto a strong potential sink (such as a cv Lole scion grafted onto a cv Wanmun rootstock) resulted in a greater harvest index and increased water-use efficiency.

In searching for sweet potato varieties with drought tolerance characters and desirable yields, the present study has shown that grafting between two cultivars with compatible scions and rootstocks is possible. The compatibility of the grafted combination between a Lole scion grafted and a Wanmun rootstock fulfils the criterion for a drought tolerant strategy and good storage root yields under water stress conditions. The ability of this grafted combination to produce high tuber yields was associated with low rate of transpiration and high water-use efficiency. In addition, compatibility and good alignment across the grafted union provided ready movement of assimilates from leaves, and easy transport of water and inorganic substances from roots.

Grafting of appropriate sweet potato materials allows the option of new farming systems to be developed so that the indigenous people of drought-prone environments, where sweet potato is the staple diet, can use the benefits to flow from the results of the present study. As a first step in that direction, it is proposed that indigenous gardeners be encouraged propagate at least three different kinds of sweet potato planting materials:

- cv Wanmun for high yields under good rainfall;
- cv Lole for subsistence yields to ensure survival of human communities under severe drought conditions;
- cv Lole scions grafted onto cv Wanmun rootstocks (or other combinations of drought tolerant sweet potato varieties grafted as scions onto varieties with good storage root sink capacity as rootstocks) for improved tuber yields under water stress conditions.

CHAPTER 6

SWEET POTATO CULTIVATION IN PAPUA: POTENTIAL FOR DEVELOPMENT

6.1 INTRODUCTION

Papua is the most eastern of the Indonesian provinces and borders on Papua New Guinea. Indigenous people of the highlands of Papua depend to a great extent on sweet potato as their main carbohydrate source and it accounts for nearly 100% of their staple diet. The crop is also the main feed for pigs which are a vital part of the culture and ritual dimensions in many Papuan ethnic groups. Even though sweet potato is grown under a wide range of environments, both genetic and environmental factors determine sweet potato growth and yields.

Regular droughts are the biggest problem threatening sweet potato growth and the lives of highland people in Papua where death from starvation is still a real and present threat. Government sources indicated 38 – 40 people died as a result of the 1997 – 1998 drought (Cenderawasih Pos, 1998), but this may be an underestimation. Urgent appeals are frequently made to government and non-government agencies to help sustain the local people, particularly through the supply of sweet potato planting materials which maximize the production of preferred food supplies.

As sweet potato constitutes the major part of the daily diet, characterization of the texture, size, yield, and taste of sweet potato tubers is common among the indigenous Papuans. The large, sweet tubers with high dry matter content are preferred for human consumption and cultivars with high starch content and sweet taste are reserved for ritual and ceremonial use. Cultivars with big, fibrous roots and small and damaged tubers are used as pig food, and are eaten by humans only during times of food shortage (Peters, 2001).

In the highlands of Papua, sweet potato consumption has been estimated at 3 kg per capita per day, or 13 kg per day for the average family (Soenarto, 1987). Each harvest is targeted on the family size and the number of pigs to be fed (10-15 kg will feed a family of three adults, three children and two big pigs; Peters, 2001). However, the average production of sweet potato in highland Papua is low (4 to 10 t/ha) compared to that of 19, 21, and 24 t/ha in China, Japan, and South Korea, respectively. Among the factors that contribute to the lower sweet potato yield is drought which devastates sweet potato plants regularly.

6.2 SWEET POTATO GENETIC RESOURCES

Cultivar Lole, which is characterized by a small leaf area, showed more drought tolerance than the other 15 cultivars tested in the present study; it grew well under low soil moisture contents (Section 2.3.2). Under water stress conditions, cv Lole had the greatest ability to maintain plant water status as shown by high transpiration efficiencies, high leaf water potential, long periods to reach permanent wilting point, and low percentage of growth reduction (Section 2.3.2.1 and 2.3.2.4). The Lole cultivar had high leaf pigment contents, low stomatal density, and thick cuticular wax (Sections 3.5.4.1; 3.5.4.2 and 5.5.5.2.3). Such plant characteristics are usually associated with effective control of transpiration, which reduces water loss and thereby give the plant a greater relative tolerance to water stress, more vigorous growth, and higher productivity when grown under water stress conditions (Parimelazhagan and Francis, 1996). The tuber yield and average tuber size of cv Lole was greater than those of cv Wanmun when the cultivars were grown under 40% of field capacity. In terms of tuber size, cv Lole grown under water stress conditions produced tubers that met the market quality size (average 247.5 g/tuber) which was comparable with those of cv Wanmun grown under well watered conditions (average 243.8 g/tuber; Section 3.5.5). However, cv Lole produced lower tuber yields than cv Wanmun under well watered conditions. The tuber yield of Lole cultivar responded well to nitrogen fertilizer up to 100 kg/ha (Section 4.3.3.2). Under low soil nitrogen conditions, plants were stunted, leaf growth was inhibited, and the leaves and stems showed chlorosis, which indicates chlorophyll damage and impaired photosynthesis (Section 4.3.2). A greater potassium supply not only promoted tuber yield (Section 4.3.3.2), but it also enhanced water use efficiency (Section 4.3.5.2). Therefore, any nitrogenous fertilizer should be applied to cv Lole in association with potassium inputs.

The Wanmun cultivar was classified as a drought susceptible cultivar (Section 2.3.2.1 and 2.3.2.4). In contrast with cv Lole, cv Wanmun produced high yields of large sweet potato tubers under well watered conditions (1228.5 g per plant), but lower masses of edible tubers under water stress conditions (Section 3.5.5.1). Greater leaf photosynthetic capacity in cv Wanmun required a high water demand for growth and transpiration (Section 3.5.3.1). Its growth and the physiological aspects including pigment concentrations, leaf water potential, and relative water content decreased as growth progressed, and their decline was greater in cv Wanmun than in cv Lole (Section 3.5.3 and 3.5.4). Therefore, tuber yield production was severely affected and declined when the water supply was restricted in cv Wanmun (Section 3.5.5).

The Lole cultivar produced significantly greater tuber sucrose content than that of cv Wanmun, and it was also greater when cv Lole was grown under restricted soil water conditions (Section 3.5.4.3). The Wanmun cultivar, on the other hand, produced greater starch content than did cv Lole (Section 3.5.4.3). Greater sucrose content gives the tubers a sweeter taste which is generally demanded by the native Papuans, while greater starch content may favour the starch production industry and pig feeding. However, the preferences of the sucrose and starch contents of sweet potato tubers may vary from region to region (Widyastuti, 1995). In the valleys of highland Papua, the people favor sweet potatoes with a soft texture and a rather high water content, whereas at higher altitudes, red-purple, elongated tubers like those of cv Lole are preferred for their taste and their greater concentration of anthocyanins. People in this area believe that such tubers provide protective mechanisms against disease, infection, and adverse conditions (Widyastuti, 1995).

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The Lole scion grafted onto Wanmun rootstock produced the greatest harvest index and tuber mass under water stress. The tuber yield of the Lole scion grafted onto the Wanmun rootstock was slightly better than the yield of cv Lole and cv Wanmun under water stress but was still lower than that of the well watered ungrafted cv Wanmun plants. Under water stressed conditions, however, the Lole scion grafted onto Wanmun rootstock, and the ungrafted cv Lole plants, produced the greatest tuber size (139 g/tuber and 129 g/tuber, respectively; Section 5.5.4). This suggests that the scion and rootstock regulated different aspects of vegetative and reproductive growth of the grafted plants including the growth of storage roots which was determined by an efficient top growth and a strong sink capacity.

There are approximately 5000 sweet potato cultivars grown in Papua (Yen, 1974). Of these, the International Potato Centre in cooperation with the Root Crops and Tuber Research Centre of Papua State University, Manokwari, collected 827 cultivars from *in situ* and *ex situ* conservation sites in the Papua highlands during the period from 1993 to 1997. The fewer numbers compared to the previous estimate of Yen (1974) is thought to be due to natural calamities such as drought, frost, and flooding during the more recent collection period. The Indonesian government, through the Department of National Education, Jakarta, and the Department of Agriculture, Papua Province, has recently provided funding for a follow-up project to the work presented in this thesis using local sweet potato cultivars. This research is about to start using 10 prominent cultivars (9 local Papuan cultivars of sweet potato obtained from the *ex situ* collection and 1 [Ciceh] cultivar introduced from Bogor) which are morphologically similar to either cv Lole in relation to smaller leaf area as an indicator drought tolerance as a result of low evapotranspiration, or cv Wanmun for their high tuber yielding and eating quality (Tables 6.1 and 6.2). The trial will screen the cultivars for drought tolerance or susceptibility, and will help to identify local cultivars that may be used in future grafting trials.

Table 6.1 The sweet potato cultivars selected with similar morphological characteristics to those of cv Lole (deeply lobed, almost divided leaves, high tuber numbers under water stress conditions) for drought tolerance screening trials.

No.	Name of cultivar	Morphological characters
1	Ciceh	Triangular and deep lobed leaves, medium leaf area, long vines, purple storage roots, sweet, watery, low yielding cultivar (11.3 t/ha).
2	Miencon	Triangular, lobed leaves, low leaf area, yellow storage roots, medium yielding cultivar (14 t/ha).
3	Tinta	Semi elliptic, triangular and lobed leaves, medium leaf area, light purple storage roots, good taste, low yielding cultivar (8 t/ha).
4	Wenda	Lobed leave, lanceolate, lower leaf area, long vines, white storage roots, slightly watery, less sweet, no yield record.
5	Bonsari	Deep lobed leaf, lanceolate, small leaf, low leaf area, long vines, yellow storage soot flesh, watery, no yield record.

Table 6.2 The sweet potato cultivars which similar morphological characteristics to those of cv Wanmun (high tuber yields under well watered condition) for drought tolerance screening trials.

No.	Name of cultivar	Morphological characters
1	Worembay	Cordate, higher leaf area, long vines, purple storage roots, delicious taste, favoured by people, high yielding cultivar (22 t/ha).
2	Sanday	Cordate, low leaf area, short vines, purple storage roots, delicious taste, medium yielding cultivar (15 t/ha).
3	Halaleke	Cordate, long vines, higher leaf area, yellow storage roots, good taste but slightly watery, good yield potency.
4	Kuyake-1	Cordate leaf, long vines, higher leaf area, yellow storage roots, slight watery, less sweet, no yield record.
5	Paniai	Triangular, lobed leaf, long vines, medium leaf area, red storage root skin, yellow flesh, good taste, no yield record.

6.3 POSSIBLE GRAFTING COMBINATIONS

Desirable characters of the root and vegetative parts of different plants can be combined by grafting to produce plants that embody cv Lole's tolerance to drought and cv Wanmun's high tuber yields (Section 5.5.2).

Therefore, it is likely that a similar result will be achieved when scions of local Papuan cultivars (providing a water use efficient source such as those of cv Lole scions) are grafted onto local rootstocks with a strong sink capacity (i.e. those similar to cv Wanmun rootstocks). Such grafted combinations are expected to produce water use efficient plants with high yield under water stress conditions.

6.4 IMPROVEMENTS TO LOCAL SWEET POTATO CULTIVATION SYSTEMS

6.4.1 Use of local soil amendments

Most of the highland Papuan soils have developed from limestone and are low in nutrients, particularly nitrogen and potassium, but are rich in phosphorus (Schroo, 1963 in Sunarto and Rumawas, 1997). On the other hand, sweet potato requires nitrogen and potassium to promote the vegetative growth and to increase tuber yields, respectively (Sections 4.3.2 and 4.3.3). An excess of soil nitrogen should be avoided as this may result in excessive top growth and depress tuber yields. Potassium additions are known to increase water use efficiency in sweet potato (Section 4.3.5.2). For areas that regularly experience droughts such the highlands of Papua, potassium fertilization will not only contribute to elevated tuber yields, but also will help the plants cope better with drought conditions. However, the introduction of chemical fertilizer is not feasible, as there is no transport infrastructure connecting the remotes areas, and using inorganic chemical fertilizers is very expensive in this region; if not used correctly, fertilizers damage the environment.

In the highlands of Papua, pig and chicken manure are available as organic inputs for sweet potato cultivation, but are not currently used. Tree legume mulch could also be applied as source of nitrogen. To increase the amount of potassium in the soils of sweet potato gardens, ash from firewood used by the local Papuans after cooking, can be spread on the tops of raised beds. Wood ashes are rich in potassium (Soenarto and Rumawas 1997) which can increase soil water retention (Section 4.3.5.2). These local resources are widely available, and the indigenous people could benefit if they were to begin to use such agronomic practices. At present, however, there is a culture of keeping sweet potato gardens free of mulch, and this will need to be addressed through an active extension programs.

The most common practice used by the indigenous Papuans to produce sweet potatoes is shifting cultivation, which has been practiced from generation to generation both on hill slopes and on flat areas. This system has evolved in response to low soil fertility by rotating the cultivation areas over a 10 – 15 annual cycle until the first area has regenerated and is ready to be re-cultivated. However, population growth has resulted in a significant agricultural intensification - a trend which will continue in the foreseeable future. As a consequence of more intense land use, soil nutrient contents may diminish faster due to removal of cultivated crops and may result in soil nutrient deficiencies. Nutrient replenishment by addition of soil amendments using available local resources such as animal manures or tree mulches (source of nitrogen) and wood ashes (source of K) to help alleviate this problem is recommended.

6.4.2 Use of better adapted cultivars

Sweet potato cultivation systems can also be improved through the introduction of cultivars that are better adapted to ranges of various environmental constrain. For instance, during dry periods, it is recommended that farmers cultivate drought tolerant local cultivars and/or grafted combinations using cultivars similar to the cv Lole as the scion on the rootstock of cultivars similar to cv Wanmun.

6.4.3 Other agronomic practices

Mounds will dry out quicker than flat garden beds, so the use of mounds should be avoided for growing sweet potatoes during dry conditions. Low water tables do not favor the roots of sweet potato plants extracting water from deeper soil layers when grown in a mounded system.

Mulch and wood ash are good practices for sweet potato production as these techniques are expected to reduce evaporation and conserve soil water under unfavorable dry conditions. They may also keep the soil warmer during the times when frosts occur in the higher altitudes of the highlands.

To avoid the complete failure of sweet potato production under extremely dry conditions, some of the land that lies adjacent to water courses, and in the vicinity swampy areas, can be used for sweet potato gardens.

The adoption of these methods separately or in combination may add greatly to the knowledge of sustainability of sweet potato production and may reduce malnutrition problems, and perhaps even eliminate deaths by starvation, that still occur regularly as a consequence of droughts in the Papuan highlands.

CHAPTER 7

GENERAL CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

7.1 GENERAL CONCLUSIONS

The overall results of the present study of sweet potato cultivars are summarised in the following conclusions:

- Water stress significantly reduced plant growth. Stem length, internode length, stem, diameter, plant biomass, leaf area, and root mass all declined in plants grown under water stressed conditions. The extent of the reduction in plant growth varied with cultivars (Section 2.3.2). Some cultivars including Lole and Hawaii were less affected, as indicated by a lower percentage of biomass reduction under water stress (Section 2.3.2).

- Under water stress, the Lole and Hawaii cultivars were able to delay wilting and had greater leaf water potentials, and thereby preserved their plant water status. They also transpired lower amounts of water than the other cultivars indicating their adaptation to dry conditions (Section 2.3.2).

- When grown under non-limiting water conditions in the field, the Beerwah Gold, LO323, NG7570, Wanmun, Mariken, L46, L135, L3, and L49 cultivars produced significantly higher tuber yields than the other cultivars. The lowest tuber yields were from the Lole, Hawaii, Markham, L18, and L11 cultivars (Section 2.3.3). This suggests that drought tolerant sweet potato cultivars tend to produce lower tuber yields, and the higher yielding cultivars are more sensitive to drought conditions.

- The plant vegetative components and tuber yields of the Lole and Wanmun cultivars declined when the soil water levels were reduced from 80% to 40% or 20% of soil field capacity (Sections 3.5.2 and 3.5.5). The Wanmun cultivar produced the highest plant mass and tuber yield under 80% of soil field capacity. On the other hand, cv Lole grown at 40% of soil field capacity produced comparable average tuber sizes as those of the Wanmun cultivar grown at 80% of soil field capacity. This suggests that 40% of soil field capacity was not below the critical soil moisture content for the development of tubers in cv Lole. Despite cv Wanmun producing greater shoot mass, cv Lole produced the greatest dry mass of long, fibrous roots. An abundance of fibrous roots that can penetrate deeply into the soil has been reported by several authors to be associated with mechanisms for drought adaptation under field conditions (Prakash, 1994; and Lin *et al*., 1996), while greater leaf area, higher stomatal densities, and thinner leaf cuticles in cv Wanmun are consistent with its high leaf transpiration rates and low drought tolerance (Sections 3.5.3 and 3.5.4).

- The plant water status of the Lole and Wanmun cultivars was affected by reducing the soil water content. Leaf water potentials and leaf relative water contents declined under increasing water stress, especially when transpiration was high at midday, and was greater in cv Wanmun than in cv Lole (Section 3.5.3). When water stressed, these cultivars transpired less water compared with corresponding well watered plants, and cv Lole transpired less than cv Wanmun. The grafted plants followed a similar pattern to that of the parent plants of the scions (Section 3.5.3). As a result, cv Lole and the Lole scion grafted onto Wanmun rootstock were able to conserve and utilize water efficiently under both well watered and water stressed conditions.

- Water stress caused a significant reduction in the concentration of leaf pigments which varied with cultivars; cv Lole had greater leaf pigment concentration than cv Wanmun under both well watered or water stressed conditions (Section 3.5.4). The higher pigment concentration is associated with increased vigour and productivity and suggest a higher relative tolerance to water stress. The chlorophyll *a*/*b* ratio increased in both cultivars grown under water stress conditions, and cv Wanmun had a higher ratio than cv Lole and the combinations of grafted plants, indicating relatively poor drought tolerance of the cultivar (Section 5.5.5).

- Stomatal density was not affected by water stress in any of the sweet potato planting materials used in the present study (Sections 3.5.4 and 5.5.5). The Wanmun cultivar leaves carried a greater stomata density than the cv Lole leaves, and the lengths of its guard cells and the thickness of the cv Wanmun leaf cuticles were greater under well-watered conditions. The non-grafted cv Lole and the Lole scions grafted onto Wanmun rootstocks had smaller leaf areas, fewer stomata, and slightly thicker leaf cuticles than the cv Wanmun and the Wanmun scions grafted onto Lole rootstocks (Sections 5.5.3 and 5.5.5). This shows that the anatomical features of the grafted plants were similar to those of the parent plants of the scions. In all cases the grafted plants had similar transpiration patterns and water-use efficiencies as the parent plants of the scions.

- The sweet potato cultivars grown under non-limiting water conditions produced lower sucrose and greater starch contents than those grown under water stressed conditions. The tubers of cv Lole had significantly higher sucrose and lower starch contents at harvest compared with those of cv Wanmun (Section 3.5.4). These factors play a major role in determining the food preferences of the indigenous Papuans.

- Tuber yields decreased when the soil water content was reduced, and the Wanmun cultivar was more affected than cv Lole (Section 3.5.5). On the other hand, the number of tubers was not affected by water stress in cv Wanmun. The Lole cultivar grown under non-limiting water conditions produced a significantly higher number of tubers, but their sizes were significantly smaller than those of the same cultivar grown under water stresses at 20% and 40% of soil field capacity. In terms of marketable tubers, the Lole cultivar grown at 40% of soil field capacity produced comparable tuber quality and sizes to those of cv Wanmun grown under non-limiting water conditions.

- The Lole cultivar yielded lower tuber masses per plant than those of cv Wanmun. This suggests that tuber yield depends greatly not only on soil water contents, but also on the cultivar (Sections 2.3.3.1 and 3.5.5).

- In a grafting trial, cv Lole scions grafted onto Wanmun rootstocks produced the greatest tuber mass compared with those produced by from non-grafted cv Lole and cv Wanmun plants under water stress conditions (Section 5.5.4). On the other hand, cv Wanmun scions were incompatible when grafted onto Lole rootstocks and produced relatively few tubers. It can be concluded that the scion controlled the growth and development of vegetative plant parts, and the rootstock controls the functioning of the tubers as storage organs.

- Plants consisting of Lole scions grafted onto Wanmun rootstocks produced the highest harvest index, showing that the ability of plants to develop storage roots was determined by efficient top growth (leaves and stems) and root growth, and also by a strong sink capacity in the root (tubers).

- Water use increased rapidly during vegetative growth of all of the sweet potato planting materials studied, but stabilized toward maturity (Section 3.5.3). As a consequence of reduced biomass production under water stress, water use by the non-grafted and grafted plants was lower during the entire growth stage when the water supply was limited to 30% of soil field capacity. The non-grafted cv Wanmun and the Wanmun scions grafted onto Lole rootstocks used relatively large amounts of water as a consequence of abundant, actively transpiring leaf surfaces (Section 5.5.6).

- Low soil nitrogen and potassium supplies led to decreased plant growth and yield, and thereby reduced the water-use efficiency of all of the planting materials studied (Sections 4.3.2; 4.3.3 and 4.3.5). The significantly greater water-use efficiency under water stress in cv Lole and Lole scions grafted onto Wanmun rootstocks was attributed to low transpiration rates as a result of small leaf surface areas, few stomata, and thick leaf cuticles in these plants (Sections 4.3.2 and 4.3.5 and 5.5.5).

- Nitrogen and potassium inputs of 100 kg/ha and 160 kg/ha, respectively, were found to be optimal for tuber yields of sweet potato cultivars grown under both well watered and water stressed conditions (Section 4.3.3). A greater nitrogen supply resulted in increasing the vegetative plant parts and reducing tuber yields. A lack of nitrogen resulted in low chlorophyll synthesis that affected overall photosynthesis and plant metabolism processes and became evident in stunted growth and reduced tuber yields. Increasing the potassium supply increased tuber yields but not the vegetative plant parts when the nitrogen supply was optimal.

7.2 FUTURE RESEARCH DIRECTIONS

The present study has produced useful information in relation to the effects of drought on water relations of a range of sweet potato cultivars. The data have helped to develop new understandings of some of the physiological mechanisms that underpin drought tolerance and drought susceptibility in sweet potato. The interactions between genotype and environmental constraints, including drought, require further study to produce the best-adapted cultivars with high tuber yield potentials and suited to different local conditions.

There are several projects that may be addressed in the future:

- Different agro-ecological conditions may produce different growth responses in the cultivars studied in the present project. Therefore, the principles of the present project should be applied in local environments with local cultivars. In order to adopt the present research technology, simple techniques should be introduced to meet local needs in areas of subsistence agriculture.

- In dealing with intermittent drought conditions, selection for genotypes that have greater transpiration efficiency and high tuber yields may be a useful approach in sweet potato breeding programs. However, the performance of a wide range of genotypes should be studied under different growing conditions throughout the year. Research institutions, scientists, extension officers, and local farmers should work cooperatively in order to manage existing cultivars better, and to ensure successful outcomes from field-based projects.

- Some of the more detailed physiological aspects of sucrose and starch production by sweet potatoes could not be answered by the present project and might be a priority for future projects. For example, the sucrose content of tubers of drought resistant cultivars increased under water stress conditions (Section 3.5.4). It has been reported by Premachandra *et al*. (1992) that an increase in solutes in the plant cell sap, including sucrose and inorganic substances such as potassium and nitrogen, may contribute to increased osmotic potential, hence increasing water use efficiency.

- The grafting method needs further study, as it was observed that tuber yield was poor when the Lole cultivar was used as a rootstock (Section 5.5.4). This was attributed to the incompatibility between the small diameter of cv Lole rootstock and greater diameter of the cv Wanmun scion. Grafting studies might be carried out with different sweet potato cultivars that may produce compatible stem sizes, and more successful grafting unions.

- A future project associated with nutrient analysis could be carried out on leaves, whole plant tissues, and tubers in a time series (from 1 month after planting until harvest) to observe nutrient assimilation and distribution patterns. The nutrient analyses of the present trial were conducted when the plants were mature. Interpreting trends in nutrient analyses needs comprehensive observations from early vegetative stages, when the mobility of nutrients is slow and tubers are undeveloped, until the plants mature.

7.3 EXTENSION OF RESEARCH RESULTS

Extension activities in the near future should focus on:

- Set up sweet potato production nurseries as demonstration plots for local farmers to demonstrate a range of varieties with desirable characters, and to demonstrate the benefits of grafting sweet potato cultivars using a simple grafting technique with simple tools such as drinking straws, ice block wrappers, and raffia rope which local people can easily use and adopt.

- Demonstrate the efficiency of sweet potato cultivation through the integration of sweet potatoes with tree legumes in crop production systems, in demonstration plots in gardens on research stations, and in community gardens. Apply chicken and pig litter or legume mulches (nitrogen sources) and wood ash (potassium source) to help maintain soil fertility, to conserve soil water, and to minimise the effects of extremely cold conditions.

- Conduct demonstrations on the land of local farmers aimed at determining the effects of pig and chicken manures on the yield of sweet potato, as there is currently little or no use of organic manures by indigenous Papuans. In fact, the use of these wastes, which may contribute to the sustainability of soil management practices, have been overlooked by the highland Papuan people.

- The Indonesian government, through the Department of National Education, Jakarta, and the Department of Agriculture, Papua Province, has recently provided funding for a follow-up project to the work presented in this thesis using local sweet potato cultivars. This research is about to start using 10 prominent cultivars which are morphologically similar to either Lole cultivar in relation to smaller leaf area, as an indication of drought tolerance as a result of low evapotranspiration, or are similar the Wanmun cultivar for their high tuber yielding and eating quality (Tables 6.1 and 6.2). The initial trial will identify drought tolerant and susceptible cultivars. This will then be followed up with a series of grafting trials using the local Papuan cultivars to produce grafted plants with a strong sink capacity (i.e. those similar to cv Wanmun rootstocks) and a water use efficient source (i.e. as those similar to cv Lole scions) to produce water use efficient plants with high yields under water stress conditions. The results of these trials should provide a wider range of food production strategies for the sweet potato farmers of the Papuan highlands.

REFERENCES

Abdollahian-Noghabi M and Froud-Williams RJ (1998) Effects of moisture stress and re-watering on growth and dry matter partitioning in three cultivars of sugar beet. *Aspects of Applied Biology* **52**, 71-78.

Alberte RS and Thornber JP (1977) Water stress effects on the content and organization of chlorophyll in mesophyll and bundle sheath chloroplasts of maize. *Plant Physiology* **59**(3), 351-353.

Allison ML, Ammerman GR, Garner JO, Hammett HL, Singletary C, Withers FT, Palmertree HD (1981) Vardaman, a new early maturing sweet potato variety for Mississippi. Mississippi Agricultural and Forestry Experiment Station, Information Sheet 1305, Mississippi.

Alves AAC and Setter TL (2000) Response of cassava to water deficit. *Crop Science* **40**, 131-137.

Anderson JM (1986) Photoregulation of the composition, function and structure of the thylakoid membranes. *Annual Review of Plant Physiology* **37**, 93–136.

Andrews PK and Marquez CS (1999) Graft incompatibility. *Horticulture Reviews* **23**, 183-231.

Apaseray MG, Saraswati P, Chadikun P (2001) Morphological characteristic and tuber culinary test of Papuan highland sweet potato (*Ipomoea batatas* L.). *Hyphere Journal* **6**(2), 6-14.

Anselmo BA, Ganga ZN, Badol EO, Heimer YM, Nejidat A (1998) Screening sweet potato for drought tolerance in the Philippine highlands and genetic diversity among selected genotypes. *Tropical Agriculture*, Trinidad. **75**, 189-196.

Asher C, Grundon N, Menzies N (2002) How to unravel and solve fertility problems. ACIAR Monograph No. 83. ACIAR. Canberra.

Ashraf MY, Azmi AR, Khan AH, Ala SA (1994) Effect of water stress on total phenols peroxidase activity and chlorophyll content in wheat (*Triticum aestivum* L.). *Acta of Plant Physiology* **16**, 185-191.

Ashraf M, Ashfag M, McNeilly T (2001) Growth and photosynthetic characteristics in pearl millet under water stress and different potassium supply. *Photosynthetica* **39** (3), 389-394.

Atwell B, Kriedemann P, Turnbull C (1999) Plants in action. Adaptation in nature, performance in cultivation. MacMillan Education Australia Pty. Ltd. South Yarra, Victoria.

Ballard C (1999) Condemned to Report History. Enso-related drought and famine in Irian Jaya, Indonesia, 1997-1998. In 'A Special report'. Resource Management in Asia Pacific Project, Division of Pacific and Asian History, Research School of Pacific and Asian Studies, Australian National University, Canberra.

Barden JA (1977) Apple tree growth, photosynthesis, dark respiration, and specific leaf weight as affected by continuous and intermittent shade. *Journal of American Society Horticulture Science* **102**(4), 391-394.

Beadle CL, Ludlow MM, Honeysett JL (1993) Water relations. In 'Photosynthesis and production in a changing environment: a field and laboratory manual'. Eds. DO Hall, JMO Scurlock, HR Bolhar-Norednkampf, RC Leegod, and SP Long. Chapman & Hall; London. 113-128 pp.

Beekman AGB and Bouma WF (1986) A possible screening technique for drought tolerance in potato. In' Potato research of tomorrow. Drought tolerance, Virus resistance and analytic breeding methods'. Proceedings of An International Seminar, Wageningen, Netherlands, 30-31 October 1985. Centre for Agricultural Publishing and Documentation; Wageningen. 55-64 pp.

Begg JE and Turner NC (1976) Crop water deficits. *Advances in Agronomy* **28**, 161-217.

Beringer H and Nothdurft F (1985) Effects of potassium on plant and cellular structures. In 'Potassium in agriculture'. Ed. ED Munson. American Society of Agronomy - Crop Science Society of America - Soil Science Society of America; Madison, Wisconsin, USA. 352-368 pp.

Bhagsari AS and Harmon (1982) Photosynthesis and photosynthate partitioning in sweet potato genotypes. *Journal of American Society Horticulture Science* **107**, 506-510.

Bhagsari AS and RH Brown (1986) Leaf photosynthesis and its correlation with leaf area. *Crop Science* **26,** 127-132.

Bhagsari AS (1990) Photosynthetic evaluation of sweet potato germplasm. *Journal of American Society Horticulture Science* **115**, 634-639.

Blum A, Mayer J, Gozlan G (1983) Associations between plant production and some physiological components of drought resistance in wheat. *Plant Cell and Environment* **6**, 210-225.

Blum A, Mayer J, Golan G (1989) Agronomic and physiological assessment of genotypic variation for drought resistance in sorghum. *Australian Journal of Agriculture Research* **40**, 49-61.

Blum A (2000) Towards standard assays of drought resistance in crop plants. http://www.cimmyt.C/WSMolecular/WsdroughtTowards.htm
[Accessed: 28/07/2000 at 16:39 pm].

Bourke RM (1984) Growth analysis of four sweet potato (*Ipomoea batatas*) cultivars in Papua New Guinea. *Tropical Agriculture,* Trinidad **61**, 177-181.

Bourke RM (1985) Influence of nitrogen and potassium fertilizer on growth of sweet potato (*Ipomoea batatas*) in Papua New Guinea. *Field Crop Research* **12**, 363-375.

Bourke RM (1989) Influence of soil moisture extremes on sweet potato yield in the Papua New Guinea Highlands. *Mountain Research and Development* **9**(3), 322-328.

Bouwkamp JC (1983) Growth and partitioning in sweet potatoes. *Annals of Tropical Research* **5**(2), 53-60.

Bouwkamp JC (1989) Differences in mid-day wilting and yield among sweet potato genotypes. *Journal of American Society Horticulture Science* **114**(3), 383-386.

Boyer JS (1982) Plant productivity and environment. *Science* **219**, 443-448.

Bradford KJ and Hsiao TC (1982) Physiological response to moderate stress. In' Encyclopaedia of plant physiology. Physiological plant ecology II. Water relations and carbon assimilation'. Eds. OL Lange, PS Nobel, CB Osmond, and H Ziegler. Heidelberg Springer; New York, Berlin. 263-324 pp.

Brown RH (1992) Photosynthesis and plant productivity in sweet potato. In 'Sweet potato technology for the 21st century'. Eds. WA Hill, CK Bonsi, PA Loretan. Tuskegee University; Tuskegee, Alabama. 273-281 pp.

Brown RW and Oosterhuis (1992) Measuring plant and soil water potentials with thermocouple psychrometer: some concerns. Review and interpretation. *Agronomy Journal* **84**, 78-86.

Buttery BR, Tan CS, Buzzell RI, Gaynor JD, MacTavish DC (1993) Stomatal numbers of soybean and response to water stress. *Plant and Soil* **149**(2), 283-288.

Campbell CS and McInnes KJ (1999) Response of in situ leaf psychrometer to cuticle removal by abrasion. *Agronomy Journal* **91**, 859-862.

Cellier F, Conejero G, Breitler JC, Casse F (1998) Molecular and physiological responses to water deficit in drought-tolerant and drought sensitive lines of sunflower. Accumulation of dehydrin transcripts correlates with tolerance. *Plant Physiology* **116**, 319-328.

Cenderawasih Pos (1998) Badai *El Nino* menyebabkan bencana kelaparan di pegunungan tengah Jaya Wijaya. Local Papua Newspaper (In Indonesian Language).

Chandrasekar V, Sairam RK, Srivastava GC (2000) Physiological and biochemical responses of hexaploid and tetraploid wheat to drought stress. *Journal of Agronomy and Crop Science* **185**, 219-227.

Cock JH, Porto MCM, El-Sharkawy MA (1985) Water use efficiency of cassava III. Influence of air humidity and water stress on gas exchange of field grown cassava. *Crop Science* **25**, 265-272.

Collins WW (1995) Sweet potato. http://www.hort.purdue.edu/newcrop/sweetpotato.html [Accessed: 9/12/00 at 8:40 am].

Collin P (2001) Plant adaptation to environmental conditions. *Année Biologique* **40**, 21-42 (CAB International, 2002. Accessed: 5/4/2002 at 12.30 pm).

Connor DJ and Cock JH (1981) Response of cassava to water shortage II. Canopy dynamics. *Field Crop Research* **4**, 285-296.

Constantin RJ, Hernandez TP, Jones LG (1974) Effects of irrigation and nitrogen fertilization on quality of sweet potato. *Journal of American Society Horticulture Science* **99**, 308-310.

Cornish K and Zeevaart JAD (1984) Abscisic acid metabolism in relation to water stress and leaf age in *Xanthium strumarium*. *Plant Physiology* **76**, 1029-1035.

Dahlin C (1988) Correlation between pigment contribution and apoproterm of the light harvesting complex II (LHC II) in wheat (*Triticum aestivum*). *Plant Physiology* **74**, 342-348.

Da Matta FM, Chaves ARM, Pinheiro HA, Ducatti C, Loureiro ME (2003) Drought tolerance of two field-grown clones of *Coffea canephora*. *Plant Science* **164**, 111-117.

Del Campo GM, Ruiz C, Baeza P, Lissarrague JR (2003) Drought adaptation strategies of four grapevine cultivars (*Vitis vinifera* L.): modification of the properties of the leaf area. *Journal International des Sciences de la Vigne et du Vin*. **37**(3), 131-143. (CAB International, 2004. Accessed: 12/12/2004 at 11.40 am).

Devlin RM and Witham FH (1983) Plant physiology. 4th ed. Willard Grant Press; Boston.

Draycott AP (1993) Nutrition. In' The sugar beet crop, science into practice'. Eds. DA Cooke and RK Scott. Chapman and Hall; London. 239-278 pp.

Duke JA (1983) *Ipomoea batatas* (L.) Lam. Handbook of Energy Crop (unpublished). Available from:http://www.hort.purdue.edu/newcrop/duke_energy/Ipomoea_batatas.html [Accessed on 9/12/00 at 8:39 am].

Eguchi T, Kitano KM, Eguchi H (1998) Water relations and dynamics of tuber growth rate in sweet potato plants (*Ipomoea batatas* Lam.). *Environment Control in Biology* **36**(2), 91-95.

Ekanayake IJ (1997) Evaluation of potato and sweet potato genotypes for drought resistance. In 'Sweet potato germplasm management training manual'. Ed. Z Huaman. International Potato Center (CIP); Lima, Peru. Sect.3.5; 2-9 pp.

Ekanayake IJ and Collins WW (2004) Effects of irrigation on sweet potato root carbohydrates and nitrogenous compounds. *Journal of Food, Agriculture and Environment* **2**(1), 1459-1463.

El-Sharkawy MA and Cock JH (1984) Water use efficiency of cassava I. Effects of air humidity and water stress on stomatal conductance and gas exchange. *Crop Science* **24**, 497-502.

Estill K, Delaney RH, Smith WK, Ditterline RL (1991) Water relations and productivity of alfalfa leaf chlorophyll variants. *Crop Science* **31**, 1229-1233.

Evans JR (1996) Developmental constraints on photosynthesis: effects of light and nutrition. In 'Photosynthesis and the Environment'. Ed. NR Baker. Kluwer Academic Publishers; Dordrecht, The Netherlands. 281–304 pp.

Evenari M, Lange OL, Schulze ED, Kappen L, Buschbom U (1977) Net photosynthesis, dry matter production, and phenological development of apricot trees (*Prunus armeniaca* L.) cultivated in the Negev Highlands Israel. *Flora* **166**, 383-414.

Fischer RA and Turner NC (1978) Plant productivity in the arid and semiarid zones. *Annual Review Plant Physiology* **29**, 277-317.

Garner Jr JO, Phromtong C, Newell L, Woods FM, Silva JL (1992) Chilling and drought stress tolerance in selected sweet potato genotypes. In' Sweet potato Technology for the 21st Century'. Eds. WA Hill, CK Bonsi, and PA Loretan. Tuskegee University, Tuskegee, AL. 318-324 pp.

Garnier E, Shipley B, Roumet C, Laurent G (2001) A standardized protocol for the determination of specific leaf area and leaf dry matter content (technical report). *Functional Ecology* **15**, 688-695.

Geigenberger P, Reimholz R, Deiting U, Sonnewald U, Stitt M (1999) Decreased expression of sucrose phosphate synthase strongly inhibits the water stress-induced synthesis of sucrose in growing potato tubers. *The Plant Journal*, **19**(2), 119-129.

George MS, Lu G, Zhou W (2002) Genotypic variation for potassium uptake and utilization efficiency in sweet potato (*Ipomoea batatas* L.). *Field Crops Research* **77**(1), 7-5.

Ghuman BS and Lal R (1983) Mulch and irrigation effects on plant-water relations and performance of cassava and sweet potato. *Field Crops Research* **7**, 13-29.

Goswami SB, Sen H, Jana PK (1995) Tuberization and yield potential of sweet potato cultivars as influenced by water management practises. *Journal of Root Crops* **21**(2), 77-81.

Hahn SK (1977) Sweet Potato. In' Ecophysiology of tropical crops'. Eds. Paulo de T. Alvin and TT Kozlowski. Academic Press; New York. 237-248 pp.

Hahn SK and Hozyo Y (1984) Sweet potato. In 'The physiology of tropical field crops'. Eds PR Goldsworthy, NM Fisher. John Wiley & Sons; United Kingdom 551-567 pp.

Haider SA and Paul NK (2003) Physio-biochemical investigations on four bread wheat cultivars under different irrigation regimes. *Bangladesh Journal of Botany* **32**(1), 39-42.

HaiQiu Y, ZhiHai W, XiuYing S, KeZhang X (2003) Changes of stomatal density, length, width and microstructure of maize leaves under water stress. *Journal of Jilin Agricultural University* **25**(3), 239-242. (CAB International, 2005. Accessed: 5/1/2005 at 11.30 am).

Hammet HL, Constantin RJ, Jones LG, Hernandez TP (1982) The effect of phosphorous and soil moisture levels on yield and processing quality of 'Centennial" sweet potatoes. *Journal of American Society Horticulture Science* **107**(1), 119-122.

Hameed M, Mansoor U, Ashraf M, Rao AR (2002) Variation in leaf anatomy in wheat germplasm from varying drought-hit habitats. *International Journal of Agriculture* **4** (1), 12-16. (CAB International, 2003. Accessed: 29/12/2003 at 11.30 am).

Hartemink AE, Johnston M, O'Sullivan JN, Poloma S (2000) Nitrogen use efficiency of taro and sweet potato in the humid lowlands of Papua New Guinea. *Agriculture, Ecosystems and Environment* **79**, 271-280.

Hill WA (1984) Effect of nitrogen nutrition on quality of three important root/tuber crops. In 'Nitrogen in crop production'. Ed. Hauck RD. American Society Agronomy, Soil Science Society of America and Crop Science Society of America. Madison, WI 627-641 pp.

Hill WA, Loretan PA, Bonsi CK (1984) The sweet potato for space missions-controlled environmental life support systems. George Washington Carver Agriculture Experimental Station, Tuskegee University. Monograph no.1, 66 pp.

Hinckley TM (1973) Responses of black locust and tomato plants after water stress. *Horticulture Science* **8**, 405-407.

Hirasawa T (2001) Physiological characterization of the rice plant for tolerance of water deficit. In' Genetic improvement of rice for water-limited environments'. Eds. J O'Toole, O Ito, and B Hardy. Proceedings of a workshop, 1-3 December, 1998. Los Banos, Laguna, Philippines. http://www.cgiar.org/irri/AbstractsWaterlimited.htm [Accessed on 5/14/01 at 4:00 pm].

Holwerda HT and Ekanayake IJ (1991) Establishment of sweet potato stem cuttings as influenced by size depth of planting water stress hormones and herbicide residues for two genotypes. *Scientia Horticulturae* **48,** 193-204.

Hopkins WG (1999) Introduction to plant physiology'. 2nd edition. John Wiley & Sons, Inc; New York.

Hsiao TC and Lauchli A (1986) Role of potassium in plant water relations. *Advanced in Plant Nutrition* **2**, 281-312.

Huaman Z (1992) Descriptor for sweet potato. International Potato Centre, Asian Vegetable Research and Development Centre (AVRDC), International Board for Plant Genetic Resources (IBPGR). Lima, Peru.

Huaman Z (1997) Botany, origin, evolution and biodiversity of the sweet potato. In 'Sweet potato germplasm management training manual'. Ed. Z Huaman. International Potato Center (CIP); Lima, Peru.

Huang B and Gao H (2000) Root physiological characteristics associated with drought resistance in tall fescue cultivars. *Crop Science* **40**, 196-207.

Hurd EA (1974) Phenotype and drought tolerance in wheat. *Agriculture Meteorology* **14,** 39-55.

Ike IF and Thurtell GW (1981) Response of indoor-grown cassava to water deficits and recovery of leaf water potential and stomatal activity after water stress. *Journal of Experimental Botany* **32,** 1029-1034.

Indira P (1989) Drought tolerant traits in sweet potato genotypes. *Journal of Root Crops* **15**, 139-144.

Indira P and Kabeerathumma S (1988) Physiological response of sweet potato under water stress. 1. Effect of water stress during the different phases of tuberization. *Journal of Root Crops* **14**(2), 37-40.

International Potato Center (CIP) (1998) CIP sweet potato facts. http://www.cipotato.org/data/sweetpotato/facts/swtpfact.htm [Accessed: 8/2/00 at 11:48 am].

Jones ST (1961) Effect of irrigation at different levels of soil moisture on yield and evapotranspiration rate of sweet potato. *Proc. Am. Soc. Hortic. Sci.* **77**, 458-462.

Jones MM, Osmond CB, Turner NC (1980) Accumulation of solutes in leaves of sorghum and sunflower in response to water deficits. *Australian Journal of Plant Physiology* **7**, 193-205.

Jones MM, Turner NC, Osmond CB (1981) Mechanisms of drought resistance. In 'The physiology and biochemistry of drought resistance in plants'. Eds. LG Paleg and D Aspinall. Academic Press; Sydney, Australia. 15-37 pp.

Jayawardena T (1984) Phosphorus fertilizer and organic matter effect on yield of sweet potato. Asian Regional Center-The Asian Vegetable Research and Development. http://www.arc-avrdc.org/html_files/research-sweetpotato.html [Accessed: 12/4/2003 at 5:30 pm].

Kaiser WM (1987) Effects of water deficit on photosynthetic capacity. *Physiol. Plant* **71**, 142-149.

Karyudi (2001) Osmoregulative capacity in birdseed millets (*Setaria italica* L. and *Panicum miliaceum* L.) in response to water stress. Summary of PhD thesis. http://www.newscrops.uq.edu.au/people/peo-7.htm [Accessed 5/14/01 at 3:21 pm].

Kay DE (1973) Root crops. In 'Crop and product digest 2'. Tropical Products Institute, London. 240 pp.

Kays SJ (1985) The physiology of yield in sweet potato. In' Sweet potato products: A natural resource for the tropics'. Ed. JC Bouwkamp. CRC Press; Boca Raton, Florida. 79-132 pp.

Kelm M, Bruck H, Hermann M, Sattelmacher (2000) Plant productivity and water use efficiency of sweetpotato (*Ipomoea batatas*) as affected by nitrogen supply. International Potato Centre Program Report 1999-2000. International Potato Centre (CIP), Lima, Peru.

Kirnak H, Kaya C, Tas I, Higgs D (2001) The influence of water deficit on vegetative growth, physiology, fruit yield and quality in eggplants. *Bulgarian Journal of Plant Science* **27**(3-4), 34-46.

Kramer PJ (1980) Drought stress and the origin of adaptation. In 'Adaptation of plants to water and high temperature stress.' Eds. NC Turner and PJ Kramer. John Wiley & Sons; New York. 7-20 pp.

Kramer PJ (1983) Water relations of plant. Academic Press Inc.; San Diego, CA. 342-415 pp.

Kriedeman PE (1986) Stomatal and photosynthetic limitations to leaf growth. In 'Plant growth, drought and salinity'. Eds. NC Turner and JB Passioura. CSIRO Australia. 15-31 pp.

Kuo G and Chen HM (1992) Source-sink relationships of sweet potato. In 'Sweet potato technology for the 21st century'. Eds. WA Hill, CK Bonsi, PA Loretan. Tuskegee University, Tuskegee, Alabama. 282-295 pp.

Lambers H, Chapin III FS, Pons TL (1998) Plant physiological ecology. Springer; New York.

Larcher W (1995) Physiological plant ecology. 3rd ed. Springer-Verlag; New York.

Leopold AC (1964) Plant growth and development. McGraw-Hill Book Company; New York. 393-409 pp.

Levitt J (1972) Responses of plants to environmental stresses. Academic Press; New York. 322-446 pp.

Lin ZBZ, Guo LJ, Guo KJ (1996) Relationship of hydraulic capacitance and drought endurance of plants. *Journal of Plant Resources and Environment* **5**(2)**,** 23-27.

Losch R, CR Jensen, MN Andersen (1992) Diurnal courses and factorial dependencies of leaf conductance and transpiration of differently potassium fertilized and watered field grown barley plants. *Plant Soil* **140**, 205-224.

Lu Z, Tamar K, Neumann PM, Nevo E (2000) Physiological characterization of drought tolerance in wild barley (*Hordeum spontaneum*) from Judean desert. *Barley Genetics Desert* Vol. 29. http://wheat.pw.usda.gov/ggpages/bgn/29/a29-09.html [Accessed: 3/13/01 at 2:58 pm].

Ludlow MM (1989) Strategies in response to water stress. In 'Structural and functional responses to environmental stresses: Water Shortage'. Eds. KH Kreeb, H Richter, and TM Hinckley. SPB Academic Publishing; London. 269-282 pp.

Ludlow MM and Muchow RC (1990) A critical evaluation of traits for improving crop yields in water-limited environments. *Advanced in Agronomy* **43**, 107-153.

Luh CL and Moowaw JC (1979) Present role and future outlook for sweet potato in tropical Asia research and development needs. In 'Proceedings of the Symposium of the International Society for Tropical Root Crops'. Manila, Philippines. 5-7 pp.

Mansfield TA and Davies WJ (1981) Stomata and stomatal mechanisms. In 'The physiology and biochemistry of drought resistance in plants'. Eds. LG Paleg and D Aspinal. Academic Press; Sydney, Australia. 315-346 pp.

Mansfield TA and Atkinson CJ (1990) Stomatal behaviour in water stressed plants. In' Stress responses in plants: Adaptation and acclimation Mechanism'. Eds. RG Alscher and JR Cumming. Wiley-Liss; New York. 241-264 pp.

Marcum KB,.Engelke MC, Morton SJ, White RH (1995) Rooting characteristics and associated drought resistance of zoysiagrass. *Agronomy Journal* **87**, 534-538.

Marschner H (1995) Mineral nutrition of higher plants. 2nd ed. Academic Press; London. 889 pp.

Marti HR and Mills HA (2002) Nitrogen and potassium nutrition affect yield, dry weight partitioning, and nutrient-use efficiency of sweet potato. *Commun. Soil Sci. Plant Anal*. **33**(1&2), 287-301.

Martin FW (1988) Sweet potato. http://echonet.org/Technotes/sweetpotato.htm [Accessed: 27/07/00 at 16:18 pm].

McCraw D (2000) Sweet potato production. http://agweb.okstate.edu/pearl/hort/vegetables/f6022.htm [Accessed: 9/12/00 at 8:47 am].

Medina AJF, Gallegos AJA, Posadas RM, Shibata JK, Lőpez TC (2002) Morphological differences on the leaf epidermis of common bean and their relationship to drought tolerance. *Agricultura Técnica en México* **28**(1), 53-64. (CAB International, 2003. Accessed: 12/12/2003 at 16.35 pm).

Monneveux P and Belhassen E (1996) The diversity of drought adaptation in the wide. *Plant Growth Regulation* **20,** 85-92.

Morgan JM (1984) Osmoregulation and water stress in higher plants. *Annual Review Plant Physiology* **35,** 299-319.

Morris HG, Ephrathl JE, Hesketh JD, Hummel JW (1998) Maize root growth under water, nitrogen, and weed stress. Agricultural Research Service, United States Department of Agriculture. Http://www.nal.usda.gov/ttic/tektran/categoryV3/Agrochemical_Technology.html [Accessed: 5/11/00 at 5:47 pm].

Mortlock MY and Fukai S (1998) Osmotic adjustment of sorghum genotypes under two nitrogen levels in the field. School of Land and Food, The University of Queensland, Brisbane, Queensland. http://www.regional.org.au/asa/1998/4/253mortlock.htm [Accessed: 5/1/2005 at 10:30 am].

Mullet JE and Whitsitt MS (1996) Plant cellular responses to water deficit. *Plant Growth Regulation* **20**, 119-124.

Mukhopadhyay SK, Sen H, Jana PK (1992) Effect of potassium on growth and yield of sweet potato. *Journal of Root Crops* **18**(1), 10-14.

Mukhopadhyay SK, Sen H, Jana PK (1999) Dry matter accumulation, starch and NPK concentration in sweet potato as influenced by planting materials. *Journal of Root Crops* **25**(1), 79-83.

Nair GM and Nair VM (1995) Influence of irrigation and fertilizers on the growth attributes of sweet potato. *Journal of Root Crops* **21**, 17-23.

Naskar SK and Roychowdhury (1995) Genotypic variation in relative water content and nitrate reductase activity in sweet potato under field drought condition. *Journal of Root Crops* **21**(1), 46-49.

Newell LL (1991) Screening sweet potato genotypes (*Ipomoea batatas* L. Lam) for drought tolerance. Abstract of MS thesis. Mississippi State University, Mississippi. (Unpublished).

Newell LL, Garner JO, Silva JL (1994) Estimation of drought tolerance in sweet potato. *International Journal of Experimental Botany* **12**(56), 119-125.

Nobel PS (1980) Leaf anatomy and water use efficiency. In 'Adaptation of plants to water and high temperature stress'. Eds. NC Turner and PJ Kramer. John Wiley & Sons; New York. 43-55 pp.

Nonami H and Boyer JS (1989) Turgor and growth at low water potentials. *Plant Physiology* **89**, 798-804.

Nordenkampf HB and Lechner E (1988) Temperature and light dependent modification of chlorophyll fluorescence kinetics in spruce needle during water stress. *Photosynthetic Res*. **18**, 287.

Norman MJT, Pearson CJ, Searle PGE (1995) Sweet potato (*Ipomoea batatas*). In 'The ecology of tropical food crops'. 2nd ed. Cambridge University Press. 291-304 pp.

O'Hair SK (1990) Tropical root and tuber crops. In 'Advances in new crops'. Eds. J Janick and JE Simon. Timber Press; Portland, Oregon. 424-428 pp.

Onwueme IC (1978) The tropical tuber crops: Yams, cassava, sweet potato and cocoyams. John Wiley & Sons; Chic`hestar, Great Britain. 234 pp.

Onwueme IC and Charles WB (1994) Tropical root and tuber crops. Production, perspectives and future prospects. Food and Agriculture Organization (FAO) of the United Nations. Plant Production and Protection Paper No. 126, Rome. 122 pp.

O'Sullivan JN, Asher CJ, Blamey FPC (1997) Nutrient disorders of sweet potato. Australian Centre for International Agricultural Research. Canberra, Australia. 53-54 pp.

O'Toole JC and Chang TT (1979) Drought resistance in cereals. Rice: A case study. In 'Stress physiology in crop plants'. Eds. H Mussels and R Staples. Wiley and Sons; New York. 373-406 pp.

Parimelazhagan T and Francis K (1996) Effects of water stress and salinity on photochemical activity of green gram (*Vigna radiata* L.). *Bioved*. **7**(1), 47-52. (In, CAB International, 2002. Accessed: 1/11/2002 at 12.30 pm).

Passioura JB (1996) Drought and drought tolerance. *Plant Growth Regulation* **20**, 79-83.

Peet M (2000) Sweet potato. Production practices. http://www.cals.ncsu.edu/sustainable/peet/profiles/pps_pot.html [Accessed 9/11/00 at 4:00 pm].

Peters D and Wheatley C (1997) Small scale agro-enterprises provide opportunities for income generation: sweet potato flour in East Java, Indonesia. http://www.eseap.cipotato.org/Library/SP-Flour.html [Accessed: 9/4/00 at 6:23pm].

Peters D (2001) Local human-sweet potato-pig systems. Characterization and research in Irian Jaya, Indonesia with limited reference to Papua New Guinea. International Potato Center (CIP) and the Australian Council for International Agricultural Research (ACIAR).

Pier PA and Berkowitz GA (1987) Modulation of water stress effects on photosynthesis by altered leaf K. *Plant Physiology* **85**, 665-661.

Prain G and Widyastuti CA (1998) Sweet potato conservation means survival for Irian Jaya families. UPWARD Fieldnotes Vol.7 No.1 June 1998, 5-6 pp.

Prakash CS (1994) Sweet potato biotechnology: Progress and potential. *Biotechnology and development monitor* **18**,18-19 http://www.pscw.uva.nl/monitor/1811.htm [Accessed: 9/5/00 at 5:55 pm].

Prakash M and Ramachandran K (2000) Effects of chemical ameliorants on stomatal frequency and water relations in brinjal (*Solanum melongena* L.) under moisture stress conditions. *Journal of Agronomy and Crop Science* **185**, 273-239.

Prakash M and Ramachandran K (2000) Effects of moisture stress and anti-transpirant on leaf chlorophyll. *Journal of Agronomy and Crop Science* **184**, 153-156.

Premachandra GS, Saneoka H, Fujita K, Ogata S (1992) Leaf water relations, osmotic adjustment, cell membrane stability, epicuticular wax load and growth as affected by increasing water deficits in sorghum. *Journal of Experimental Botany* **43**, 1569-1576.

Pugnaire FI, Endolz LS and Pardos J (2002) Constrains by water stress on plant growth. In 'Handbook of plant and crop physiology'. 2nd ed. (Ed. M. Pessarakli). Marcel Dekker. Inc. New York. 247-259.

Ravi V and Indira P (1999) Crop physiology of sweet potato. *Horticulture Reviews* **23**, 277-338.

Raven PH, Evert RF, Eichhorn SE (1999) Biology of Plant. 6th ed. WH Freeman and Company Worth Publishers. New York. 729 pp.

Ray LL, Wendt CW, Roark B, Quisenberry JE (1974) Genetic modification of cotton plants for more efficient water use. *Agriculture Meteorology* **14,** 31-38.

Reddy VR, Acock B, Baker DN, Acock M (1989) Seasonal leaf area-leaf weight relationships in the cotton canopy. *Agronomy Journal* **81**,1-4.

Reynoso D, Huaman Z, Aguilar C (1997) Methods for flowering induction in sweet potato. In 'Sweetpotato germplasm management'. Training manual. (Ed. Z Huaman). International Potato Centre (CIP). Lima, Peru. Section 2.7.

Riga P and Vartanian N (1999) Sequential expression of adaptive mechanisms is responsible for drought resistance in tobacco. *Australian Journal of Plant Physiology* **26**, 211-220.

Robitaille HA and Lawrence BE (1992) Cropping systems for mass education. In 'Sweet potato technology for the 21st century'. Eds. WA Hill, CK Bonsi, PA Loretan. Tuskegee University, Tuskegee, Alabama. 126-132 pp.

Rufty Jr TE and Huber SC (1983) Changes in starch formation and activities of sucrose phosphate synthase and cytoplasmic fructose-1, 6-bisphosphate in response to source-sink alterations. *Plant Physiology* **72**, 474-480.

Ruinard J (1969) Notes on sweet potato research in West New Guinea (West Irian). In 'Proceedings of the international symposium on tropical root crops'. Vol. I. Eds. EA Tai, WB Charles, EF Iton, PH Hayness, and KA Leslie. University of the West Indies; Trinidad. 88-111 pp.

Russell EJ and Russell WJ (1973) Soil conditions and plant growth.10th ed. Longmans Green Co. Ltd; London. 31-33 pp.

Salih AA, Ali IA, Lux A, Luxova M, Cohen Y, Sugimoto Y, Inanaga S (1999) Rooting, water uptake, and xylem structure adaptation to drought of two sorghum cultivars. *Crop Science* **39**, 168-173.

Sam O, Jeréz E, Dell'Amico J, Ruiz-Sánchez MC (2000) Water stress induced changes in anatomy of tomato leaf epidermis. *Biologia Plantarum* **43**(2), 275-277.

Sangakkara UR, Frehner M, Nösberger J (2000) Effect of soil moisture and potassium fertilizer on shoot water potential, photosynthesis and partitioning of carbon in mungbean and cowpea. *Journal of Agronomy and Crop Science* **185**, 201-207.

Sanger JE (1971) Quantitative investigation of leaf pigments from their inception in buds through autumn coloration to decomposition in falling leaves. *Ecology* **52**, 1075-1089.

Saraswati P, Johnston M, Coventry R, Holtum J (2004) Identification of drought tolerant sweet potato (*Ipomoea batatas* (L.) Lam) cultivars. In 'New directions for a diverse planet'. Eds. T Fischer, N Turner, J Angus, L McIntyre, M Robertson, A Borrell, and D. Lloyd. Handbook and abstracts for the 4th International Crop Science Congress, Brisbane, Australia, 26 September-1 October 2004.

Satchithananantham S and Bandara DC (2002) Physiological responses of maize (*Zea mays* L.) to the interactive effects of nitrogen fertilizer and water regimes. *Tropical Agricultural Research* **12**, 22-32.

Schneider J, Widyastuti CA, Djazuli M (1993) Sweet potato in the Baliem Valley area, Irian Jaya. In 'A report on collection and study of sweet potato germplasm, April-May 1993'. International Potato Center (CIP), ESEAP-Region; Bogor, Indonesia.

Schultheis JR and Wilson LG (2000) What is the difference between a sweet potato and a yam ? http://www.ces.ncsu.edu/depts/hort/hil/hil-23-a.html [Accessed 9/12/00 at 8:44 AM].

Schulze E.D (1986) Whole-plant responses to drought. In 'plant growth, drought and salinity'. Eds. NC Turner and JB Passioura. CSIRO Australia. 127-141 pp.

Scott LE and Bouwkamp JC (1974) Seasonal mineral accumulation by the sweet potato. *Horticulture Science* **9,** 233-237.

Scott GJ (1992) Transforming traditional food crops: product development for roots and tubers. In 'Product development for root and tuber crops'. Eds. GJ Scott, S Wiersema, and PI Ferguson. Proceedings of the international workshop, Visca, Baybay, Leyte, Philippines, April 22-May 1, 1991, International Potato Centre (CIP); Lima, Peru. Volume 1, 3-20 pp.

Sen Gupta A, Berkowitz GA, Pier PA (1989) Maintenance of photosynthesis at low leaf water potential in wheat. Role of potassium status and irrigation history. *Plant Physiology* **89**, 1358-1365.

Sen H, Mukhopadhyaya SK, Gosami SB (1990) Performance of some promising sweet potato hybrids in Rajendranagar. *Journal of Root Crops* **16**(1), 46-47.

Shaw B, Thomas TH, Cooke DT (2002) Responses of sugar beet (*Beta vulgaris* L.) to drought and nutrient deficiency stress. *Plant Growth Regulation* **37**, 77-83.

Siddique MRB, Hamid A, Islam MS (2000) Drought stress effects on water relations of wheat. *Botany Bulletin Acad. Sinica* **41,** 35-39.

Sims DA and Gamon JA (2003) Estimating anthocyanin, chlorophyll, and cariotenoid concentrations using hyperspectral reflectance. http://vcsars.calstatela.edu/esa_posters/ds/dan_esa99.html [Accessed: 16/04/2003 at 15.30 pm].

Sinclair TR and Ludlow MM (1985) Who taught plants thermodynamics? The unfulfilled potential of plant water potential. *Australian Journal of Plant Physiology* **33**, 213-217.

Singh TN, Aspenall D, Paleg LG (1972) Proline accumulation and varietal adaptability to drought in barley: a potential metabolic measure of drought resistance. *Nature New Biology* **236**, 188-189.

Sinha SK, Aggarwal PK, Khanna CR (1985) Irrigation in India: a physiological and phenological approach to water management in grain crops. *Advance Irrigation* **3**, 129-212.

Sivan P, Asher CJ, Blamey FPC (1996) Effects of potassium on drought tolerance of taro and tannia. In 'Mineral nutrient disorder of root crops in the Pacific'. Eds. ET Craswell, CJ Asher and JN O'Sullivan. Proceedings of a workshop, Nuku'alofa, Kingdom of Tonga, 17-20 April 1995. The Australian Center for International Agricultural Research (ACIAR); Canberra, Australia.100-104 pp.

Soenarto (1997) Wen hipere suatu budidaya ubijalar di lembah Balliem, Irian Jaya. M.Sc. Thesis. Fakultas Paska Sarjana. Institut Pertanian Bogor. Indonesia. (In Indonesian Language).

Soenarto and Rumawas F (1997) An agro-ecological analysis of *wen-tinak*, a sustainable sweet potato wetland production system in the Baliem Valley, Irian Jaya, Indonesia. *Science in New Guinea.* **23**(2), 55-66.

Stanislaw G, Morio I. Yasuhiro K, Akira (1997) Differences in drought tolerance between cultivars of field bean and field pea: A Comparison of drought-resistance and drought-sensitive cultivars. *Acta Physiologiae Plantarum* **19**(3), 349-357.

Sullivan CY (1971) Technique for measuring plant drought stress. In 'Drought injury and resistance in crops'. Eds. KL Larson and FD Eastin. Crop Science Society of America, Madison, Wisconsin. Special publication No. 2. 1-18 pp.

Suja G and Nayar TVR (1996) Water management in tropical tuber crops: a critical evaluation. *Journal of Root Crops* **22**(2), 65-77.

Swindale LD and Bidinger FR (1981) Introduction: the human consequences of drought and crop research priorities for their alleviation. In 'The physiology and biochemistry of drought resistance in plants'. Eds. LG Paleg and D Aspinal. Academic Press; Sydney, Australia. 1-13 pp.

Taiz L and Zeiger E (2002) Plant physiology. Sinauer Associates, Inc.; Sunderland, Massachusetts.

Taufatofua P (1994) Agronomic manipulation of sweet potato (*Ipomoea batatas* L.) grown under water limiting conditions. PhD thesis. University of Queensland. 168 p. (Unpublished).

Taufatofua P and Fukai S (1996) Effects of nitrogen and water stress on growth and yield of sweet potato. In 'Proceedings of a workshop, Nuku'alofa, Kingdom of Tonga, 17-20 April 1995'. The Australian Centre for International Agricultural Research [ACIAR] Canberra, Australia No. 65. 76-79 pp.

Topp GC (1993) Soil water content. In 'Soil sampling and methods of analysis'. Ed. MR Carter. Canadian Society of Soil Science. Lewish Publishers. 541-557 pp.

Toshihiko E, Masaharu K, Hiromi E (1998) Water relations and dynamics of tuber growth rate in sweet potato plants (*Ipomoea batatas* Lam). *Environment Control in Biology* **36**(2), 91-95.

Turner NC (1975) Concurrent comparison of stomatal behaviour, water status, and evaporation of maize in soil at high or low water potential. *Plant Physiology* **55,** 932-936.

Turner NC (1979) Drought resistance and adaptation to water deficits in crop plants. In 'Stress physiology in crop plants'. Eds. H Mussel and RC Staples. John Wiley & Sons; New York. 343-72 pp.

Turner NC (1986) Crop water deficits: a decade of progress. *Advances in Agronomy* **39,** 1-51.

Turner NC, Wright GC, Siddique KHM (2001) Adaptation of grain legumes (pulses) to water-limited environments. *Advances in Agronomy* **71**, 195-231.

Valenzuela H, Fukuda S, Arakaki A (2000) Sweet potato production guidelines for Hawaii. http://www.extento.hawaii.edu/kbase/reports/sweetpot_prod.htm [Accessed: 9/4/00 at 6:29 pm].

Van der Mescht A, de Ronde JA, Rossouw FT (1999) Chlorophyll fluorescence and chlorophyll content as a measure of drought tolerant in potato. Abstract . *South African Journal of Science.* Vol 95, number 9 http://www.nrf.ac.za/sajs/absep99j.stm [Accessed: 1/12/2005 at 5:50 pm].

Van Loon CD (1981) The effect of water stress on potato growth, development and yield. *American Potato Journal* **58**, 51-69.

Van Oosterom EJ, Mahalakshmi V, Arya GK, Dave HR, Gothwal BD, Joshi AK, Joshi P, Kapoor RL, Sagar P, Saxena MBL, Singhania DL, Vyas KL (1995) Effect of yield potential, drought escape and drought tolerance on yield of pearl millet (*Pennisetum glaucum*) in different stress environment. *Indian Journal of Agriculture Sciences* **65**(9), 629-35.

Vasudevan K, Padmaja G, Jayakumar S (1996) Effect of nitrogen and potassium levels on growth, yield and nutrient uptake of *Colocasia*. *Journal of Root Crops* **22**(2), 139-143.

Villagarcia MR and Collins WW (1998) Nitrate uptake and nitrogen use efficiency of two sweet potato genotypes during early stages of storage root formation. *Journal of American Society Horticulture Science* **123**(5), 814-820.

Villarreal RL, Tsou SC, Lo HF, Chiu SC (1985) Sweet potato vine tips as vegetables. In 'Sweet potato products: a natural resource for the tropics'. Ed. JC Bouwkamp. CRC Press; Boca Raton, Florida. 175-183 pp.

Walker DW and Miller Jr. C (1986) Rate of water loss from detached leaves of drought resistant and susceptible genotypes of cowpea. *Horticulture Science* **21**, 131-132.

Wang Y, Xi G, Zhang L, Hu Z, Guan R (1995) Effects of potassium fertilizer on sweet potato. In' Proceedings of the First Chinese-Japanese Symposium on Sweet Potato and Potato'. Eds. Q Liu, T Kokubo. Beijing Agricultural University Press; Beijing. 199-203 pp.

Widyastuti CA (1995) The collection of associated knowledge during short germplasm collections: field experiences in Java and Irian Jaya. In 'Indigenous Knowledge in Conservation of Crop Genetic Resources'. Ed. J Schneider. International Potato Center (CIP) and Central Research Institute for Food Crops (CRIFC), Bogor. 35-45 pp.

Willmer C and Fricker M (1996) The distribution of stomata. In 'Stomata'. 2nd ed. Chapman and Hall; London. 12-35 pp.

Wintermans JFGM and De Mots A (1965) Spectrophotometric characteristics of chlorophyll *a* and *b* and their pheophytin in ethanol. *Biochemical Biophysical Acta* **109**, 448-453.

Woolfe JA (1992) Sweet potato: An untapped food resource. Cambridge University Press; Cambridge, United Kingdom.

Xia MZ (1990) Physiological effects of water stress during the flowering and podding stages of *Vicia faba*. *Plant Physiology Communications* **1**, 14-19 (CAB International, 2002. Accessed: 4/5/2002 at 11.30 am).

Yamasaki S and Dillenburg LR (1999) Measurements of leaf relative water content in *Araucaria angustifolia*. *Revista Brasilleira de Fisiologia Vegetal* **11**(2), 69-75.

Yen DE (1974) The sweet potato in the Pacific and Oceania: An essay in ethno botany. Bishop Museum Press; Honolulu.

Yen DE (1982) Sweet potato in historical perspective. In 'Sweet potato'. Eds. RL Villareal and TD Griggs. Proceedings of the First International Symposium. Asian Vegetable Research and Development Centre (AVRDC), Taiwan. 2-30 pp.

Zeevaart JAD and Creelman RA (1988) Metabolism and physiology of abscisic acid. *Annual Review Plant Physiology* **39**, 439-473.

Zobayed SMA, Afreen F, Kubota C, Kozai T (2000) Water control and survival of *Ipomoea batatas* grown photoautotrophically under forced ventilation and photomixotrophically under natural ventilation. *Annals of Botany* **86**, 603-610.

APPENDIX A1

MATERIALS AND METHODS

1. SOIL MOISTURE STATUS

1.1 SOIL MOISTURE AT FIELD CAPACITY

Field capacity (FC) is defined as the water content remaining in the soil after saturation, followed by drainage for 48 hours (Lambers *et al*., 1998). Twelve soil samples were taken from the growing media in three of the pots used in each of the experiments reported in this thesis to determine moisture content at field capacity. Computations of the field capacity of the growing media used for each experiment are presented in the relevant chapters.

To determine the soil moisture content at field capacity, 5L pots of soil were saturated with water after which they were allowed to drain for 48 hours. Approximately 50 g samples of soil were taken from the middle of the pots and about 6 cm below the soil surface. They were immediately weighed, dried to constant weight at 105 ^{0}C, then reweighed. The soil water content of air dried soil was also determined by weighing approximately 40 g of an air dry soil sample that was then dried to constant weight at 105 ^{0}C, and reweighed.

To determine the amount of water needed to bring 1 kg of air dried soil to field capacity, the following calculations were used:

% Moisture at field capacity/ mass of 105 ^{0}C dried soil = a

(Mass of soil sample after free drainage - Mass of oven dry soil) x 100 / (Mass of oven-dry soil)

% Moisture Air-dried soil/mass of 105 ^{0}C dried soil = b

(Mass of air-dried soil sample - Mass of oven-dried soil) x 100 / (Mass of oven-dry soil)

Amount of water needed to bring air-dried soil to field capacity

(a – b) / b x 1000 units: g water/kg air dry soil.

1.2 SOIL MOISTURE AT WILTING POINT

Water was withheld from the pots containing growing plants. After the plants showed signs of severe wilting, some water was applied and the plants revived. As water was progressively withheld, there came a time when the plants no longer revived after water was applied. The soil moisture at this stage of plant growth is called the permanent wilting point. Soil samples were collected from the soils beneath the plants that had died at permanent wilting point. The samples were weighed, and oven-dried at 105 ^{o}C to a constant weight to determine the soil moisture at wilting point.

The calculation of soil moisture at the wilting point is as follows:

Soil moisture at wilting point =

100 (Mass of soil at Wilting Point – Mass of oven dry soil) / (Mass of oven dry soil)

2. FERTILIZER APPLICATION

For experiments 2 and 3, a complete soluble fertilizer (Osmocote) was applied every second week (1 g/plant) for three months. Additional potassium was given as 1 g of potassium sulphate /plant at one week after planting. The calculation of fertilizer requirement is presented in Appendix A4, section 1. The chemical composition of Osmocote fertilizer is shown in Table A1.1.

Table A1.1 The chemical composition of Osmocote fertilizer (%).

N	**P**	**K**	**S**	**Mg**	**B**	**Cu**	**Fe**	**Mn**	**Mo**	**Zn**
28	1.8	14	0.5	0.5	0.025	0.07	0.16	0.05	0.002	0.06

A different method of fertilizer application was employed in the nutrient experiment and is discussed in Chapter 4.

3. PLANT GROWTH OBSERVATIONS

Variables measured were plant growth (height, length of longest shoot, basal diameter of shoots) tuber yield, plant water relations, morphology, anatomy, leaf chemical contents, and tuber organic contents. The methods used are set out below.

3.1 Morpho-physiological plant growth traits

- ***Fresh and dry plant biomass***

Leaf, vine, root, and tuber components were weighed separately and dried to constant weight (normally for 48 hours) in an oven (70^{o} C). Before weighing, tubers were washed to remove soil, air-dried for approximately 30 minutes, and weighed to obtain fresh weight.

- ***Branch number and the amount of leaf senescence per plant***

Number of branches was counted at harvest time, while senescence's leaves that had been collected from 1 to 4 months after planting were also weighed at harvest time.

- ***Leaf area (LA)***

Leaf area was determined using Paton Electronic Planimeter (Paton Industries, Stepney-SA) at harvest time, expressed in cm^2/plant. Leaf area is an important parameter as it is usually very closely related to photosynthetic efficiency (Taiz and Zeiger, 2002). Leaf area expansion is affected when a water deficit develops, however rapid leaf area expansion can adversely affect water availability (Taiz and Zeiger, 2002).

- ***Specific leaf area (SLA)***

Specific leaf area is expressed in cm^2/g or m^2/kg, is the ratio between leaf area and leaf dry mass (Reddy *et al*., 1989). SLA indicates leaf thickness, and has been related to leaf structure, growth and net photosynthesis (Barden, 1977). The computation of specific leaf area is as follows:

Specific leaf area (cm^2/g) = (area of leaves) / (mass of leaves) per plant

- ***Specific leaf weight (SLW)***

Specific leaf weight (specific leaf mass) is expressed in g/cm^2, is the ratio between leaf mass and leaf area and is an indicator of leaf thickness (Nobel, 1980). The calculation of specific leaf weight is as follows:

Specific leaf weight (g/cm^2) = (Mass of leaves) / (Area of leaves) per plant.

- ***Leaf dry matter content (LDMC)***

Leaf dry matter content is determined by the ratio of leaf dry mass to fresh mass. Specific leaf area and leaf dry matter content reflect a fundamental trade-off in plant functioning between a rapid production of biomass (high SLA, low LDMC species) and an efficient conservation of nutrients (low SLA, high LDMC species) (Garnier *et al*., 2001). The calculation of leaf dry matter content is as follows:

Leaf dry matter content = (Leaf dry mass) / (Leaf fresh mass) per plant

- ***Harvest index (HI)***

Harvest index gives an indication of the relative distribution of assimilates between the storage root and the remainder of the plant (Kuo and Chen, 1992). It is defined as the ratio of economic yield to biological yield at maturity (Ludlow and Muchow, 1990). This ratio varies on the ability of a genotype to partition current assimilates to the economic yield and the reallocation of stored or structural assimilates to the economic yield (Turner *et al*., 2001). Harvest index was measured as follows:

Harvest index = mass of tubers / shoot and root mass (g/plant)

3.2 Pigment contents

Plants contain pigment molecules that absorb light used in plant physiological process (Hopkins, 1999). Chlorophyll is the pigment primarily responsible for harvesting light energy used in photosynthesis (Hopkins, 1999). Carotene is lipid soluble, which also collects energy for photosynthesis and protects the chlorophyll against photo-oxidation (Leopold, 1964; Hopkins, 1999). Loss of photosynthetic pigments results in leaf deterioration. In potato, the levels of chlorophyll *a*, chlorophyll *b*, total chlorophyll concentration and the chlorophyll *a*/*b* ratio of cultivars can be used as an indication of drought tolerance after four weeks without water (van der Mescht *et al*., 1999). Chlorophyll *a*/*b* ratio is an index for determining photosynthetic efficiency. A high chlorophyll *a*/*b* ratio also indicates that the ratio between photo system II/photo system I contents change in stressed leaves (Anderson, 1986).

Photosynthetic pigments were determined using the method described by Wintermans and de Mots (1965). Young fully expanded leaves were collected from the plants as the maximum apparent photosynthetic rates of most crop species occur in the young fully expanded leaves (Brown, 1992). Approximately 2 g of fresh leaves were cut and weighed. The leaves were ground with a mortar and pestle with a pinch of acid-washed sand, 0.2 g $CaCO_3$, and 5 mL ethanol 100%. The solution was transferred to centrifuge tubes and made up to 25 mL of ethanol 100% and centrifuged for 15 minutes at 3,000 rpm to separate the supernatant from the cell materials and sand. The optical density of the supernatant was determined at 470, 649, 665 and 740 nm on a DMS 90 Varian Techtron UV-Visible Spectrophotometer, made by Varian Techtron Pty Limited, Australia. The amount of chlorophyll *a*, *b* and carotene were determined using the formula of Wintermans and de Mots (1965) below, after the 740 nm absorbance reading (A740) was subtracted from the others values to correct for background absorbance:

Chlorophyll *a* (g/mL) = 13.7 A665 – 5.76 A649

Chlorophyll *b* (g/mL) = 25.8 A649 – 7.60 A665

Carotene (g/mL) = (1000A470 – 2.05 Ca – 114.8 Cb)/245

3.3 Plant anatomy

Studies on leaf and stem anatomy were carried out under the guidance of Mrs. S. Reilly in the Histology Laboratory of the School of Marine and Tropical Biology, James Cook

University. Young fully developed leaves and stems were collected from each of the experimental pots for microscopic analysis. Transverse leaf sections were cut from the middle of each leaf (1 cm x 2 cm), and stems were cut (3 cm) at the third node from the end of the stem. Leaves and stems were put in the 10 mL of the botanical fixative (formaldehyde acetic acid alcohol), which contains 27% formaldehyde, 70% ethanol, 3% glacial acetic acid for two days. After immersion in the botanical fixative for 2 days, the plant tissues were stored in 70% ethanol. The tissues then were transferred to cassettes, embedded in paraffin wax, and sliced using a microtome (6 µm thick sections were made); plant tissues were processed through the alcohol series and stained with alcian blue and safranine. Leaf (transverse sections) and stem section were observed under a compound Olympus microscope to observe the leaf structure and the thickness of the leaf cuticle.

The epidermis of fresh leaf samples was dissected manually to study the density of stomata. Stomatal frequency or density, the lengths of guard cells and stomatal pores were measured at a magnification of 400X under an Olympus compound microscope. Stomata density was calculated based on the division between the number of stomata in the field of view at (40X) magnification and true area of the field of view, which approximately 45 mm^2 (Willmer and Fricker, 1996). All anatomical sections were photographed using a microscope digital camera DP 12 system.

The width and length of guard cells and length of stomatal pores were measured as indicated in Fig. A1.1

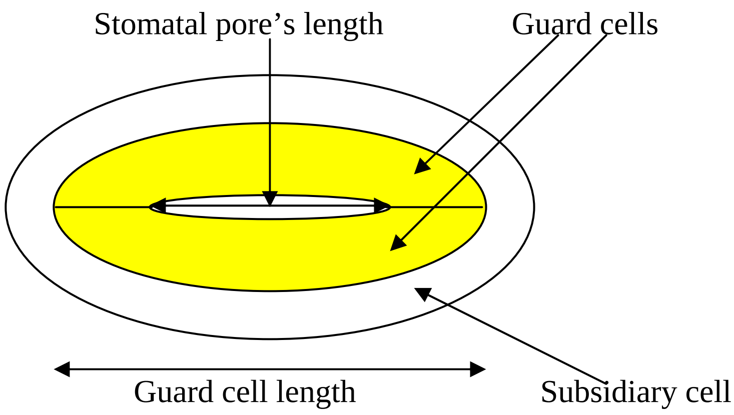

Figure A1.1 Measurements made on stomatal pores.

3.4 Plant water relations

The measurement of the components of plant water relations such as transpiration, leaf water potential (LWP), and relative water content (RWC) is an important part of understanding plant biomass production. Leaf water potential and relative water content, which are the components of plant water status, were measured on plants between 2 and 3 months after planting, as it has been reported that relative water content of sweet potato did not differ significantly at the first month of growth, however relative water content subsequently declined with age (Naskar and Roychowdhury, 1995).

- ***Transpiration***

Monitoring the weight loss of moist soil in an experimental pot over a given time interval once evaporative and drainage losses have been prevented is the most reliable method for measuring plant transpiration and is easily adapted for potted plants (Kirnak *et al*., 2001). The rate of water loss was determined by weighing the pots every 2 days at the same time of day (Riga and Vartanian, 1999), and recording the amount of water needed to bring the soil to a given field capacity. The soil surface in the pots was covered with black polyethylene plastic in the preliminary experiment while the remainder of experiments used aluminium foil to prevent the evaporation. A portable balance was used to weigh the pots from 0 to 15 kg with an accuracy of ± 5 g. The calculation of the water lost or transpiration rate is as follows:

Transpiration rate (g day^{-1}) = Initial weight of pot – (Weight of pot after 48 hours) / 2

- ***Leaf water potential***

Leaf water potential was measured in young fully expanded leaves taken from full light positions. The two methods used to measure leaf water potential involve a pressure chamber and thermocouple psychrometer (Beadle *et al*., 1993). The thermocouple psychrometer is highly sensitive instrument in which if used with inadequate procedures and attention can jeopardize the results (Brown and Oosterhuis, 1992). At equivalent water potentials, plant tissues may require longer equilibration time than solutions, and the equilibrium time may differ widely among different plant species (Brown and Oosterhuis, 1992). It is important to get the accurate readings by knowing the right equilibration time (Tru Psychrometer Water Potential Meter Operator Manual).

Preliminary studies were made to determine the optimum amount of leaf abrasion and equilibration time of leaf samples inside the thermocouple psychrometer chambers for sweet potato. The SC10A, Decagon Device Inc**.** Tru Psychrometer calibrates itself to a salt solution of 0.5 molal KCl (Tru Psychrometer Water Potential Meter Operator Manual). KCl in the sample cup of Tru Psychrometer equilibrated within a certain time, and the vapour pressure was monitored by repeated measurements. The results showed that KCl equilibrated with the air within the sample cup of thermocouple psychrometer within 7 to 9 minutes (Table A1.2 and Figure A1.2) at temperatures between 26 and 27 ^oC.

Table A1.2 Tru Psychrometer calibration with KCl at different equilibration times.

Sample No.	Equilibrium time of KCl with temperature (minutes)								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	-0.61	-0.54	-0.49	-0.47	-0.44	-0.44	-0.40	-0.39	-0.39
2	-0.59	-0.51	-0.44	-0.43	-0.41	-0.38	-0.34	-0.34	-0.35
3	-0.58	-0.51	-0.45	-0.45	-0.42	-0.40	-0.38	-0.40	-0.40
4	-0.57	-0.57	-0.54	-0.53	-0.45	-0.45	-0.42	-0.41	-0.42
Average (MPa)	**-0.59**	**-0.53**	**-0.48**	**-0.47**	**-0.43**	**-0.42**	**-0.38**	**-0.38**	**-0.39**

The numbers in each cell of the table indicate the value of leaf water potential of sweet potato leaf samples.

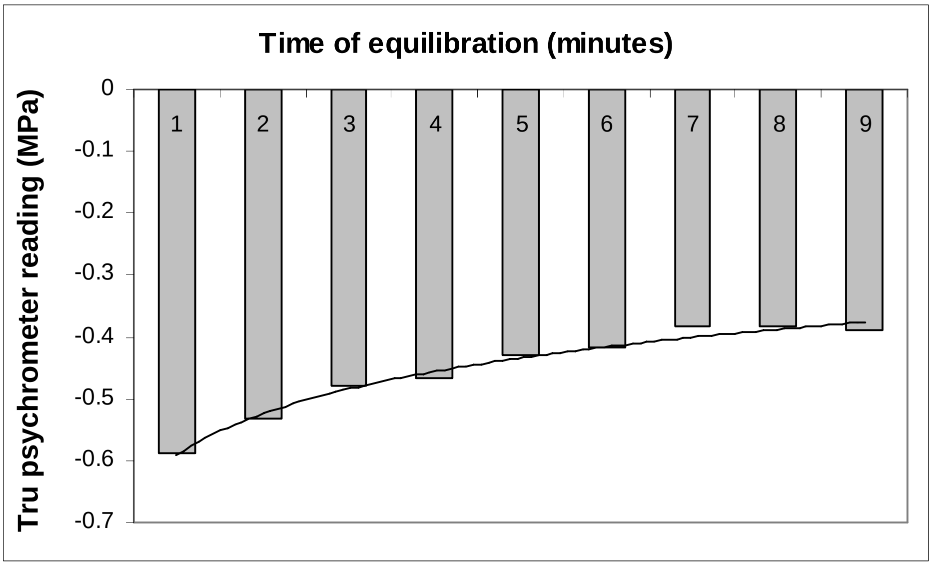

Figure A1.2 Time required for salt solution (KCl) to equilibrate with the air inside the sample cup of thermocouple psychrometer.

Leaf samples need time to come to temperature equilibrium inside the cup chamber of the psychrometer (Tru Psychrometer Water Potential Meter Operator Manual). Based on a preliminary trial, the standard equilibration time curve of a Peltier thermocouple for sweet potato leaf was from 2 to 3 hours (Figure A1.3).

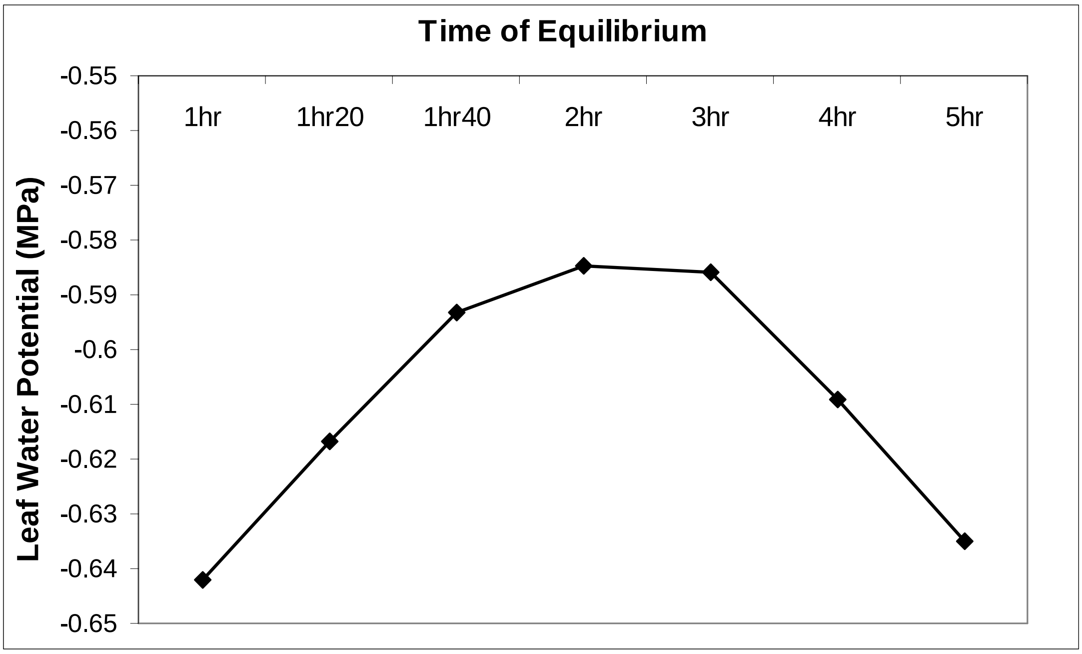

Figure A1.3 Curve of the equilibrium time of sweet potato leaves in the sample cup of thermocouple psychrometer (Data represents the mean of 4 replications).

To increase the water vapour conductance across the leaf epidermis, the waxy leaf cuticle should be removed or broken by abrasion (Brown and Oosterhuis, 1992). Fine (600-grit) sandpaper was used as it was found to be the best method in producing the greatest conductance (Campbell and McInnes, 1999). The preliminary trial of leaf abrasion examined six abrasion treatments (leaves rubbed 1, 2, 3, 4, 5, and 6 times) were compared to determine the most effective rubbing number. An analysis of variance of the results showed that there was a significant difference across the leaf rubbing treatments (Table A1.3). Based on the Duncan Multiple Range Test, 2, 3, and 4 leaf rubbings were significantly different from 1 and 6 leaf rubbings, while 5 leaf rubbings was not significantly different from all other treatments.

The four leaf rubbings had the smallest standard error (Figure A1.4) and was accepted as the most effective way to increase leaf vapour conductance of sweet potato.

Excessive rubbing may have allowed moisture to be lost from the leaf prior to putting it in the sample chamber of the Tru Psychrometer Water Potential Meter.

Table A1.3 Analyses variance of leaf rubbing treatments.

	Sum of squares	df	Mean Square	F	Sig.
Between groups	0.074	5	0.015	4.227	0.003
Within groups	0.169	48	0.004		
Total	0.243	53			

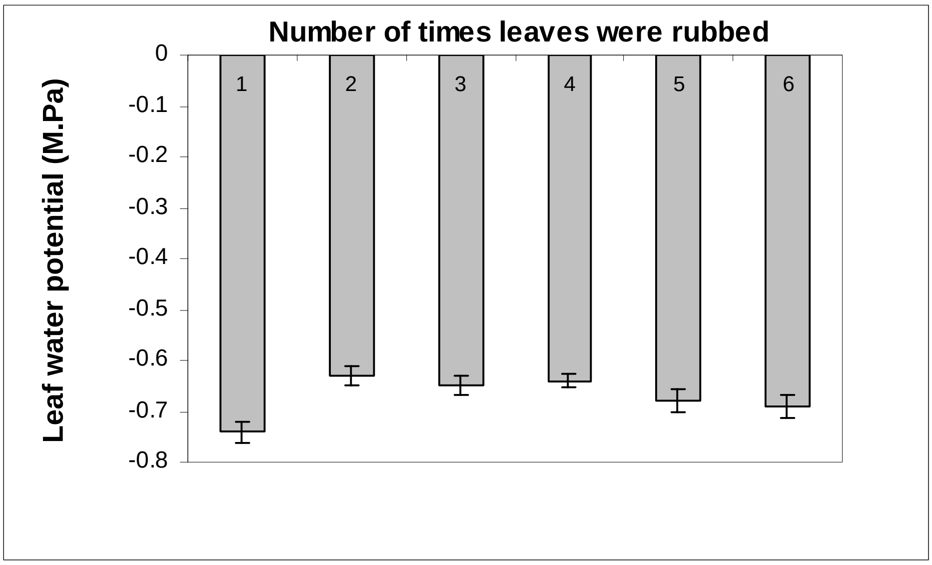

Figure A1.4 Average leaf water potential as affected by the number of leaf rubbings. Vertical bars represent standard errors of the means of nine replications.

A Scholander type pressure chamber (Plant Moisture Stress, Corvalis, Oregon) was used to determine leaf water potential. It is a rapid method, portable, and is commonly used as a field instrument (Sullivan 1971). Sweet potato leaves were detached and quickly placed in a pressure chamber with the cut end protruding a few millimetres from the top exit. The plant part was sealed in the chamber with a rubber stopper. When the leaf was severed the xylem sap, which was under tension, receded from the cut (Sullivan, 1971). When pressure was slowly applied to the chamber, the sap was forced back to the cut end. Some bubbles appeared first, but the pressure when sap first wet the cut surface was taken as equal to the tension and water potential of the tissue before it was excised (Sullivan, 1971). The latex appeared as a thick white fluid, which easily recognised from the clear xylem sap bubble when emerged from the cut.

- ***Relative water content (RWC) of leaf tissue***

This method is also used to assess the water status of plants. Leaf relative water content was measured using the method of Kramer (1980); Weatherley (1950) *in* Sullivan (1971) and Chandrasekar *et al.,* (2000). Leaf discs (10 mm in diameter) were taken from young fully expanded leaves in the field, and sealed in tubes. Weatherley (1950) in Sullivan (1971) used leaf discs in order to shorten the saturation time. The tubes containing leaf samples were immediately placed on ice in an insulated cool box but not frozen, and immediately brought to the laboratory. Leaf discs that were cut from the leaves were directly weighed to determine fresh weight (FW). Samples were then floated in 100 mL of distilled water in a closed Petri dish under low light for 4 hours for unstressed leaves, and for 5 hours for leaves from water stressed plants. The optimal times for imbibition were determined in a preliminary experiment described below. Leaf samples were taken out of water and were surface-dried with paper tissues, and their turgid masses (TW) were recorded. The samples were packed in paper bags, and oven dried at 65 ^{o}C for 48 hours for dry mass (DW) determination. The leaf discs were weighed using an analytical balance with precision of 0.00001 g. The calculation of leaf relative water content is as follow:

Leaf relative water content (%) = 100 (FW-DW) / (TW-DW)

Despite its simplicity, the technique needs to be adjusted for different plants. Adjustment is mainly related to the length and environmental conditions of the imbibition period needed to obtain the turgid mass (Yamasaki and Dillenburg, 1999). Therefore, it is essential to determine the accurate saturation times for particular species at the onset of experiment (Sullivan, 1971).

To calculate the leaf relative water content, a preliminary study was conducted to determine the appropriate saturation time. The pattern of water absorption between untreated controls and water stressed plants was observed in a preliminary trial. Young fully expanded leaves were collected from sweet potato cultivars. Leaf discs of (1 cm diameter) several replications were cut, weighed, and floated in distilled water from 1 to 8 hours. After imbibing, the leaves were weighed and oven dried at 60 ^{o}C. The leaf discs were weighed using an analytical balance with precision of 0.00001 g. Relative water content was calculated as the formula given in Appendix A1, section 3.4. It shows that unstressed sweet potato leaves require 4 hours imbibition, whereas stressed sweet potato leaves require 5 to 6 hours to reach the saturation time (Figure A1.5).

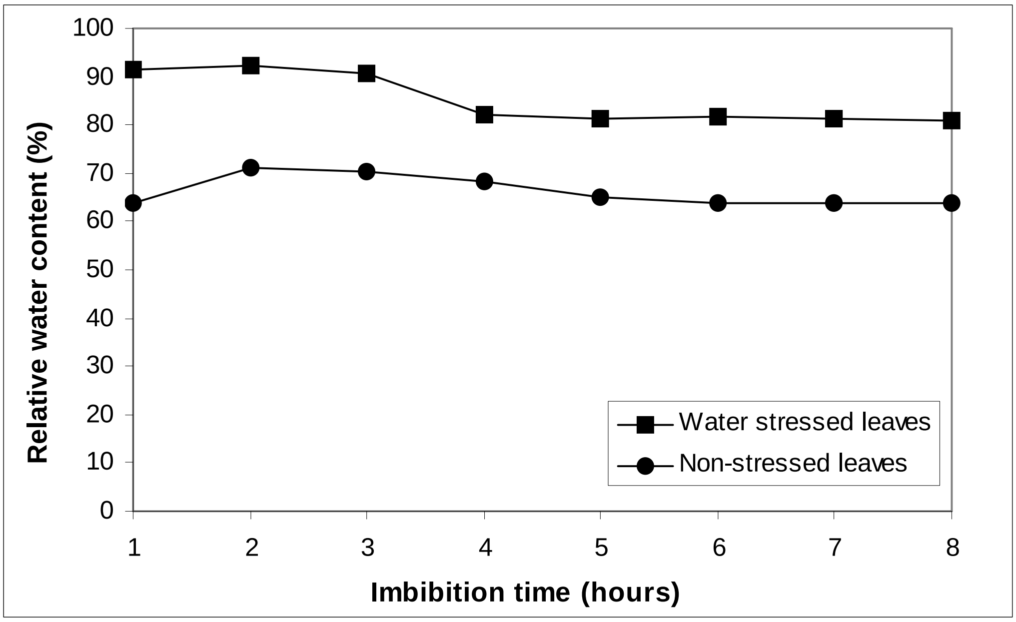

Figure A1.5 Effect of imbibition times on the determination of relative water content of stressed and non-water stressed sweet potato leaves.

Based on the saturation curves of Fig. A1.5, there were 2 phases for unstressed leaves, namely 1-3 hours, and 4-8 hours. According to Weatherley (1950) in Sullivan (1971), the first phase is where the most rapid uptake of water is associated with tissue growth or perhaps penetration of water into the intercellular spaces. The second phase is the saturation time, when no more tissue growth possibly occurred. However, in the stressed leaf, there were 3 phases (Figure A1.5), namely 1 hour, 2-4 hours, and 5-8 hours. In the first phase, the sweet potato leaf slowly absorbed water, and was probably related to the reactivation of cell structural function, followed by the second phase in which the leaf regained its full turgidity. The third phase shows that leaf achieved saturation. According to Yamasaki and Dillenburg (1999), the narrow leaves of *Araucaria angustifolia* require a longer periods of imbibition than broad leaf species. Also, leaves that develop under drought conditions require longer period of imbibition than those that developed under conditions of higher water availability, probably as a consequence of drought-induced structural changes in the leaf tissue.

- ***Water use efficiency (WUE)***

This parameter is defined as the yield of plant product per unit of crop water used, and is important in all areas of plant production (Atwell *et al*., 1999). It is defined in two ways. First, the water use efficiency of productivity is the ratio between above-ground gain in biomass and the loss of water during the production of that biomass; the water lost may refer to total transpiration only. Second, photosynthetic water use efficiency is the ratio between carbon gain in photosynthesis and the lost of water in transpiration (Lambers *et al*., 1998). Water use efficiency plays an important role in productivity and survival under drought stress (Da Matta *et al*., 2003). Water use efficiency is the amount of the harvested product produced per unit of water used. A plant that has higher water use efficiency will resist drought better (Taiz and Zeiger, 2002). Water use efficiency was measured as follows:

Water use efficiency [g/kg of H_2O] = dry biomass (g/plant)/ the amount of water used (kg/plant)

3.5 Tuber organic contents

Tubers were harvested and dried to constant weight in an oven at 60^0C (normally 48 hours). The dried tubers were ground to powder using a plant grinding machine (Micro-Feinmühle-Gulatti DCFH 48 type) made by Janke and Keenkel IKA-Labortechnik. The powdered samples were kept in brown paper bags prior to analysis. Soluble carbohydrates and total non-structural carbohydrates were analysed by the Analytical Laboratory, School of Land and Food Sciences, University of Queensland, Brisbane using the methods set out as follow:

- **Analysis of tuber organic components**

  This procedure permits the determination of soluble carbohydrates (CHO) and Total Non-Structural Carbohydrates (TNSC) with discrimination between starch and fructosan polysaccharides.

- **Reagents**

  1. Buffer pH 4.9. Dissolve 16.4 g Na acetate in 1L double deionised water (0.2 M). Prepare 0.2 M acetic acid by diluting 11.5 mL of glacial acetic acid to 1L. Mix 100 mL of 0.2M acetic acid with 150 mL of 0.2M Na acetate. Adjust to pH 4.9. Add 50 mg thymol and store at 5 °C.
  2. Amylase enzyme. Weigh out 300 mg of Amylase enzyme (MP Biomedicals catalogue No. 0215037505) in 200 mL double deionised water add 100 mg $CaCl_2$, and one crystal of thymol. Store at 5 °C. Discard after 5 days.
  3. Trichloroacetic acid 20%. Dissolve 100 g of trichloroacetic acid in 500 mL double deionised water.
  4. HCl 0.1 M. Dilute 10 mL HCl to 1 L with double deionised water.
  5. NaOH 0.1 M. Dissolve 400 mg NaOH in 100 mL double deionised water.
  6. Potassium ferricyanide. Dissolve 750 mg of $K_3Fe(CN)_6$ + 20 g Na_2CO_3 in 1 L double deionised water.

- **Stock standards**

  1. Glucose standard 20 mg/mL. Weigh out 1000 mg of AR glucose and dissolve in 30 mL double deionised water, dilute to 50 mL in a volumetric flask. Store at 5 °C.

- **Procedure**

Sample Preparation

Weigh 100-200 mg of plant material (ground to pass a 1 mm sieve) into a 50 mL polypropylene tube. Extract each sample with 3 x 15 mL of 80% ethanol at 80 °C in a water bath for 3 minutes to extract the soluble carbohydrates. Dilute the extracts to 50 mL and retain for soluble carbohydrates determination. Dry the 50 mL tubes overnight in the waterbath. Add 15 mL of double deionised water to each tube and mix on vortex mixer. Place in the waterbath at 95 °C and heat for 1 hour. Agitate the tubes every 10 minutes to solubilize the starch. Cool to room temperature and add 10 mL of buffer plus 10 mL of amylase enzyme. Cap, vortex the tubes and incubate @ 55 °C for 2 hours. Cool and add 9 mL of 20% trichloroacetic acid, vortex, re-cap the tubes and centrifuge at 2500 rpm for 10 minutes. Transfer the supernatant into a 100 mL volumetric flask and then add 15 mL of double deionised water to the tube, cap and vortex. Centrifuge the tubes again and transfer the supernatant to the volumetric flask. Dilute to 100 mL and mix. Filter 10 mL through a Whatman glass fibre filter (GF/B) into a 10 mL plastic tube.
Note: For coloured samples or those known to contain phenolics, it is then necessary to pass the filtered solution through a pre methanol wetted 300 mg C-18 Sep-Pak tube discarding the first 1 mL of solution.

For a recovery test, weigh out 25, 50 and 100 mg quantities of starch and process these, along with a blank, using the following sample preparation procedure. Weigh out a separate 100 mg sample of starch into a dry pre-weighed beaker, dry at 65 °C for 6 hours and reweigh. Calculate the moisture content of the starch and the correction factor to correct for this in the recovery calculation.

Glucose standards

The glucose standards must be processed through the same sample preparation process as for the samples. Pipette 0.0, 0.50, 1.00, 1.50, 2.00, 2.50, 3.00 mL of the glucose standard into separate 50 mL polypropylene tubes, add 15 mL of double deionised water, cap and heat at 95 °C in a water bath for 1 hour. Cool to room temperature and add 10 mL of buffer plus 10 mL of amylase enzyme. Cap, vortex the tubes, and incubate at 55 °C for 2 hours. Add 9 mL of 20% trichloroacetic acid and vortex. Transfer into a 100 mL volumetric flask and dilute to 100 mL and mix. Final concentrations of glucose are: 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.60 mg/mL.

Colorimetric analysis

For the starch hydrolysed samples, take 0.2 mL of the final prepared sample, add to 0.4 mL of 0.1 M HCl. Where fructosans are to be included as part of the total non-structural carbohydrates determination, heat at 85 °C for 10 minutes and cool, otherwise if starch only is to be determined, proceed directly to the next step. Add 0.4 mL of 0.1 M NaOH + 5.0 mL of the potassium ferricyanide reagent into a 10 mL tube, cap and heat at 85 °C for 20 minutes. Cool and measure the absorbance at 420 nm.

The soluble carbohydrate content was determined by filtering the diluted ethanol extract through a GF/B filter and if necessary treat with a tube to remove any phenolics. Then pipette 0.2 mL of extract into a 10 mL tube, add 0.4 mL of 0.1M HCl, heat at 85 °C for 10 minutes, cool and add 0.4 mL of 0.1 M NaOH + 5.0 mL of the ferricyanide reagent, vortex and heat at 85 °C for 20 min. Cool and measure the absorbance at 420nm. Prepare a standard curve from glucose standards of 0, 0.05, 0.1, 0.15, 0.20 mg/mL in 80% ethanol.

The colorimetric step for the standards prepared for starch analysis then follows the same steps as for the samples.

Calculations

For the calculation of percentage starch or percentage total non-structural carbohydrates an inverse calibration curve for the glucose standards was fitted using Table Curve (Jandel scientific equation fitting program). This equation was used to calculate the glucose concentrations in the sample. Then using the sample weights, calculate the starch concentration in the samples using the equation:

% Starch = (mg/mL glucose*100/mg sample*100)*0.9

For the calculation of soluble carbohydrate the following equation was used:

% Soluble carbohydrate = (mg/mL glucose*50/mg sample*100)

APPENDIX A2

PLANT MEASUREMENTS AND RESULTS OF STATISTICAL ANALYSES OF CHAPTER 2

Table A2: 1 Matrix multiple comparison of the mean of main stem length of 15 sweet potato cultivars (Experiment 1a).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-														
2	*	-													
3	*	*	-												
4	*	*	*	-											
5	*	*	*	ns	-										
6	*	*	*	*	*	-									
7	*	ns	*	*	*	ns	-								
8	*	ns	*	ns	*	ns	ns	-							
9	*	ns	*	ns	*	ns	ns	ns	-						
10	*	ns	*	ns	*	ns	ns	ns	ns	-					
11	ns	*	ns	*	*	*	*	*	*	*	-				
12	*	ns	*	*	*	*	ns	ns	ns	ns	*	-			
13	*	ns	*	*	*	*	ns	ns	*	*	*	ns	-		
14	*	*	*	ns	*	ns	ns	ns	ns	ns	*	ns	*	-	
15	*	ns	*	ns	*	ns	ns	ns	ns	ns	*	ns	ns	ns	-

Table A2: 2 Matrix multiple comparison of the mean of main stem length of 15 sweet potato cultivars (Experiment 1b).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-														
2	*	-													
3	*	*	-												
4	*	*	*	-											
5	*	*	*	*	-										
6	*	*	*	ns	*	-									
7	*	ns	*	*	*	ns	-								
8	*	ns	*	*	*	ns	ns	-							
9	*	ns	*	ns	*	ns	ns	ns	-						
10	*	ns	*	ns	*	ns	ns	ns	ns	-					
11	ns	*	ns	*	*	*	*	*	*	*	-				
12	*	ns	*	*	*	*	ns	ns	ns	ns	ns	-			
13	*	ns	*	*	*	*	ns	ns	*	*	*	ns	-		
14	*	*	*	ns	*	ns	ns	ns	ns	ns	*	ns	*	-	
15	*	ns	*	ns	*	ns	ns	ns	ns	ns	*	ns	ns	ns	-

Number 1-15 represents cultivars (1= Beerwah Gold, 2= Hawaii, 3 =Lole, 4=Markham, 5= Mariken, 6= Wanmun, 7= NG7570, 8= LO323, 9= L3, 10= L11, 11= L18, 12= L46, 13= L49, 14= L131, 15= L135).
ns= not significant; ***** = significant different at $p < 0.05$, Bonferroni test.

Table A2: 3 Matrix multiple comparison of the mean of dry plant biomass of 15 sweet potato cultivars (Experiment 1a).

	1														
1	-	2													
2	ns	-	3												
3	*	ns	-	4											
4	ns	ns	ns	-	5										
5	ns	ns	*	ns	-	6									
6	ns	ns	*	ns	ns	-	7								
7	ns	ns	ns	ns	ns	ns	-	8							
8	ns	*	*	*	ns	ns	*	-	9						
9	ns	ns	*	ns	ns	ns	ns	ns	-	10					
10	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	11				
11	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	-	12			
12	ns	ns	*	ns	ns	ns	ns	*	ns	ns	ns	-	13		
13	ns	*	*	ns	ns	ns	ns	ns	ns	*	*	ns	-	14	
14	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	*	-	15
15	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	*	ns	-

Number 1-15 represents cultivars (1= Beerwah Gold, 2= Hawaii, 3 =Lole, 4=Markham, 5= Mariken, 6= Wanmun, 7= NG7570, 8= LO323, 9= L3, 10= L11, 11= L18, 12= L46, 13= L49, 14= L131, 15= L135).
ns= not significant; ***** = significant different at $p < 0.05$, Bonferroni test.

Table A2: 4 Matrix multiple comparison of the mean of dry plant biomass of 15 sweet potato cultivars (Experiment 1b).

	1														
1	-	2													
2	*	-	3												
3	*	ns	-	4											
4	ns	*	*	-	5										
5	ns	*	*	ns	-	6									
6	ns	*	*	ns	ns	-	7								
7	*	ns	*	*	*	*	-	8							
8	ns	*	*	ns	ns	ns	*	-	9						
9	ns	*	*	ns	ns	ns	*	ns	-	10					
10	ns	*	*	ns	ns	ns	ns	*	ns	-	11				
11	*	ns	*	*	*	*	ns	*	ns	ns	-	12			
12	ns	*	*	ns	ns	ns	ns	*	*	ns	ns	-	13		
13	ns	*	*	ns	ns	ns	*	ns	ns	ns	*	ns	-	14	
14	*	ns	ns	*	*	*	*	*	*	*	ns	*	*	-	15
15	ns	*	*	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	*	-

Number 1-15 represents cultivars (1= Beerwah Gold, 2= Hawaii, 3 =Lole, 4=Markham, 5= Mariken, 6= Wanmun, 7= NG7570, 8= LO323, 9= L3, 10= L11, 11= L18, 12= L46, 13= L49, 14= L131, 15= L135).
ns= not significant; ***** = significant different at $p < 0.05$, Bonferroni test.

Table A2: 5 Matrix multiple comparison of the mean of dry leaf mass of 15 sweet potato cultivars (Experiment 1a).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-														
2	ns	-													
3	ns	*	-												
4	ns	ns	*	-											
5	ns	ns	ns	ns	-										
6	ns	ns	ns	ns	ns	-									
7	*	ns	*	ns	*	ns	-								
8	ns	ns	*	ns	ns	ns	ns	-							
9	ns	ns	*	ns	ns	ns	ns	ns	-						
10	*	ns	*	ns	*	ns	ns	ns	ns	-					
11	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	-				
12	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	-			
13	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	-		
14	ns	*	ns	*	ns	*	*	*	*	*	*	*	*	-	
15	ns	ns	ns	ns	ns	ns	*	ns	ns	*	ns	ns	ns	ns	-

Number 1-15 represents cultivars (1= Beerwah Gold, 2= Hawaii, 3 =Lole, 4=Markham, 5= Mariken, 6= Wanmun, 7= NG7570, 8= LO323, 9= L3, 10= L11, 11= L18, 12= L46, 13= L49, 14= L131, 15= L135).
ns= not significant; ***** = significant different at $p < 0.05$, Bonferroni test.

Table A2: 6 Matrix multiple comparison of the mean of dry leaf mass of 15 sweet potato cultivars (Experiment 1b).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-														
2	ns	-													
3	ns	ns	-												
4	ns	ns	ns	-											
5	*	ns	ns	*	-										
6	ns	ns	ns	ns	ns	-									
7	ns	ns	ns	ns	ns	ns	-								
8	ns	*	*	ns	*	*	*	-							
9	ns	ns	ns	ns	ns	ns	ns	ns	-						
10	ns	ns	ns	ns	ns	ns	ns	*	ns	-					
11	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	-				
12	ns	*	ns	ns	*	ns	ns	ns	ns	ns	ns	-			
13	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-		
14	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	
15	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-

Number 1-15 represents cultivars (1= Beerwah Gold, 2= Hawaii, 3 =Lole, 4=Markham, 5= Mariken, 6= Wanmun, 7= NG7570, 8= LO323, 9= L3, 10= L11, 11= L18, 12= L46, 13= L49, 14= L131, 15= L135).
ns= not significant; ***** = significant different at $p < 0.05$, Bonferroni test.

Table A2: 7 Matrix multiple comparison of the mean of leaf area of 15 sweet potato cultivars (Experiment 1a).

	1														
1	-	2													
2	ns	-	3												
3	*	*	-	4											
4	*	ns	*	-	5										
5	ns	ns	*	*	-	6									
6	ns	ns	*	ns	ns	-	7								
7	*	ns	*	ns	*	ns	-	8							
8	ns	ns	*	ns	ns	ns	ns	-	9						
9	ns	ns	*	ns	ns	ns	ns	ns	-	10					
10	ns	ns	*	*	ns	ns	*	*	ns	-	11				
11	ns	ns	*	*	ns	ns	*	*	ns	ns	-	12			
12	ns	ns*	*	*	ns	*	*	*	*	ns	ns	-	13		
13	ns	ns	*	*	ns	ns	*	ns	ns	ns	ns	ns	-	14	
14	ns	*	ns	*	ns	*	*	*	*	ns	ns	ns	ns	-	15
15	ns	*	ns	*	ns	*	*	*	*	ns	ns	ns	ns	ns	-

Table A2: 8 Matrix multiple comparison of the mean of leaf area of 15 sweet potato cultivars (Experiment 1b).

	1														
1	-	2													
2	ns	-	3												
3	*	*	-	4											
4	ns	ns	*	-	5										
5	ns	ns	*	ns	-	6									
6	ns	ns	*	ns	ns	-	7								
7	ns	ns	*	ns	ns	ns	-	8							
8	ns	ns	*	ns	ns	ns	ns	-	9						
9	ns	ns	*	ns	ns	ns	ns	ns	-	10					
10	ns	ns	*	ns	ns	ns	ns	ns	ns	-	11				
11	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	-	12			
12	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	-	13		
13	ns	ns	*	ns	ns	ns	*	*	ns	ns	ns	ns	-	14	
14	*	ns	ns	*	ns	*	*	*	*	*	*	*	ns	-	15
15	ns	ns	ns	*	ns	ns	*	*	*	ns	ns	*	ns	ns	-

Number 1-15 represents cultivars (1= Beerwah Gold, 2= Hawaii, 3 =Lole, 4=Markham, 5= Mariken, 6= Wanmun, 7= NG7570, 8= LO323, 9= L3, 10= L11, 11= L18, 12= L46, 13= L49, 14= L131, 15= L135).
ns= not significant; ***** = significant different at $p< 0.05$, Bonferroni test.

Table A2: 9 Matrix multiple comparison of the mean of internode length of 15 sweet potato cultivars (Experiment 1b).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-														
2	*	-													
3	ns	*	-												
4	*	*	*	-											
5	*	*	*	ns	-										
6	*	ns	*	*	*	-									
7	*	ns	*	ns	*	ns	-								
8	*	ns	*	ns	*	ns	ns	-							
9	*	ns	*	ns	*	ns	ns	ns	-						
10	*	ns	*	ns	*	*	ns	ns	ns	-					
11	ns	*	ns	*	*	*	*	*	*	*	-				
12	*	ns	*	*	*	ns	ns	*	*	*	*	-			
13	ns	ns	*	*	*	ns	ns	*	*	*	*	ns	-		
14	*	ns	*	*	*	ns	ns	ns	ns	ns	*	ns	ns	-	
15	ns	ns	*	*	*	ns	ns	*	*	*	*	ns	ns	ns	-

Table A2: 10 Matrix multiple comparison of internodes diameter of 15 sweet potato cultivars (Experiment 1b).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-														
2	*	-													
3	*	ns	-												
4	ns	*	*	-											
5	*	ns	ns	*	-										
6	ns	*	*	ns	*	-									
7	*	ns	*	*	ns	*	-								
8	*	ns	ns	*	ns	*	ns	-							
9	ns	*	*	ns	*	ns	*	*	-						
10	ns	*	*	ns	*	ns	*	*	ns	-					
11	ns	*	*	ns	*	ns	*	*	ns	ns	-				
12	ns	*	*	ns	*	ns	*	*	ns	ns	ns	-			
13	*	*	*	*	*	*	*	*	*	*	*	*	-		
14	*	ns	ns	*	ns	*	ns	ns	*	*	*	*	*	-	
15	*	ns	ns	*	ns	*	ns	ns	*	*	*	*	*	ns	-

Number 1-15 represents cultivars (1= Beerwah Gold, 2= Hawaii, 3 =Lole, 4=Markham, 5= Mariken, 6= Wanmun, 7= NG7570, 8= LO323, 9= L3, 10= L11, 11= L18, 12= L46, 13= L49, 14= L131, 15= L135).
ns= not significant; ***** = significant different at $p < 0.05$, Bonferroni test.

Table A2: 11 Matrix multiple comparison of root masses of 15 sweet potato cultivars under well watered supplied (Experiment 1b).

	1														
1	-	2													
2	ns	-	3												
3	*	ns	-	4											
4	ns	ns	*	-	5										
5	ns	*	*	ns	-	6									
6	ns	ns	ns	ns	*	-	7								
7	ns	ns	ns	ns	*		-	8							
8	ns	*	*	ns	ns	*	*	-	9						
9	ns	ns	*	ns	ns	ns	ns	ns	-	10					
10	*	ns	ns	ns	*	ns	ns	*	*	-	11				
11	ns	ns	ns	*	*	ns	ns	*	*	ns	-	12			
12	ns	ns	ns	ns	*	ns	ns	*	ns	ns	ns	-	13		
13	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	*	ns	-	14	
14	*	ns	ns	*	*	ns	ns	*	*	ns	ns	ns	ns	-	15
15	ns	ns	ns	ns	*	ns	ns	*	ns	ns	ns	ns	ns	ns	-

Table A2: 12 Matrix multiple comparison of root masses of 15 sweet potato cultivars under well watered supplied (Experiment 1b).

	1														
1	-	2													
2	ns	-	3												
3	ns	ns	-	4											
4	ns	ns	ns	-	5										
5	ns	ns	ns	ns	-	6									
6	ns	ns	ns	ns	ns	-	7								
7	ns	ns	ns	ns	ns	ns	-	8							
8	ns	ns	ns	ns	ns	ns	ns	-	9						
9	ns	ns	ns	ns	ns	ns	ns	ns	-	10					
10	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	11				
11	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	12			
12	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	13		
13	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	14	
14	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	15
15	*	ns	ns	*	ns	ns	ns	ns	*	ns	ns	*	*	ns	-

Number 1-15 represents cultivars (1= Beerwah Gold, 2= Hawaii, 3 =Lole, 4=Markham, 5= Mariken, 6= Wanmun, 7= NG7570, 8= LO323, 9= L3, 10= L11, 11= L18, 12= L46, 13= L49, 14= L131, 15= L135).
ns= not significant; * = significant different at p< 0.05, Bonferroni test.

Table A2: 13 Matrix multiple comparison of leaf dry matter content of 15 sweet potato cultivars (Experiment 1b).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-														
2	*	-													
3	*	ns	-												
4	ns	ns	ns	-											
5	*	ns	ns	ns	-										
6	*	ns	ns	ns	ns	-									
7	*	ns	*	*	ns	ns	-								
8	ns	*	*	ns	*	*	*	-							
9	*	ns	ns	ns	ns	ns	ns	*	-						
10	*	ns	ns	ns	ns	ns	ns	*	ns	-					
11	*	ns	ns	*	ns	ns	ns	*	ns	ns	-				
12	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	*	-			
13	*	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	-		
14	*	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	-	
15	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	-

Table A2: 14 Matrix multiple comparison of specific leaf area of 15 sweet potato cultivars (Experiment 1b).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-														
2	ns	-													
3	ns	ns	-												
4	ns	ns	ns	-											
5	*	ns	*	ns	-										
6	ns	ns	ns	ns	ns	-									
7	*	ns	*	ns	ns	ns	-								
8	ns	ns	ns	ns	ns	ns	*	-							
9	*	ns	*	ns	ns	ns	ns	ns	-						
10	ns	ns	*	ns	ns	ns	ns	ns	ns	-					
11	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	-				
12	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	-			
13	ns	ns	ns	ns	*	ns	*	ns	ns	ns	ns	ns	-		
14	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	
15	ns	ns	ns	ns	*	ns	*	ns	ns	ns	ns	ns	ns	ns	-

Number 1-15 represents cultivars (1= Beerwah Gold, 2= Hawaii, 3 =Lole, 4=Markham, 5= Mariken, 6= Wanmun, 7= NG7570, 8= LO323, 9= L3, 10= L11, 11= L18, 12= L46, 13= L49, 14= L131, 15= L135).
ns= not significant; ***** = significant different at $p < 0.05$, Bonferroni test.

Table A2: 15 Matrix multiple comparison of the number of days to reach permanent wilting point in 15 sweet potato cultivars. Data was presented from the experiment 1b.

	1														
1	-	2													
2	*	-	3												
3	*	ns	-	4											
4	*	ns	*	-	5										
5	ns	*	*	*	-	6									
6	ns	*	*	ns	ns	-	7								
7	ns	*	*	ns	ns	ns	-	8							
8	ns	*	*	ns	ns	ns	ns	-	9						
9	ns	*	*	ns	ns	ns	ns	ns	-	10					
10	*	ns	*	ns	ns	ns	ns	ns	ns	-	11				
11	*	ns	*	ns	ns	ns	ns	ns	ns	ns	-	12			
12	*	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	-	13		
13	*	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	14	
14	*	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	15
15	*	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-

Table A2: 16 Matrix multiple comparison of the shoot fresh mass of 15 sweet potato cultivars (Field experiment).

	1														
1	-	2													
2	ns	-	3												
3	ns	ns	-	4											
4	ns	ns	ns	-	5										
5	*	*	*	ns	-	6									
6	ns	ns	ns	ns	ns	-	7								
7	ns	ns	ns	ns	*	ns	-	8							
8	ns	ns	ns	ns	ns	ns	ns	-	9						
9	ns	ns	ns	ns	ns	ns	ns	ns	-	10					
10	*	ns	ns	ns	ns	ns	ns	ns	ns	-	11				
11	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	-	12			
12	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	13		
13	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	14	
14	*	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	-	15
15	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	nsn	ns	ns	ns	-

Number 1-15 represents cultivars (1= Beerwah Gold, 2= Hawaii, 3 =Lole, 4=Markham, 5= Mariken, 6= Wanmun, 7= NG7570, 8= LO323, 9= L3, 10= L11, 11= L18, 12= L46, 13= L49, 14= L131, 15= L135).
ns= not significant; ***** = significant different at p< 0.05, Bonferroni test.

Table A2: 17 Matrix multiple comparison of marketable tuber number of 15 sweet potato cultivars (Field experiment).

	1														
1	-	2													
2	*	-	3												
3	*	ns	-	4											
4	*	ns	ns	-	5										
5	ns	*	*	*	-	6									
6	*	ns	ns	ns	ns	-	7								
7	ns	*	*	ns	ns	ns	-	8							
8	ns	*	*	*	ns	*	ns	-	9						
9	*	ns	ns	ns	*	ns	ns	*	-	10					
10	*	ns	ns	ns	*	ns	*	*	ns	-	11				
11	*	ns	ns	ns	*	ns	*	*	ns	ns	-	12			
12	*	ns	ns	ns	*	ns	ns	*	ns	ns	ns	-	13		
13	*	ns	ns	ns	*	ns	ns	*	ns	ns	ns	ns	-	14	
14	*	ns	ns	ns	*	ns	*	*	ns	ns	ns	ns	ns	-	15
15	*	ns	ns	ns	*	ns	*	*	ns	ns	ns	ns	ns	ns	-

Table A2: 18 Matrix multiple comparison of tuber yields of 15 sweet potato cultivars (Field experiment).

	1														
1	*	2													
2	*	-	3												
3	*	*	-	4											
4	ns	ns	ns	-	5										
5	ns	*	*	*	-	6									
6	ns	*	*	*	ns	-	7								
7	ns	*	*	*	ns	ns	-	8							
8	ns	*	*	*	ns	ns	ns	-	9						
9	*	ns	*	ns	ns	ns	*	ns	-	10					
10	*	ns	ns	ns	*	*	*	*	*	-	11				
11	*	ns	ns	ns	*	*	*	*	ns	ns	-	12			
12	*	*	*	*	ns	ns	ns	*	ns	*	*	-	13		
13	*	ns	ns	ns	ns	ns	*	ns	ns	*	ns	ns	-	14	
14	ns	*	*	*	ns	ns	ns	*	ns	*	*	ns	ns	-	15
15	*	ns	*	ns	ns	ns	*	ns	ns	*	ns	ns	ns	ns	-

Number 1-15 represents cultivars (1= Beerwah Gold, 2= Hawaii, 3 =Lole, 4=Markham, 5= Mariken, 6= Wanmun, 7= NG7570, 8= LO323, 9= L3, 10= L11, 11= L18, 12= L46, 13= L49, 14= L131, 15= L135).
ns= not significant; ***** = significant different at $p < 0.05$, Bonferroni test.

Table A2: 19 Analysis of variance on the main stem length of fifteen sweet potato cultivars as affected by soil water stress in experiment 1a.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected Model	17.515	29	.604	17.191	.000
Intercept	2111.743	1	2111.743	60104.534	.000
Water	7.507	1	7.507	213.672	.000
Cultivars	9.545	14	.682	19.405	.000
Water * Cultivars	.463	14	3.309E-02	.942	.521
Error	2.108	60	3.513E-02		
Total	2131.367	90			
Corrected Total	19.624	89			

a R Squared = .893 (Adjusted R Squared = .841).

Table A2: 20 Analysis of variance on the main stem length of fifteen sweet potato cultivars as affected by soil water stress in experiment 1b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected Model	17.196	29	.593	30.250	.000
Intercept	2900.241	1	2900.241	147955.370	.000
Water	3.754	1	3.754	191.531	.000
Cultivars	12.939	14	.924	47.148	.000
Water * Cultivars	.503	14	3.590E-02	1.831	.046
Error	1.764	90	1.960E-02		
Total	2919.201	120			
Corrected Total	18.960	119			

a R Squared = .907 (Adjusted R Squared = .877).

Table A2: 21 Analysis of variance on total dry weight of plant biomass of fifteen sweet potato cultivars as affected by soil water conditions, after being transformed to natural logarithmic in Experiment 1a.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected Model	42.601	29	1.469	246.929	.000
Intercept	706.923	1	706.923	118827.887	.000
Water	41.544	1	41.544	6983.272	.000
Cultivars	.648	14	4.629E-02	7.781	.000
Water * Cultivars	.409	14	2.920E-02	4.909	.000
Error	.357	60	5.949E-03		
Total	749.881	90			
Corrected Total	42.958	89			

a R Squared = .992 (Adjusted R Squared = .988).

Table A2: 22 Analysis of variance on the dry weight of plant biomass from fifteen sweet potato cultivars as affected by soil water conditions in Experiment 1b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected Model	19878.077	29	685.451	231.889	.000
Intercept	54420.442	1	54420.442	18410.522	.000
Water	18128.318	1	18128.318	6132.839	.000
Cultivars	990.915	14	70.780	23.945	.000
Water * Cultivars	758.844	14	54.203	18.337	.000
Error	266.035	90	2.956		
Total	74564.553	120			
Corrected Total	20144.112	119			

a R Squared = .987 (Adjusted R Squared = .983).

Table A2: 23 Analysis of variance on the leaf dry mass of fifteen sweet potato cultivars as affected by soil water conditions in Experiment 1a.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected Model	3499.259	29	120.664	124.813	.000
Intercept	3933.411	1	3933.411	4068.661	.000
Water	3426.363	1	3426.363	3544.178	.000
Cultivars	36.897	14	2.635	2.726	.004
Water * Cultivars	35.999	14	2.571	2.660	.004
Error	58.005	60	.967		
Total	7490.675	90			
Corrected Total	3557.264	89			

a R Squared = .984 (Adjusted R Squared = .976).

Table A2: 24 Analysis of variance on leaf dry mass of fifteen sweet potato cultivars as affected by soil water conditions in Experiment 1b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected Model	2127.235	29	73.353	146.060	.000
Intercept	6484.136	1	6484.136	12911.143	.000
Water	2028.395	1	2028.395	4038.919	.000
Cultivars	57.548	14	4.111	8.185	.000
Water * Cultivars	47.190	14	3.371	6.712	.000
Error	44.697	89	.502		
Total	8592.968	119			
Corrected Total	2171.932	118			

a R Squared = .979 (Adjusted R Squared = .973).

Table A2: 25 Analysis of variance on leaf area of fifteen sweet potato cultivars as affected by soil water conditions after being transformed to natural logarithmic in Experiment 1a.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected Model	41.751	29	1.440	312.899	.000
Intercept	4941.461	1	4941.461	1073956.497	.000
Water	39.485	1	39.485	8581.545	.000
Cultivars	.965	14	6.893E-02	14.982	.000
Water * Cultivars	1.301	14	9.294E-02	20.199	.000
Error	.276	60	4.601E-03		
Total	4983.488	90			
Corrected Total	42.027	89			

a R Squared = .993 (Adjusted R Squared = .990).

Table A2: 26 Analysis of variance on leaf area of fifteen sweet potato cultivars as affected by soil water conditions after being transformed to natural logarithmic in Experiment 1b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected Model	62.089	29	2.141	230.260	.000
Intercept	6585.001	1	6585.001	708206.275	.000
Water	59.713	1	59.713	6422.014	.000
Cultivars	1.398	14	9.986E-02	10.740	.000
Water * Cultivars	.978	14	6.985E-02	7.512	.000
Error	.837	90	9.298E-03		
Total	6647.927	120			
Corrected Total	62.926	119			

a R Squared = .987 (Adjusted R Squared = .982).

Table A2: 27 Analysis of variance on the length of internodes of fifteen sweet potato cultivars as affected by soil water conditions in Experiment 1b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected Model	370.771	29	12.785	17.503	.000
Intercept	3786.757	1	3786.757	5183.985	.000
Water	.420	1	.420	.575	.450
Cultivars	369.897	14	26.421	36.170	.000
Water * Cultivars	.454	14	3.240E-02	.044	1.000
Error	65.742	90	.730		
Total	4223.270	120			
Corrected Total	436.513	119			

a R Squared = .849 (Adjusted R Squared = .801).

Table A2: 28 Analysis of variance on the diameter of internodes of fifteen sweet potato cultivars as affected by soil water conditions in Experiment 1b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected Model	57.632	29	1.987	28.178	.000
Intercept	1068.630	1	1068.630	15151.904	.000
Water	15.480	1	15.480	219.489	.000
Cultivars	38.246	14	2.732	38.735	.000
Water * Cultivars	3.906	14	.279	3.956	.000
Error	6.347	90	7.053E-02		
Total	1132.610	120			
Corrected Total	63.980	119			

a R Squared = .901 (Adjusted R Squared = .869).

Table A2: 29 Analysis of variance on the root fresh mass of fifteen sweet potato cultivars as affected by soil water conditions in Experiment 1b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected Model	262.240	29	9.043	353.776	.000
Intercept	1026.560	1	1026.560	40161.602	.000
Water	259.951	1	259.951	10169.937	.000
Cultivars	1.275	14	9.110E-02	3.564	.000
Water * Cultivars	1.014	14	7.242E-02	2.833	.001
Error	2.300	90	2.556E-02		
Total	1291.100	120			
Corrected Total	264.541	119			

a R Squared = .991 (Adjusted R Squared = .989).

Table A2: 30 Analysis variance of root dry mass of fifteen sweet potato cultivars as affected by soil water stress in Experiment 1b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected Model	113.846	29	3.926	65.555	.000
Intercept	139.917	1	139.917	2336.453	.000
Water	107.627	1	107.627	1797.252	.000
Cultivars	3.629	14	.259	4.328	.000
Water * Cultivars	2.590	14	.185	3.090	.001
Error	5.390	90	5.988E-02		
Total	259.153	120			
Corrected Total	119.236	119			

a R Squared = .955 (Adjusted R Squared = .940).

Table A2: 31 Analysis variance of leaf dry matter content of fifteen sweet potato cultivars as affected by stress watered plant in Experiment 1b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected Model	.372	29	1.281E-02	25.027	.000
Intercept	5.024	1	5.024	9815.451	.000
Water	.213	1	.213	416.835	.000
Cultivars	6.886E-02	14	4.919E-03	9.610	.000
Water * Cultivars	8.932E-02	14	6.380E-03	12.464	.000
Error	4.607E-02	90	5.119E-04		
Total	5.491	120			
Corrected Total	.418	119			

a R Squared = .890 (Adjusted R Squared = .854).

Table A2: 32 Analysis variance of specific leaf area of fifteen sweet potato cultivars as affected by stress water treatment in Experiment 1b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected Model	3.719	29	.128	6.927	.000
Intercept	3779.581	1	3779.581	204174.101	.000
Water	.518	1	.518	27.979	.000
Cultivars	1.457	14	.104	5.624	.000
Water * Cultivars	1.743	14	.125	6.726	.000
Error	1.666	90	1.851E-02		
Total	3784.966	120			
Corrected Total	5.385	119			

a R Squared = .691 (Adjusted R Squared = .591).

Table A2: 33 Analysis variance of leaf transpiration of fifteen sweet potato cultivars as affected by stress water conditions recorded between 7 and 27 days after planting (DAP). Data is presented from the experiment 1a.

		Sum of Squares	df	Mean Square	F	$P_{(HO)}$
7 DAP (transformation)	Between Groups	.023	14	.002	1.365	.230
	Within Groups	.036	30	.001		
	Total	.059	44			
9 DAP (transformation)	Between Groups	.095	14	.007	1.422	.203
	Within Groups	.143	30	.005		
	Total	.238	44			
11 DAP (transformation)	Between Groups	.269	14	.019	2.266	.029*
	Within Groups	.255	30	.008		
	Total	.524	44			
13 DAP (transformation)	Between Groups	1.184	14	.085	1.953	.061
	Within Groups	1.299	30	.043		
	Total	2.483	44			
15 DAP	Between Groups	1340856.53	14	95775.467	3.313	.003*
	Within Groups	867298.66	30	28909.956		
	Total	2208155.20	44			
17 DAP (transformation)	Between Groups	3.116	14	.223	3.011	.006*
	Within Groups	2.218	30	.074		
	Total	5.334	44			
19 DAP transformation)	Between Groups	3.399	14	.243	4.668	.000*
	Within Groups	1.560	30	.052		
	Total	4.959	44			
21 DAP (transformation)	Between Groups	1.381	14	.099	2.996	.006*
	Within Groups	.988	30	.033		
	Total	2.369	44			
23 DAP (transformation)	Between Groups	.519	14	.037	1.874	.073
	Within Groups	.593	30	.020		
	Total	1.112	44			
25 DAP	Between Groups	22094.578	14	1578.184	1.281	.275
	Within Groups	36965.333	30	1232.178		
	Total	59059.911	44			
27 DAP (transformation)	Between Groups	.227	14	.016	1.192	.330
	Within Groups	.400	30	.013		
	Total	.623	44			

* Significant at 0.05>P>0.01.

Table A2: 34. Analysis variance of leaf transpiration of fifteen sweet potato cultivars as affected by stress water conditions recorded between 7 and 27 days after planting (DAP). Data is presented from the experiment 1b.

		Sum of Squares	df	Mean Square	F	$P_{(HO)}$
7 DAP (transformation)	Between Groups	.318	14	.023	4.092	.000
	Within Groups	.249	45	.006		
	Total	.567	59			
9 DAP (transformation)	Between Groups	.154	14	.011	2.176	.025
	Within Groups	.227	45	.005		
	Total	.381	59			
11 DAP (transformation)	Between Groups	.057	14	.004	1.316	.236
	Within Groups	.138	45	.003		
	Total	.195	59			
13 DAP (transformation)	Between Groups	.017	14	.001	1.337	.224
	Within Groups	.040	45	.001		
	Total	.057	59			
15 DAP	Between Groups	.012	14	.001	1.267	.265
	Within Groups	.032	45	.001		
	Total	.044	59			
17 DAP (transformation)	Between Groups	.016	14	.001	2.115	.029
	Within Groups	.025	45	.001		
	Total	.041	59			
19 DAP (transformation)	Between Groups	.011	14	.001	1.537	.137
	Within Groups	.023	45	.001		
	Total	.033	59			
21 DAP (transformation)	Between Groups	.014	14	.00	2.457	.011
	Within Groups	.018	45	.001		
	Total	.031	59			

* Significant at 0.05>P>0.01.

Table A2: 35 Analysis variance of the number of days to reach permanent wilting point of fifteen sweet potato cultivars as affected by water stress conditions in Experiment 1b.

	Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Between Groups	216.500	14	15.464	12.317	.000
Within Groups	56.500	45	1.256		
Total	273.000	59			

Table A2: 36 Analysis variance of leaf water potential of fifteen sweet potato cultivars as affected by water stress conditions in Experiment 1b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected Model	2879.925	29	99.308	102.110	.000
Intercept	6264.509	1	6264.509	6441.310	.000
Water	2845.541	1	2845.541	2925.850	.000
Cultivars	21.005	14	1.500	1.543	.112
Water * Cultivars	13.379	14	.956	.983	.477
Error	87.530	90	.973		
Total	9231.963	120			
Corrected Total	2967.455	119			

a R Squared = .971 (Adjusted R Squared = .961).

Table A2: 37 Analysis variance of the fresh plant mass of fifteen sweet potato cultivars grown under normal watering conditions in the field. Data was transformed into natural logarithmic.

	Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Between Groups	6.672	14	.477	5.282	.000
Within Groups	6.677	74	.090		
Total	13.349	88			

Table A2: 38 Analysis variance of the tuber number of fifteen sweet potato cultivars grown under normal watering conditions in the field.

	Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Between Groups	17.082	13	1.314	14.973	.000
Within Groups	6.055	69	.088		
Total	23.137	82			

Table A2: 39 Analysis variance of mass of tubers of fifteen sweet potato cultivars grown under normal watering conditions in the field.

	Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Between Groups	40.875	13	2.920	35.269	.000
Within Groups	6.209	69	.083		
Total	47.083	82			

APPENDIX A3

PLANT MEASUREMENTS AND RESULTS OF STATISTICAL ANALYSES OF CHAPTER 3

Table A3: 1 Analysis variance of the main stem length as affected by soil water levels and sweet potato cultivars (Lole and Wanmun) at 1 month after planting (data was transformed into ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	15.732	5	3.146	659.044	.000
Intercept	342.807	1	342.807	71802.017	.000
Water levels	.717	2	.358	75.041	.000
Cultivars	14.842	1	14.842	3108.686	.000
Water * Cultivar	.174	2	8.702E-02	18.227	.000
Error	8.594E-02	18	4.774E-03		
Total	358.625	24			
Corrected Total	15.818	23			

a R Squared = .995 (Adjusted R Squared = .993).

Table A3: 2 Analysis variance of main stem length as affected by soil water levels and sweet potato cultivars (Lole and Wanmun) at 2 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	65126.05	5	13025.21	188.97	.000
Intercept	151765.51	1	151765.51	2201.82	.000
Water levels	12818.14	2	6409.07	92.98	.000
Cultivars	48195.84	1	48195.84	699.22	.000
Water * Cultivar	4112.06	2	2056.03	29.82	.000
Error	1240.68	18	68.92		
Total	218132.25	24			
Corrected Total	66366.74	23			

a R Squared = .981 (Adjusted R Squared = .976).

Table A3: 3 Analysis variance of main stem length as affected by soil water levels and sweet potato cultivars (Lole and Wanmun) at 3 months after planting (data was transformed into ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	9.34	5	1.869	1460.564	.000
Intercept	439.25	1	439.25	343249.2	.000
Water	1.74	2	.87	679.83	.000
Cultivar	7.56	1	7.56	5907.871	.000
Water * Cultivar	4.516E-0	2	2.258E-0	17.64	.000
Error	2.303E-02	18	1.280E-03		
Total	448.624	24			
Corrected Total	9.368	23			

a R Squared = .998 (Adjusted R Squared = .997).

Table A3: 4 Analysis variance of main stem length as affected by soil water levels and sweet potato cultivars (Lole and Wanmun) at 4 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	61183.875	5	12236.775	1091.757	.000
Intercept	175959.375	1	175959.375	15698.978	.000
Water levels	11489.250	2	5744.625	512.532	.000
Cultivars	46552.042	1	46552.042	4153.342	.000
Water * Cultivar	3142.583	2	1571.292	140.190	.000
Error	201.750	18	11.208		
Total	237345.000	24			
Corrected Total	61385.625	23			

a R Squared = .997 (Adjusted R Squared = .996).

Table A3: 5 Analysis variance of main stem length as affected by soil water levels and sweet potato cultivars (Lole and Wanmun) at 5 months after planting (data was transformed into ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	9.165	5	1.833	281.564	.000
Intercept	418.150	1	418.150	64230.128	.000
Water levels	2.248	2	1.124	172.648	.000
Cultivars	6.755	1	6.755	1037.563	.000
Water * Cultivar	.162	2	8.124E-02	12.479	.000
Error	.117	18	6.510E-03		
Total	427.432	24			
Corrected Total	9.282	23			

a R Squared = .987 (Adjusted R Squared = .984).

Table A3: 6 Analysis variance of branch number as affected by soil water levels and sweet potato cultivars (Lole and Wanmun) at 1 month after planting (data was transformed into ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	21.389	5	4.278	365.393	.000
Intercept	32.599	1	32.599	2784.482	.000
Water levels	1.358	2	.679	58.009	.000
Cultivars	19.466	1	19.466	1662.772	.000
Water * Cultivar	.564	2	.282	24.089	.000
Error	.211	18	1.171E-02		
Total	54.198	24			
Corrected Total	21.599	23			

a R Squared = .990 (Adjusted R Squared = .998).

Table A3: 7 Analysis variance of branch number as affected by soil water levels and sweet potato cultivars (Lole and Wanmun) at 2 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	396.000	5	79.200	142.560	.000
Intercept	1176.000	1	1176.000	2116.800	.000
Water levels	60.250	2	30.125	54.225	.000
Cultivars	308.167	1	308.167	554.700	.000
Water * Cultivar	27.583	2	13.792	24.825	.000
Error	10.000	18	.556		
Total	1582.000	24			
Corrected Total	406.000	23			

a R Squared = .975 (Adjusted R Squared = .969).

Table A3: 8 Analysis variance of branch number as affected by soil water levels and sweet potato cultivars (Lole and Wanmun) at 3 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	1801.833	5	360.367	682.800	.000
Intercept	2816.667	1	2816.667	5336.842	.000
Water levels	371.083	2	185.542	351.553	.000
Cultivars	1204.167	1	1204.167	2281.579	.000
Water * Cultivar	226.583	2	113.292	214.658	.000
Error	9.500	18	.528		
Total	4628.000	24			
Corrected Total	1811.333	23			

a R Squared = .995 (Adjusted R Squared = .993).

Table A3: 9 Analysis variance of branch number as affected by soil water levels and sweet potato cultivars (Lole and Wanmun) at 4 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	1748.875	5	349.775	645.738	.000
Intercept	2838.375	1	2838.375	5240.077	.000
Water levels	392.250	2	196.125	362.077	.000
Cultivars	1134.375	1	1134.375	2094.231	.000
Water * Cultivar	222.250	2	111.125	205.154	.000
Error	9.750	18	.542		
Total	4597.000	24			
Corrected Total	1758.625	23			

a R Squared = .994 (Adjusted R Squared = .993).

Table A3: 10 Analysis variance of branch number as affected by soil water levels and sweet potato cultivars (Lole and Wanmun) at 5 months after planting (data was transformed into ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	1548.833	5	309.767	796.543	.000
Intercept	2604.167	1	2604.167	6696.429	.000
Water levels	416.083	2	208.042	534.964	.000
Cultivars	912.667	1	912.667	2346.857	.000
Water * Cultivar	220.083	2	110.042	282.964	.000
Error	7.000	18	.389		
Total	4160.000	24			
Corrected Total	1555.833	23			

a R Squared = .996 (Adjusted R Squared = .994).

Table A3: 11 Analysis of variance on the biomass fresh weight of Lole and Wanmun sweet potato cultivars at one month after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	7.487	5	1.497	625.28	.000
Intercept	439.296	1	439.296	183431.18	.000
Water levels	2.706	2	1.353	564.91	.000
Cultivars	4.211	1	4.211	1758.51	.000
Water *Cultivar	.570	2	.285	119.03	.000
Error	4.311E-02	18	2.395E-03		
Total	446.827	24			
Corrected Total	7.53	23			

R Squared = .994 (Adjusted R Squared = .993).

Table A3: 12 Analysis of variance on the biomass fresh weight of Lole and Wanmun sweet potato cultivars at two months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	319015.542	5	63803.108	236.324	.000
Intercept	1299350.270	1	1299350.270	4812.748	.000
Water levels	282678.516	2	141339.258	523.516	.000
Cultivars	34088.344	1	34088.344	126.262	.000
Water * Cultivar	2248.682	2	1124.341	4.165	.033
Error	4859.657	18	269.981		
Total	1623225.470	24			
Corrected Total	323875.200	23			

a R Squared = .985 (Adjusted R Squared = .981).

Table A3: 13 Analysis of variance on the biomass fresh weight of Lole and Wanmun sweet potato cultivars at three months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	240436.732	5	48087.346	245.901	.000
Intercept	1179843.070	1	1179843.070	6033.276	.000
Water levels	188344.981	2	94172.490	481.563	.000
Cultivars	45823.820	1	45823.820	234.326	.000
Water * Cultivar	6267.931	2	3133.965	16.026	.000
Error	3520.007	18	195.556		
Total	1423799.810	24			
Corrected Total	243956.740	23			

a R Squared = .986 (Adjusted R Squared = .982).

Table A3: 14 Analysis of variance on the biomass fresh weight of Lole and Wanmun sweet potato cultivars at four months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	141787.753	5	28357.551	1048.855	.000
Intercept	789452.827	1	789452.827	29199.340	.000
Water levels	130474.301	2	65237.150	2412.914	.000
Cultivars	9809.127	1	9809.127	362.808	.000
Water * Cultivar	1504.326	2	752.163	27.820	.000
Error	486.660	18	27.037		
Total	931727.240	24			
Corrected Total	142274.413	23			

a R Squared = .997 (Adjusted R Squared = .996).

Table A3: 15 Analysis of variance on the biomass fresh weight of Lole and Wanmun sweet potato cultivars at five months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	98415.325	5	19683.06	367.48	.000
Intercept	537123.840	1	537123.84	10028.08	.000
Water levels	92681.417	2	46340.70	865.18	.000
Cultivars	4224.107	1	4224.10	78.86	.000
Water * Cultivar	1509.801	2	754.90	14.09	.000
Error	964.115	18	53.56		
Total	636503.280	24			
Corrected Total	99379.440	23			

a R Squared = .990 (Adjusted R Squared = .988).

Table A3: 16 Analysis of variance on the biomass dry weight of Lole and Wanmun sweet potato cultivars at one month after planting as affected by different soil water levels in experiment 2b (data was transformed using ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	5.600	5	1.120	174.747	.000
Intercept	99.522	1	99.522	15526.910	.000
Water levels	1.731	2	.866	135.069	.000
Cultivars	3.663	1	3.663	571.426	.000
Water * Cultivar	.206	2	.103	16.086	.000
Error	.115	18	6.410E-03		
Total	105.238	24			
Corrected Total	5.716	23			

a R Squared = .980 (Adjusted R Squared = .974).

Table A3: 17 Analysis of variance on the biomass dry weight of Lole and Wanmun sweet potato cultivars at two months after planting as affected by different soil water levels in experiment 2b (data was transformed using ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	8.811	5	1.762	187.612	.000
Intercept	233.753	1	233.753	24887.069	.000
Water levels	7.641	2	3.820	406.738	.000
Cultivars	.690	1	.690	73.503	.000
Water * Cultivar	.480	2	.240	25.542	.000
Error	.169	18	9.393E-03		
Total	242.733	24			
Corrected Total	8.980	23			

a R Squared = .981 (Adjusted R Squared = .976).

Table A3: 18 Analysis of variance on the biomass dry weight of Lole and Wanmun sweet potato cultivars at three months after planting as affected by different soil water levels in experiment 2b (data was transform using ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	4.878	5	.976	290.846	.000
Intercept	229.133	1	229.133	68309.314	.000
Water levels	4.652	2	2.326	693.484	.000
Cultivars	.141	1	.141	42.033	.000
Water * Cultivar	8.463E-02	2	4.231E-02	12.615	.000
Error	6.038E-02	18	3.354E-03		
Total	234.071	24			
Corrected Total	4.938	23			

a R Squared = .988(Adjusted R Squared = .984).

Table A3: 19 Analysis of variance on the biomass dry weight of Lole and Wanmun sweet potato cultivars at four months after planting as affected by different soil water levels.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	4306.193	5	861.239	165.120	.000
Intercept	16716.482	1	16716.482	3204.949	.000
Water levels	4164.516	2	2082.258	399.219	.000
Cultivars	6.615	1	6.615	1.268	.275
Water * Cultivar	135.063	2	67.531	12.947	.000
Error	93.885	18	5.216		
Total	21116.560	24			
Corrected Total	4400.078	23			

a R Squared = .979 (Adjusted R Squared = .973).

Table A3: 20 Analysis of variance on the biomass dry weight of Lole and Wanmun sweet potato cultivars at five months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	3008.129	5	601.626	162.242	.000
Intercept	10647.094	1	10647.094	2871.234	.000
Water levels	2699.377	2	1349.689	363.975	.000
Cultivars	1.084	1	1.084	.292	.595
Water * Cultivar	307.668	2	153.834	41.485	.000
Error	66.747	18	3.708		
Total	13721.970	24			
Corrected Total	3074.876	23			

a R Squared = .978 (Adjusted R Squared = .972).

Table A3: 21 Analysis of variance on leaf fresh weight of Lole and Wanmun sweet potato cultivars at one month after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	13576.528	5	2715.306	696.530	.000
Intercept	46376.042	1	46376.042	11896.377	.000
Water levels	5939.583	2	2969.792	761.811	.000
Cultivars	5203.815	1	5203.815	1334.882	.000
Water * Cultivar	2433.130	2	1216.565	312.073	.000
Error	70.170	18	3.898		
Total	60022.740	24			
Corrected Total	13646.698	23			

a R Squared = .995 (Adjusted R Squared = .993).

Table A3: 22 Analysis of variance on leaf fresh weight of Lole and Wanmun sweet potato cultivars at two months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	41063.970	5	8212.794	208.784	.000
Intercept	259708.815	1	259708.815	6602.25	.000
Water levels	39530.628	2	19765.314	502.469	.000
Cultivars	1229.802	1	1229.802	31.264	.000
Water * Cultivar	303.541	2	151.770	3.858	.040
Error	708.055	18	39.336		
Total	301480.840	24			
Corrected Total	41772.025	23			

a R Squared = .983 (Adjusted R Squared = .978).

Table A3: 23 Analysis of variance on leaf fresh weight of Lole and Wanmun sweet potato cultivars at three months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	14670.508	5	2934.102	271.139	.000
Intercept	149278.827	1	149278.827	13794.794	.000
Water levels	12162.741	2	6081.370	561.977	.000
Cultivars	2336.427	1	2336.427	215.908	.000
Water * Cultivar	171.341	2	85.670	7.917	.003
Error	194.785	18	10.821		
Total	164144.120	24			
Corrected Total	14865.293	23			

a R Squared = .987 (Adjusted R Squared = .983).

Table A3: 24 Analysis of variance on leaf fresh weight of Lole and Wanmun sweet potato cultivars at four months after planting as affected by different soil water levels in experiment 2b (data was transformed using ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	5.048	5	1.010	487.542	.000
Intercept	396.632	1	396.632	191550.95	.000
Water levels	4.503	2	2.252	1087.425	.000
Cultivars	.501	1	.501	242.094	.000
Water * Cultivar	4.300E-02	2	2.150E-02	10.384	.001
Error	3.727E-02	18	2.071E-03		
Total	401.717	24			
Corrected Total	5.085	23			

a R Squared = .993 (Adjusted R Squared = .991).

Table A3: 25 Analysis of variance on leaf fresh weight of Lole and Wanmun sweet potato cultivars at five months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	10139.094	5	2027.819	206.018	.000
Intercept	48357.304	1	48357.304	4912.904	.000
Water levels	9463.870	2	4731.935	480.745	.000
Cultivars	516.154	1	516.154	52.439	.000
Water * Cultivar	159.070	2	79.535	8.080	.000
Error	177.173	18	9.843		
Total	58673.570	24			
Corrected Total	10316.266	23			

a R Squared = .983 (Adjusted R Squared = .978).

Table A3: 26 Analysis of variance on leaf dry weight of Lole and Wanmun sweet potato cultivars at one month after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	107.246	5	21.449	114.687	.000
Intercept	606.598	1	606.598	3243.442	.000
Water levels	49.702	2	24.851	132.876	.000
Cultivars	48.866	1	48.866	261.284	.000
Water * Cultivar	8.678	2	4.339	23.200	.000
Error	3.366	18	.187		
Total	717.210	24			
Corrected Total	110.612	23			

a R Squared = .970 (Adjusted R Squared = .961).

Table A3: 27 Analysis of variance on leaf dry weight of Lole and Wanmun sweet potato cultivars at two months after planting as affected by different soil water levels in experiment 2b.
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Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	409.263	5	81.853	212.219	.000
Intercept	3142.248	1	3142.248	8146.914	.000
Water levels	371.560	2	185.780	481.672	.000
Cultivars	32.308	1	32.308	83.766	.000
Water * Cultivar	5.394	2	2.697	6.993	.000
Error	6.943	18	.386		
Total	3558.453	24			
Corrected Total	416.205	23			

a R Squared = .983 (Adjusted R Squared = .979).

Table A3: 28 Analysis of variance on leaf dry weight of Lole and Wanmun sweet potato cultivars at three months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	421.928	5	84.386	82.238	.000
Intercept	3290.042	1	3290.042	3206.321	.000
Water levels	421.023	2	210.512	205.155	.000
Cultivars	.482	1	.482	.469	.502
Water * Cultivar	.423	2	.212	.206	.816
Error	18.470	18	1.026		
Total	3730.440	24			
Corrected Total	440.398	23			

a R Squared = .958 (Adjusted R Squared = .946).

Table A3: 29 Analysis of variance on leaf dry weight of Lole and Wanmun sweet potato cultivars at four months after planting as affected by different soil water levels in experiment 2b (data was transformed using ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	8.942	5	1.788	167.006	.000
Intercept	87.267	1	87.267	8148.983	.000
Water levels	8.665	2	4.333	404.585	.000
Cultivars	.214	1	.214	20.006	.000
Water * Cultivar	6.269E-02	2	3.134E-02	2.927	.079
Error	.193	18	1.071E-02		
Total	96.402	24			
Corrected Total	9.135	23			

a R Squared = .979 (Adjusted R Squared = .973).

Table A3: 30 Analysis of variance on leaf dry weight of Lole and Wanmun sweet potato cultivars at five months after planting as affected by different soil water levels in experiment 2b (data was transformed using ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	10.586	5	2.117	104.264	.000
Intercept	75.980	1	75.980	3741.906	.000
Water levels	10.146	2	5.073	249.832	.000
Cultivars	.280	1	.280	13.766	.002
Water * Cultivar	.160	2	8.008E-02	3.944	.038
Error	.365	18	2.031E-02		
Total	86.931	24			
Corrected Total	10.951	23			

a R Squared = .967 (Adjusted R Squared = .957).

Table A3: 31 Analysis of variance on leaf area of Lole and Wanmun sweet potato cultivars at one month after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	21678253.020	5	4335650.604	1305.156	.000
Intercept	77035646.8	1	77035646.78	23189.954	.000
Water levels	13654124.40	2	6827062.201	2055.143	.000
Cultivars	6403422.411	1	6403422.411	1927.615	.000
Water * Cultivar	1620706.208	2	810353.104	243.940	.000
Error	59794.929	18	3321.941		
Total	98773694.7	24			
Corrected Total	21738048.0	23			

a R Squared = .997 (Adjusted R Squared = .996).

Table A3: 32 Analysis of variance on leaf area of Lole and Wanmun sweet potato cultivars at two months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	82162747.53	5	16432549.51	581.109	.000
Intercept	327769711.79	1	327769711.8	11591.007	.000
Water levels	63169803.12	2	31584901.56	1116.945	.000
Cultivars	18434372.88	1	18434372.88	651.900	.000
Water * Cultivar	558571.529	2	279285.764	9.876	.000
Error	509002.787	18	28277.933		
Total	410441462.112	24			
Corrected Total	82671750.32	23			

a R Squared = .994 (Adjusted R Squared = .992).

Table A3: 33 Analysis of variance on leaf area of Lole and Wanmun sweet potato cultivars at two months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	82162747.53	5	16432549.51	581.109	.000
Intercept	327769711.79	1	327769711.8	11591.007	.000
Water levels	63169803.12	2	31584901.56	1116.945	.000
Cultivars	18434372.88	1	18434372.88	651.900	.000
Water * Cultivar	558571.529	2	279285.764	9.876	.000
Error	509002.787	18	28277.933		
Total	410441462.112	24			
Corrected Total	82671750.32	23			

a R Squared = .994 (Adjusted R Squared = .992).

Table A3: 34 Analysis of variance on leaf area of Lole and Wanmun sweet potato cultivars at three months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	77095072.00	5	15419014.40	750.412	.000
Intercept	258854207.04	1	258854207.04	12597.908	.000
Water levels	56615814.69	2	28307907.35	1377.688	.000
Cultivars	19189889.68	1	19189889.68	933.933	.000
Water * Cultivar	1289367.636	2	644683.818	31.375	.000
Error	369853.123	18	20547.396		
Total	336319132.17	24			
Corrected Total	77464925.13	23			

a R Squared = .995 (Adjusted R Squared = .994).

Table A3: 35 Analysis of variance on the leaf area of Lole and Wanmun sweet potato cultivars at four months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	18354107.73	5	3670821.546	663.978	.000
Intercept	99652699.65	1	99652699.65	18025.175	.000
Water levels	15420913.72	2	7710456.864	1394.667	.000
Cultivars	2594199.138	1	2594199.138	469.239	.000
Water * Cultivar	338994.865	2	169497.432	30.659	.000
Error	99513.518	18	5528.529		
Total	118106320.891	24			
Corrected Total	18453621.24	23			

a R Squared = .995(Adjusted R Squared = .993).

Table A3: 36 Analysis of variance on the leaf area of Lole and Wanmun sweet potato cultivars at five months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	4883599.501	5	976719.900	248.134	.000
Intercept	50529740.08	1	50529740.08	12837.013	.000
Water levels	4313127.082	2	2156563.541	547.872	.000
Cultivars	93238.200	1	93238.200	23.687	.000
Water * Cultivar	477234.219	2	238617.110	60.620	.000
Error	70852.564	18	3936.254		
Total	55484192.14	24			
Corrected Total	4954452.065	23			

a R Squared = .986 (Adjusted R Squared = .982).

Table A3: 37 Analysis of variance of the leaf senescence of Lole and Wanmun sweet potato cultivars affected by different soil water levels after being transformed to ln in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	15.248	5	3.050	94.424	.000
Intercept	157.723	1	157.723	4883.665	.000
Water levels	8.402	2	4.201	130.083	.000
Cultivars	6.430	1	6.430	199.091	.000
Water * Cultivar	.415	2	.208	6.431	.003
Error	1.744	54	3.230E-02		
Total	174.715	60			
Corrected Total	16.992	59			

a R Squared = .897 (Adjusted R Squared = .888).

Table A3: 38 Analysis of variance of root fresh weight of Lole and Wanmun sweet potato cultivars at one month after planting as affected by different soil water levels in experiment 2b (data was transformed using ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	10.247	5	2.049	368.753	.000
Intercept	163.284	1	163.284	29379.886	.000
Water levels	.645	2	.322	57.989	.000
Cultivars	9.308	1	9.308	1674.767	.000
Water * Cultivar	.295	2	.147	26.510	.000
Error	.100	18	5.558E-03		
Total	173.632	24			
Corrected Total	10.347	23			

a R Squared = .990(Adjusted R Squared = .988).

Table A3: 39 Analysis of variance of root fresh weight of Lole and Wanmun sweet potato cultivars at two months after planting as affected by different soil water levels in experiment 2b (data was transformed using ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	6.120	5	1.224	432.637	.000
Intercept	301.329	1	301.329	106500.78	.000
Water levels	3.282	2	1.641	580.018	.000
Cultivars	.101	1	.101	35.558	.000
Water * Cultivar	2.738	2	1.369	483.795	.001
Error	5.093E-02	18	2.829E-03		
Total	307.500	24			
Corrected Total	6.171	23			

a R Squared = .992 (Adjusted R Squared = .989).

Table A3: 40 Analysis of variance on the root fresh weight of Lole and Wanmun sweet potato cultivars at three months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	12340.055	5	2468.011	213.347	.000
Intercept	72765.204	1	72765.204	6290.186	.000
Water levels	1795.124	2	897.562	77.590	.000
Cultivars	6464.917	1	6464.917	558.860	.000
Water * Cultivar	4080.015	2	2040.008	176.348	.000
Error	208.225	18	11.568		
Total	85313.484	24			
Corrected Total	12548.280	23			

a R Squared = .983 (Adjusted R Squared = .979).

Table A3: 41 Analysis of variance on the root fresh weight of Lole and Wanmun sweet potato cultivars at four months after planting as affected by different soil water levels after being transformed to ln in experiment 2b (data was transformed using ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	15.504	5	3.101	381.502	0.000
Intercept	364.981	1	364.981	44906.099	0.000
Water levels	4.064	2	2.032	250.031	0.000
Cultivars	8.842	1	8.842	1087.917	0.000
Water * Cultivar	2.597	2	1.299	159.765	0.000
Error	.146	18	8.128E-03		
Total	380.631	24			
Corrected Total	15.650	23			

a R Squared = .991 (Adjusted R Squared = .988).

Table A3: 42 Analysis of variance on the root fresh weight of Lole and Wanmun sweet potato cultivars at five months after planting as affected by different soil water levels in experiment 2b (data was transformed using ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	12.714	5	2.543	116.041	.000
Intercept	327.113	1	327.113	14927.867	.000
Water	2.959	2	1.480	67.525	.000
Cultivar	7.360	1	7.360	335.853	.000
Water * Cultivar	2.395	2	1.198	54.652	.000
Error	.394	18	2.191E-02		
Total	340.221	24			
Corrected Total	13.108	23			

a R Squared = .970 (Adjusted R Squared = .962).

Table A3: 43 Analysis of variance on the root dry weight of Lole and Wanmun sweet potato cultivars at one month after planting as affected by different soil water levels in experiment 2b (data was transformed using ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	3.877	5	.775	84.021	.000
Intercept	38.947	1	38.947	4220.447	.000
Water levels	.363	2	.182	19.679	.000
Cultivars	3.238	1	3.238	350.831	.000
Water * Cultivar	.276	2	.138	14.95	.000
Error	.166	18	9.228E-03		
Total	42.990	24			
Corrected Total	4.043	23			

a R Squared = .959 (Adjusted R Squared = .948).

Table A3: 44 Analysis of variance on the root dry weight of Lole and Wanmun sweet potato cultivars at two months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	317.662	5	63.532	49.246	.000
Intercept	1942.560	1	1942.560	1505.728	.000
Water levels	266.126	2	133.063	103.141	.000
Cultivars	41.870	1	41.870	32.455	.000
Water * Cultivar	9.666	2	4.833	3.746	.044
Error	23.222	18	1.290		
Total	2283.445	24			
Corrected Total	340.884	23			

a R Squared = .932 (Adjusted R Squared = .913).

Table A3: 45 Analysis of variance on the root dry weight of Lole and Wanmun sweet potato cultivars at three months after planting as affected by different soil water levels in experiment 2b (data was transformed using ln transformations).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	4.545	5	.909	37.780	.000
Intercept	111.697	1	111.697	4642.695	.000
Water levels	2.581	2	1.290	53.633	.000
Cultivars	.962	1	.962	40.004	.000
Water * Cultivar	1.002	2	.501	20.814	.000
Error	.433	18	2.406E-02		
Total	116.674	24			
Corrected Total	4.978	23			

a R Squared = .913 (Adjusted R Squared = .889).

Table A3: 46 Analysis of variance on the root dry weight of Lole and Wanmun sweet potato cultivars at four months after planting as affected by different soil water levels in experiment 2b (data was transformed using ln transformations).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	8.223	5	1.645	110.112	.000
Intercept	103.660	1	103.660	6940.313	.000
Water levels	2.703	2	1.352	90.499	.000
Cultivars	2.899	1	2.899	194.120	.000
Water * Cultivar	2.620	2	1.310	87.720	.000
Error	.269	18	1.494E-02		
Total	112.152	24			
Corrected Total	8.492	23			

a R Squared = .968 (Adjusted R Squared = .960).

Table A3: 47 Analysis of variance on the root dry weight of Lole and Wanmun sweet potato cultivars at five months after planting as affected by different soil water levels in experiment 2b.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	558.707	5	111.741	147.270	.000
Intercept	1299.776	1	1299.776	1713.049	.000
Water levels	252.553	2	126.276	166.427	.000
Cultivars	109.312	1	109.312	144.069	.000
Water * Cultivar	196.843	2	98.421	129.715	.000
Error	13.658	18	.759		
Total	1872.141	24			
Corrected Total	572.365	23			

a R Squared = .976 (Adjusted R Squared = .970).

Table A3: 48 Analysis of variance of leaf transpiration as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), at 1 month after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	174089.810	5	34817.962	217.063	.000
Intercept	1661972.280	1	1661972.280	10361.126	.000
Water levels	124409.685	2	62204.843	387.800	.000
Cultivars	40833.333	1	40833.333	254.565	.000
Water * Cultivar	8846.792	2	4423.396	27.576	.000
Error	6736.993	42	160.405		
Total	1842799.083	48			
Corrected Total	180826.803	47			

a R Squared = .963 (Adjusted R Squared = .958).

Table A3: 49 Analysis of variance of leaf transpiration as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), at 2 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	2355367.373	5	471073.475	1648.707	.000
Intercept	9416686.740	1	9416686.740	32957.406	.000
Water levels	2123791.556	2	1061895.778	3716.523	.000
Cultivars	214563.674	1	214563.674	750.950	.000
Water * Cultivar	17012.143	2	8506.072	29.770	.000
Error	12000.363	42	285.723		
Total	11784054.47	48			
Corrected Total	2367367.736	47			

a R Squared = .995 (Adjusted R Squared = .994).

Table A3: 50 Analysis of variance of leaf transpiration as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), at 3 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	3665504.800	5	733100.960	7385.673	.000
Intercept	16828361.69	1	16828361.69	169538.41	.000
Water levels	3535936.657	2	1767968.329	17811.511	.000
Cultivars	120377.439	1	120377.439	1212.750	.000
Water * Cultivar	9190.704	2	4595.352	46.296	.000
Error	4168.915	42	99.260		
Total	20498035.41	48			
Corrected Total	3669673.715	47			

a R Squared = .999 (Adjusted R Squared = .999).

Table A3: 51 Analysis of variance of leaf transpiration as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), 4 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	3469685.635	5	693937.127	3486.249	.000
Intercept	18080105.283	1	18080105.28	90832.085	.000
Water levels	3428088.225	2	1714044.113	8611.134	.000
Cultivars	31803.829	1	31803.829	159.778	.000
Water * Cultivar	9793.581	2	4896.791	24.601	.000
Error	8360.090	42	199.050		
Total	21558151.01	48			
Corrected Total	3478045.725	47			

a R Squared = .998 (Adjusted R Squared = .997).

Table A3: 52 Analysis of variance of leaf transpiration as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), at 5 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	1230576.181	5	246115.236	422.791	.000
Intercept	6535475.455	1	6535475.455	11227.015	.000
Water levels	1140705.151	2	570352.576	135.710	.000
Cultivars	78999.638	1	78999.638	979.784	.000
Water * Cultivar	10871.392	2	5435.696	9.338	.002
Error	10478.169	42	582.120		
Total	7776529.806	48			
Corrected Total	1241054.350	47			

a R Squared = .992 (Adjusted R Squared = .989).

Table A3: 53 Analysis of variance of leaf water potential as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), two months after planting at early morning (6.00 am).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	7.396E-03	5	1.479E-03	2.436	.096
Intercept	3.502	1	3.502	5765.961	.000
Water levels	2.406E-03	2	1.203E-03	1.981	.181
Cultivars	1.701E-03	1	1.701E-03	2.802	.120
Water * Cultivar	3.288E-03	2	1.644E-03	2.708	.107
Error	7.287E-03	12	6.073E-04		
Total	3.516	18			
Corrected Total	1.468E-02	17			

a R Squared = .504 (Adjusted R Squared = .297).

Table A3: 54 Analysis of variance of leaf water potential as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), two months after planting at midday (12.00-1.00 pm).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	.318	5	6.363E-02	22.641	.000
Intercept	18.954	1	18.954	6744.111	.000
Water levels	.124	2	6.188E-02	22.019	.000
Cultivars	.162	1	.162	57.734	.000
Water * Cultivar	3.214E-02	2	1.607E-02	5.718	.018
Error	3.373E-02	12	2.810E-03		
Total	19.306	18			
Corrected Total	.352	17			

a R Squared = .904 (Adjusted R Squared = .864).

Table A3: 55 Analysis of variance of leaf water potential as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), two months after planting at late afternoon (6.00 pm).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	1.100	5	.220	205.550	.000
Intercept	7.898	1	7.898	7377.929	.000
Water levels	9.733E-02	2	4.867E-02	45.465	.000
Cultivars	.972	1	.972	908.111	.000
Water * Cultivar	3.073E-02	2	1.537E-02	14.355	.001
Error	1.285E-02	12	1.070E-03		
Total	9.011	18			
Corrected Total	1.113	17			

a R Squared = .988 (Adjusted R Squared = .984).

Table A3: 56 Analysis of variance of leaf water potential as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), three months after planting at early morning (06.00 am).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	1.866E-02	5	3.733E-03	5.746	.006
Intercept	8.506	1	8.506	13093.542	.000
Water levels	1.139E-02	2	5.693E-03	8.764	.005
Cultivars	6.422E-03	1	6.422E-03	9.885	.008
Water * Cultivar	8.554E-04	2	4.277E-04	.658	.535
Error	7.796E-03	12	6.497E-04		
Total	8.533	18			
Corrected Total	2.646E-02	17			

a R Squared = .705 (Adjusted R Squared = .583).

Table A3: 57 Analysis of variance of leaf water potential as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), three months after planting at midday (12.00-01.00 pm).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	7.828E-02	5	1.566E-02	20.692	.000
Intercept	26.028	1	26.028	34400.912	.000
Water levels	7.197E-02	2	3.598E-02	47.558	.000
Cultivars	3.444E-03	1	3.444E-03	4.553	.054
Water * Cultivar	2.866E-03	2	1.433E-03	1.894	.193
Error	9.079E-03	12	7.566E-04		
Total	26.115	18			
Corrected Total	8.736E-02	17			

a R Squared = .896 (Adjusted R Squared = .853).

Table A3: 58 Analysis of variance of leaf water potential as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), three months after planting at late afternoon (6.00-1.00 pm).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	.279	5	5.572E-02	55.649	.000
Intercept	12.003	1	12.003	11988.049	.000
Water levels	.101	2	5.048E-02	50.412	.000
Cultivars	.163	1	.163	162.812	.000
Water * Cultivar	1.463E-02	2	7.314E-03	7.305	.008
Error	1.202E-02	12	1.001E-03		
Total	12.294	18			
Corrected Total	.291	17			

a R Squared = .959 (Adjusted R Squared = .941).

Table A3: 59. Analysis of variance of leaf relative water content as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), two months after planting at early morning (6.00 pm).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	67.876	5	13.575	2.125	.090
Intercept	248153.423	1	248153.423	38848.499	.000
Water levels	67.020	2	33.510	5.246	.011
Cultivars	.614	1	.614	.096	.759
Water * Cultivar	.242	2	.121	.019	.981
Error	191.632	12	6.388		
Total	248412.930	18			
Corrected Total	259.508	17			

a R Squared = .262 (Adjusted R Squared = .138).

Table A3: 60 Analysis of variance of leaf relative water content as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), two months after planting at midday (12.00-01.00 pm).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	1021.212	5	204.242	26.821	.000
Intercept	190066.934	1	190066.934	24959.181	.000
Water levels	972.827	2	486.414	63.875	.000
Cultivars	1.778E-02	1	1.778E-02	.002	.962
Water * Cultivar	48.367	2	24.184	3.176	.056
Error	228.453	12	7.615		
Total	191316.600	18			
Corrected Total	1249.666	17			

a R Squared = .817 (Adjusted R Squared = .787).

Table A3: 61 Analysis of variance of leaf relative water content as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), two months after planting at late afternoon (6.00 pm).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	51.148	5	10.230	12.242	.000
Intercept	233466.134	1	233466.134	279395.677	.000
Water levels	44.291	2	22.145	26.502	.000
Cultivars	3.423	1	3.423	4.096	.052
Water * Cultivar	3.435	2	1.718	2.055	.146
Error	25.068	12	.836		
Total	233542.350	18			
Corrected Total	76.216	17			

a R Squared = .671 (Adjusted R Squared = .616).

Table A3: 62 Analysis of variance of leaf relative water content as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), three months after planting at early morning (6.00 pm).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	240.548	5	48.110	6.980	.000
Intercept	230768.147	1	230768.147	33481.051	.000
Water levels	170.344	2	85.172	12.357	.000
Cultivars	62.147	1	62.147	9.017	.005
Water * Cultivar	8.057	2	4.029	.584	.564
Error	206.775	12	6.892		
Total	231215.470	18			
Corrected Total	447.323	17			

a R Squared = .538 (Adjusted R Squared = .461).

Table A3: 63 Analysis of variance of leaf relative water content as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), three months after planting at midday (12.00-01.00 pm).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	420.956	5	84.191	26.086	.000
Intercept	206873.361	1	206873.361	64098.194	.000
Water levels	317.744	2	158.872	49.225	.000
Cultivars	94.090	1	94.090	29.153	.000
Water * Cultivar	9.122	2	4.561	1.413	.259
Error	96.823	12	3.227		
Total	207391.140	18			
Corrected Total	517.779	17			

a R Squared = .813 (Adjusted R Squared = .782).

Table A3: 64 Analysis of variance of leaf relative water content as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), three months after planting at late afternoon (6.00 pm).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	446.366	5	89.273	37.083	.000
Intercept	217016.222	1	217016.222	90145.894	.000
Water levels	418.695	2	209.347	86.960	.000
Cultivars	18.634	1	18.634	7.740	.009
Water * Cultivar	9.037	2	4.519	1.877	.171
Error	72.222	12	2.407		
Total	217534.810	18			
Corrected Total	518.588	17			

a R Squared = .861 (Adjusted R Squared = .838).

Table A3: 65 Analysis of variance of leaf chlorophyll concentration as affected by water stress levels and sweet potato cultivars (Lole and Wanmun) at two months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	5595689.028	5	1119137.806	96.238	.000
Intercept	454771759.49	1	454771759.49	39107.116	.000
Water	3965139.474	2	1982569.737	170.487	.000
Cultivars	1077453.571	1	1077453.571	92.653	.000
Water * Cultivar	553095.983	2	276547.991	23.781	.000
Error	558185.993	48	11628.875		
Total	460925634.51	54			
Corrected Total	6153875.02	53			

a R Squared = .909 (Adjusted R Squared = .900).

Table A3: 66 Analysis of variance of leaf chlorophyll concentration as affected by water stress levels and sweet potato cultivars (Lole and Wanmun) at three months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	5435077.698	5	1087015.540	378.297	.000
Intercept	245056888.639	1	245056888.63	85283.256	.000
Water	1158967.907	2	579483.954	201.669	.000
Cultivars	4057475.790	1	4057475.790	1412.059	.000
Water * Cultivar	218634.001	2	109317.000	38.044	.000
Error	137925.440	48	2873.447		
Total	250629891.772	54			
Corrected Total	5573003.138	53			

a R Squared = .975 (Adjusted R Squared = .973).

Table A3: 67 Analysis of variance of leaf carotene concentration as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), two months after planting (data was transformed using ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	.715	5	.143	27.895	.000
Intercept	2108.491	1	2108.491	411534.78	.000
Water levels	.444	2	.221	43.284	.000
Cultivars	6.140E-02	1	6.140E-02	11.985	.000
Water * Cultivar	.210	2	.105	20.461	.000
Error	.246	48	5.123E-03		
Total	2109.452	54			
Corrected Total	.961	53			

a R Squared = .744 (Adjusted R Squared = .717).

Table A3: 68 Analysis of variance of leaf carotene concentration as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), three months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	1.555	5	.311	118.240	.000
Intercept	1906.693	1	1906.693	725001.040	.000
Water levels	.501	2	.251	95.343	.000
Cultivars	1.036	1	1.036	393.831	.000
Water * Cultivar	1.758E-02	2	8.790E-03	3.34	.044
Error	.126	48	2.630E-0		
Total	1908.374	54			
Corrected Total	1.681	53			

a R Squared = .925(Adjusted R Squared = .917).

Table A3: 69 Analysis of variance of stomata density (adaxial leaf surface) as affected by water stress levels on 2 sweet potato cultivars (Lole and Wanmun).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	63.829	5	12.766	17.140	.000
Intercept	3436.484	1	3436.484	4614.020	.000
Water levels	1.823	2	.911	1.224	.312
Cultivars	61.395	1	61.395	82.432	.000
Water * Cultivar	.612	2	.306	.411	.668
Error	17.875	48	.745		
Total	3518.187	54			
Corrected Total	81.704	53			

a R Squared = .781(Adjusted R Squared = .736).

Table A3: 70 Analysis of variance of stomata density (abaxial leaf surface) as affected by water stress levels on 2 sweet potato cultivars (Lole and Wanmun).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	1392.249	5	278.450	222.677	.000
Intercept	20427.601	1	20427.601	16336.030	.000
Water levels	3.335	2	1.668	1.334	.282
Cultivars	1375.890	1	1375.890	1100.304	.000
Water * Cultivar	13.024	2	6.512	5.208	.013
Error	30.011	48	1.250		
Total	21849.861	54			
Corrected Total	1422.260	53			

a R Squared = .979 (Adjusted R Squared = .975).

Table A3: 71 Analysis of variance of the sucrose concentration of tuber as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), three months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	50.318	5	10.064	5.887	.006
Intercept	3618.169	1	3618.169	2116.576	.000
Water levels	8.741	2	4.371	2.557	.119
Cultivars	35.842	1	35.842	20.96	.001
Water * Cultivar	5.734	2	2.867	1.67	.228
Error	20.513	48	1.709		
Total	3689.000	54			
Corrected Total	70.831	53			

a R Squared = .710 (Adjusted R Squared = .590).

Table A3: 72 Analysis of variance of the sucrose concentration of tuber as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), three 6 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	973.745	5	194.749	15.534	.000
Intercept	5010.005	1	5010.005	399.628	.000
Water levels	567.250	2	283.625	22.624	.000
Cultivars	374.467	1	374.467	29.870	.000
Water * Cultivar	32.028	2	16.014	1.277	.314
Error	150.440	48	12.537		
Total	6134.190	54			
Corrected Total	1124.185	53			

a R Squared = .866 (Adjusted R Squared = .810).

Table A3: 73 Analysis of variance of the starch concentration of tuber as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), three 3 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	53.207	5	10.641	3.388	.039
Intercept	20563.92	1	20563.920	6546.703	.000
Water levels	13.903	2	6.952	2.213	.152
Cultivars	27.380	1	27.380	8.717	.012
Water * Cultivar	11.923	2	5.962	1.898	.192
Error	37.693	48	3.141		
Total	20654.820	54			
Corrected Total	90.900	53			

a R Squared = .585 (Adjusted R Squared = .413).

Table A3: 74 Analysis of variance of the starch concentration of tuber as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), three 6 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	843.069	5	168.614	7.569	.002
Intercept	23754.734	1	23754.734	1066.404	.000
Water levels	231.848	2	115.924	5.204	.024
Cultivars	604.361	1	604.361	27.131	.000
Water * Cultivar	6.861	2	3.431	.154	.859
Error	267.307	48	22.276		
Total	24865.110	54			
Corrected Total	1110.376	53			

a R Squared = .759 (Adjusted R Squared = .659).

Table A3: 75 Analysis of variance of tuber yield as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), at 2 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	183720.216	5	36744.043	188.050	.000
Intercept	433106.249	1	433106.249	2216.565	.000
Water levels	76432.865	2	38216.433	195.585	.000
Cultivars	85600.737	1	85600.737	438.090	.000
Water * Cultivar	21686.614	2	10843.307	55.494	.000
Error	3517.115	18	195.395		
Total	620343.581	24			
Corrected Total	187237.331	23			

a R Squared = .981 (Adjusted R Squared = .976).

Table A3: 76 Analysis of variance of tuber yield as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), at 3 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	678874.798	5	135774.960	262.053	.000
Intercept	2318816.667	1	2318816.667	4475.436	.000
Water levels	368829.836	2	184414.918	355.930	.000
Cultivars	225156.882	1	225156.882	434.564	.000
Water * Cultivar	84888.081	2	42444.040	81.919	.000
Error	9326.175	18	518.121		
Total	3007017.640	24			
Corrected Total	688200.973	23			

a R Squared = .986 (Adjusted R Squared = .983).

Table A3: 77 Analysis of variance of tuber yield as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), at 4 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	881338.667	5	176267.733	243.198	.000
Intercept	4004852.300	1	4004852.300	5525.517	.000
Water levels	566934.663	2	283467.332	391.101	.000
Cultivars	190121.800	1	190121.800	262.312	.000
Water * Cultivar	124282.203	2	62141.102	85.736	.000
Error	13046.262	18	724.792		
Total	4899237.230	24			
Corrected Total	894384.930	23			

a R Squared = .985 (Adjusted R Squared = .981).

Table A3: 78 Analysis of variance of tuber yield as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), at 5 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	1385346.982	5	277069.396	306.624	.000
Intercept	6186933.760	1	6186933.760	6846.896	.000
Water levels	907275.816	2	453637.908	502.028	.000
Cultivars	314897.95	1	314897.950	348.488	.000
Water * Cultivar	163173.216	2	81586.608	90.289	.000
Error	16265.008	18	903.612		
Total	7588545.750	24			
Corrected Total	1401611.990	23			

a R Squared = .988 (Adjusted R Squared = .985).

Table A3: 79 Analysis of variance of tuber yield as affected by water stress levels and sweet potato cultivars (Lole and Wanmun), at 6 months after planting (data was transformed into ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	4.551	5	.910	215.499	.000
Intercept	984.273	1	984.273	233036.32	.000
Water levels	3.729	2	1.864	441.432	.000
Cultivars	.467	1	.467	110.627	.000
Water * Cultivar	.355	2	.177	42.002	.000
Error	7.603E-02	18	4.224E-03		
Total	988.900	24			
Corrected Total	4.627	23			

a R Squared = .984 (Adjusted R Squared = .979).

Table A3: 80 Analysis of variance of tuber number as affected by water stress levels and sweet potato cultivars, Lole and Wanmun (data was transferred using artan transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	.188	5	3.751E-02	14.013	.000
Intercept	42.103	1	42.103	15728.835	.000
Water levels	.109	2	5.464E-02	20.411	.000
Cultivars	1.888E-02	1	1.888E-02	7.055	.016
Water * Cultivar	5.939E-02	2	2.970E-02	11.094	.001
Error	4.818E-02	18	2.677E-03		
Total	42.339	24			
Corrected Total	.236	23			

a R Squared = .796 (Adjusted R Squared = .739).

Table A3: 81 Means of leaf water potential of Lole and Wanmun sweet potato cultivars as affected by three soil water levels at 2 and 3 months after planting.

Cultivars	Soil FC (%)	Leaf water potential (MPa)					
		2 months			3 months		
		6:00 am	12:00-1.00 pm	6:00 pm	6:00 am	12:00-1.00 pm	6:00 pm
Lole	20	-0.43a	-0.99c	-0.50c	-0.68a	-1.26c	-0.77c
	40	-0.43a	-0.92b	-0.41b	-0.68a	-1.16b	-0.72b
	80	-0.43a	-0.88a	-0.38a	-0.70b	-1.14a	-0.66a
Wanmun	20	-0.48a	-1.26f	-0.97f	-0.68b	-1.31c	-1.03f
	40	-0.46a	-1.14e	-0.97e	-0.71b	-1.21b	-0.93e
	80	-0.42a	-0.96d	-0.74d	-0.72a	-1.13a	-0.77d

Values within a column followed by the same letter symbol are not significantly different (p<0.05). All the interactions are significant (p<0.05).

Table A3: 82 Means of leaf relative water content of Lole and Wanmun sweet potato cultivars as affected by three soil water levels at 2 and 3 months after planting.

Cultivars	Soil FC (%)	Relative water content (%)					
		2 months			3 months		
		6:00 am	12:00-1.00 pm	6:00 pm	6:00 am	12:00-1.00 pm	6:00 pm
Lole	20	81.31b	65.23c	79.61b	79.03b	74.26c	74.31c
	40	83.50a	72.48b	80.11b	82.00b	77.66b	79.71b
	80	84.65a	80.20a	82.78a	83.10a	80.33a	81.05a
Wanmun	20	81.03b	68.55c	79.25b	75.26e	69.96f	71.51f
	40	83.45a	70.71b	80.10b	79.33d	74.15e	78.61e
	80	84.20a	78.78a	81.31a	81.65c	78.45d	80.63d

Values within a column followed by the same letter symbol are not significantly different (p<0.05). All the interactions are significant (p<0.05).

APPENDIX A4

CALCULATION FOR THE FERTILIZER REQUIREMENTS, PLANT MEASUREMENTS AND RESULTS OF STATISTICAL ANALYSES OF CHAPTER 4

1 Calculation for the fertilizer requirements

A = Лr^{2} = Л (13)^{2} = 530.7 g cm^{-2}.

Nitrogen (NH_4NO_3)
= 2.86 mg cm^{-2} x 530.7 mg/pot
= 1.52 g/pot
2.86 mg cm^{-2} x 1.52 g/pot
= 4.347 g/pot

Potassium (KCl)
= 1.61 mg cm^{-2} x 530.7 mg/pot
= 0.854 g/pot
1.61 mg cm^{-2} x 0.854 mg/pot
=1.375 g/pot

Magnesium ($MgCl_2.6H_2O$)
= 2.50 mg cm^{-2} x 530.7 mg/pot
= 1.326 g/pot
2.50 mg cm^{-2} x 1.326 mg/pot
= 3.315 g/pot

Fe Na EDTA
= 0.33 mg cm^{-2} x 530.7 mg/pot
= 0.175 g/pot
0.33 mg cm^{-2} x 0.175 mg/pot
= 0.058 g/pot

Manganese ($MnCl_2.4H_2O$)
= 0.164 mg cm^{-2} x 530.7 mg/pot
= 0.087 g/pot
0.164 mg cm^{-2} x 0.087 mg/pot
= 0.014 g/pot

Copper ($CuCl_2.2H_2O$)
= 0.0804 mg cm^{-2} x 530.7 mg/pot
= 0.0427 g/pot
0.0804 mg cm^{-2} x 0.0427 g/pot
= 0.0034 g/pot

Phosphorus ($NaH_2PO4.2H_2O$)
= 1.73 mg cm^{-2} x 530.7 mg/pot
= 0.918 g/pot
1.73 mg cm^{-2} x 0.918 mg/pot
= 1.588 g/pot

Calcium ($CaCl_2$)
= 0.98 mg cm^{-2} x 530.7 mg/pot
= 0.520 g/pot
0.98 mg cm^{-2} x 0.520 mg/pot
= 0.510 g/pot

Sodium (Na_2SO_4)
= 1.11 mg cm^{-2} x 530.7 mg/pot
= 589.077 g/pot
1.11 mg cm^{-2} x 589.077 mg/pot
= 0.654 g/pot

Boron (H_3BO_3)
= 0.114 mg cm^{-2} x 530.7 mg/pot
= 0.060 g/pot
0.114 mg cm^{-2} x 0.060 mg/pot
= 0.007 g/pot

Zinc ($ZnCl_2$)
= 0.083 mg cm^{-2} x 530.7 mg/pot
= 0.044 g/pot
0.083 mg cm^{-2} x 0.044 g/pot
= 0.0037 g/pot

Molybdenum ($([NH_4]_6 MoO_{24}.4H_2O)$)
= 0.0684 mg cm^{-2} x 530.7 mg/pot
= 0.0363 g/pot
0.0684 mg cm^{-2} x 0.0363 mg/pot
= 0.0025 g/pot

Figure A4.1 Effects of nitrogen (20, 100, and 200 kg of N / ha) and potassium (16, 80, and 160 kg of K / ha) applications on the average daily transpiration of Lole and Wanmun cultivars grown under 30% and 80% of the soil field capacity, between 1and 5 months after planting.

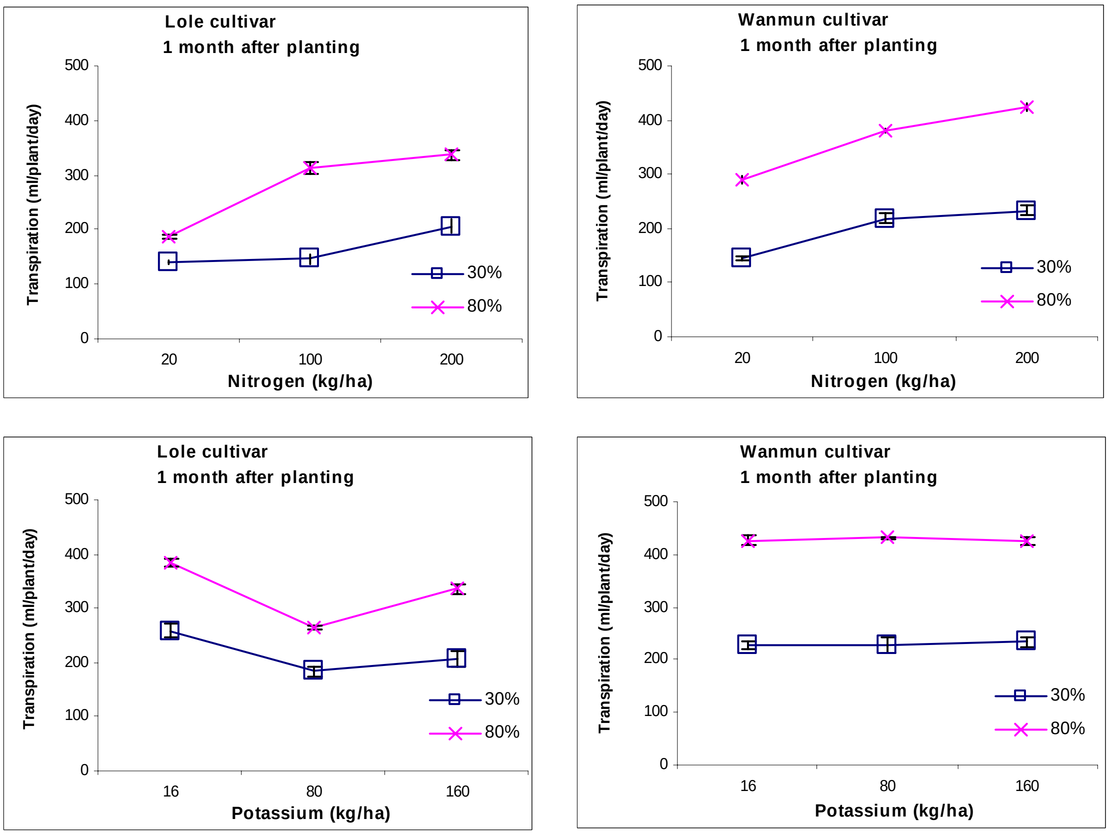

Figure A4.1 (continued)

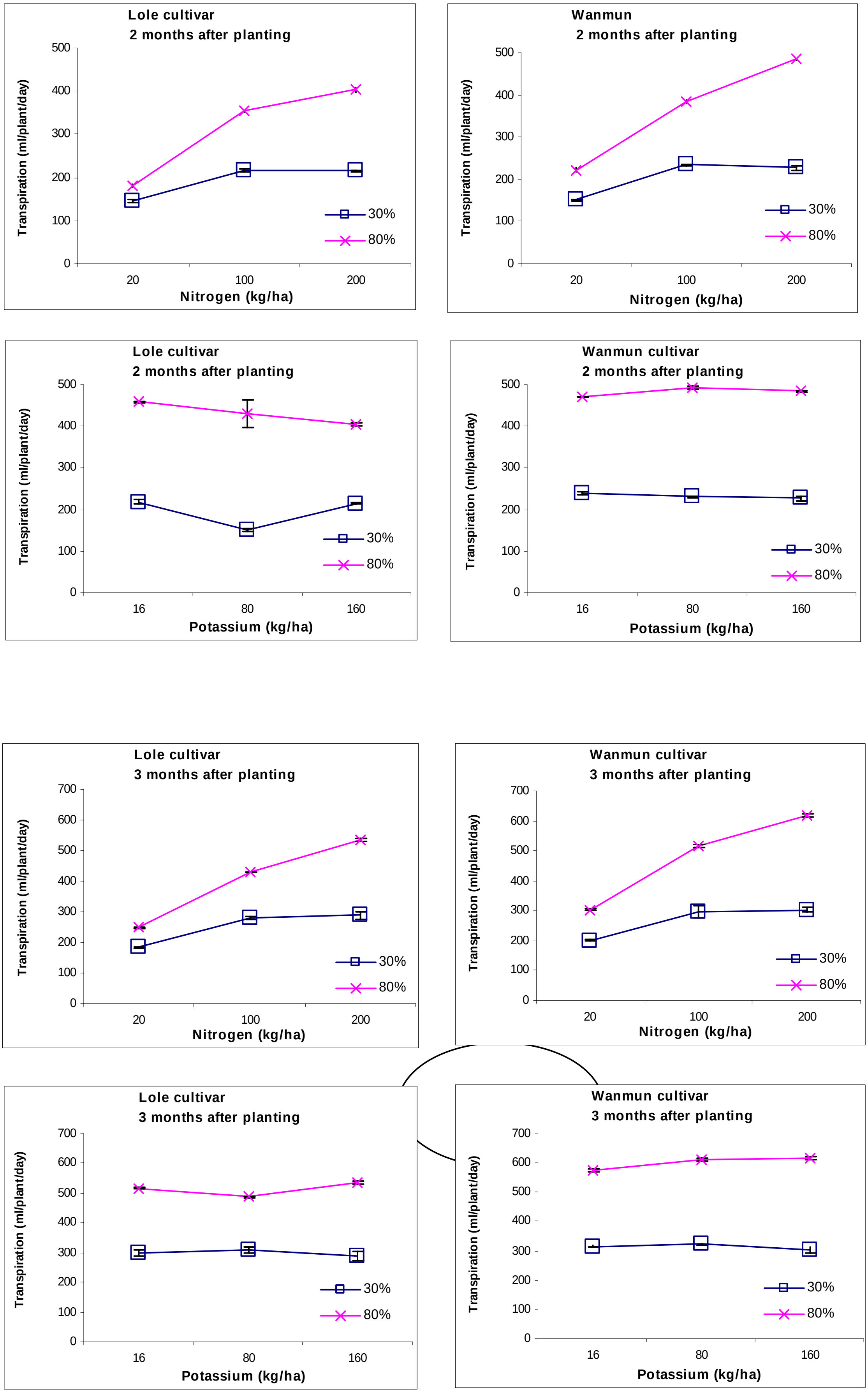

Figure A4.1 (continued)

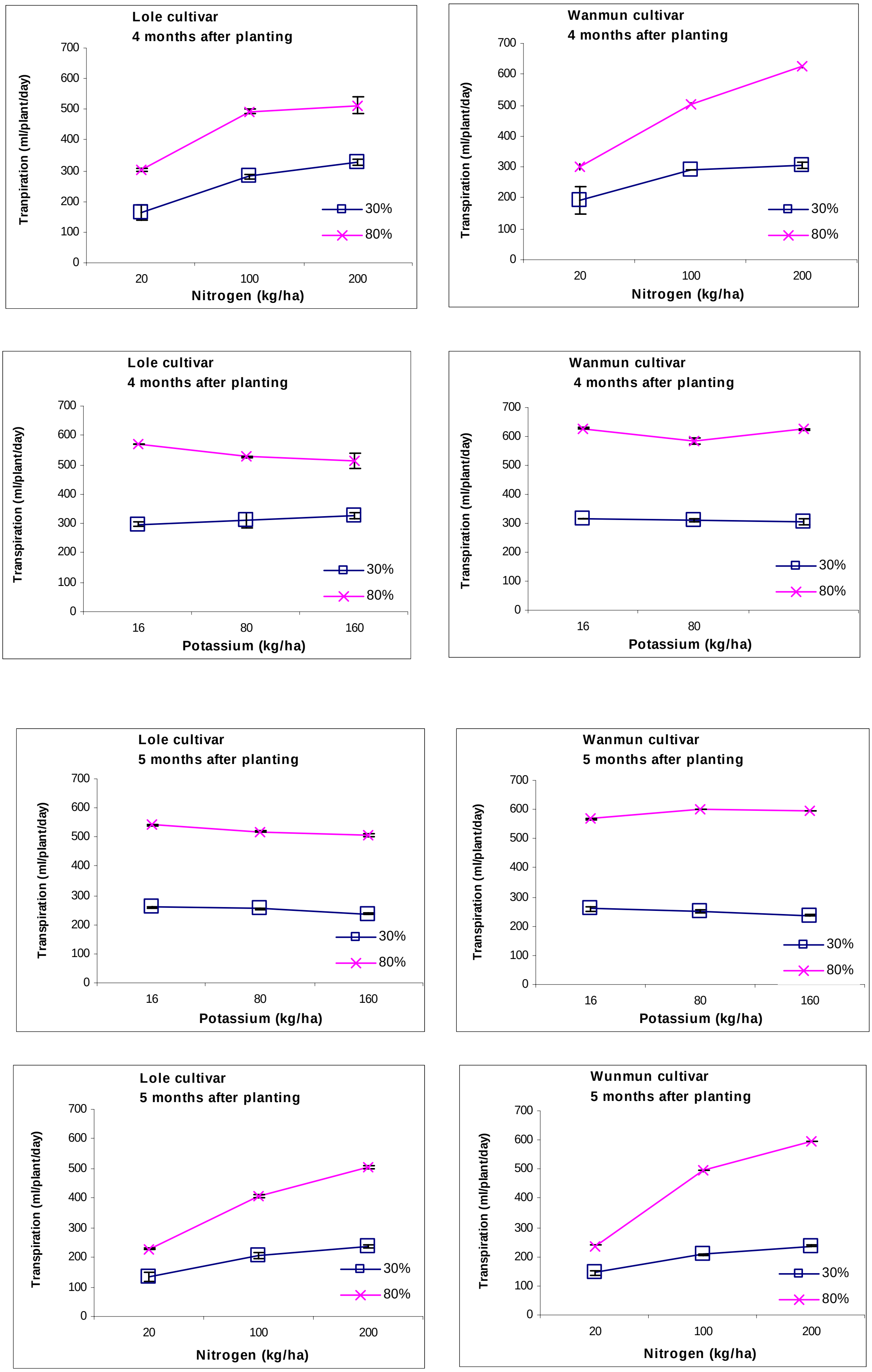

Table A4: 1 Analysis variance of shoots dry weight of Lole and Wanmun sweet potato cultivars as affected by nitrogen levels (20, 100, and 200 kg N/ha) under 30 and 80% soil field capacity (data was transformed into ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	21.770	11	1.979	125.227	.000
Intercept	322.392	1	322.392	20399.24	.000
Cultivars (C)	.541	1	.540	34.172	.000
Water levels (W)	3.250	1	3.251	205.709	.000
Nutrient levels (N)	17.555	2	8.778	555.395	.000
Water*Cultivar	8.366E-03	1	8.366E-03	.529	.472
Cultivar*Nutrient	.241	2	.121	7.625	.002
Water*Nutrient	2.771E-02	2	1.385E-02	.877	.425
W*C*N	.147	2	7.341E-02	4.645	.016
Error	.569	36	1.580E-02		
Total	344.731	48			
Corrected total	22.339	47			

a R Squared = .975 (Adjusted R Squared = .967).

Table A4: 2 Analysis variance of shoot dry weight of Lole and Wanmun sweet potato cultivars as affected by potassium levels (16, 80, and 160 kg K/ha) under 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	3577.008	11	325.183	17.740	.000
Intercept	32807.792	1	32807.792	1789.761	.000
Cultivars (C)	625.974	1	625.974	34.149	.000
Water levels (W)	2381.492	1	2381.492	129.917	.063
Nutrient levels (N)	143.900	2	71.950	3.925	.029
Water*Cultivar	184.632	1	184.632	10.072	.003
Cultivar*Nutrient	149.633	2	74.816	4.081	.025
Water*Nutrient	34.738	2	17.369	.948	.397
W*C*N	56.640	2	28.320	1.545	.227
Error	659.910	36	18.331		
Total	37044.710	48			
Corrected total	4236.918	47			

a R Squared = .844 (Adjusted R Squared = .797).

Table A4: 3 Analysis variance of leaf dry mass of Lole and Wanmun sweet potato cultivars as affected by nitrogen levels (20, 100, and 200 kg N/ha) under 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	920.668	11	83.697	65.668	.000
Intercept	2108.340	1	2108.340	1654.191	.000
Cultivars (C)	9.684	1	9.684	7.598	.009
Water levels (W)	156.313	1	156.313	122.642	.000
Nutrient levels (N)	658.626	2	329.313	258.377	.000
Water*Cultivar	1.880	1	1.880	1.475	.232
Cultivar*Nutrient	29.456	2	14.728	11.555	.000
Water*Nutrient	47.954	2	23.977	18.812	.000
W*C*N	16.756	2	8.378	6.573	.004
Error	45.884	36	1.275		
Total	3074.892	48			
Corrected total	966.552	47			

a R Squared = .953 (Adjusted R Squared = .938).

Table A4: 4 Analysis variance of leaf dry mass of Lole and Wanmun sweet potato cultivars as affected by potassium levels (16, 80, and 160 kg K/ha) under 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	366.164	11	33.288	20.185	.000
Intercept	4968.046	1	4968.046	3012.566	.000
Cultivars (C)	40.719	1	40.719	24.692	.000
Water levels (W)	286.310	1	286.310	173.615	.000
Nutrient levels (N)	9.462	2	4.731	2.869	.070
Water*Cultivar	8.259	1	8.259	5.008	.032
Cultivar*Nutrient	13.300	2	6.650	4.033	.026
Water*Nutrient	7.298	2	3.649	2.213	.124
W*C*N	.816	2	.408	.247	.782
Error	59.368	36	1.649		
Total	5393.577	48			
Corrected total	425.532	47			

a R Squared = .860 (Adjusted R Squared = .818).

Table A4: 5 Analysis variance of leaf area of Lole and Wanmun sweet potato cultivars as affected by nitrogen levels (20, 100, and 200 kg N/ha) under 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	26539268.89	11	2412660.809	303.764	.000
Intercept	59023331.58	1	59023331.59	7431.278	.000
Cultivars (C)	1048085.324	1	1048085.324	131.958	.000
Water levels (W)	3074122.272	1	3074122.272	387.045	.000
Nutrient levels (N)	20526076.69	2	10263038.35	1292.158	.000
Water*Cultivar	8935.292	1	8935.292	1.125	.296
Cultivar*Nutrient	552858.035	2	276429.017	34.804	.002
Water*Nutrient	992533.883	2	496266.942	62.482	.425
W*C*N	336657.394	2	168328.697	21.193	.016
Error	285931.950	36	7942.554		
Total	85848532.43	48			
Corrected total	26825200.85	47			

a R Squared = .989 (Adjusted R Squared = .986).

Table A4: 6 Analysis variance of leaf area of Lole and Wanmun sweet potato cultivars as affected by potassium levels (16, 80, and 160 kg K/ha) under 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	13088653.52	11	1189877.593	35.027	.000
Intercept	191774266.38	1	191774266.38	5645.334	.000
Cultivars (C)	5539820.836	1	5539820.836	163.078	.000
Water levels (W)	6242627.914	1	6242627.914	183.767	.063
Nutrient levels (N)	598790.386	2	299395.193	8.813	.001
Water*Cultivar	146953.160	1	146953.160	4.326	.045
Cultivar*Nutrient	143093.657	2	71546.828	2.106	.136
Water*Nutrient	73516.236	2	36758.118	1.082	.350
W*C*N	343851.331	2	171925.666	5.061	.012
Error	1222934.501	36	33970.403		
Total	206085854.40	48			
Corrected total	14311588.02	47			

a R Squared = .915 (Adjusted R Squared = .888).

Table A4: 7 Analysis variance of specific leaf weight (mass) of Lole and Wanmun sweet potato cultivars as affected by nitrogen levels (20, 100, and 200 kg N/ha) under 30 and 80% soil FC (data was transformed into ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	.684	11	6.216E-02	1.671	.121
Intercept	155.535	1	155.535	4180.157	.000
Cultivars (C)	.365	1	.365	9.815	.003
Water levels (W)	6.389E-02	1	6.389E-02	1.717	.198
Nutrient levels (N)	.103	2	5.133E-02	1.380	.265
Water*Cultivar	2.991E-04	1	2.991E-04	.008	.929
Cultivar*Nutrient	.139	2	6.932E-02	1.863	.170
Water*Nutrient	1.221E-02	2	6.104E-03	.164	.849
W*C*N	8.565E-04	2	4.283E-04	.012	.989
Error	1.339	36	3.721E-02		
Total	157.558	48			
Corrected total	2.023	47			

a R Squared = .338 (Adjusted R Squared = .136).

Table A4: 8 Analysis variance of specific leaf weight (mass) of Lole and Wanmun sweet potato cultivars as affected by potassium levels (16, 80, and 160 kg K/ha) under 30 and 80% soil field capacity (data was transformed into ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	1.150	11	.105	4.266	.000
Intercept	126.407	1	126.407	5160.173	.000
Cultivars (C)	.354	1	.354	14.466	.001
Water levels (W)	.157	1	.157	6.424	.016
Nutrient levels (N)	.387	2	.194	7.899	.001
Water*Cultivar	2.560E-02	1	2.560E-02	1.045	.313
Cultivar*Nutrient	.146	2	7.284E-02	2.974	.064
Water*Nutrient	2.213E-03	2	1.106E-03	.045	.956
W*C*N	7.740E-02	2	3.870E-02	1.580	.220
Error	.882	36	2.450E-02		
Total	128.439	48			
Corrected total	2.039	47			

a R Squared = .566 (Adjusted R Squared = .433).

Table A4: 9 Analysis variance of root dry mass of Lole and Wanmun sweet potato cultivars as affected by nitrogen levels (20, 100, and 200 kg N/ha) under 30 and 80% soil field capacity (data was transformed into ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	14.359	11	1.305	18.498	.002
Intercept	86.365	1	86.365	1223.855	.000
Cultivars (C)	5.858	1	5.858	83.019	.001
Water levels (W)	2.545	1	2.545	36.070	.029
Nutrient levels (N)	5.050	2	2.525	35.783	.001
Water*Cultivar	.207	1	.207	2.936	.095
Cultivar*Nutrient	.163	2	8.132E-02	1.156	.327
Water*Nutrient	.218	2	.109	1.544	.227
W*C*N	.317	2	.158	2.246	.120
Error	2.540	36	7.057E-02		
Total	103.264	48			
Corrected total	16.899	47			

a R Squared = .850 (Adjusted R Squared = .804).

Table A4: 10 Analysis variance of root dry mass of Lole and Wanmun sweet potato cultivars as affected by potassium levels (16, 80, and 160 kg K/ha) under 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	670.346	11	60.941	9.982	.000
Intercept	2069.840	1	2069.840	339.027	.000
Cultivars (C)	428.443	1	428.443	70.176	.000
Water levels (W)	150.982	1	150.982	24.730	.000
Nutrient levels (N)	1.369	2	.685	.112	.894
Water*Cultivar	49.829	1	49.829	8.162	.007
Cultivar*Nutrient	3.531	2	1.766	.289	.751
Water*Nutrient	19.167	2	9.583	1.570	.222
W*C*N	17.025	2	8.513	1.394	.261
Error	219.789	36	6.105		
Total	2959.975	48			
Corrected total	890.135	47			

a R Squared = .753 (Adjusted R Squared = .678).

Table A4: 11 Analysis variance of tuber yields of Lole and Wanmun sweet potato cultivars as affected by nitrogen levels (20, 100, and 200 kg N/ha) under 30 and 80% soil field capacity (data was transformed into ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	3054032.229	11	277639.294	700.827	.000
Intercept	8635185.021	1	8635185.021	21797.231	.000
Cultivars (C)	38476.688	1	38476.688	97.124	.000
Water levels (W)	678538.521	1	678538.521	1712.790	.000
Nutrient levels (N)	2046415.792	2	1023207.896	2582.817	.000
Water*Cultivar	59572.521	1	59572.521	150.375	.000
Cultivar*Nutrient	15767.375	2	7883.687	19.900	.000
Water*Nutrient	190215.042	2	95107.521	240.074	.000
W*C*N	25046.292	2	12523.146	31.611	.000
Error	14261.750	36	396.160		
Total	11703479.00	48			
Corrected total	3068293.979	47			

a R Squared = .995 (Adjusted R Squared = .994).

Table A4: 12 Analysis variance of tuber yields of Lole and Wanmun sweet potato cultivars as affected by potassium levels (16, 80, and 160 kg K/ha) under 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	1088852.729	11	98986.612	133.742	.000
Intercept	11031377.52	1	11031377.52	14904.609	.000
Cultivars (C)	4700.521	1	4700.521	6.351	.016
Water levels (W)	735817.688	1	735817.688	994.171	.000
Nutrient levels (N)	229836.542	2	114918.271	155.267	.000
Water*Cultivar	2310.187	1	2310.187	3.121	.086
Cultivar*Nutrient	33701.542	2	16850.771	22.767	.000
Water*Nutrient	51476.375	2	25738.187	34.775	.000
W*C*N	31009.875	2	15504.938	20.949	.000
Error	26644.750	36	740.132		
Total	12146875.00	48			
Corrected total	1115497.479	47			

a R Squared = .976 (Adjusted R Squared = .969).

Table A4: 13 Analysis variance of total chlorophyll of Lole and Wanmun sweet potato cultivars as affected by nitrogen levels (20, 100, and 200 kg N/ha) under 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	25585915.04	11	2325992.277	598.221	.000
Intercept	115312892.88	1	115312892.88	29657.292	.000
Cultivars (C)	334262.340	1	334262.340	85.969	.000
Water levels (W)	2475242.324	1	2475242.324	636.607	.000
Nutrient levels (N)	22398465.364	2	11199232.68	2880.328	.000
Water*Cultivar	16588.971	1	16588.971	4.267	.000
Cultivar*Nutrient	3572.287	2	1786.143	.459	.000
Water*Nutrient	338704.579	2	169352.289	43.556	.000
W*C*N	19079.187	2	9539.594	2.453	.000
Error	139974.483	36	3888.180		
Total	141038782.412	48			
Corrected total	25725889.53	47			

a R Squared = .995 (Adjusted R Squared = .993).

Table A4: 14 Analysis variance of total chlorophyll of Lole and Wanmun sweet potato cultivars as affected by potassium levels (16, 80, and 160 kg K/ha) under 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	7311260.568	11	664660.052	454.968	.000
Intercept	242531092.472	1	242531092.47	166015.6	.000
Cultivars (C)	142603.268	1	142603.268	97.614	.009
Water levels (W)	5638943.690	1	5638943.690	3859.928	.000
Nutrient levels (N)	1473601.046	2	736800.523	504.349	.000
Water*Cultivar	3251.033	1	3251.033	2.225	.086
Cultivar*Nutrient	21127.506	2	10563.753	7.231	.006
Water*Nutrient	15913.035	2	7956.518	5.446	.000
W*C*N	15820.989	2	7910.495	5.415	.000
Error	52592.171	36	1460.894		
Total	249894945.21	48			
Corrected total	7363852.739	47			

a R Squared = .993 (Adjusted R Squared = .991).

Table A4: 15 Analysis variance of carotene concentration of Lole and Wanmun sweet potato cultivars as affected by nitrogen levels (20, 100, and 200 kg N/ha) under 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	1053838.634	11	95803.512	714.159	.000
Intercept	5556060.100	1	5556060.100	41417.16	.000
Cultivars (C)	10281.055	1	10281.055	76.639	.000
Water levels (W)	94955.550	1	94955.550	707.838	.000
Nutrient levels (N)	929223.635	2	464611.817	3463.408	.000
Water*Cultivar	1730.120	1	1730.120	12.897	.001
Cultivar*Nutrient	1358.492	2	679.246	5.063	.012
Water*Nutrient	15662.345	2	7831.172	58.377	.000
W*C*N	627.437	2	313.719	2.339	.111
Error	4829.355	36	134.149		
Total	6614728.088	48			
Corrected total	1058667.98	47			

a R Squared = .995 (Adjusted R Squared = .994).

Table A4: 16 Analysis variance of carotene concentration of Lole and Wanmun sweet potato cultivars as affected by potassium levels (16, 80, and 160 kg K/ha) under 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	291452.324	11	26495.666	300.004	.000
Intercept	11005703.76	1	11005703.76	124614.9	.000
Cultivars (C)	6012.087	1	6012.087	68.073	.009
Water levels (W)	211650.331	1	211650.331	2396.465	.000
Nutrient levels (N)	70132.808	2	35066.404	397.048	.000
Water*Cultivar	28.979	1	28.979	.328	.570
Cultivar*Nutrient	1340.860	2	670.430	7.591	.002
Water*Nutrient	1290.826	2	645.413	7.308	.002
W*C*N	996.434	2	498.217	5.641	.007
Error	3179.437	36	88.318		
Total	11300335.52	48			
Corrected total	294631.762	47			

a R Squared = .998 (Adjusted R Squared = .986)

Table A4: 17 Analysis variance of chlorophyll *a*/*b* ratio of Lole and Wanmun sweet potato cultivars as affected by nitrogen levels (20, 100, and 200 kg N/ha) under 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	.206	11	1.869E-02	1.204	.319
Intercept	1029.940	1	1029.940	66338.38	.000
Cultivars (C)	5.145E-04	1	5.145E-04	.033	.857
Water levels (W)	4.852E-02	1	4.852E-02	3.125	.086
Nutrient levels (N)	3.540E-02	2	1.770E-02	1.140	.331
Water*Cultivar	5.593E-03	1	5.593E-03	.360	.552
Cultivar*Nutrient	1.043E-03	2	5.215E-04	.034	.967
Water*Nutrient	.112	2	5.578E-02	3.593	.038
W*C*N	3.007E-02	2	1.504E-03	.097	.908
Error	.559	36	1.553E-02		
Total	1030.704	48			
Corrected total	.765	47			

a R Squared = .269 (Adjusted R Squared = .046).

Table A4: 18 Analysis variance of chlorophyll *a*/*b* ratio of Lole and Wanmun sweet potato cultivars as affected by potassium levels (16, 80, and 160 kg K/ha) under 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	.133	11	1.207E-02	4.754	.000
Intercept	1014.854	1	1014.854	399846.4	.000
Cultivars (C)	8.417E-04	1	8.417E-04	.332	.568
Water levels (W)	.122	1	.122	47.952	.000
Nutrient levels (N)	3.185E-04	2	1.593E-04	.063	.939
Water*Cultivar	2.624E-03	1	2.624E-03	1.034	.316
Cultivar*Nutrient	3.002E-04	2	1.501E-04	.059	.943
Water*Nutrient	4.779E-03	2	2.390E-03	.941	.399
W*C*N	2.152E-03	2	1.076E-03	.421	.658
Error	9.137E-02	36	2.538E-03		
Total	1015.078	48			
Corrected total	.224	47			

a R Squared = .592 (Adjusted R Squared = .648).

Table A4: 19 Analysis variance of transpiration in Lole and Wanmun sweet potato cultivars affected by nitrogen levels (20, 100, and 200 kg N/ha) and soil water regimes (30 and 80% soil field capacity), at 1 month after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	403459.854	11	36678.169	138.690	.000
Intercept	3039630.021	1	3039630.021	11493.65	.000
Cultivars (C)	43260.021	1	43260.021	163.578	.000
Water levels (W)	234221.021	1	234221.021	885.652	.000
Nutrient levels (N)	100213.510	2	50106.755	189.467	.000
Water*Cultivar	7625.521	1	7625.521	28.834	.000
Cultivar*Nutrient	530.948	2	265.474	1.004	.377
Water*Nutrient	11909.885	2	5954.943	22.517	.000
W*C*N	5698.948	2	2849.474	10.775	.000
Error	9520.625	36	264.462		
Total	3452610.500	48			
Corrected total	412980.479	47			

a R Squared = .977 (Adjusted R Squared = .970).

Table A4: 20 Analysis variance of transpiration in Lole and Wanmun sweet potato cultivars as affected by potassium levels (16, 80, and 160 kg K/ha) and soil water regimes (30 and 80% soil field capacity), at 1 month after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	388853.141	11	35350.286	94.553	.000
Intercept	4331707.922	1	4331707.922	11586.25	.000
Cultivars (C)	288377.505	1	288377.505	771.339	.000
Water levels (W)	37548.047	1	37548.047	100.432	.000
Nutrient levels (N)	17933.344	2	8966.672	23.984	.000
Water*Cultivar	21909.380	1	21909.380	58.602	.000
Cultivar*Nutrient	887.948	2	443.974	1.188	.000
Water*Nutrient	20037.406	2	10018.703	26.798	.317
W*C*N	2159.510	2	1079.755	2.888	.069
Error	13459.188	36	373.866		
Total	4734020.250	48			
Corrected total	402312.328	47			

a R Squared = .967 (Adjusted R Squared = .956)

Table A4: 21 Analysis variance of transpiration in Lole and Wanmun sweet potato cultivars as affected by nitrogen levels (20, 100, and 200 kg N/ha) and soil water regimes (30 and 80% soil field capacity), at 2 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	530854.661	11	48259.515	1090.167	.000
Intercept	3446846.303	1	3446846.303	77863.14	.000
Cultivars (C)	235879.490	1	235879.490	5328.441	.000
Water levels (W)	11817.394	1	11817.394	266.951	.000
Nutrient levels (N)	218985.363	2	109492.682	2473.404	.000
Water*Cultivar	4406.736	1	4406.736	99.547	.000
Cultivar*Nutrient	56818.252	2	28409.126	641.753	.000
Water*Nutrient	1335.051	2	667.525	15.079	.000
W*C*N	1612.374	2	806.187	18.212	.000
Error	1593.648	36	44.268		
Total	3979294.612	48			
Corrected total	532448.309	47			

a R Squared = .997 (Adjusted R Squared = .996).

Table A4: 22 Analysis variance of transpiration in Lole and Wanmun sweet potato cultivars as affected by potassium levels (16, 80, and 160 kg K/ha) and soil water regimes (30 and 80% soil field capacity), at 2 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	752212.812	11	68382.983	174.826	.000
Intercept	5386163.519	1	5386163.519	13770.11	.000
Cultivars (C)	709183.475	1	709183.475	1813.078	.000
Water levels (W)	23700.000	1	23700.000	60.591	.000
Nutrient levels (N)	3332.063	2	1666.031	4.259	.022
Water*Cultivar	647.168	1	647.168	1.655	.207
Cultivar*Nutrient	5062.700	2	2531.350	6.472	.004
Water*Nutrient	5872.946	2	2936.473	7.507	.002
W*C*N	4414.460	2	2207.230	5.643	.007
Error	14081.360	36	391.149		
Total	6152457.691	48			
Corrected total	766294.173	47			

a R Squared = .982 (Adjusted R Squared = .976).

Table A4: 23 Analysis variance of transpiration in Lole and Wanmun sweet potato cultivars as affected by nitrogen levels (20, 100, and 200 kg N/ha) and soil water regimes (30 and 80% soil field capacity), at 3 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	861679.788	11	78334.526	297.627	.000
Intercept	5895218.926	1	5895218.926	22398.47	.000
Cultivars (C)	398713.306	1	398713.306	1514.883	.000
Water levels (W)	25195.835	1	25195.835	95.730	.000
Nutrient levels (N)	350096.645	2	175048.323	665.084	.000
Water*Cultivar	10102.548	1	10102.548	38.384	.000
Cultivar*Nutrient	76490.064	2	38245.032	145.309	.000
Water*Nutrient	493.563	2	246.781	.938	.401
W*C*N	587.827	2	293.914	1.11	.338
Error	9475.104	36	263.197		
Total	6766373.818	48			
Corrected total	871154.892	47			

a R Squared = .989 (Adjusted R Squared = .986).

Table A4: 24 Analysis variance of transpiration in Lole and Wanmun sweet potato cultivars as affected by potassium levels (16, 80, and 160 kg K/ha) and soil water regimes (30 and 80% soil field capacity), at 3 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	812399.918	11	73854.538	366.160	.000
Intercept	8930246.909	1	8930246.909	44274.81	.000
Cultivars (C)	753868.612	1	753868.612	3737.567	.000
Water levels (W)	31365.187	1	31365.187	155.504	.000
Nutrient levels (N)	956.780	2	478.390	2.372	.108
Water*Cultivar	15980.364	1	15980.364	79.228	.000
Cultivar*Nutrient	5069.526	2	2534.763	12.567	.000
Water*Nutrient	2244.851	2	1122.425	5.565	.008
W*C*N	2914.597	2	1457.299	7.225	.002
Error	7261.214	36	201.700		
Total	9749908.041	48			
Corrected total	819661.132	47			

a R Squared = .991 (Adjusted R Squared = .988).

Table A4: 25 Analysis variance of transpiration in Lole and Wanmun sweet potato cultivars as affected by nitrogen levels (20, 100, and 200 kg N/ha) and soil water regimes (30 and 80% soil field capacity), at 4 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	884879.735	11	80443.612	61.595	.000
Intercept	6156396.650	1	6156396.650	4713.890	.000
Cultivars (C)	464035.005	1	464035.005	355.307	.000
Water levels (W)	6154.005	1	6154.005	4.712	.037
Nutrient levels (N)	358214.390	2	179107.195	137.141	.000
Water*Cultivar	3488.895	1	3488.895	2.671	.111
Cultivar*Nutrient	34809.242	2	17404.621	13.327	.000
Water*Nutrient	2793.726	2	1396.863	1.070	.354
W*C*N	15384.472	2	7692.236	5.890	.006
Error	47016.431	36	1306.012		
Total	7088292.816	48			
Corrected total	931896.166	47			

a R Squared = .950 (Adjusted R Squared = .954).

Table A4: 26 Analysis variance of transpiration of Lole and Wanmun sweet potato cultivars as affected by potassium levels (16, 80, and 160 kg K/ha) and soil water regimes (30 and 80% soil field capacity), at 4 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	882446.075	11	80222.370	124.511	.000
Intercept	9399544.792	1	9399544.792	14588.74	.000
Cultivars (C)	834924.610	1	834924.610	1295.861	.000
Water levels (W)	16131.667	1	16131.667	25.037	.000
Nutrient levels (N)	2940.702	2	1470.351	2.282	.117
Water*Cultivar	17799.252	1	17799.252	27.626	.000
Cultivar*Nutrient	5158.245	2	2579.122	4.003	.027
Water*Nutrient	581.642	2	290.821	.451	.640
W*C*N	4909.957	2	2454.978	3.810	.032
Error	23194.847	36	644.301		
Total	10305185.717	48			
Corrected total	905640.921	47			

a R Squared = .974 (Adjusted R Squared = .967).

Table A4: 27 Analysis variance of transpiration of Lole and Wanmun sweet potato cultivars as affected by nitrogen levels (20, 100, and 200 kg N/ha) and soil water regimes (30 and 80% soil field capacity), at 5 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	1061621.556	11	96511.051	635.353	.000
Intercept	4392105.538	1	4392105.538	28914.16	.000
Cultivars (C)	564254.543	1	564254.543	3714.607	.000
Water levels (W)	12815.835	1	12815.835	84.369	.000
Nutrient levels (N)	363779.806	2	181889.903	1197.420	.000
Water*Cultivar	10109.615	1	10109.615	66.554	.000
Cultivar*Nutrient	101575.836	2	50787.918	334.348	.000
Water*Nutrient	3372.217	2	1686.108	11.100	.000
W*C*N	5713.704	2	2856.852	18.807	.000
Error	5468.456	36	151.902		
Total	5459195.550	48			
Corrected total	1067090.012	47			

a R Squared = .995 (Adjusted R Squared = .993).

Table A4: 28 Analysis variance of transpiration of Lole and Wanmun sweet potato cultivars as affected by potassium levels (16, 80, and 160 kg K/ha) and soil water regimes (30 and 80% soil field capacity), at 5 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	1151802.409	11	104709.310	1828.744	.000
Intercept	7769861.333	1	7769861.333	135700.3	.000
Cultivars (C)	1118043.537	1	1118043.537	19526.58	.000
Water levels (W)	12891.812	1	12891.812	225.155	.000
Nutrient levels (N)	1704.403	2	852.202	14.884	.000
Water*Cultivar	13574.894	1	13574.894	237.085	.000
Cultivar*Nutrient	778.378	2	389.189	6.797	.003
Water*Nutrient	2271.812	2	1135.906	19.839	.000
W*C*N	2537.572	2	1268.786	22.159	.000
Error	2061.270	36	57.258		
Total	8923725.013	48			
Corrected total	1153863.679	47			

a R Squared = .998 (Adjusted R Squared = .998).

Table A4: 29 Analysis variance of water use efficiency of Lole and Wanmun sweet potato cultivars as affected by nitrogen levels (20, 100, and 200 kg N/ha) and soil water regimes (30 and 80% soil field capacity).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	15.174	11	1.379	13.631	.000
Intercept	318.613	1	318.613	3148.325	.000
Cultivars (C)	1.950E-02	1	1.950E-02	.193	.663
Water levels (W)	.885	1	.885	8.742	.005
Nutrient levels (N)	9.984	2	4.992	49.327	.000
Water*Cultivar	1.738	1	1.738	17.174	.000
Cultivar*Nutrient	1.375	2	.688	6.795	.003
Water*Nutrient	.550	2	.275	2.719	.079
W*C*N	.622	2	.311	3.073	.059
Error	3.643	36	.101		
Total	337.430	48			
Corrected total	18.817	47			

a R Squared = .806 (Adjusted R Squared = .747).

Table A4: 30 Analysis variance of water use efficiency of Lole and Wanmun sweet potato cultivars as affected by potassium levels (16, 80, and 160 kg K/ha) and soil water regimes (30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(HO)}$
Corrected model	5.383	11	.489	6.485	.000
Intercept	335.358	1	335.358	4443.887	.000
Cultivars (C)	1.769	1	1.769	23.443	.000
Water levels (W)	.174	1	.174	2.308	.137
Nutrient levels (N)	1.802	2	.901	11.936	.000
Water*Cultivar	7.229E-02	1	7.229E-02	.958	.334
Cultivar*Nutrient	8.858E-02	2	4.429E-02	.587	.561
Water*Nutrient	.261	2	.130	1.729	.192
W*C*N	1.217	2	.608	8.062	.001
Error	2.717	36	7.547E-02		
Total	343.458	48			
Corrected total	8.100	47			

a R Squared = .665 (Adjusted R Squared = .562).

Table A4: 31 Means of shoot dry mass, leaf dry mass, leaf area, and specific leaf weight as affected by soil water regimes (30 and 80% soil field capacity) and nitrogen levels (N20, N100, and N200).

	Shoot dry mass (g/plant)	**Leaf dry mass** (g/plant)	**Leaf area** (cm^2/plant)	**Specific leaf weight** (mg/cm^2)
Water levels				
30%	12.27b	4.82b	855.83b	5.94a
80%	21.12a	8.43a	1361.97a	6.42a
Cultivars				
Lole	14.22d	6.18d	961.13d	6.71c
Wanmun	19.17c	7.08c	1256.66c	5.66d
Nutrient levels				
N20	6.40g	1.80g	276.69g	6.54e
N100	15.19f	7.28f	1175.71f	6.26e
N200	28.51e	10.80e	1874.30e	5.74e
Cultivar*Water				
Lole*30%	10.79	4.18	694.42	6.42
Lole*80%	17.65	8.18	1227.84	6.98
Wanmun*30%	13.75	5.47	1017.24	5.45
Wanmun*80%	24.59	8.68	1496.09	5.85
Cultivar*Nutrient				
Lole*N20	6.21	1.73	236.03	7.26
Lole*N100	13.84	7.54	1067.51	7.05
Lole*N200	22.61	9.26	1579.85	5.82
Wanmun*N20	6.59	1.86	317.34	5.82
Wanmun*N100	16.53	7.03	1283.90	5.49
Wanmun*N200	34.40	12.34	2168.75	5.65
Water*Nutrient				
30%*N20	4.69	1.31	211.31	6.29
30%*N100	11.84	5.28	896.59	6.08
30%*N200	20.29	7.89	1459.59	5.44
80%*N20	8.11	2.29	342.07	6.79
80%*N100	18.53	9.29	1454.82	6.44
80%*N200	36.73	13.72	2289.01	6.02
W*C*N				
30*L*N20	4.72	1.23	177.24	6.94
30*L*N100	9.89	4.54	663.57	6.84
30*L*N200	17.76	6.76	1242.44	5.49
80*L*N20	7.70	2.24	294.82	7.57
80*L*N100	17.80	10.55	1471.45	7.24
80*L*N200	27.46	11.76	1917.27	6.14
30*W*N20	4.66	1.39	245.37	5.63
30*W*N100	13.79	6.02	1129.61	5.32
30*W*N200	22.81	9.01	1676.74	5.39
80*W*N20	8.52	2.34	389.32	6.00
80*W*N100	19.26	8.04	1438.20	5.65
80*W*N200	46.00	15.67	2660.76	5.90

Values within a column followed by the same letter symbol are not significantly different ($p<0.05$). All the interactions are significant ($p<0.05$).

Table A4: 32 Means of shoot and leaf dry mass, leaf area and specific leaf weight as affected by soil water regimes (30 and 80% soil field capacity) and potassium levels (K16, K80, and K160).

	Shoot dry mass (g/plant)	**Leaf dry mass** (g/plant)	**Leaf area** (cm^2/plant)	**Specific leaf weight** (mg/cm^2)
Water levels				
30%	19.10b	7.73b	1638.19b	4.90b
80%	33.19a	12.62a	2359.46a	5.44a
Cultivars				
Lole	22.53d	9.25d	1659.10d	5.58c
Wanmun	29.76c	11.10c	2338.55c	4.76d
Nutrient levels				
K16	24.41f	9.82f	2145.24e	4.65f
K80	25.52ef	9.90ef	1976.93f	5.11f
K160	28.51e	10.80e	1874.30f	5.74e
Cultivar*Water				
Lole*30%	17.45	7.23	1353.80	5.41
Lole*80%	27.62	11.28	1964.40	5.74
Wanmun*30%	20.75	8.24	1922.59	4.38
Wanmun*80%	38.76	13.95	2754.51	5.13
Cultivar*Nutrient				
Lole*K16	22.81	8.86	1728.71	5.12
Lole*K80	22.18	9.64	1668.73	5.79
Lole*K160	22.61	9.26	1579.85	5.81
Wanmun*K16	26.00	10.79	2561.78	4.19
Wanmun*K80	28.86	10.15	2285.12	4.43
Wanmun*K160	34.40	12.34	2168.75	5.65
Water*Nutrient				
30%*K16	18.16	7.86	1821.85	4.41
30%*K80	18.85	7.45	1633.15	4.84
30%*K160	20.29	7.89	1459.59	5.44
80%*K16	30.65	11.78	2468.64	4.90
80%*K80	32.19	12.35	2320.71	5.38
80%*K160	36.73	13.72	2289.01	6.02
W*C*N				
30*L*K16	17.30	7.47	1551.56	4.86
30*L*K80	17.30	7.45	1267.40	5.88
30*L*K160	17.76	6.76	1242.44	5.49
80*L*K16	28.32	10.24	1905.87	5.37
80*L*K80	27.07	11.84	2070.07	5.71
80*L*K160	27.46	11.76	1917.27	6.14
30*W*K16	19.03	8.26	2092.13	3.96
30*W*K80	20.41	7.45	1998.89	3.80
30*W*K160	22.81	9.01	1676.74	5.39
80*W*K16	32.98	13.33	3031.42	4.43
80*W*K80	37.31	12.86	2571.36	5.06
80*W*K160	46.00	15.67	2660.76	5.90

Values within a column followed by the same letter symbol are not significantly different ($p<0.05$). All the interactions are significant ($p<0.05$).

Table A4: 33 Means of root dry mass and tuber yields as affected by soil water regimes (30 and 80% soil field capacity) and nitrogen levels (20, 100 and 200 kg/ha).

	Root dry mass (g/plant)	**Tuber weight** (g/plant**)**
Water levels		
30%	3.57b	305.25b
80%	5.65a	543.04a
Cultivars		
Lole	6.31c	395.83d
Wanmun	2.90d	452.46c
Nutrient levels		
N20	2.68g	132.31g
N100	4.81f	578.75e
N200	6.33e	561.37f
Cultivar*Water		
Lole*30%	4.70	312.17
Lole*80%	7.93	479.50
Wanmun*30%	2.43	298.33
Wanmun*80%	3.37	606.58
Cultivar*Nutrient		
Lole*N20	3.45	125.38
Lole*N100	6.52	527.50
Lole*N200	8.97	534.63
Wanmun*N20	1.92	139.25
Wanmun*N100	3.11	630.00
Wanmun*N200	3.69	588.13
Water*Nutrient		
30%*N20	2.18	100.63
30%*N100	3.07	400.75
30%*N200	5.45	414.38
80%*N20	3.19	164.00
80%*N100	6.56	756.75
80%*N200	7.21	708.38
W*C*N		
30*L*N20	2.71	99.50
30*L*N100	3.46	411.00
30*L*N200	7.91	426.00
80*L*N20	4.18	151.25
80*L*N100	9.58	644.00
80*L*N200	10.03	643.25
30*W*N20	1.64	101.75
30*W*N100	2.67	390.50
30*W*N200	2.99	402.75
80*W*N20	2.19	176.75
80*W*N100	3.54	869.50
80*W*N200	4.39	773.50

Values within a column followed by the same letter symbol are not significantly different ($p<0.05$). All the interactions are significant ($p<0.05$).

Table A4: 34 Means of root dry mass and tuber yields as affected by soil water regimes (30 and 80% soil field capacity) and potassium levels (K16, K80, and K160).

	Root dry mass (g/plant)	**Tuber weight** (g/plant**)**
Water levels		
30%	4.79b	355.58b
80%	8.34a	603.21a
Cultivars		
Lole	9.55c	489.29c
Wanmun	3.58d	469.50d
Nutrient levels		
K16	6.70e	392.12g
K80	6.67e	484.68f
K160	6.33e	561.37e
Cultivar*Water		
Lole*30%	6.76	372.42
Lole*80%	12.35	606.17
Wanmun*30%	2.82	338.75
Wanmun*80%	4.33	600.25
Cultivar*Nutrient		
Lole*K16	10.00	427.13
Lole*K80	9.70	506.13
Lole*K160	8.97	534.63
Wanmun*K16	3.40	357.13
Wanmun*K80	3.65	463.25
Wanmun*K160	3.69	588.13
Water*Nutrient		
30%*K16	4.47	314.63
30%*K80	4.46	337.75
30%*K160	5.45	414.38
80%*K16	8.93	469.63
80%*K80	8.89	631.63
80%*K160	7.21	708.38
W*C*N		
30*L*K16	6.31	325.75
30*L*K80	6.07	365.50
30*L*K160	7.91	426.00
80*L*K16	13.70	528.50
80*L*K80	13.32	646.75
80*L*K160	10.03	643.25
30*W*K16	2.64	303.50
30*W*K80	2.85	310.00
30*W*K160	2.99	402.75
80*W*K16	4.16	410.75
80*W*K80	4.45	616.50
80*W*K160	4.39	773.50

Values within a column followed by the same letter symbol are not significantly different ($p<0.05$). All the interactions are significant ($p<0.05$).

Table A4: 35 Means of total chlorophyll, carotene and the chlorophyll *a*/*b* ratio of Lole and Wanmun as affected by soil water regimes (30 and 80% soil field capacity) and nitrogen levels (N20, N100, and N200).

	Total chlorophyll (mg/g)	**Carotene** (mg/g)	**Chlorophyll** *a*/*b* ratio (mg/g)
Water levels			
30%	1.32b	0.30b	4.66a
80%	1.78a	0.38a	4.60a
Cultivars			
Lole	1.63c	0.35c	4.63c
Wanmun	1.45d	0.33d	4.64c
Nutrient levels			
N20	0.82g	0.19g	4.64e
N100	1.37f	0.31f	4.66e
N200	2.46e	0.52e	4.60e
Cultivar*Water			
Lole*30%	1.39	0.30	4.65
Lole*80%	1.88	0.41	4.61
Wanmun*30%	1.26	0.29	4.68
Wanmun*80%	1.68	0.36	4.59
Cultivar*Nutrient			
Lole*N20	0.90	0.20	4.64
Lole*N100	1.46	0.33	4.65
Lole*N200	2.54	0.53	4.60
Wanmun*N20	0.74	0.17	4.65
Wanmun*N100	1.27	0.29	4.67
Wanmun*N200	2.39	0.52	4.59
Water*Nutrient			
30%*N20	0.66	0.15	4.61
30%*N100	1.19	0.28	4.73
30%*N200	2.12	0.46	4.66
80%*N20	0.98	0.23	4.68
80%*N100	1.54	0.33	4.59
80%*N200	2.81	0.59	4.53
W*C*N			
30*L*N20	0.73	0.16	4.60
30*L*N100	1.24	0.29	4.70
30*L*N200	2.19	0.46	4.65
80*L*N20	1.07	0.25	4.67
80*L*N100	1.68	0.36	4.60
80*L*N200	2.89	0.61	4.55
30*W*N20	0.59	0.13	4.61
30*W*N100	1.14	0.27	4.75
30*W*N200	2.05	0.45	4.67
80*W*N20	0.90	0.21	4.69
80*W*N100	1.40	0.30	4.58
80*W*N200	2.73	0.58	4.51

Values within a column followed by the same letter symbol are not significantly different ($p<0.05$). All the interactions are significant ($p<0.05$).

Table A4: 36 Means of total chlorophyll, carotene and the chlorophyll *a*/*b* ratio of Lole and Wanmun as affected by soil water regimes (30 and 80% soil field capacity) and potassium levels (K16, K80, and K160).

	Total chlorophyll (mg/g)	**Carotene** (mg/g)	**Chlorophyll** *a*/*b* **ratio** (mg/g)
Water levels			
30%	1.91b	0.41b	4.65a
80%	2.59a	0.55a	4.55b
Cultivars			
Lole	2.30c	0.49c	4.60c
Wanmun	2.19d	0.47d	4.59d
Nutrient levels			
K16	2.03g	0.43g	4.60e
K80	2.25f	0.48f	4.60e
K160	2.46e	0.52e	4.60e
Cultivar*Water			
Lole*30%	1.97	0.42	4.65
Lole*80%	2.64	0.56	4.56
Wanmun*30%	1.84	0.40	4.65
Wanmun*80%	2.54	0.53	4.54
Cultivar*Nutrient			
Lole*K16	2.10	0.45	4.60
Lole*K80	2.27	0.49	4.60
Lole*K160	2.54	0.53	4.60
Wanmun*K16	1.97	0.41	4.60
Wanmun*K80	2.22	0.47	4.59
Wanmun*K160	2.39	0.52	4.59
Water*Nutrient			
30%*K16	1.67	0.36	4.65
30%*K80	1.93	0.42	4.64
30%*K160	2.12	0.46	4.66
80%*K16	2.40	0.50	4.55
80%*K80	2.57	0.54	4.56
80%*K160	2.81	0.59	4.53
W*C*N			
30*L*K16	1.73	0.38	4.65
30*L*K80	1.99	0.43	4.64
30*L*K160	2.19	0.46	4.65
80*L*K16	2.47	0.52	4.56
80*L*K80	2.56	0.54	4.57
80*L*K160	2.89	0.61	4.55
30*W*K16	1.61	0.34	4.65
30*W*K80	1.87	0.41	4.64
30*W*K160	2.05	0.45	4.67
80*W*K16	2.33	0.49	4.55
80*W*K80	2.57	0.54	4.55
80*W*K160	2.73	0.58	4.51

Values within a column followed by the same letter symbol are not significantly different ($p<0.05$). All the interactions are significant ($p<0.05$).

Table A4: 37 Means of the daily transpiration of Lole and Wanmun cultivars as affected by soil water regimes (30 and 80% soil field capacity) and nitrogen levels (N20, N100, and N200).

	Daily transpiration (g/day/plant)					WUE (g/kg of H2O)
Water levels	**1st** month	**2nd** month	**3rd** month	**4th** month	**5th** month	
30%	181.79b	197.87b	259.31b	259.82b	194.07b	2.56a
80%	321.50a	338.07a	441.59a	456.46a	410.92a	2.60a
Cultivars						
Lole	221.63d	252.28d	327.54d	346.81d	286.15d	2.71c
Wanmun	281.67c	283.66c	373.36c	369.46c	318.83c	2.44d
Nutrient levels						
N20	190.41g	174.58g	233.86g	239.38g	185.37g	1.93f
N100	264.41f	297.30f	381.45f	392.66f	328.19f	2.95e
N200	300.13e	332.03e	436.05e	442.36e	393.92e	2.84e
Cultivar*Water						
Lole*30%	164.38	191.76	250.91	257.01	192.24	2.50
Lole*80%	278.88	312.80	404.17	436.61	380.06	2.92
Wanmun*30%	199.21	203.98	267.72	262.61	195.90	2.61
Wanmun*80%	364.13	363.35	479.01	476.30	441.77	2.27
Cultivar*Nutrient						
Lole*N20	163.63	162.95	191.84	233.31	180.88	2.19
Lole*N100	229.81	285.00	289.85	386.88	305.99	3.10
Lole*N200	271.44	308.90	296.25	420.24	371.59	2.84
Wanmun*N20	217.19	186.20	275.88	245.45	189.86	1.67
Wanmun*N100	299.00	309.61	473.05	398.45	350.40	2.80
Wanmun*N200	328.81	355.17	575.85	464.47	416.25	2.85
Water*Nutrient						
30%*N20	142.81	147.47	215.33	177.34	138.68	1.68
30%*N100	182.69	225.44	355.33	286.21	206.68	3.01
30%*N200	219.88	220.70	411.97	315.88	236.85	2.98
80%*N20	238.00	201.69	252.39	301.42	232.06	2.19
80%*N100	346.13	369.17	407.57	499.11	449.71	2.89
80%*N200	380.38	443.37	460.13	568.84	550.98	2.71
W*C*N						
30*L*N20	140.50	144.25	182.91	163.16	133.29	1.66
30*L*N100	146.25	216.28	281.24	280.74	206.32	3.13
30*L*N200	206.38	214.76	288.58	327.14	237.13	2.71
80*L*N20	186.75	181.65	247.75	303.46	228.48	2.73
80*L*N100	313.38	353.72	429.42	493.01	405.66	3.07
80*L*N200	336.50	403.03	535.35	513.35	506.05	2.97
30*W*N20	145.13	150.68	200.77	191.52	144.08	1.70
30*W*N100	219.13	234.61	298.46	291.68	207.04	2.89
30*W*N200	233.38	226.65	303.92	304.61	236.58	3.24
80*W*N20	289.25	221.73	304.01	299.38	235.63	1.65
80*W*N100	378.88	384.62	516.68	505.22	493.76	2.71
80*W*N200	424.25	483.70	616.34	624.32	595.91	2.45

Values within a column followed by the same letter symbol are not significantly different ($p<0.05$). All the interactions are significant ($p<0.05$).

Table A4: 38 Means of the daily transpiration of Lole and Wanmun cultivars as affected by soil water regimes (30 and 80% of soil field capacity) and potassium levels (K16, K80, and K160).

	Daily transpiration (g/day/plant)					WUE (g/kg of H2O)
Water levels	1st month	2nd month	3rd month	4th month	5th month	
30%	222.90b	213.43b	306.01b	310.63b	249.71b	2.84a
80%	377.92a	456.53a	556.65a	574.41a	554.95a	2.45b
Cultivars						
Lole	272.44b	312.76b	405.77b	424.19b	385.95b	2.70a
Wanmun	328.38a	357.20a	456.89a	460.85a	418.72a	2.59b
Nutrient levels						
K16	324.22a	346.33a	425.34b	452.19a	406.88a	2.38b
K80	276.88c	326.57bc	432.61ab	433.02b	406.21a	2.70a
K160	300.13b	332.03b	436.05a	442.36ab	393.92b	2.84a
Cultivar*Water						
Lole*30%	216.30	194.88	298.69	311.56	250.14	2.86
Lole*80%	328.58	430.64	512.85	536.82	521.75	2.55
Wanmun*30%	229.50	231.98	313.33	309.71	249.28	2.81
Wanmun*80%	427.25	482.42	600.47	612.00	588.16	2.35
Cultivar*Nutrient						
Lole*K16	243.38	338.10	407.31	433.01	400.13	2.40
Lole*K80	205.44	291.29	398.03	419.31	386.12	2.87
Lole*K160	219.88	308.90	411.97	420.24	371.59	2.84
Wanmun*K16	405.06	354.57	443.36	471.36	413.63	2.36
Wanmun*K80	348.31	361.86	467.19	446.73	426.30	2.54
Wanmun*K160	380.38	355.17	460.13	464.47	416.25	2.85
Water*Nutrient						
30%*K16	321.63	228.61	306.14	305.80	259.57	2.59
30%*K80	224.25	190.98	315.64	310.23	252.72	2.94
30%*K160	271.44	220.70	296.25	315.88	236.85	2.98
80%*K16	326.81	464.06	544.54	598.58	554.19	2.18
80%*K80	329.50	462.17	549.57	555.81	559.69	2.47
80%*K160	328.81	443.37	575.85	568.84	550.98	2.71
W*C*N						
30*L*K16	259.00	218.20	297.86	296.82	259.38	2.67
30*L*K80	183.50	151.68	309.64	310.72	253.92	3.18
30*L*K160	206.38	214.76	288.58	327.14	237.13	2.71
80*L*K16	384.25	457.99	516.76	569.20	540.88	2.13
80*L*K80	265.00	430.89	486.42	527.90	518.31	2.55
80*L*K160	336.50	403.03	535.35	513.35	506.05	2.97
30*W*K16	227.75	239.02	314.41	314.77	259.75	2.50
30*W*K80	227.38	230.27	321.65	309.74	251.53	2.70
30*W*K160	233.38	226.65	303.92	304.61	236.58	3.24
80*W*K16	425.88	470.13	572.32	627.96	567.50	2.23
80*W*K80	431.63	493.45	612.73	583.72	601.06	2.38
80*W*K160	424.26	483.70	616.34	624.32	595.91	2.45

Values within a column followed by the same letter symbol are not significantly different ($p<0.05$). All the interactions are significant ($p<0.05$).

APPENDIX A5

PLANT MEASUREMENTS AND RESULTS OF STATISTICAL ANALYSES OF CHAPTER 5

Table A5: 1 Analysis variance of fresh shoot biomass of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown at 30 and 80% soil field capacity at 1 month after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	20763.370	7	2966.196	81.587	.000
Intercept	295857.200	1	295857.200	8137.726	.000
Water levels	15677.640	1	431.223	431.223	.000
Cultivars	3780.635	3	34.663	34.663	.000
Water levels * Cultivars	1305.095	3	11.966	11.966	.000
Error	1163.400	32			
Total	317783.970	40			
Corrected Total	21926.770	39			

a R Squared = .947 (Adjusted R Squared = .935).

Table A5: 2 Analysis variance of fresh shoot biomass of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at 2 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	167310.375	7	23901.482	80.069	.000
Intercept	2037168.225	1	2037168.225	6824.398	.000
Water levels	113955.625	1	113955.625	381.745	.000
Cultivars	45871.475	3	15290.492	51.222	.000
Water levels * Cultivars	7483.275	3	2494.425	8.356	.000
Error	9552.400	32	298.513		
Total	2214031.000	40			
Corrected Total	176862.775	39			

a R Squared = .946 (Adjusted R Squared = .934).

Table A5: 3 Analysis variance of fresh shoot biomass of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at 5 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	644019.175	7	92002.739	96.586	.000
Intercept	3876930.225	1	3876930.225	4070.054	.000
Water levels	229977.225	1	229977.225	241.433	.000
Cultivars	361493.475	3	120497.825	126.500	.000
Water levels * Cultivars	52548.475	3	17516.158	18.389	.000
Error	30481.600	32	952.550		.000
Total	4551431.000	40			
Corrected Total	674500.775	39			

a R Squared = .955 (Adjusted R Squared = .945).

Table A5: 4 Analysis variance of dry shoot biomass of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at 1 month after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	824.289	7	117.756	196.607	.000
Intercept	7307.290	1	7307.290	12200.371	.000
Water levels	625.997	1	625.997	1045.176	.000
Cultivars	158.416	3	52.805	88.165	.000
Water levels * Cultivars	39.876	3	13.292	22.192	.000
Error	19.166	32	.599		
Total	8150.746	40			
Corrected Total	843.455	39			

a R Squared = .977 (Adjusted R Squared = .972).

Table A5: 5 Analysis variance of dry shoot biomass of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at 2 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	4421.917	7	631.702	66.946	.000
Intercept	41186.232	1	41186.232	4364.782	.000
Water levels	2875.907	1	2875.907	304.779	.000
Cultivars	1400.329	3	466.776	49.467	.000
Water levels * Cultivars	145.681	3	48.560	5.146	.005
Error	301.953	32	9.436		
Total	45910.102	40			
Corrected Total	4723.870	39			

a R Squared = .936 (Adjusted R Squared = .922).

Table A5: 6 Analysis variance of dry shoot biomass of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at 5 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	5.299	7	.757	213.377	.000
Intercept	290.133	1	290.133	81774.963	.000
Water levels	2.601	1	2.601	733.022	.000
Cultivars	2.444	3	.815	229.653	.000
Water levels * Cultivars	.254	3	8.474E-02	23.884	.000
Error	.114	32	3.548E-03		
Total	295.546	40			
Corrected Total	5.413	39			

a R Squared = .979 (Adjusted R Squared = .974).

Table A5: 7 Analysis variance of fresh leaf weight of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at harvest time.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	63786.620	7	9112.374	127.769	.000
Intercept	460338.480	1	460338.480	6454.607	.000
Water levels	53513.614	1	53513.614	750.338	.000
Cultivars	8185.242	3	2728.414	38.256	.000
Water levels * Cultivars	2087.763	3	695.921	9.758	.000
Error	2282.220	32	71.319		
Total	526407.320	40			
Corrected Total	66068.839	39			

a R Squared = .965 (Adjusted R Squared = .958).

Table A5: 8 Analysis variance of leaf dry weight of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at harvest time.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	896.065	7	128.009	162.770	.000
Intercept	10027.989	1	10027.989	12751.097	.000
Water levels	665.366	1	665.366	846.047	.000
Cultivars	169.401	3	56.467	71.801	.000
Water levels * Cultivars	61.297	3	20.432	25.981	.000
Error	25.166	32	.786		
Total	10949.220	40			
Corrected Total	921.231	39			

a R Squared = .973 (Adjusted R Squared = .967).

Table A5: 9 Analysis variance of leaf area of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at harvest time.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	10435276.05	7	1490753.722	808.115	.000
Intercept	164613830.51	1	164613830.51	89234.651	.000
Water levels	3491829.009	1	3491829.009	1892.867	.000
Cultivars	5459673.782	3	1819891.261	986.535	.000
Water levels * Cultivars	1483773.267	3	494591.089	268.11	.000
Error	59031.358	32	1844.73		
Total	175108137.928	40			
Corrected Total	10494307.41	39			

a R Squared = .994 (Adjusted R Squared = .993).

Table A5: 10 Analysis variance of specific leaf weight of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at harvest time.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	52.497	7	7.500	45.148	.000
Intercept	2409.452	1	2409.452	14505.098	.000
Water levels	36.472	1	36.472	219.563	.000
Cultivars	5.922	3	1.974	11.885	.000
Water levels * Cultivars	10.103	3	3.368	20.274	.000
Error	5.316	32	.166		
Total	2467.265	40			
Corrected Total	57.813	39			

a R Squared = .908 (Adjusted R Squared = .888).

Table A5: 11 Analysis variance of root fresh weight of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at 1 month after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	4902.264	7	700.323	28.587	.000
Intercept	78739.002	1	78739.002	3214.148	.000
Water levels	2861.172	1	2861.172	116.794	.000
Cultivars	1218.807	3	406.269	16.584	.000
Water levels * Cultivars	822.285	3	274.095	11.189	.000
Error	783.924	32	24.498		
Total	84425.190	40			
Corrected Total	5686.188	39			

a R Squared = .862 (Adjusted R Squared = .832).

Table A5: 12 Analysis variance of root dry weight of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at 1 months after planting (data was transformed into ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	14.763	7	2.109	425.906	.000
Intercept	659.169	1	659.169	133114.01	.000
Water levels	8.159	1	8.159	1647.620	.000
Cultivars	5.253	3	1.751	353.614	.000
Water levels * Cultivars	1.351	3	.450	90.959	.000
Error	.158	32	4.952E-03		
Total	674.091	40			
Corrected Total	14.922	39			

a R Squared = .989 (Adjusted R Squared = .987).

Table A5: 13 Analysis variance of root fresh weight of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at 2 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	220454.575	7	31493.511	71.178	.000
Intercept	326705.625	1	326705.625	738.380	.000
Water levels	48511.225	1	48511.225	109.639	.000
Cultivars	129609.675	3	43203.225	97.643	.000
Water levels * Cultivars	42333.675	3	14111.225	31.892	.000
Error	14158.800	32	442.463		
Total	561319.000	40			
Corrected Total	234613.375	39			

a R Squared = .940 (Adjusted R Squared = .926).

Table A5: 14 Analysis variance of root dry weight of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at 2 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	283.556	7	40.508	365.760	.000
Intercept	2057.790	1	2057.790	18580.499	.000
Water levels	195.806	1	195.806	1768.002	.000
Cultivars	44.613	3	14.871	134.275	.000
Water levels * Cultivars	43.137	3	14.379	129.832	.000
Error	3.544	32	.111		
Total	2344.890	40			
Corrected Total	287.100	39			

a R Squared = . 988 (Adjusted R Squared = .985).

Table A5: 15 Analysis variance of root fresh weight of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at 5 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	1010.046	7	144.292	65.554	.000
Intercept	2733.401	1	2733.401	1241.816	.000
Water levels	754.119	1	754.119	342.605	.000
Cultivars	145.745	3	48.582	22.071	.000
Water levels * Cultivars	110.182	3	36.727	16.686	.000
Error	70.436	32	2.201		
Total	3813.883	40			
Corrected Total	1080.482	39			

a R Squared = .935 (Adjusted R Squared = .921).

Table A5: 16 Analysis variance of root dry weight of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at 5 months after planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	35.580	7	5.083	121.281	.000
Intercept	206.723	1	206.723	4932.550	.000
Water levels	10.791	1	10.791	257.474	.000
Cultivars	24.018	3	8.006	191.03	.000
Water levels * Cultivars	.771	3	.257	6.132	.002
Error	1.341	32	4.191E-02		
Total	243.644	40			
Corrected Total	36.921	39			

a R Squared = .964 (Adjusted R Squared = .956).

Table A5: 17 Analysis variance of tuber weight of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at harvest time.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	1743833.400	7	249119.057	134.039	.000
Intercept	4609104.771	1	4609104.771	2479.937	.000
Water levels	634614.943	1	634614.943	341.456	.000
Cultivars	825056.200	3	275018.733	147.974	.000
Water levels * Cultivars	136731.756	3	45577.252	24.523	.000
Error	52039.600	32	1858.557		
Total	7551074.000	40			
Corrected Total	1795873.000	39			

a R Squared = .971(Adjusted R Squared = .964).

Table A5: 18 Analysis variance of tuber number of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at harvest time.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	228.306	7	32.615	91.322	.000
Intercept	583.393	1	583.393	1633.500	.000
Water levels	55.736	1	55.736	156.060	.000
Cultivars	62.206	3	20.735	58.059	.000
Water levels * Cultivars	93.850	3	31.283	87.593	.000
Error	10.000	32	.357		
Total	855.000	40			
Corrected Total	238.306	39			

a R Squared = .958 (Adjusted R Squared = .948).

Table A5: 19 Analysis variance of average weight of tuber of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80 % soil field capacity at harvest time (data was transformed into ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	30.003	7	4.286	36.167	.000
Intercept	620.744	1	620.744	5237.886	.000
Water levels	.579	1	.579	4.883	.035
Cultivars	25.640	3	8.547	72.118	.000
Water levels * Cultivars	4.066	3	1.355	11.437	.000
Error	3.318	32	.119		
Total	741.576	40			
Corrected Total	33.322	39			

a R Squared = .900 (Adjusted R Squared = .876).

Table A5: 20 Analysis variance of harvest index of tuber of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at harvest time.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	2.130	7	.304	140.785	.000
Intercept	7.787	1	7.787	3602.617	.000
Water levels	4.479E-0	1	4.479E-02	20.721	.000
Cultivars	2.075	3	.692	320.011	.000
Water levels * Cultivars	1.024E-02	3	3.414E-03	1.57	.214
Error	6.916E-02	32	2.161E-03		
Total	9.986	40			
Corrected Total	2.199	39			

a R Squared = .969 (Adjusted R Squared = .962).

Table A5: 21 Analysis variance of chlorophyll *a* concentration of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	4704196.706	7	672028.101	23.346	.000
Intercept	204175008.24	1	204175008.24	7093.068	.000
Water levels	3477944.600	1	3477944.600	120.824	.000
Cultivars	487115.758	3	162371.919	5.641	.003
Water levels * Cultivars	739136.347	3	246378.782	8.559	.000
Error	1151405.826	32	28785.146		
Total	210030610.77	40			
Corrected Total	5855602.531	39			

a R Squared = .803 (Adjusted R Squared = .769).

Table A5: 22 Analysis variance of chlorophyll *b* concentration of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80 % soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	574296.347	7	82042.335	13.609	.000
Intercept	15577588.697	1	15577588.690	2583.929	.000
Water levels	415672.797	1	415672.797	68.950	.000
Cultivars	112653.910	3	37551.303	6.229	.001
Water levels * Cultivars	45969.640	3	15323.213	2.542	.070
Error	241145.759	32	6028.644		
Total	16393030.800	40			
Corrected Total	815442.107	39			

a R Squared = .704 (Adjusted R Squared = .653).

Table A5: 23 Analysis variance of carotene concentration of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	172538.647	7	24648.378	20.807	.000
Intercept	10083728.677	1	10083728.678	8512.317	.000
Water levels	132445.786	1	132445.786	111.806	.000
Cultivars	13148.899	3	4382.966	3.700	.019
Water levels * Cultivars	26943.962	3	8981.321		.000
Error	47384.180	32	1184.604	7.582	
Total	10303651.50	40			
Corrected Total	219922.827	39			

a R Squared = .785 (Adjusted R Squared = .747).

Table A5: 24 Analysis variance of total chlorophyll concentration of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	8280913.520	7	1182987.646	20.271	.000
Intercept	332545403.483	1	332545403.48	5698.251	.000
Water levels	6298351.860	1	6298351.860	107.924	.000
Cultivars	861846.214	3	287282.071	4.923	.005
Water levels * Cultivars	1120715.446	3	373571.815	6.401	.001
Error	2334368.139	32	58359.203		
Total	343160685.145	40			
Corrected Total	10615281.65	39			

a R Squared = .780 (Adjusted R Squared = .742).

Table A5: 25 Analysis variance of chlorophyll *a*/*b* ratio of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity (data was transformed into ln transformation).

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	.320	7	4.569E-02	8.277	.000
Intercept	80.996	1	80.996	14672.909	.000
Water levels	6.127E-02	1	6.127E-02	11.099	.002
Cultivars	.244	3	8.126E-02	14.721	.000
Water levels * Cultivars	1.480E-02	3	4.934E-03	.894	.453
Error	.221	32	5.520E-03		
Total	81.537	40			
Corrected Total	.541	39			

a R Squared = .592(Adjusted R Squared = .520).

Table A5: 26 Analysis variance of stomata density of upper (adaxial) leaves surface of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at harvest time.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	550.99	7	78.71	6.02	0.00
Intercept	19262.35	1	19262.35	1471.93	0.00
Water levels	20.86	1	20.86	1.59	0.21
Cultivars	463.58	3	154.53	11.81	0.00
Water levels * Cultivars	66.54	3	22.18	1.70	0.19
Error	418.77	32	13.09		
Total	20232.10	40			
Corrected Total	969.75	39			

a R Squared = .568 (Adjusted R Squared = .474).

Table A5: 27 Analysis variance of stomatal density of lower (abaxial) leaves surface of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at harvest time.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	3202.84	7	457.55	12.23	.000
Intercept	93659.38	1	93659.38	2503.77	.000
Water levels	134.44	1	134.44	3.60	.067
Cultivars	2925.80	3	975.27	26.07	.000
Water levels * Cultivars	142.59	3	47.53	1.27	.301
Error	1197.04	32	37.41		
Total	98059.26	40			
Corrected Total	4399.88	39			

a R Squared = .728 (Adjusted R Squared = .668).

Table A5: 28 Analysis variance of length of guard cell of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	147.360	7	21.051	68.534	.000
Intercept	4611.685	1	4611.685	15013.623	.000
Water levels	5.069	1	1.690	5.501	.002
Cultivars	142.045	3	142.045	462.435	.000
Water levels * Cultivars	.246	3	8.183E-02	.266	.849
Error	22.116	32	.307		
Total	4781.160	40			
Corrected Total	169.476	39			

a R Squared = .870 (Adjusted R Squared = .857).

Table A5: 29 Analysis variance of cuticle thickness of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	12.011	7	1.716	7.122	.000
Intercept	424.121	1	424.121	1760.242	.000
Water levels	9.113	1	9.113	37.820	.000
Cultivars	2.585	3	.862	3.577	.018
Water levels * Cultivars	.313	3	.104	.434	.730
Error	17.348	32	.241		
Total	453.480	40			
Corrected Total	29.350	39			

a R Squared = .409 (Adjusted R Squared = .352).

Table A5: 30 Analysis variance of leaf water potential of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	92.500	7	13.214	35.238	.000
Intercept	1441.500	1	1441.500	3844.000	.000
Water levels	80.667	1	80.667	215.111	.000
Cultivars	11.500	3	3.833	10.222	.001
Water levels * Cultivars	.333	3	.111	.296	.828
Error	6.000	32	.375		
Total	1540.000	40			
Corrected Total	98.500	39			

a R Squared = .939 (Adjusted R Squared = .912).

Table A5: 31 Analysis variance of leaf relative water content of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	930.931	7	132.990	29.991	.000
Intercept	170202.754	1	170202.754	38383.218	.000
Water levels	758.207	1	758.207	170.987	.000
Cultivars	162.022	3	54.007	12.179	.000
Water levels * Cultivars	10.702	3	3.567	.805	.504
Error	106.423	32	4.434		
Total	171240.109	40			
Corrected Total	1037.355	39			

a R Squared = .897 (Adjusted R Squared = .867).

Table A5: 32 Analysis variance of transpiration in Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole under 30 and 80% soil field capacity at the first month of planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	776946.64	7	110992.38	1216.77	.000
Intercept	4603486.80	1	4603486.80	50466.18	.000
Water levels	752843.84	1	752843.84	8253.13	.000
Cultivars	17396.75	3	5798.92	63.57	.000
Water levels * Cultivars	6706.05	3	2235.35	24.51	.000
Error	2919.02	32	91.22		
Total	5383352.46	40			
Corrected Total	779865.66	39			

a R Squared = .996 (Adjusted R Squared = .995).

Table A5: 33 Analysis variance of transpiration in Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80 % soil field capacity at the second month of planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	2122057.14	7	303151.02	1424.27	.000
Intercept	10445351.00	1	10445351.00	49074.49	.000
Water levels	2107498.56	1	2107498.56	9901.48	.000
Cultivars	12496.27	3	4165.42	19.57	.000
Water levels * Cultivars	2062.32	3	687.44	3.23	.035
Error	6811.10	32	212.85		
Total	12574219.25	40			
Corrected Total	2128868.24	39			

a R Squared = .997 (Adjusted R Squared = .996).

Table A5: 34 Analysis variance of transpiration in Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at the third month of planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	1275782.04	7	182254.58	1732.20	.000
Intercept	11369743.64	1	11369743.64	108061.23	.000
Water levels	1264869.23	1	1264869.23	12021.67	.000
Cultivars	10083.07	3	3361.02	31.94	.000
Water levels * Cultivars	829.75	3	276.58	2.63	.067
Error	3366.90	32	105.22		
Total	12648892.58	40			
Corrected Total	1279148.94	39			

a R Squared = .997 (Adjusted R Squared = .997).

Table A5: 35 Analysis variance of transpiration in Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at the fourth month of planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	1322479.906	7	188925.701	3082.626	.000
Intercept	11571627.61	1	11571627.61	188809.70	.000
Water levels	1310910.642	1	1310910.642	21389.61	.000
Cultivars	9488.859	3	3162.953	51.609	.000
Water levels * Cultivars	2080.405	3	693.468	11.315	.000
Error	1961.192	32	61.287		
Total	12896068.71	40			
Corrected Total	1324441.09	39			

a R Squared = .999 (Adjusted R Squared = .998).

Table A5: 36 Analysis variance of transpiration in Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at the fifth month of planting.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	1707323.90	7	243903.41	300.79	.000
Intercept	11968360.00	1	11968360.00	14759.75	.000
Water levels	1682230.23	1	1682230.23	2074.58	.000
Cultivars	24349.25	3	8116.42	10.00	.000
Water levels * Cultivars	744.43	3	248.14	.30	.821
Error	25948.10	32	810.88		
Total	13701632.00	40			
Corrected Total	1733272.00	39			

a R Squared = .985 (Adjusted R Squared = .982).

Table A5: 37 Analysis variance of water use efficiency of tuber of Lole and Wanmun cultivars, Lole grafted onto Wanmun and Wanmun grafted onto Lole grown on 30 and 80% soil field capacity at harvest time.

Source	Type III Sum of Squares	df	Mean Square	F	$P_{(H0)}$
Corrected Model	8.051	7	1.155	6.912	.000
Intercept	438.706	1	438.706	2636.514	.000
Water levels	1.394	1	1.394	8.378	.007
Cultivars	5.030	3	1.677	10.077	.000
Water levels * Cultivars	1.627	3	.542	3.259	.034
Error	5.325	32	.166		
Total	452.082	40			
Corrected Total	13.376	39			

a R Squared = .602(Adjusted R Squared = .515).

Table A5: 38 Means of the daily transpiration of Lole and Wanmun cultivars as affected of soil water regimes (30 and 80% soil field capacity) and potassium levels (K16, K80, and K160).

	Daily transpiration (g/day/plant)					WUE (g/kg of H2O)
Water levels	**1st month**	**2nd month**	**3rd month**	**4th month**	**5th month**	
30%	202.06b	281.48b	355.32b	356.83b	341.93b	3.50a
80%	476.44a	740.55a	710.97a	718.89a	752.08a	3.13b
Cultivars						
Lole	337.06b	490.40b	520.36b	526.81c	523.30b	3.46a
Wanmun	373.93a	534.45a	553.89a	558.83a	580.10a	3.58a
L-W	321.63c	497.95b	515.33b	519.90c	523.15b	3.51a
W-L	324.36c	521.25a	543.00a	545.89b	561.45a	2.70b
Cultivar*Water						
Lole*30%	200.54	269.80	344.38	354.14	323.40	3.72
Wanmun*30%	217.40	295.90	368.38	377.20	377.40	3.62
L-W*30%	201.58	273.20	341.74	342.32	316.90	3.99
W-L*30%	188.70	287.00	366.78	353.64	350.00	2.67
Lole*80%	473.58	711.00	696.34	699.48	723.20	3.21
Wanmun*80%	530.46	773.00	739.40	740.46	782.80	3.54
L-W*80%	441.68	722.70	688.92	697.48	729.40	3.02
W-L*80%	460.02	755.50	719.22	738.14	772.90	2.73

Values within a column followed by the same letter symbol are not significantly different ($p<0.05$). All the interactions are significant ($p<0.05$).