LIMITATIONS TO SWEET POTATO GROWTH IN SMALL VOLUMES OF SOIL IMPOSED BY WATER AND NUTRIENT STRESS, ACIDITY AND SALINITY.

A.J. Dowling[1, 4], F.P.C. Blamey[2] and T. Hoa[3]

ABSTRACT

Sweet potato (Ipomoea batatas *(L.) Lam.) is an important smallholder root crop in Papua New Guinea, and there is an increasing requirement for its use as a diagnostic test species in agricultural research programs. As a result, it was decided to investigate sweet potato growth under conditions of water and nutrient stress, soil acidity and soil salinity using procedures with a small volume (1.7 L) of potted soil. An Orthoxic Tropudult soil deficient in phosphorus (P) and sulfur (S) from the Highlands Agricultural Experiment Station at Aiyura was assessed. Well-defined growth responses were apparent from about 10 days after sowing. Water stress dramatically reduced growth. As water stress increased, vines decreased in length and had fewer leaves, lower whole plant (tops plus roots) fresh weights and lower dry top weights. Water stress also masked effects of nutrient stress. Nutrient stress (P and S deficiency) reduced whole plant fresh weight and dry top weight without affecting vine length or number of leaves. Phosphorus and S requirements for 90% of maximum yield were equivalent to 48 and 25 kg ha^{-1}, respectively. Sweet potato proved intolerant of soluble salts at the high level (electrical conductivity of 1:5 soil:water extract 1.87 dS m^{-1}) imposed. Application of lime raised pH (1:5 soil:water) from 5.0 to 5.8, but had little effect on growth. Limitations on plant size and period of growth imposed by a small volume of soil strongly suggest that soil water must be maintained between field capacity and 50% of field capacity if other factors (e.g. nutrition) are to be effectively assessed and extrapolated to the field.*

***Key Words**: Sweet potato, Water stress, Phosphorus, Sulfur, Lime, Salinity*

INTRODUCTION

Sweet potato (*Ipomoea batatas* (L.) Lam.) is the most important staple food crop throughout the Highlands of Papua New Guinea (Bourke 1985). At the village or smallholder level, sweet potato gardens are managed according to traditional shifting cultivation practices. These practices typically include a period of fallow where grass or woody regrowth is encouraged for the maintenance of soil physical and nutritional properties. Thus the effective life-span of a typical garden soil will depend, initially, upon its physical and nutritional status and, subsequently, upon its rate of physical and nutritional degradation under cropping. In parts of Enga, and Southern and Western Highlands Provinces of PNG, the productive life of a garden is often extended by the use of organic manures, and the interplanting and sequential harvesting of crops, but rarely by application of inorganic fertiliser or by use of soil amendments (e.g. mulch, lime). Also in the Aiyura area of the Eastern Highlands Province, legumes (usually peanut or winged bean) are planted in rotation with sweet potato (Bourke 1990).

Due to an increasing requirement for use of sweet potato as a diagnostic test species in experiments in the field (e.g. Wayi and Konabe 1993), in controlled environments (e.g. Bourke 1977) and in solution culture (e.g. O'Sullivan *et al.* 1993), it was decided to investigate the response of sweet potato to a variety of factors and amendments likely to modify its growth in small volumes of soil (i.e. in pots) under controlled conditions. Using an Orthoxic Tropudult soil, deficient in phosphorus (P) and sulfur (S) (Dowling *et al.* 1994), simple short-duration pot studies were conducted to describe sweet potato growth responses to: (1)

[1, 3] Department of Agriculture, PNG University of Technology, Private Mail Bag, Lae, PNG

[2] Department of Agriculture, The University of Queensland, Brisbane, Qld 4072, Australia

[4] Current address: Soil and Crop Evaluation Project, Koronivia Research Station, PO Box 77, Nausori, Fiji.

combinations of water and nutrient stress, soil acidity and soil salinity; and (2) rates of applied P and S.

METHODS

Experimental Soil

The experimental soil was collected from the north-facing slope of the International Board of Soil Research and Management (IBSRAM) project site on the Highlands Agricultural Experiment Station (HAES) (6° 19' S, 145° 55' E) at an altitude of 1650 m in the Aiyura valley near Kainantu, Eastern Highlands Province, PNG. Wayi and Konabe (1993) have classified this soil as an Orthoxic Tropudult (after Soil Survey Staff 1990).

A composite surface (0 to 0.15 m) soil sample of six 80 kg subsamples was collected, and then air dried and sieved <5 mm. Dowling *et al.* (1994) described this surface soil as being strongly acid (pH 5.4 in 1:5 soil:water), containing allophane and active Al (pH 7.9 in 1:50 soil:NaF solution), and being strongly P-fixing (P retention 73%) with low P availability (3.8 mg kg^{-1} Olsen-P). Maize (*Zea mays* L.) growth was reduced by P and S deficiency. A 2 kg subsample of soil was retained for determination of air dry field capacity (FC) and saturated soil water contents, and assessment of plant available water content.

Air dry and saturation gravimetric soil water contents were determined using procedures given by Rayment and Higginson (1992). Gravimetric water content at FC was determined after packing approximately 200 g of air dry soil into a 300 mm column. Water was applied uniformly to the top of the column, allowed to infiltrate and redistribute for 24 h, and FC in the top 50 mm was assumed. After discarding the surface 10 mm, the 10 to 20 mm layer was placed in a tared dish, weighed, dried at 105° C for 48 h, reweighed, and gravimetric water content at FC determined.

Pot trials utilised shadehouse and laboratory facilities of the Department of Agriculture, PNG University of Technology, Lae. All pot trials involved the use of 165 mm diameter (1.7 L) PVC pots, each lined with a plastic bag and containing 1.9 kg air-dry soil packed to a density of 1.1 g cm^{-3}.

Assessment of water and nutrient stress, soil acidity and soil salinity

Treatments were imposed to reflect a range of PAW contents, soil nutrient levels, soil acidity levels and salt contents. Water stress (W) treatments were: (1) limited water (W_L), in which the soil was watered to FC twice weekly; (2) adequate water (W_A), in which the soil was watered to FC daily; and (3) excess water (W_E), in which the soil was watered to saturation daily. Nutrients (Nutr), lime (Lime) and salt were either applied or not applied. These factors were then combined to result in the following treatments: (1) W_L; (2) W_L + Nutr; (3) W_L + Nutr + Lime; (4) W_A; (5) W_A + Nutr; (6) W_A + Nutr + Lime; (7) W_A + Nutr + Salt; (8) W_E; and (9) W_E + Nutr. Treatments were arranged in a completely randomised experimental design with four replications.

Fertiliser grade nutrients were applied (kg ha^{-1}) as follows: mixed NPK (as 6% N, 6% P, 5% K) at 160 N, 160 P and 130 K; Ca and N (calcium nitrate with 12% N, 17% Ca) at 40 N and 50 Ca; elemental S (100% S) at 75 S. After being thoroughly mixed, lime ($CaCO_3$, 2.3 t ha^{-1}) or salt (NaCl, 6.5 t ha^{-1}) were added to the appropriate treatments. After mixing, pots were wet to FC with distilled water and sealed. After a 10 day incubation period, two sweet potato (cv. Wanmun) vine cuttings were planted in each pot. Each vine cutting consisted of a growing tip and three nodes (leaves removed), and was approximately 150 mm in length. The base of the cutting was placed horizontally against the wall of the pot at a depth of approximately 40 mm, and the growing tip allowed to protrude 20 to 50 mm above the soil. A granular plastic mulch (depth 10 mm; Hostalen®, Hoeschst, Australia) was added to minimise evaporative losses from the soil surface 7 days after sowing (DAS). To facilitate pot movement for watering to FC, a stake was placed in the centre of each pot. Vines would be later tied to this stake. Pots were then watered to weight with distilled water as required; twice weekly to FC for W_L, daily to FC for W_A, and daily to saturation for W_E. Vines were grown for 42 days until well-defined growth responses were evident. Individual vine lengths and leaf numbers were recorded prior to harvest. Plants tops were cut at ground level and fresh weights immediately recorded. Plant tops were then dried (70° C for 72 hours) and reweighed. A 25 mm diameter soil core was then taken from each pot, dried at 40° C for 48 hours and sieved <2 mm, and pH (1:5 soil:water) and salinity (electrical conductivity of 1:5 soil:water suspension) determined using procedures given in Rayment and Higginson (1992). Roots were carefully removed from the soil under a stream of water, and root fresh weights recorded. Whole plant fresh weights were than calculated as the sum of top and root fresh weights.

Analysis of variance was used to test effects of treatments on vine length, number of leaves, whole plant fresh weight and dry top weight. Pairwise comparisons of treatment means were performed by the protected least significant difference (l.s.d.) test at $P<0.05$.

Assessment of P and S requirements

Treatments consisted of seven P and seven S rates (0, 20, 40, 80, 160, 320 and 640 kg ha^{-1}), applied as $Ca(H_2PO_4)_2 H_2O$ and $CaSO_4 2H_2O$, respectively. Basal S (160 kg ha^{-1}) was applied to pots amended with P, and basal P (160 kg^{-1}) to pots amended with S; no other basal nutrients were applied since this soil was shown by Dowling *et al.* (1994) to be deficient only in P and S. Treatments were arranged in a completely randomised experimental design with three replications. After mixing, pots were wet to FC with distilled water and sealed. After a 10 day incubation period, two sweet potato (cv Wanmun) vines were planted in each pot as described previously. These were thinned to one vine per pot, 7 DAS and a granular plastic mulch (10 mm depth) added to minimise evaporative losses from the soil surface. Each vine was tied to a stake placed in the centre of its pot to facilitate watering and vine extesion. Pots were watered (to weight) daily to FC with distilled water. Vines were grown for 28 days when well-defined growth responses were evident. Individual vine lengths and number of leaves were recorded prior to harvest, and the vines harvested as described prevoiusly.

Analysis of variance was used to test effects of applied P and S. Pairwise comparisons of treatment means were performed by the protected least significant difference (l.s.d.) test at $P<0.05$. Mitscherlich relations of the form $y = a - be^{-kx}$ were fitted to data describing dry matter yield of plant tops (y) and applied P or S (x). Maximum yield (a, Y_{MAX}) was calculated, and absolute yields converted to relative yields. Mitscherlich relations were fitted to relative yield and applied P or S to remove the effect of differences in Y_{MAX} on the curvature co-efficient (k). The P and S requirements for 90% Y_{MAX} were then calculated.

RESULTS AND DISCUSSION

For this Orthoxic Tropudult soil, the air-dry water content was 16%, the water content at FC was 42%, and the water content at saturation was 55%. With pots containing 1900 g of air-dry soil, oven dry (105°C) soil mass was 1650 g. Water added to air-dry soil for FC and saturation were calculated as 440 and 650 g, but for convenience, pot mass at FC and at saturation was rounded to 2400 and 2600 g, respectively.

Water and nutrient stress, soil acidity and soil salinity

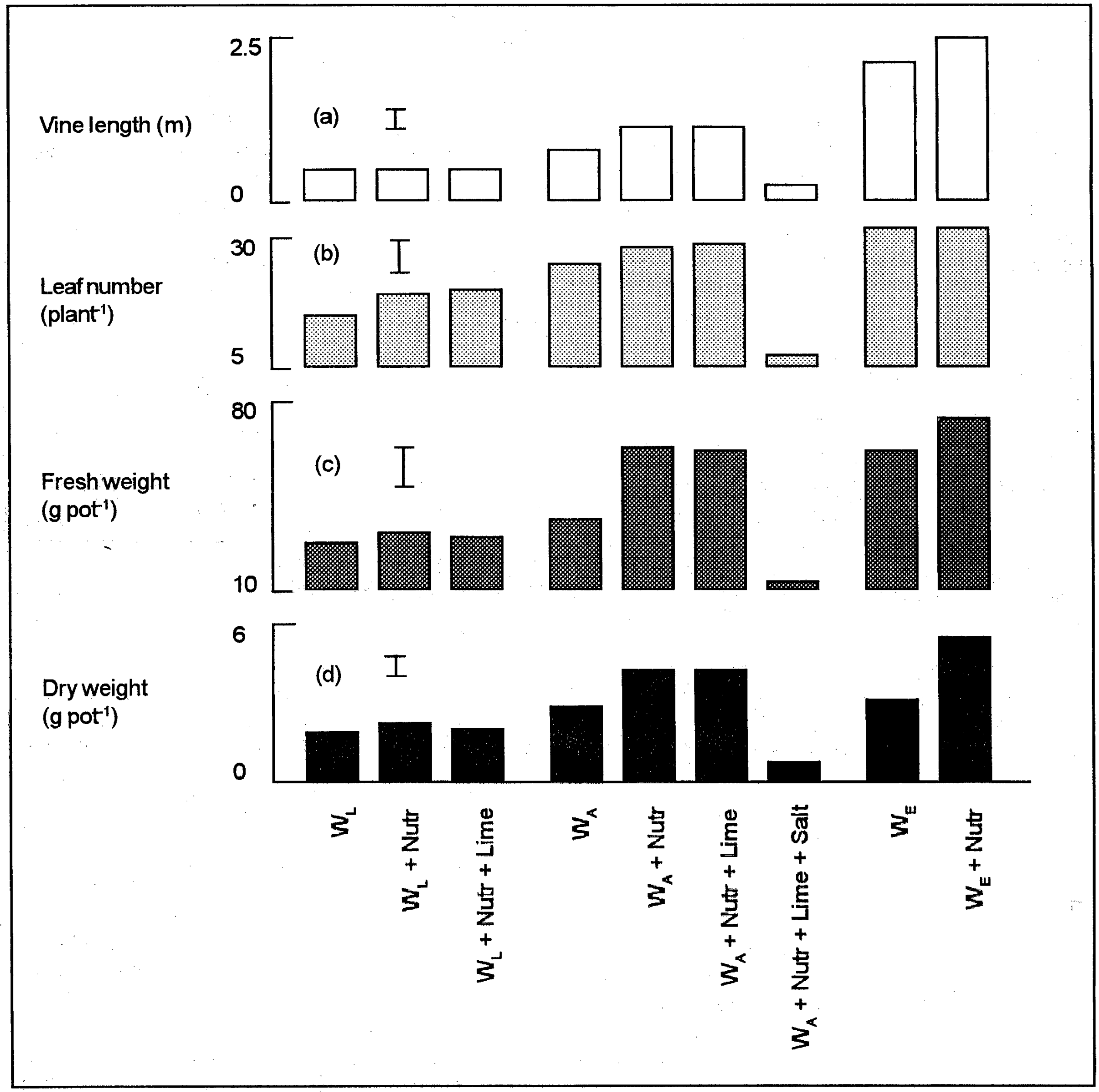
Visible growth responses to treatments were apparent from about 10 DAS. Vines in W_E pots were the longest and greenest, whereas those in W_A+Salt and W_L pots were the shortest and displayed a mild purple discolouration of leaf veins and underside of the leaf. Water stress appeared to limit vine growth more severely than did nutrient stress (P and S deficiency) or soil acidity. The presence of a high level of salt (NaCl)

Table 1. **Treatment effect on soil pH (1:5 soil:water) and electrical conductivity (1:5 soil:water) where WLA = adequate water supply, WE = excess water supply, Nutr = added nutrients, Lime = added lime and Salt = added NaCl following harvest of sweet potato grown in an Orthoxic Tropudult soil.**

Treatment	pH (1:5)	Electrical Conductivity (dS m-1)
WL	5.3 a[1]	0.03 a
WL+Nutr	5.3 a	0.24 b
WL+Nutr+Lime	5.7 b	0.32 b
WA	5.3 a	0.02 a
WA+Nutr	5.3 a	0.37 b
WA+Nutr+Lime	5.8 b	0.43 b
WA+Nutr+Salt	5.3 a	1.87 c
WE	5.3 a	0.03 a
WE+Nutr	5.3 a	0.36 b
l.s.d. (p=0.05)	0.1	0.19

[1] *Means followed by a common letter are not significantly different (P<0.05).*

Figure 1. **Treatment effects on (a) vine length, (b) number of leaves, (c) whole plant fresh weight, and (d) dry top weight with water where W_L = limited water supply, W_A = adequate water supply, W_E = excess water supply, Nutr = added nutrients. Lime = added lime and salt = added NaCl for sweet poptato grown in an Orthoxic Tropult soil from the Highlands Agricultural Experiment Station, Aiyura. Vertical bars show l.s.d. at p=0.05**



dramatically reduced growth. Visible symptoms of P and S deficiency, as described by O'Sullivan *et al.* (1993), were not observed.

At harvest, vine length ranged from 0.22 to 3.64 m, leaf number from 4 to 40 plant^{-1}, whole plant fresh weight from 10 to 102 g pot^{-1}, and top dry weight from 0.50 to 6.72 g pot^{-1}. Variations in these variables were highly inter-correlated ($r>0.77$), and similarly affected ($P<0.05$) by treatment (Figure 1). Treatment also had significant effects on soil pH which ranged from 5.3 to 5.8, and on soil salinity where electrical conductivity (EC) meas-

Table 2. **Effects of applied phosphorus and sulfur on vine length, number of leaves, whole plant fresh weight, and dry weight of plant tops for sweet potato grown in an Orthoxic Tropudult soil.**

Application rate (kg ha^{-1})	Vine length (m)	Number of leaves ($plant^{-1}$)	Whole plant fresh weight (g pot^{-1})	Dry weight of plant tops (g pot^{-1})
(a) Phosphorus				
0	0.43 a[1]	12 a	24 a	1.53 a
20	0.93 b	16 b	34 b	2.44 b
40	0.97 bc	19 bc	43 cd	2.88 bcd
80	1.09 bcd	19 cd	46 de	3.07 cde
160	1.24 cd	22 cd	54 e	3.53 e
320	1.26 cd	21 cd	47 de	3.14 cde
640	1.38 d	21 cd	44 c	2.94 bcde
(b) Sulfur				
0	0.50 a	13 a	25 a	1.51 a
20	1.21 bcd	21 cd	42 cd	2.94 bcde
80	1.13 bcd	21 cd	49 de	3.59 e
160	1.37 d	23 d	45 cd	3.25 de
320	1.38 d	21 cd	45 d	3.29 de
640	0.98 b	18 bc	37 bc	2.57 bc

[1] Means followed by a common letter are not significantly different ($p<0.05$).

ures ranged from 0.02 to 1.87 dS m^{-1} (Table 1). Only lime (2.3 t ha^{-1}) increased pH, but salinity was increased by application of nutrients and especially by application of NaCl (6.5 t ha^{-1}).

Water stress. The degree of water stress was quantified as the range in plant available water (PAW) between irrigations. After each irrigation, PAW was assumed to be 100% at saturation and 0% at 'air dry', and calculated to be 71% at FC. Water used between irrigations was recorded on two occasions, *viz.* at 21 and 35 DAS. At 21 DAS, W_L pots used 100 to 130 mL over 3 days, W_A pots 80 to 100 mL per day and WE pots 100 to 160 mL per day between irrigations. Corresponding values at 35 DAS were: W_L pots 150 to 200 mL; W_A pots 130 to 160 mL; and W_E pots 180 to 240 mL. With W_E pots wet to saturation and W_A and W_L pots wet to FC, these water use data suggest W_E pots were maintained at >66% PAW, W_A pots at 49 to 71% PAW, and W_L pots at 43 to 71% PAW. Thus, water stress increased with irrigation treatment ($W_E < W_A < W_L$) as PAW decreased from >66% under W_E to between 43 to 71% under W_L.

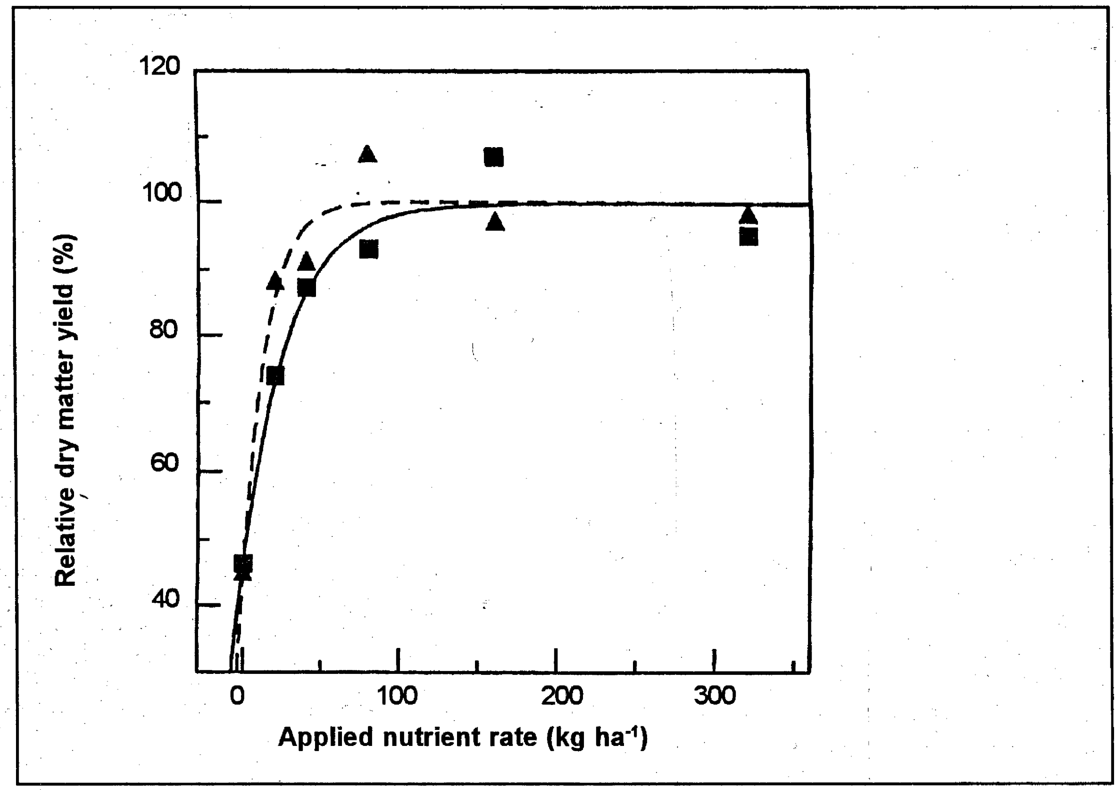
The impact of water stress on vine growth and dry matter production was dramatic (Figure 1). As water stress increased (other stresses not limiting *viz.* W_E+Nutr < W_A+Nutr < W_L+Nutr), vine length decreased from 2.49 to 0.59 m, leaf number decreased from 32 to 19 $plant^{-1}$, whole plant fresh weight decreased from 76 to 32 g pot^{-1} and dry top weight decreased from 5.33 to 2.20 g pot^{-1}. Similar patterns of decrease were apparent when nutrients (viz. $W_E < W_A < W_L$) and soil acidity (viz. W_E+Nutr+Lime < W_A+Nutr+Lime < W_L +Nutr+Lime) may have been limiting.

Nutrient stress. Nutrient stress was minimised by application (kg ha^{-1}) of 200 N, 160 P, 130 K, 50 Ca and 75 S. As nutrient stress increased, whole plant fresh weight decreased from 62 to 37 g pot^{-1} (W_A+Nutr > W_A) and dry top weight decreased (WE+Nutr > WE) from 5.33 to 4.43 g pot^{-1} and 4.30 to 2.80 g pot^{-1} (WA+Nutr >W_A). In contrast, vine length and number of leaves were little affected (Figure 1). As water stress increased, the impact of nutrient stress on dry matter production became less apparent.

Figure 2. **Mitscherlich fits to data describing the relationship between relative yield of dry tops and applied P (■, solid line) and applied S (▲, dashed line) for sweet potato grown in an Orthoxic Tropudult soil from the Highlands Agricultural Experiment Station, Aiyura. Fitted Equations are:**

For P, $RY = 100 - 53\ e^{-0.035x}$ ($n = 6$, $R^2 = 0.96$)
For S, $RY = 100 - 55\ e^{-0.067x}$ ($n = 6$. $R^2 = 0.96$)

(For convenience, data for 640 kg ha^{-1} additions of P and S are not included.)



Soil acidity. This soil was strongly acidic (pH 5.3). Although the addition of lime (2.3 t ha^{-1}) raised soil pH levels from 5.3 to 5.8 (Table 1), liming had little effect on plant growth and dry matter production (Figure 1).

Salinty. The impact of salt (6.5 t ha^{-1} NaCl), which increased soil EC from <0.03 to 1.87 dS m^{-1} (Table 1), on plant growth and dry matter production was dramatic, and perhaps more pronounced than for water stress (Figure 1). With adequate water and nutrition, salinity markedly depressed growth and dry matter production (W_A+Nutr > W_A+Nutr+Salt), vine length decreased from 1.37 to 0.30 m, leaf number decreased from 28 to 6 per plant, fresh weight decreased from 62 to 11 g pot^{-1} and dry weight decreased from 4.3 to 0.74 g pot^{-1}. Clearly, sweet potato was unable to tolerate this high level of soil salinity, and further work in this regard is warranted.

P and S requirements

With applied P, vine length ranged from 0.35 to 1.80 m, leaf number from 10 to 25 per plant, whole plant fresh weight from 20 to 57 g pot^{-1}, and dry top weight from 0.99 to 4.03 g pot^{-1}. For applied S, vine length ranged from 0.36 to 1.77 m, number of leaves from 11 to 25, whole plant fresh weight from 20 to 63 g pot^{-1}, and top dry weight from 1.12 to 4.37g pot^{-1}. Plant growth variables were inter-correlated (r>0.81), and were similarly influenced (P<0.05) by the rate of P or S application (Table 2).

Using data describing the weight of dry tops, separate Mitscherlich relations were developed to describe sweet potato growth responses to appled P and S, and Y_{MAX} (with approximate SE) estimated. For applied P, Y_{MAX} was 3.30 ($\pm$ 0.12) g pot^{-1}; and for applied S, Y_{Max} was 3.34 ($\pm$ 0.11) g pot^{-1}. Using these estimates of Y_{MAX}, separate relative growth responses to applied P and S were developed (Figure 2), and equivalent P and S requirements for 90% of Y_{MAX} calculated as 48 kg P ha^{-1} and 25 kg S ha^{-1}.

CONCLUSIONS

For this Othoxic Tropudult, sweet potato growth was depressed by water and nutritient stress and by soil salinity, but not by soil acidity. Simple procedures were used to grow vines in small volumes (1.7 L) of soil. However, considerable care was necessary at planting due to the mass of the planting material and its immediate requirement for water. Water requirements were minimised firstly, by removing as many leaves as possible and, secondly, by placing as much of the planting material in contact with wet soil as possible. Daily watering was essential. Senescing leaves were also removed during early growth.

Water stress dramatically reduced sweet potato growth, a result with great implications in pot experimentation. As water stress increased, vines became shorter with fewer leaves and lower whole plant fresh weights and dry top weights. Water stress also masked effects of nutrient stress. Nutrient stress acted to reduce plant growth, but had little effect on vine length or number of leaves. Given P and S deficiency in this soil, P and S requirements for 90% Y_{MAX} were equivalent to 48 and 25 kg ha^{-1}, respectively. Sweet potato proved intolerant of soluble salts at the high level (EC 1.87 dS m^{-1}) imposed in this experiment. Soil acidity was unlikely to limit sweet potato growth, and by inference, tuber yield on this soil. Further, the application of lime did not appear to induce potential micronutrient deficiency (e.g. Fe, Mn, Cu or Zn) or cation imbalance.

The results from this study suggest that sweet potato has great potential as a test species in short duration glasshouse studies. Although not exhibiting nutritional disorders as given by O'Sullivan *et al.* (1993), the value of sweet potato as a test species for tropical soils was recognised and its use is to be encouraged. However, with the limitations on plant size and period of growth that are imposed by a small volume of soil, it will be crucial to control and maintain soil water contents within defined limits (e.g. FC to 50% of FC) if other factors (e.g. nutrition, acidity and salinity) are to be effectively assessed and extrapolated to the field. The qualitative extrapolation of any response to the field must be questioned if the factor being examined (e.g. nutrition) does not clearly dominate all others (e.g. water, acidity and salinity) (De Vries 1980).

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