EFFECTS OF CULTIVAR, LEAF POSITION, AND STEM TISSUE
ON GROWTH OF SINGLE-LEAF CUTTINGS
OF *IPOMOEA BATATAS* LAM

by

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(ABSTRACT)

Sweet potato single-leaf cuttings of cultivars 'Centennial,' 'Jewel,' and 'Nemagold' were planted in plastic pots containing steam-sterilized sand. Fully opened leaves were counted from the terminal apex on stock plant stems, and leaf positions 1 to 3 and 7 to 9 were referred to as mean leaf positions 2 and 8 respectively. Dry weight and its partitioning among plant organs (leaf, stem, petiole, new shoot, fibrous roots, and storage roots) differed among the three cultivars. 'Centennial' had the highest storage root dry weights in both the first (December - March) and second (April - June) experiments. The new shoot and storage root dry weights of 'Centennial' and 'Jewel' were 3 to 25 times greater at 79 days after planting (DAP) in the second experiment than at 70 DAP in the first experiment. The new shoot was the dominant sink in 'Nemagold' between 28 and 70 DAP in the first experiment but not in the second experiment, and the storage root never became a strong sink

in either experiment. A shift from leaf dry weight increase to decrease was observed in the first experiment but not in the second experiment.

Leaves in mean leaf position 2 showed higher original plant material (leaf, petiole, and stem) dry weight than mean leaf position 8, but there were no significant differences in final storage root dry weight between these two mean leaf positions in both experiments. Mean leaf position 2 approximate net assimilation rate (NAR) values based on leaf and new shoot dry weight exceeded mean leaf position 8 approximate NAR values in both experiments.

Plants with stem attachment had higher new shoot and storage root dry weights than plants without stem attachment. Dry weight of the original leaf decreased in plants with stem attachment but not in plants without stem attachment.

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GENERAL INTRODUCTION

Sweet potato (Ipomoea batatas Lam) is a multiple use crop plant. The tender shoot portions can be used as a vegetable, the mature portions used to feed animals, and the storage roots used as food for humans and animals (Dahniya, 1979; Villareal *et al.*, 1979). Removal of above-ground parts has generally reduced storage root yield, but the effects have varied (Bartolini 1982; Dahniya 1979; Gonzalez, 1977; Hozyo, 1982). Thus, two questions arise :

1. What is the relationship between above-ground shoot growth and below-ground storage root formation, growth, and yield ?
2. What characteristics of sweet potato cultivars are associated with increased production of storage roots ?

Sweet potato is a warm season crop whose storage roots typically take 120 or more days to reach harvest maturity. It also requires a relatively large area for growth. Thus, investigations of the relationship between sweet potato shoot and root growth under field conditions are subject to seasonal limitations. An alternate approach involves the use of single-leaf cuttings (Isbell, 1931; Yarwood, 1946).

This approach can be used under greenhouse conditions less subject to seasonality and more amenable to control and measurement of the growing environment than field experiments. Moreover, modification of Martin's (1982) single-leaf planting technique could provide further observations about the utility of single-leaf cuttings as a research method. In addition, information obtained by studying single-leaf cuttings might be applied in commercial propagation.

Sweet potato storage root yield may be influenced by both photosynthetic activity and storage root sink capacity (Hahn,1977). In order to maintain high photosynthetic activity, efficient translocation of assimilate from the leaves into storage roots is critical (Tsuno and Fujise, 1965). Fellows and Geiger (1974) reported that leaf sugar export is triggered when sugar accumulates to a threshold pressure gradient for mass flow. The export of assimilate is also affected by leaf position on the stem (Larson and Gordon, 1969).

The objective of this study was to use sweet potato single-leaf cuttings to test the effects of cultivar, leaf position, photosynthetically active leaf area, and associated stem tissue on sweet potato shoot and root growth, source-sink relationships, and how these relationships affect storage root yield. Based on this objective, four experiments were designed:

Experiment I : Cultivar x leaf position
(conducted for 21 days)

Experiment II : Cultivar x leaf position x leaf covering
(conducted for 70 days)

Experiment III: Leaf covering techniques
(conducted for 28 days)

Experiment IV : Cultivar x leaf position x stem attachment (conducted for 79 days)

The format of this thesis includes :

1. A review of literature on the factors investigated.
2. A manuscript giving condensed results from two of the four experiments (experiments II and IV). In the manuscript, these two experiments are refered to as the "first experiment" and "second experiment," respectively.

Experiments II and IV were selected for two reasons:

1. The two experiments were sufficiently long for storage roots, the economically most important organ, to form.
2. The two experiments compared cultivar and leaf

position in different seasons (winter versus spring), thus permitting observations on possible effects of seasonal differences.

REVIEW OF LITERATURE

The Sweet Potato Storage Root and the Process of Its Growth

While the sweet potato storage root is not a tuber, its process of formation appears analogous to that of a tuber (Wilson, 1982). The major zones in the mature tuber of white potato are the periderm, cortex, vascular cylinder, perimedullary zone, and central pith. The first region to grow is the pith, then cortical cells become filled with starch, and finally the pericyclic and perimedullary zones show the greatest growth activity and become filled with starch. In sweet potato, the formation of secondary cambia coincides with the formation of an active meristematic zone. The primary cambium continues to function while the development of secondary cambia is taking place and a large amount of storage parenchyma is being formed. In the mature fleshy root, the pericyclic zone is composed of large parenchymatous cells which are filled with starch (Hayward, 1938). Hence, both the white potato tuber and the sweet potato storage root show similarity in the pattern of starch deposition in the pericyclic zone.

In this study the term 'storage root' will be used to describe the 'tuber' or 'tuberous root' of sweet potato.

All three terms used in the literature will be considered synonymous here.

Wilson (1982) defined storage root development (so-called "tuberization") in sweet potato as the sum of all the processes from initiation of potential storage roots through the formation of mature storage roots. He identified three major steps in this process: initiation, development, and growth. Storage root initiation refers to the differentiation of cells in potentially starch accumulating, thick roots. Storage root development refers to the qualitative changes in growth that take place in the sweet potato root system in the course of the transformation of potential storage roots into mature storage roots. Storage root growth is defined as the quantitative changes in the size and weight of storage roots that take place in the course of the same transformation, resulting in final storage root yield.

Distribution of Photosynthates between Source and Sink

A "source" is a plant organ having the capacity to conduct photosynthesis and export a portion of the resulting photosynthate. A "sink" is any growing or metabolizing tissue with the capacity to import photosynthate which it does not produce, or in excess of what it produces. Thus, photosynthate moves from the source, where it is produced, to the sink, where it is stored or used. Plant yield is a result of both source potential to photosynthesize and sink capacity to utilize photosynthate. Photosynthetic rates may control plant growth rates, but translocation and utilization of photosynthate in growth may limit photosynthesis (Brown, 1984).

As in most plant species, source potential of sweet potato is the product of leaf area and photosynthetic rate (Tsuno and Fujise, 1965). Sink capacity, or strength, in the case of sweet potato refers especially to the ability of the storage roots to attract photosynthate. It is the product of the size of the sink multiplied by its activity. Activity refers to the amount of translocate attracted by the sink per unit sink weight (Canny, 1984).

These two indicators of growth can thus be expressed in the following formulae (adapted from Canny, 1984; Tsuno and Fujise, 1965) :

1. Source potential = leaf NAR x leaf area

2. Sink capacity = root RGR x root dry weight

where NAR, or an approximation of NAR, is a measure of photosynthetic rate, and root RGR is a measure of sink activity.

Hahn (1977) found that sink capacity was more limiting than source potential in determining sweet potato storage root yield. When sink capacity increased, more production and supply by the source occurred. The rate of sweet potato photosynthesis may depend on the demands of the major sink (the storage root). Hahn (1977) also noted that changes in growth stage and environmental conditions could affect the balance between source potential and sink capacity.

The rate at which photosynthates are exported from leaves to roots may affect sweet potato storage root development more than photosynthetic rates per se, and the rate of movement of assimilates is determined, in part, by the growth rates of the storage root (Austin and Aung, 1973). The demand for photosynthate in roots influences translocation, photosynthesis, and hence plant growth (Turner and Bidwell, 1965). Increased storage root growth can result in greater dry matter productivity of sweet potato foliage (Wilson, 1982).

Leaves can be both sources and sinks. Brown (1984) explained this as follows:

" Leaves act as importers of photosynthate [sinks] during their early growth and as exporters [sources] later. Immature leaves grow at rates faster than can be supplied by their limited photosynthesis. Later, they produce much more photosynthate than they need. Prior to full expansion, leaves reach a point when they export more photosynthate than they import."

Larson and Gordon (1969) also found that in cottonwood (Populus deltoides) trees, maximum C^{14} export occurred when a leaf had just attained maximum size. As a leaf at any one position aged, the direction of translocation within the leaf gradually shifted from upward (into the leaf) to bi-directional and finally to downward (out of leaf). Once this transition is complete, no assimilates move into mature leaves (Canny, 1984). In field experiments, Austin and Aung (1973) found that maximum vegetative top weight preceded maximum storage root development, and vegetative top weights remained constant or decreased after rapid increases in storage root weight began.

Cultivar Differences in Patterns of Dry Matter Distribution

Austin and Aung (1973) found that sweet potato cultivars with similar leaf morphology may behave dissimilarly in dry matter distribution. In their studies, three cultivars were used, 'Centennial,' 'Julian,' and 'Nemagold.' 'Centennial' and 'Julian' had similar leaf morphology, but were different from 'Nemagold.' Both 'Centennial' and 'Nemagold' showed higher growth of the stem, which was considered an intermediate sink. 'Julian' showed greater efficiency in accumulation of dry matter in storage roots, since a lesser amount of assimilates was stored or used by the stem.

Effect of Leaf Age and Position on the Growth of Single-Leaf Cuttings

Rooting ability of single-leaf cuttings varies with the age of the leaf used, but there are conflicting reports on what is the best age. Wilson (1969) found that mature leaves rooted more easily than young leaves, while Martin (1982) found that younger leaves rooted well but older leaves formed petiole callus only. Martin suggested the use of the first three fully expanded apical leaves of actively growing stems for rooting. Spence (1971) used the second opened leaf.

Position on the stem can affect the ability of leaves to export photosynthate to other parts of the plant. In cottonwood trees, Larson and Gordon (1969) found that leaves in lower positions from the stem terminal reached maturity quickly and began exporting photosynthate when demands of other parts of the plant were high. Leaves at higher stem positions matured more slowly, but senescence was delayed, so their effective export life was longer.

Effects of the Stem in Rooting Single-Leaf Cuttings

In difficult-to-root varieties , rooting of leaf cuttings is often facilitated by taking the cuttings with a piece of stem still attached. After incubation in a humid propagation bin for 2 or 3 days, such leaves root easily when severed and placed in water (Wilson, 1969).

The stem may also serve as a temporary sink for assimilate. Incoll and Neales (1970) found in Jerusalem artichoke (*Helianthus tuberosus*) that the tubers were not the initial sink for assimilates; rather, the stem served as a temporary sink before tuberization began, and then assimilate moved from the stem to the tubers. Since tuberization in *Helianthus tuberosus* is short day, the timing of transfer of dry matter from the stem to the tuber was dependent on tuber initiation, and may be induced by the onset of short days.

The Single-Leaf Phytomodel Concept and Uses

Wilson (1969) defined as a "phytomodel" a modified plant or plant organ that has both a photosynthetic surface and roots and is therefore an independent metabolic unit, capable of integrated growth by cell division, cell expansion, and cell differentiation.

Detached leaf cultures have been used to study various physiological processes of plants (Isbell, 1931; Shive and Robbins, 1937). One of these processes is rooting.

Rooting ability of detached leaves is strongly affected by the medium in which leaves are rooted. Solution culture of detached sweet potato leaves produced only fibrous roots, while sand culture resulted in storage root generation (Spence, 1971; Spence and Humphries, 1972). Martin (1982) described the growth of rooted leaves of sweet potato in sand culture as follows : callusing at the base of the petiole in 3 to 4 days followed by root formation in 6 to 10 days. Storage roots and fibrous roots could not be easily distinguished until the fourth week.

In most detached-leaf culture studies (Martin, 1982; Spence, 1971; Spence and Humphries, 1972; Yarwood, 1946), the leaf was shaded and no nutrient solution was applied at planting. After 2 weeks, the shading was removed.

Nutrient solution was beneficial only after fibrous roots were formed (Martin, 1982). However, in a preliminary experiment (unpublished data), successful rooting occurred in single-leaf cuttings without shading and with application of half-strength Hoagland's No. 1 solution (Hoagland and Arnon, 1950) at 100 ml per plant daily.

MANUSCRIPT ON KEY EXPERIMENTS

INTRODUCTION

Sweet potato (*Ipomoea batatas* Lam) is a multiple-use crop plant. The most important part is the storage root, used as food for humans and animals. Young leaves are used as a vegetable, and mature stems and leaves are used as animal feed (Dahniya, 1979, Villareal *et al*., 1979).

Dry matter distribution among plant parts and yield of sweet potato roots are influenced by both photosynthetic (source) potential and storage root (sink) capacity (Hahn, 1977). Source potential is the product of leaf area and photosynthetic rate (Tsuno and Fujise, 1965). Sink capacity, or strength, is the product of the size of the sink multipled by its activity. Activity refers to the amount of translocate attracted by the sink per unit sink weight per day (Canny, 1984).

Source potential and sink capacity are related through translocation from the source to the sink of assimilates produced by the source. The efficient translocation of assimilates from the leaves can contribute to high photosynthetic activity (Tsuno and Fujise, 1965). Thus, a sweet potato cultivar having a small leaf area can produce a large yield of storage roots (Austin and Aung, 1973). The export of assimilate is also affected by leaf age and leaf position on the stem (Larson and Gordon, 1969). The stem can serve as a temporary sink for assimilates before tuberization begins in Jerusalem artichoke (Incoll and Neales, 1970).

The objective of this study was to determine the effects of cultivar, leaf position, and the attachment of 1 cm of stem on shoot and root growth of sweet potato single-leaf cuttings. The single-leaf system (Martin, 1982) was used because it provides a simple mechanism for evaluating the relative distribution of photosynthate between the root sink and the leaf sink (Wilson, 1969) and allows better control of external factors than field experiments. The single-leaf system might also be applied in commercial propagation.

MATERIALS AND METHODS

Fully unfolded leaves on rapidly growing sweet potato stock plant stems were classified by their positions counted from the terminal bud. First to third and seventh to ninth fully opened leaves were grouped into mean leaf positions 2 and 8 respectively. Plastic pots (9.5 cm tall x 12.7 cm diameter) were filled with steam-sterilized sand. The leaves were cut with 1 cm of stem still attached, except for one set of treatments in the second experiment. Attempts were made to remove the axillary bud. The leaves were planted individually in the plastic pots under full sunlight in a greenhouse. Half-strength Hoagland's No. 1 solution (Hoagland and Arnon, 1950) was applied to saturation daily.

The single leaves were cut and planted on 24 and 25 December 1985 and on 28 and 29 March 1986 for the first and second experiments respectively. In both experiments, three cultivars, 'Centennial,' 'Jewel,' and 'Nemagold,' were evaluated. In the first experiment, the three cultivars, mean leaf positions 2 and 8, and leaf covering techniques (uncovered or covering of randomly selected left or right halves of leaves) were evaluated using a randomized complete block design arranged in a 3 x 2 x 2 factorial with

12 replicates. In the second experiment, the same three cultivars, the same two mean leaf positions (2 and 8), and presence or absence of 1 cm of stem were evaluated using a randomized complete block design arranged in a 3 x 2 x 2 factorial with 12 replicates.

Plant growth was evaluated at 7, 28, 49, and 70 days after planting (DAP) in the first experiment, and at 7, 28, 49, and 79 DAP in the second experiment. At each sampling date, three replicates each of plants were removed from the pots, roots washed, and plants separated into leaf, petiole, original stem, new shoot, fibrous roots, and storage roots. Storage roots were classified by their morphological appearance as lateral swelling. Roots which did not show lateral swelling were classified as fibrous roots. Dry weights of each plant part were determined after drying in an oven at 80°C for 48 hours.

The dry weight increase of each organ as a percentage of total plant dry weight increase between two sampling days was calculated by the formula :

$$\% \text{ Dry weight increase} = \frac{W2 - W1}{TOTWT2 - TOTWT1} \times 100\%$$

where W1 and W2 are the dry weights of the particular plant organ at sampling days t1 and t2 respectively, and (TOTWT2 - TOTWT1) is the difference in the total dry weights of all organs which increased in dry weight between these two sampling days. Hence, this formula shows the dry weight increase of a given organ as a percentage of the total dry weight increase of all organs which functioned as sinks, increasing in dry weight, between sampling days t1 and t2.

The percentage dry weight increase was calculated for three time periods :

Period 1 : 7 to 28 DAP;

Period 2 : 28 to 49 DAP;

Period 3 : 49 to 70 (first experiment) or 79 (second experiment) DAP.

Based on the percentage dry weight increase, three terms will be used for a given period in this study:

1. Dominant sink : a plant organ with a percentage dry weight increase greater than 50%. The dominant sink thus utilized more photosynthate than all other organs combined during the given period.
2. Strongest sink: a plant organ with a percentage dry

weight increase greater than 33% but less than 50%, and ranked first in percentage dry weight increase. The strongest sink thus utilized more photosynthate than any other single organ during the given time period.

3. Strong sink : a plant organ with a percentage dry weight increase greater 33% but less than 50%, and ranked second in percentage dry weight increase.

An approximate value for the mean net assimilation rate (NAR) between two sampling days based on the dry weight of photosynthetic organs was calculated by the following formula :

$$\text{Approximate NAR} = \frac{(TWT2 - TWT1)}{(SWT2 - SWT1)} \times \frac{[LN(SWT2) - LN(SWT1)]}{(t2 - t1)}$$

where SWT1 and SWT2 are the combined dry weights of the leaf and new shoot, and TWT1 and TWT2 are total plant dry weights at sampling days t1 and t2 respectively. In this formula, the source weight terms are used in place of leaf areas used in the conventional formula for NAR (Radford, 1967), because:

1. The leaf areas of small new shoot leaves could not be measured using the same leaf area measurement technique as for the original leaf.
2. Leaf weight showed a significant correlation ($r = 0.96$) with leaf area at 7 DAP.

Approximate NAR values were calculated for the same three time periods as the percentage dry weight increase.

Statistical analysis was done by analysis of variance using the general linear models program of the Statistical Analysis System (SAS Institute, 1985). Both main effects and interactions were assessed for each plant organ at each sampling date. Only the main effects of cultivar, mean leaf position, and stem attachment are presented here. All but two interactions among the main effects were non-significant.

RESULTS

Cultivar Effects

The dry weights of regenerating plant organs were different among the three cultivars. In both experiments, storage root dry weight was highest in 'Centennial' on the last sampling date. New shoot dry weight was highest in 'Nemagold' in the first experiment, but less than and not significantly different from that of 'Centennial' and 'Jewel' in the second experiment. 'Centennial' and 'Jewel' new shoot and storage root dry weights were 3 to 25 times greater at the last sampling date in the second experiment than in the first experiment, but 'Nemagold' new shoot and storage root dry weights were less in the second experiment (Figs. 1 and 2).

The timing of the shift from leaf dry weight increase to decrease differed among the three cultivars. In the first experiment, 'Centennial' leaf dry weights decreased at 49 DAP after increasing from 7 to 28 DAP. 'Jewel' and 'Nemagold' leaf dry weights did not decrease until 70 DAP. The initial storage root dry weight increase coincided with leaf dry weight decrease (Fig. 1). In the second experiment, 'Centennial' and 'Jewel' leaf dry weights continued

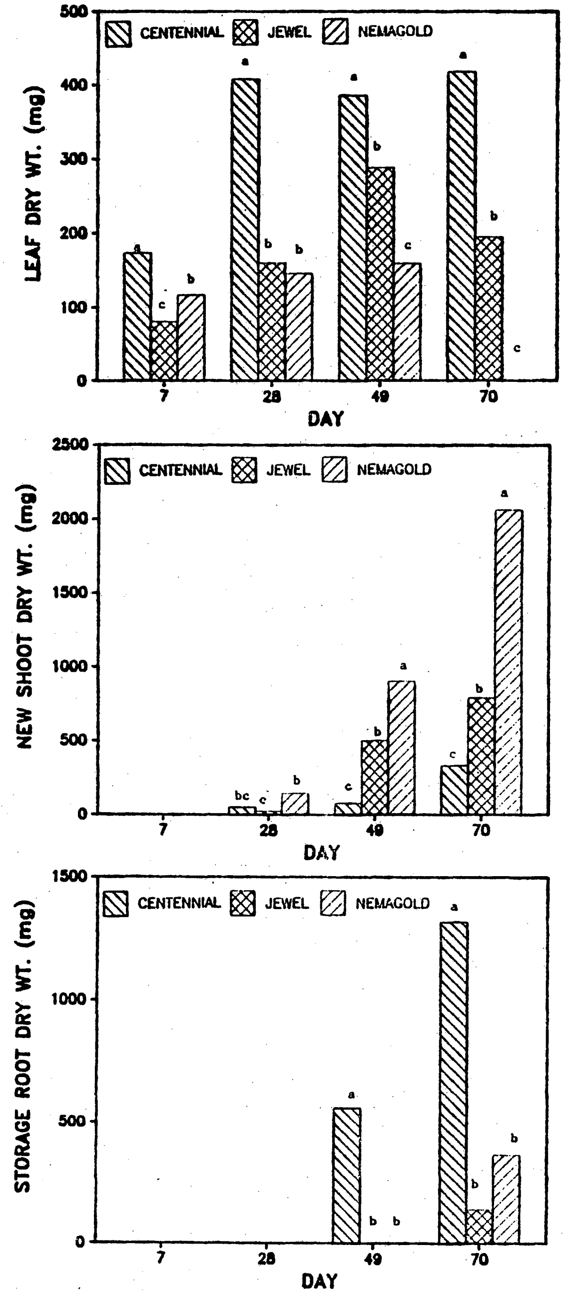

Fig. 1. Effect of cultivar on dry weights of plant organs on four sampling days in the first experiment (Winter, 1986). Statistical significance by two orthogonal comparisons ('Centennial' vs. 'Jewel' and 'Nemagold'; 'Jewel' vs. 'Nemagold'): means with different letters were significantly (5% level) different for the respective comparisons.

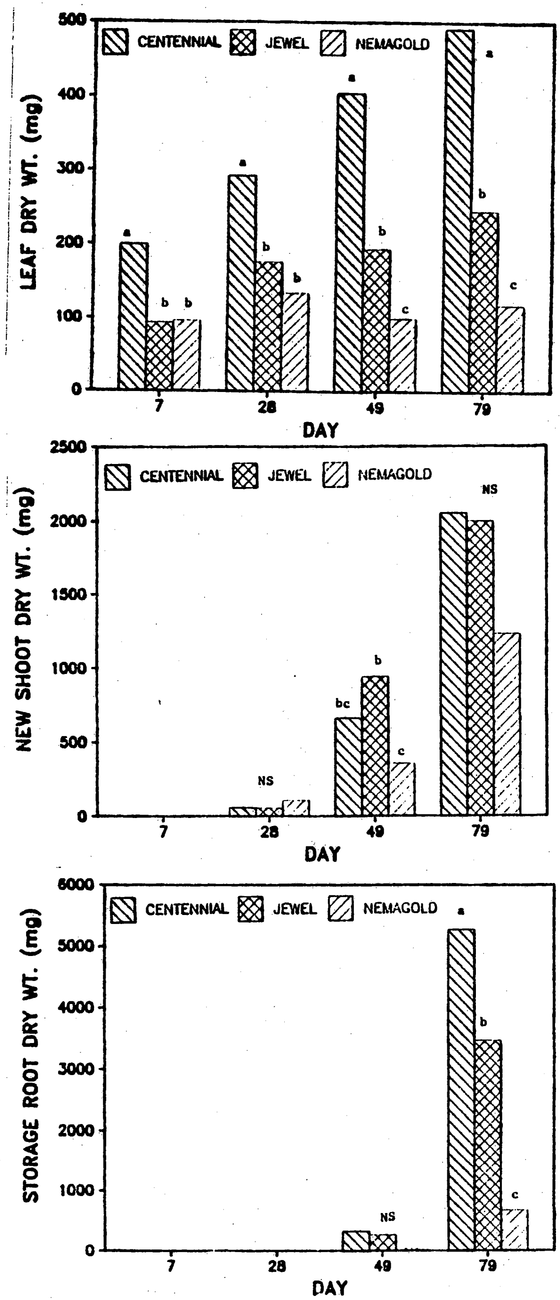

Fig. 2. Effect of cultivar on dry weights of plant organs on four sampling days in the second experiment (Spring, 1986). Statistical significance by two orthogonal comparisons ('Centennial' vs. 'Jewel' and 'Nemagold'; 'Jewel' vs. 'Nemagold'): means with different letters were significantly (5% level) different for the respective comparisons, or non-significant (NS).

to increase up to 79 DAP. 'Nemagold' leaf dry weight decreased at 49 DAP (Fig. 2).

Partitioning of total plant dry weight increase varied among the three cultivars after 28 DAP. In the first experiment, storage root dry weight increase made up the greatest percentage of 'Centennial' total plant weight increase. New shoot dry weight increase made up the greatest percentage of 'Jewel' and 'Nemagold' total plant dry weight increase. In the second experiment, storage root dry weight increase made up the greatest percentage of total plant dry weight increase of both 'Centennial' and 'Jewel' in the last sampling period. The storage root was a much weaker sink in 'Nemagold' (Fig. 3).

The timing of periods when the storage root showed the greatest sink strength versus when the new shoot showed the greatest sink strength also differed among the three cultivars in the two experiments. In the first experiment, the new shoot never became a strong sink in 'Centennial,' but the new shoot did show a greater percentage dry weight increase in 'Centennial' in period 3 than in period 2. This was after the period of greatest 'Centennial' storage root sink strength in period 2. The storage root never became a strong sink in 'Jewel' and 'Nemagold' up to 70

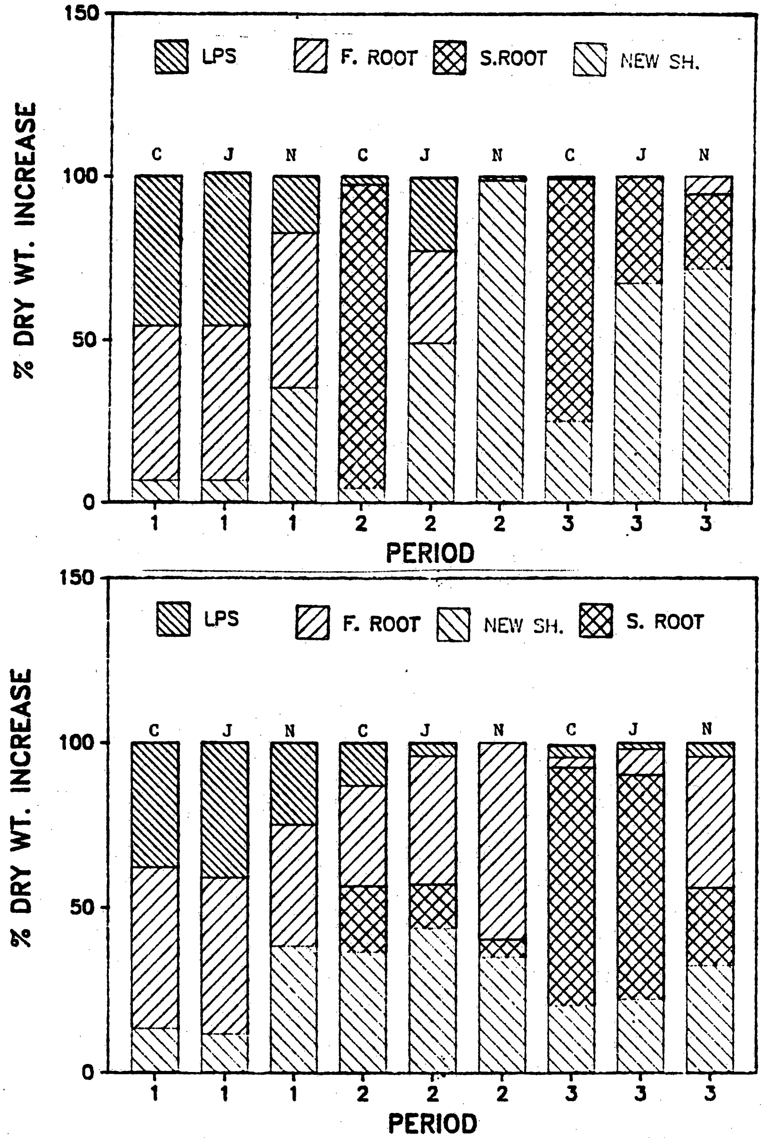

Fig. 3. Effect of cultivar on dry weight increase of plant organs as a percentage of total plant dry weight increase during three time periods in the first (Winter, 1986) and second (Spring, 1986) experiments. Period 1 was 7 to 28 days after planting (DAP), period 2 was 28 to 49 DAP, and period 3 was 49 to 70 (first experiment) or 79 (second experiment) DAP. LPS refers to the combined dry weight increase of leaf, petiole, and stem. F.ROOT refers to fibrous roots, S. ROOT refers to storage roots, and NEW SH. refers to new shoot. C refers to 'Centennial' ; J refers to 'Jewel'; N refers to 'Nemagold.'

DAP. In the second experiment, the period when the storage root was the dominant sink followed the period when the new shoot was the strongest sink in 'Centennial' and 'Jewel.' In 'Nemagold' the storage root never became a strong sink (Fig. 3).

Mean Leaf Position Effects

New shoot and storage root dry weights of the two leaf positions were not significantly different in the first experiment (Fig. 4). In the second experiment, new shoot dry weights were significantly higher in mean leaf position 8 at 28 and 49 DAP, but storage root dry weights were again not significantly different (Fig. 5).

No shift from leaf dry weight increase to decrease was observed in either mean leaf position 2 or 8 in both experiments. Leaf dry weights continued to increase up to the last sampling day. In both mean leaf positions, storage root dry weight was measurable earlier in the second experiment than in the first experiment (Figs. 4 and 5).

Partitioning of total plant dry weight increase was similar for the two mean leaf positions in each period in both experiments. Dominant (or strongest) and strong sinks in the two mean leaf positions showed a similar progress-

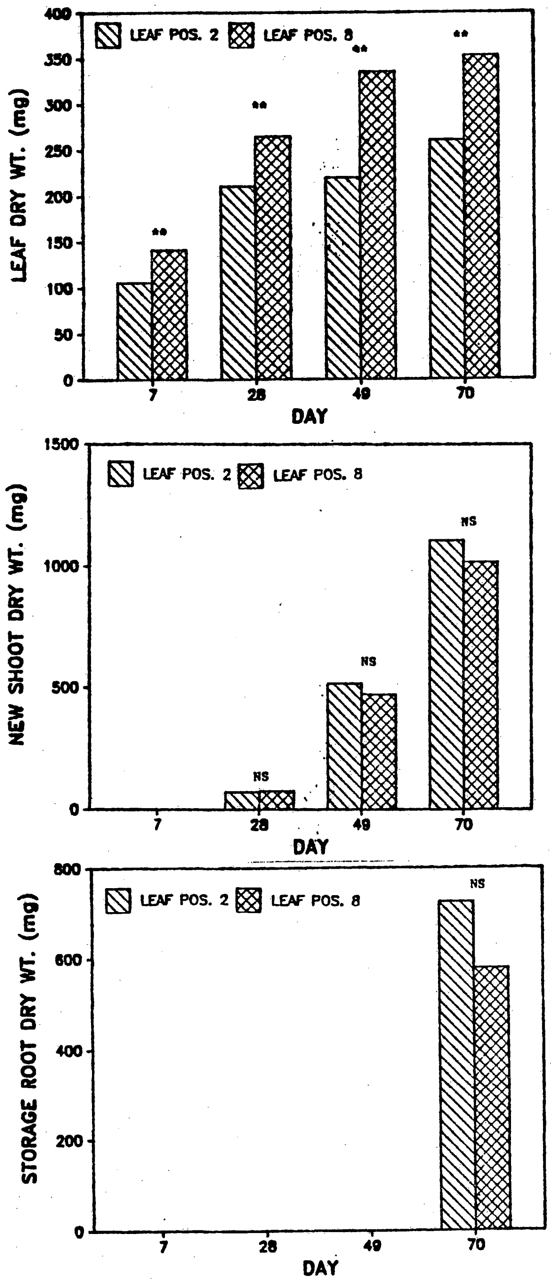

Fig. 4. Effect of mean leaf position on dry weights of plant organs on four sampling days in the first experiment (Winter, 1986). Statistical significance at the 1% (**) level, or non-significant (NS).

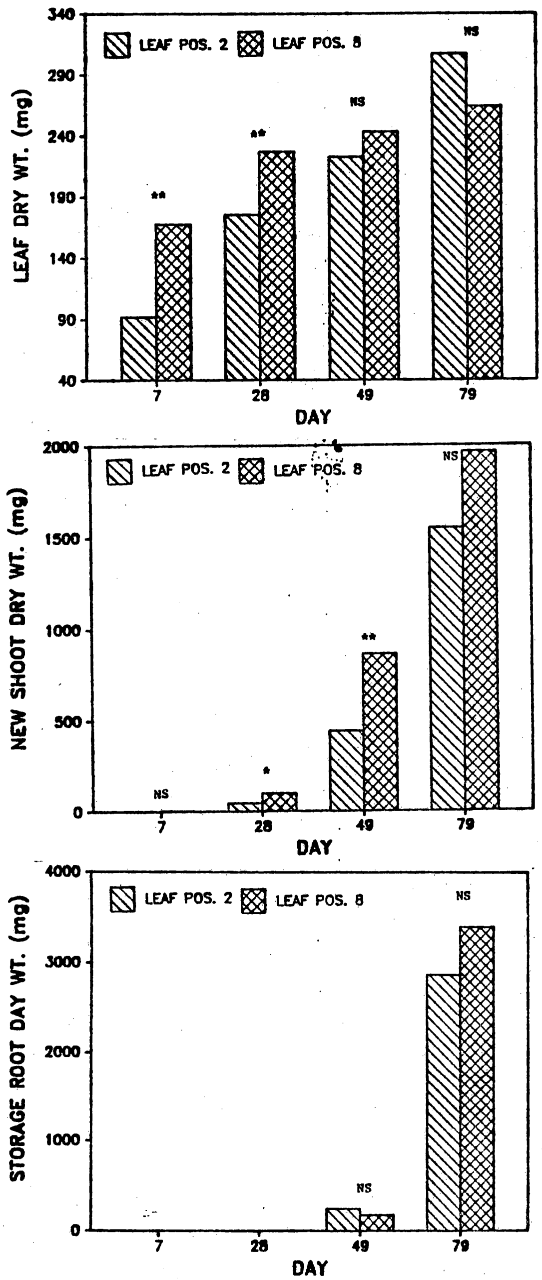

Fig. 5. Effect of mean leaf position on dry weights of plant organs on four sampling days in the second experiment (Spring, 1986). Statistical significance at the 1% (**) or 5% (*) levels, or non-significant (NS).

ion: fibrous root first, then new shoot, and finally storage roots (Fig. 6).

Approximate NAR values were higher in mean leaf position 2 in both experiments, except period 2 in the first experiment. Source potentials, calculated based on the product of source (leaf and new shoot) weight and approximate NAR, were approximately equal between the two leaf positions, except in the last time period. In period 3, approximate NAR values in mean leaf position 2 were more than double those in mean leaf position 8, resulting in greater source potential in mean leaf position 2 (Table 1).

Stem Attachment Effects

The dry weights of the new shoot and storage roots were significantly higher with stem attachment (Fig. 7). The timing of the shift from leaf dry weight increase to decrease differed between plants with and without stem attachment. Leaf dry weight of plants with stem attachment decreased after 49 DAP, while leaf dry weight of plants without stem attachment continued to increase up to 79 DAP (Fig 7).

Partitioning of total plant dry weight increase was different between plants with and without stem attachment

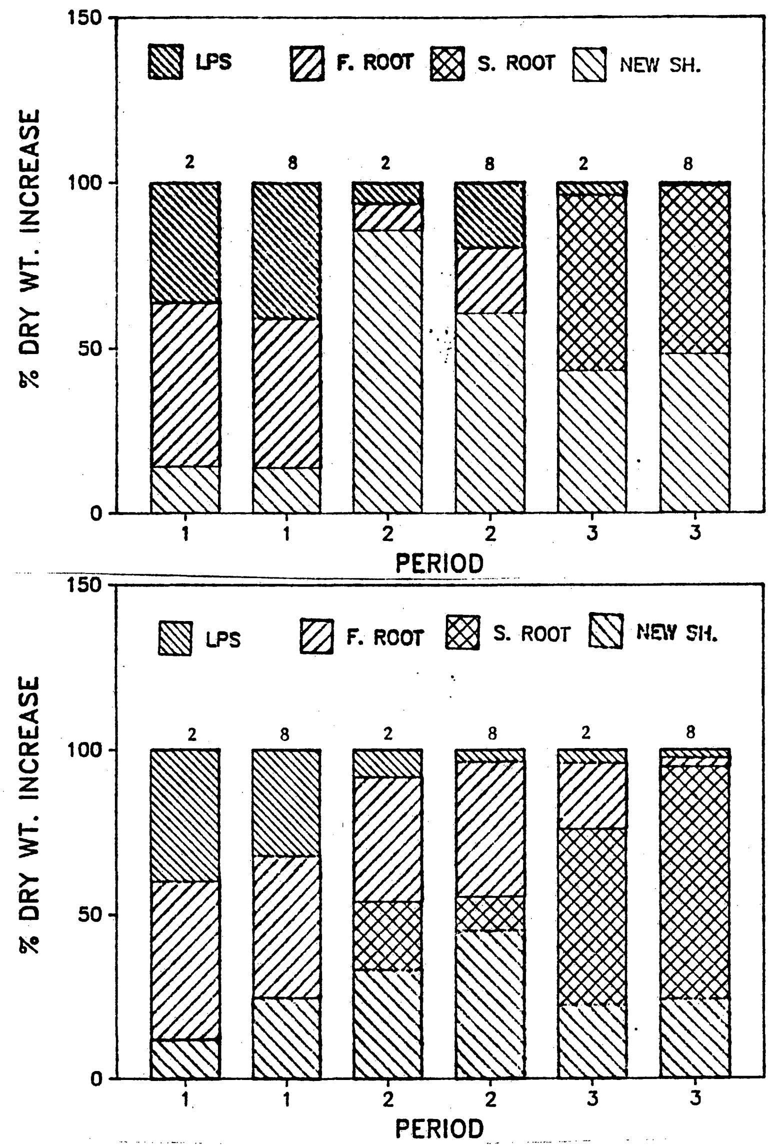

Fig. 6. Effect of mean leaf position on dry weight increase of plant organs as a percentage of total plant dry weight increase during three time periods in the first (Winter, 1986) and second (Spring, 1986) experiments. Period 1 was 7 to 28 days after planting (DAP), period 2 was 28 to 49 DAP, and period 3 was 49 to 70 (first experiment) or 79 (second experiment) DAP. LPS refers to the combined dry weight increase of leaf, petiole, and stem, F.ROOT refers to fibrous root, S. ROOT refers to storage root, and NEW SH. refers to new shoot. 2 refers to mean leaf position 2 and 8 refers to mean leaf position 8.

Table 1. Effect of two mean leaf positions on approximate mean net assimilation rates (NAR) values based on leaf and new shoot dry weights, ratio of approximate NAR values, ratio of source dry weights, and ratio of source potentials, during three time periods in the first (Winter, 1986) and second (Spring, 1986) experiments.

Period[z]	Approximate NAR (total mg· source $mg^{-1}\cdot day^{-1}$) Mean leaf pos. 2	Mean leaf pos. 8	Ratio of approximate NAR values[y]	Ratio of mean source dry weights[x]	Ratio of source potential[w]
		First experiment			
1	0.14	0.11	1.27	0.81	1.03
2	0.08	0.09	0.89	0.92	0.82
3	0.05	0.02	2.50	0.93	2.33
		Second experiment			
1	0.13	0.09	1.44	0.64	0.92
2	0.11	0.08	1.38	0.62	0.86
3	0.08	0.04	2.00	0.76	1.52

[z] Period 1 : 7 to 28 days after planting (DAP);
Period 2 : 28 to 49 DAP;
Period 3 : 49 to 70 (first experiment) or 79 (second experiment) DAP.

[y] Ratio of approximate NAR value for mean leaf position 2 divided by approximate NAR value for mean leaf position 8 in each time period.

[x] Ratio of mean source (leaf and new shoot) dry weight for mean leaf position 2 divided by mean source (leaf and new shoot) dry weight for mean leaf position 8 in each time period.

* Ratio of source potential for mean leaf position 2 divided by source potential for mean leaf position 8, in each time period, where source potential is calculated here as the product of approximate NAR and mean source dry weight.

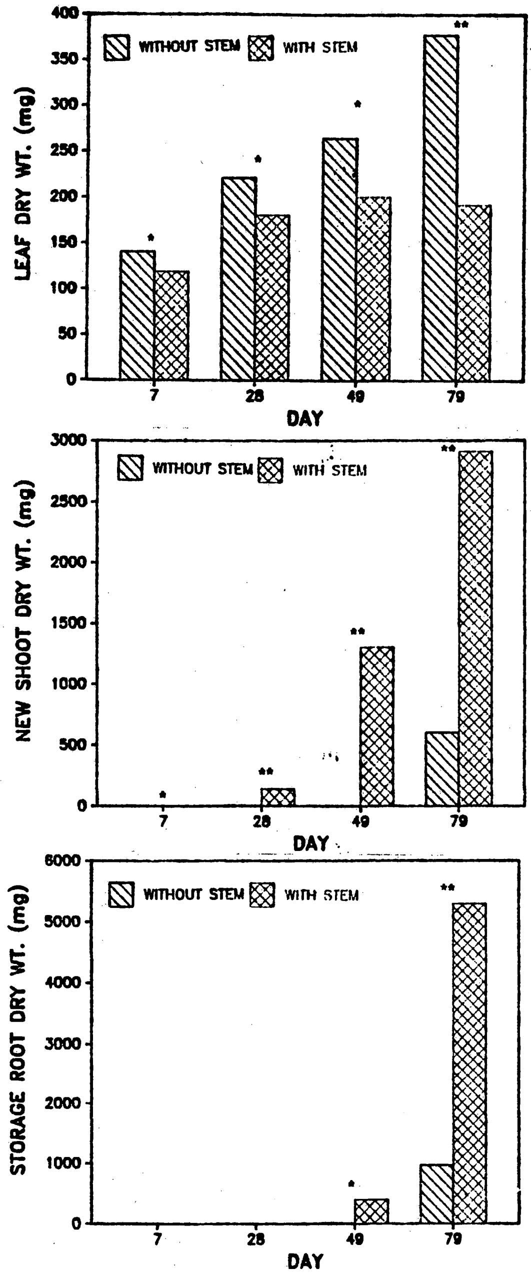

Fig. 7. Effect of stem tissue on dry weights of plant organs on four sampling days in the second experiment (Spring, 1986). Statistical significance at 1% (**) or 5% (**) levels, or non-significant (NS).

before 49 DAP. Original plant materials (leaf and petiole) were the dominant sink in plants without stem attachment in period 1, and then fibrous roots were the dominant sink in period 2. In plants with stem attachment, fibrous roots were the strongest sink in period 1, and then the new shoot became the strongest sink in period 2. The storage root was the dominant or strongest sink in period 3 in both plants with stem attachment and in plants without stem attachment (Fig. 8).

The timing of periods when the storage root showed the greatest sink strength versus when the new shoot showed the greatest sink strength differed between plants with and without stem attachment. In plants with stem attachment, the period when the new shoot became the strongest sink preceded the period when the storage root was the dominant sink. In plants without stem attachment, the new shoot never became a strong sink (Fig. 8).

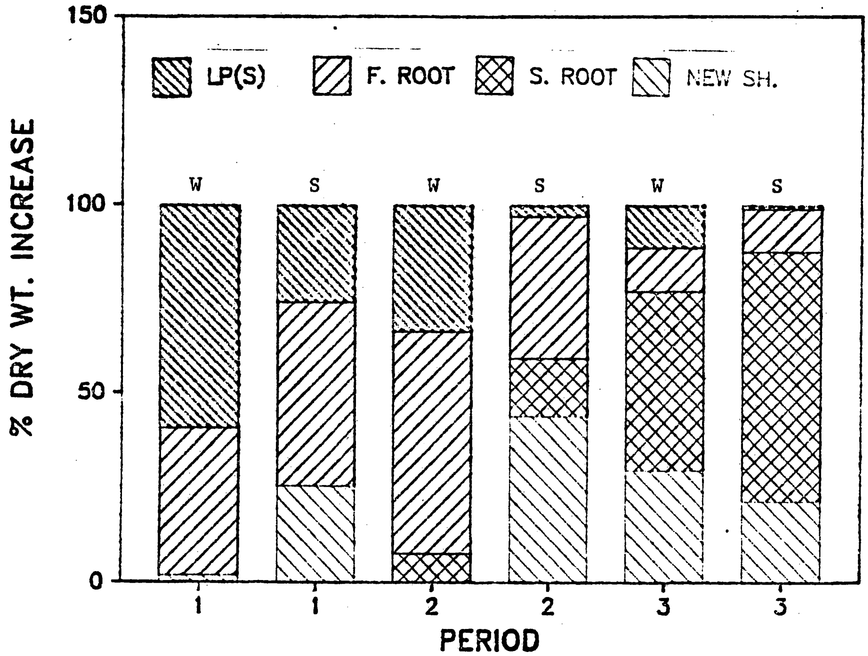

Fig. 8. Effect of stem tissue on dry weight increase of plant organs as a percentage of total plant dry weight increase during three time periods in the second experiment (Spring, 1986). Period 1 was 7 to 28 days after planting (DAP), period 2 was 28 to 49 DAP, and period 3 was 49 to 79 DAP. LP(S) refers to the combined dry weight increase of leaf, petiole, and stem for plants with stem attachment or the combined dry weight increase of leaf and petiole for plants without stem attachment. F. ROOT refers to fibrous roots, S. ROOT refers to storage roots, and NEW SH. refers to new shoot.
W refers to plants without stem attachment and S refers to plants with stem attachment.

DISCUSSION

CULTIVAR EFFECTS

The three cultivars of this study all showed different patterns of partitioning of total plant dry weight increase over the 70 to 79 DAP time period of these two experiments. These patterns also changed from the first to second experiments, done in different seasons. These observations further support Hahn's (1977) statement that the balance between source potential and sink capacity will change with the change in growth stage of plants and in environmental conditions.

The first experiment was done during the winter (January through March), when mean maximum greenhouse ambient air temperatures were 30.5 ± 5.2 °C. In the spring (April through June), when the second experiment was done, maximum greenhouse ambient air temperatures were 33.1 ± 5.5 °C, during the first 35 days (unpublished data). Maximum temperatures increased further in May and June (personal observation; data unavailable after 36 DAP). Mean day length was 3 hours and 30 minutes longer in the second experiment (Woolard and Christie, 1959).

These seasonal differences may explain four key differences in partitioning patterns in the two experiments:

1. The presence in the winter but absence in the spring of a shift from original leaf dry weight increase to decrease in 'Centennial' and 'Jewel.'
2. The change in the timing of when the storage root in 'Centennial' showed greatest sink strength in relation to when the new shoot showed greatest sink strength.
3. The increased sink strength of the storage root in 'Jewel' in the spring compared to the winter.
4. The absence of change in storage root sink strength and the reduction in new shoot sink strength in 'Nemagold' in the spring compared to the winter.

Key difference 1 : changes in original leaf growth pattern

The difference in the growth pattern of the original leaf in 'Centennial' and 'Jewel' may be explained as a change in systems of source and sink in the two experiments. In the first experiment, the decrease in original leaf dry weight coincided with an increase in storage root dry weight. In other studies, similar changes have been observed in the source when the sink begins rapid growth. For example, Leopold and Kriedmann (1975) stated that: "The period of potato tuber growth coincided with a period of no increase in leaf area and even a decrease during later weeks." Likewise, in a study by Austin, Aung, and Graves (1970), when rapid increases in storage root weight occurred, sweet potato above-ground organ weights remained constant or decreased. These observations suggest that the original leaves in the first experiment served as a net exporter when storage root dry weight increase was observed. That is, the original leaf was influenced as a source and senescence was accelerated by the storage root functioning as a dominant or strong sink.

In the second experiment, the original leaf and the new shoot were the source while the storage root was the dominant sink. Storage root dry weight increased rapidly from 49 DAP, but original leaf dry weight also continued to increase concurrently. Larson and Gordon (1969) stated for cottonwood (Populus deltoides) trees that as a leaf at any one position aged, its translocation pattern gradually shifted from upward to bi-directional and finally to a predominantly downward direction. The differences between the two experiments reported here suggest that the photosynthates translocated to the storage root were mainly from the new shoot in the second experiment, and that the new shoot leaves were in a stage of bi-directional transporting. That is, 'Centennial' and 'Jewel' new shoot leaves expanded faster and shifted to export earlier in the second experiment. The faster shift to export enabled new shoot leaves to supply photosynthate for generation of both more new shoot leaves and storage roots.

In general, younger leaves have higher rates of photosynthesis than older leaves (Larson and Gordon, 1969). Hence, the photosynthesizing cells in the new shoot leaves may have produced more assimilates per unit area, resulting in higher solute concentrations in the new shoot leaves than in the original leaf. The pressure flow theory requires that sugar accumulation in the leaf phloem reach a threshold point to produce a pressure gradient for mass flow (Fellows and Geiger, 1974). The new shoot leaves hence may have been able to attain this threshold point faster than the original leaf.

Differences in both temperature and day length may explain why 'Centennial' and 'Jewel' new shoots grew faster and functioned earlier as a source in the second experiment. Higher temperatures accelerate leaf expansion. Leopold and Kriedmann (1975) found that the sooner leaves expand the sooner they became contributing organs. Longer day length in the second experiment also meant that more time was available for photosynthesis.

Key differences 2, 3 and 4 : changes in storage root sink strength

Wilson (1982) observed that sweet potato cultivars have an exceptionally wide range of leaf and storage root morphological characteristics. Cultivar differences in storage root sink strength in the first experiment can be associated with differences in original leaf and petiole size. The changes in storage root sink strength in the second experiment may be explained by cultivar differences in which plant organ responds most to temperature and day length.

'Centennial' and 'Nemagold' represented opposite extremes in leaf area and petiole length at all sampling days in both experiments. 'Centennial' leaf area was 2.6 times that of 'Nemagold,' and petiole length was 1.4 times that of 'Nemagold' at the time of planting in the first experiment (unpublished data). The larger initial photosynthetic area may be the reason why the storage root became the dominant sink earlier in 'Centennial' in the first experiment. That is, 'Centennial' storage root sink strength in the first experiment reflected greater source potential. In contrast, the growth pattern in the winter in 'Nemagold' with lowest leaf area and petiole length was to partition more photosynthate in new shoot generation for building photosynthetic capacity.

In the spring, greater 'Centennial' new shoot growth may be explained as a greater initial response to increased temperature and day length in competition with the storage root. In contrast, 'Nemagold' underground organs (fibrous and storage roots) attracted more photosynthates in the spring, so the new shoot showed less sink strength (Fig. 3). The storage roots appeared earlier but did not show increased sink strength. This suggests that in 'Nemagold' the roots may show greater response to temperature than the new shoot, or that the new shoot may respond negatively to increased day length. It also suggests that the storage root was still limited by small source potential.

'Jewel' original leaf area and petiole length were intermediate, but closer to 'Nemagold' (unpublished data). Like 'Nemagold,' in the winter 'Jewel' partitioned more photosynthate into new shoot generation. In the spring, however, unlike 'Nemagold,' 'Jewel' showed greater new shoot growth. This can be interpreted as a positive response by the new shoot to increased temperature and day length. Also, the storage root actually appeared earlier in the spring, perhaps in response to temperature, and gained in sink strength. Thus, both new shoot and storage root showed a balanced response.

Comparison of cultivar effects in the greenhouse study and the field

The experiments of Austin and Aung (1973) were done in the field. Two cultivars, 'Centennial' and 'Nemagold,' were the same as in this study. Root and total plant dry weights were higher in 'Centennial' than in 'Nemagold' in both years (Figs. 1 and 2 in Austin and Aung, 1973). These results parallel the results obtained in both experiments reported here with single-leaf cuttings in the greenhouse. This supports the idea that the single-leaf system can be used for physiological studies that might be correlated with field results.

MEAN LEAF POSITION EFFECTS

The higher original plant material (leaf, petiole, and stem) dry weights in mean leaf position 8 were in agreement with the larger leaf areas and longer petiole length of the original leaves in mean leaf position 8 at the time of planting (unpublished data). However, mean leaf position 2 showed higher approximate NAR values than mean leaf position 8 in both experiments. Since source potential is the product of photosynthetic rate and leaf area (or leaf weight since leaf area and weight are highly correlated), the resulting source potentials of these two mean leaf positions were similar except in period 3. The similar storage root dry weight in mean leaf positions 2 and 8 can thus be explained by the similar earlier source potentials of the two mean leaf positions.

Mean leaf position 2 showed higher approximate NAR (a measure of photosynthetic efficiency) than mean leaf position 8 in both experiments. Larson and Gordon (1969) used photosynthetic efficiency as an indicator of leaf age. Thus, leaf age may be a better label than leaf position. That is, leaves in mean leaf position 2 might be better referred to as "younger" leaves and leaves in mean leaf position 8 as "older" leaves.

STEM ATTACHMENT EFFECTS

New organs (fibrous roots and new shoot) were generated earlier in plants with stem attachment than in plants without stem attachment. However, stem dry weight did not decrease up to 79 DAP, and stem dry weight was only a small percentage of total plant dry weight at day 7 (unpublished data). Therefore, the faster dry matter increase in new shoot and storage roots in plants with stem attachment cannot be attributed primarily to dry matter transfer from stem tissue.

On the other hand, the original leaf shifted to net export in plants with stem attachment but not in plants without stem attachment (Fig. 7). This suggests that the original leaf in plants with stem attachment may have reached the threshold point for mass flow earlier. This may have been due to a stronger sink "pull" of assimilates by the new shoot. It may also have been due to more efficient translocation in the stem phloem in plants with stem attachment, compared to plants without stem phloem connected to the new shoot or roots. The result was greater source potential, due to rapid new shoot growth, in plants with stem attachment.

CONCLUSIONS

This study showed that different cultivars have different dry weight distribution patterns, and that these patterns may change in different ways in response to environmental conditions. Increased temperature and longer days may have differing effects on source potential and storage root sink strength depending on the cultivar used. Smaller source potential can limit storage root sink strength, and increased source potential in response to temperature and day length can result in delayed increases in storage root sink strength.

For multi-purpose use, the best sweet potato cultivar may be one in which both source potential and storage root sink strength respond positively at the same time to changes in environmental factors such as these. This study suggests that 'Jewel' might best fit these criteria.

In this study, however, the above conclusions are based only on seasonal observations. These conclusions thus suggest several hypotheses about the effects of increased temperature and day length, which could be tested under controlled conditions:

1. 'Centennial' storage root formation is delayed.
2. 'Jewel' storage root formation is accelerated and storage root sink strength increased.
3. 'Nemagold' storage root formation is accelerated but storage root sink strength is not affected.

Such investigations of environmental effects with these and other cultivars using the single-leaf system might ultimately lead to development of a cultivar typology. This typology would classify cultivars based on changes in the timing and magnitude of storage root sink strength as affected by changes in source potential in response to specific environmental factors. These factors might include not only those observed here, temperature and day length, but also other held constant in this study, such as moisture and nutrition. Correlation with field studies would be needed to confirm the usefulness of the typology.

The results of this study also suggest that mean leaf position may be less important than stem attachment in the single-leaf system. This has two possible implications for methods in future experiments using the single-leaf system. First, since mean leaf position did not affect storage root yield up to 79 DAP, all leaf positions up to leaf position 9 may be used. Second, plants with stem attachment showed higher new shoot and storage root production, so the use of stem attachment is recommended for the single-leaf system.

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APPENDIX A

Method of Estimation of Leaf Area

Actual leaf areas were calculated using the formula :

$$\text{Leaf area} = \frac{\text{leaf weight}}{\text{weight of 3 discs}} \times 104\ mm^2 \times 3$$

The most appropriate formula for estimation of the area of irregularly shaped leaves was determined based on stepwise regression (SAS Institute, 1985) of leaf area calculated from the leaf area formulae on the following independent variables: leaf length, (leaf length x leaf width), $(\text{leaf length})^2$, $(\text{leaf width})^2$, and (leaf length + leaf width) (Bernadine and Proctor, 1985; Hughes and Proctor, 1981; Kobayashi and Ueunten, 1984; Manivel and Weaver, 1974).

Using stepwise analysis, the following equations were chosen to estimate leaf areas at 8 and 21 DAP respectively in experiment I:

LFAREA = 4925.69 + 1.64 LFLW - 74.82 (LFL + LFW);

LFAREA = -243.43 + 0.15 LFL2 - 0.51 LFW2;

where LFL = the product of leaf length and width;

LFW = leaf width;

LFAREA = leaf area;

LFL2 = leaf length squared;

LFW2 = leaf width squared;

Coefficients of determination (R^2) were = 0.90 for 8 DAP and 0.81 for 21 DAP. Both were highly significant.

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APPENDIX B

Measurements Taken on Half and Full Leaf Uncovered Treatments

1. Leaf width:
   a. Full leaf uncovered treatments: record 1 value for whole width.
   b. Half leaf covered treatments: record leaf width of covered half and uncovered half separately.
2. Disc dry weights:
   a. Full leaf uncovered treatments: 4 discs total, 2 from each half; record weight of the 4 discs as 1 value.
   b. Half leaf covered treatments: 4 discs total, 2 discs each from the covered and uncovered halves; record weights of the 2 discs from each half separately.
3. Remaining leaf dry weights:
   a. Full leaf uncovered treatments: 1 value.
   b. Half leaf covered treatments: keep covered and uncovered halves separate, and record weights separately for each half.

APPENDIX C

Table 1. Effect of cultivar on dry weights of plant organs on four sampling days in the first experiment (Winter, 1986).

Organ	Cultivar: Centennial	Jewel	Nemagold	Statistical[z] significance
		7 DAP[y]		
Leaf (mg)	173.7	80.4	116.7	**
New shoot (mg)	0.0	0.0	0.0	-
Storage root (mg)	0.0	0.0	0.0	-
		28 DAP		
Leaf (mg)	408.5	159.9	145.6	**
New shoot (mg)	54.6	21.6	145.5	**
Storage root (mg)	0.0	0.0	0.0	-
		49 DAP		
Leaf (mg)	385.9	288.4	158.8	**
New shoot (mg)	81.3	502.7	903.7	**
Storage root (mg)	561.1	0.0	0.0	**
		70 DAP		
Leaf (mg)	418.4	195.3	0.0	**
New shoot (mg)	334.4	791.2	2062.9	**
Storage root (mg)	1318.3	138.3	363.1	**

[z] Statistical significance at the 1% (**) level, non-significant (NS), or not determined (-).

[y] DAP : Days after planting.

Table 2. Effect of cultivar on dry weights of plant organs on four sampling days in the second experiment (Spring, 1986).

Organ	Cultivar: Centennial	Jewel	Nemagold	Statistical[z] significance
		7 DAP[y]		
Leaf (mg)	200.0	93.4	96.4	**
New shoot (mg)	0.5	1.2	4.4	NS
Storage root (mg)	0.0	0.0	0.0	-
		28 DAP		
Leaf (mg)	292.9	176.8	134.2	**
New shoot (mg)	61.3	57.2	106.6	NS
Storage root (mg)	0.0	0.0	0.0	-
		49 DAP		
Leaf (mg)	405.0	194.3	99.8	**
New shoot (mg)	664.9	943.6	356.2	*
Storage root (mg)	330.5	269.5	37.8	NS
		79 DAP		
Leaf (mg)	491.7	246.0	118.4	**
New shoot (mg)	2051.7	1996.0	1230.0	NS
Storage root (mg)	5272.6	3470.5	671.6	**

[z] Statistical significance at the 1% (**) or 5% (*) levels, non-significant (NS), or not determined (-).

[y] DAP : days after planting.

Table 3. Effect of cultivar on dry weight increase of plant organs as a percentage of total plant dry weight increase during three time periods in the first experment (Winter, 1986).

Plant organ	Cultivar: Centennial	Jewel	Nemagold
		Period 1[z]	
Leaf, petiole, and stem (%)	45.69	46.63	17.20
New shoot (%)	6.66	6.75	35.29
Fibrous root (%)	47.64	47.63	47.51
Total plant (%)[y]	100.00	100.00	100.00
		Period 2	
Leaf, petiole, and stem (%)	2.57	22.22	1.20
New shoot (%)	4.43	49.05	98.71
Fibrous root (%)	0.00	28.32	0.10
Storage root (%)	93.00	0.00	0.00
Total plant (%)[y]	100.00	100.00	100.00
		Period 3	
Leaf, petiole, and stem (%)	2.10	0.00	2.66
New shoot (%)	24.52	67.60	70.13
Fibrous root (%)	0.00	0.00	5.24
Storage root (%)	73.38	32.40	21.97
Total plant (%)[y]	100.00	100.00	100.00

[z] Period 1 : 7 to 28 DAP;
Period 2 : 28 to 49 DAP;
Period 3 : 49 to 70 (first experiment) or 79 (second experiment) DAP.

[y] Totals of plant organ percentages may not add to exactly 100% due to rounding.

Table 4. Effect of cultivar on dry weight increase of plant organs as a percentage of total plant dry weight increase during three time periods in the second experment (Spring, 1986).

Plant organ	Cultivar: Centennial	Jewel	Nemagold
		Period 1[z]	
Leaf, petiole, and stem (%)	37.72	40.90	24.73
New shoot (%)	13.39	11.71	38.34
Fibrous root (%)	48.89	47.38	36.93
Total plant (%)[y]	100.00	100.00	100.00
		Period 2	
Leaf, petiole, and stem (%)	12.98	4.01	0.00
New shoot (%)	36.55	43.79	35.06
Fibrous root (%)	30.46	38.88	59.58
Storage root (%)	20.01	13.31	5.31
Total plant (%)[y]	100.00	100.00	100.00
		Period 3	
Leaf, petiole, and stem (%)	3.70	1.87	4.20
New shoot (%)	20.43	22.34	32.48
Fibrous root (%)	3.05	7.85	39.76
Storage root (%)	72.82	67.94	23.56
Total plant (%)[y]	100.00	100.00	100.00

[x] Period 1 : 7 to 28 DAP;
Period 2 : 28 to 49 DAP;
Period 3 : 49 to 70 (first experiment) or 79 (second experiment) DAP.

[y] Totals of plant organ percentages may not add to exactly 100% due to rounding.

Table 5. Effect of mean leaf position on dry weights of plant organs on four sampling days in the first experiment (Winter, 1986).

Organ	Mean leaf position 2	Mean leaf position 8	Statistical[z] significance
	7 DAP[y]		
Leaf (mg)	105.7	141.5	**
New shoot (mg)	0.0	0.0	-
Storage root (mg)	0.0	0.0	-
	28 DAP		
Leaf (mg)	210.6	265.4	**
New shoot (mg)	73.7	77.2	NS
Storage root (mg)	0.0	0.0	-
	49 DAP		
Leaf (mg)	219.8	335.7	**
New shoot (mg)	518.3	473.4	NS
Storage root (mg)	0.0	0.0	-
	70 DAP		
Leaf (mg)	260.7	353.0	**
New shoot (mg)	1108.5	1019.6	NS
Storage root (mg)	726.4	579.5	NS

[z] Statistical significance at the 1% (**) or 5% (*) levels, non-significant (NS), or not determined (-).

[y] DAP : days after planting.

Table 6. Effect of mean leaf position on dry weights of plant organs on four sampling days in the second experiment (Spring, 1986).

Organ	Mean leaf position 2	Mean leaf position 8	Statistical[z] significance
		7 DAP[y]	
Leaf (mg)	91.9	167.9	**
New shoot (mg)	1.1	3.0	NS
Storage root (mg)	0.0	0.0	-
		28 DAP	
Leaf (mg)	175.4	227.2	**
New shoot (mg)	49.3	100.8	*
Storage root (mg)	0.0	0.0	-
		49 DAP	
Leaf (mg)	222.7	243.4	NS
New shoot (mg)	445.1	864.7	**
Storage root (mg)	248.8	176.4	NS
		79 DAP	
Leaf (mg)	306.8	263.9	NS
New shoot (mg)	1552.8	1965.5	NS
Storage root (mg)	2874.1	3402.4	NS

[z] Statistical significance at the 1% (**) or 5% (*) levels, non-significant (NS), or not determined (-).

[y] DAP : days after planting.

Table 7. Effect of mean leaf position on dry weight increase of plant organs as a percentage of total plant dry weight increase during three time periods in the first experiment (Winter, 1986).

Plant Organ	Mean leaf position 2	Mean leaf position 8
	Period 1[z]	
Leaf, petiole, and stem (%)	36.02	40.89
New shoot (%)	14.19	13.74
Fibrous root (%)	49.80	45.37
Total plant (%)[y]	100.00	100.00
	Period 2	
Leaf, petiole, and stem (%)	6.30	19.58
New shoot (%)	85.58	60.65
Fibrous root (%)	8.12	19.78
Total plant (%)[y]	100.00	100.00
	Period 3	
Leaf, petiole, and stem (%)	3.81	0.87
New shoot (%)	43.12	48.10
Fibrous root (%)	0.00	0.00
Storage root (%)	53.07	51.03
Total plant (%)[y]	100.00	100.00

[z] Period 1 : 7 to 28 DAP;
Period 2 : 28 to 49 DAP;
Period 3 : 49 to 70 (first experiment) or 79 (second experiment) DAP.

[y] Totals of plant organ percentages may not add to exactly 100% due to rounding.

Table 8. Effect of mean leaf position on dry weight increase of plant organs as a percentage of total plant dry weight increase during three time periods in the second experiment (Spring, 1986).

Plant Organ	Mean leaf position 2	8
	Period 1[z]	
Leaf, petiole, and stem (%)	39.99	32.14
New shoot (%)	11.96	24.69
Fibrous root (%)	48.05	43.17
Total plant (%)[y]	100.00	100.00
	Period 2	
Leaf, petiole, and stem (%)	8.27	3.56
New shoot (%)	33.18	45.10
Fibrous root (%)	37.70	40.92
Storage root (%)	20.85	10.42
Total plant (%)[y]	100.00	100.00
	Period 3	
Leaf, petiole, and stem (%)	3.94	2.38
New shoot (%)	22.59	24.17
Fibrous root (%)	19.94	2.63
Storage root (%)	53.53	70.83
Total plant (%)[y]	100.00	100.00

[z] Period 1 : 7 to 28 DAP;
Period 2 : 28 to 49 DAP;
Period 3 : 49 to 70 (first experiment) or 79 (second experiment) DAP.

[y] Totals of plant organ percentages may not add to exactly 100% due to rounding.

Table 9. Effect of stem tissue on dry weights of plant organs on four sampling days in the second experiment (Spring, 1986).

Organ	Stem attachment: Without stem	With stem	Statistical[z] significance
	7 DAP[y]		
Leaf (mg)	140.8	119.0	*
New shoot (mg)	0.0	4.1	*
Storage root (mg)	0.0	0.0	-
	28 DAP		
Leaf (mg)	221.3	181.3	*
New shoot (mg)	4.9	145.1	**
Storage root (mg)	0.0	0.0	-
	49 DAP		
Leaf (mg)	264.7	201.4	*
New shoot (mg)	2.4	1307.5	**
Storage root (mg)	18.3	406.9	*
	79 DAP		
Leaf (mg)	378.0	192.7	**
New shoot (mg)	603.9	2914.5	**
Storage root (mg)	971.0	5305.4	**

[z] Statistical significance at the 1% (**) or 5% (*) levels, non-significant (NS), or not determined (-).

[y] DAP : days after planting.

Table 10. Effect of stem tissue on dry weight increase of plant organs as a percentage of total plant dry weight increase during three time periods in the second experiment (Spring, 1986).

Plant organ	Stem tissue: Without stem	Stem tissue: With stem
	Period 1[z]	
Leaf, petiole, and stem (%)	59.16	25.62
New shoot (%)	1.98	25.67
Fibrous root (%)	38.86	48.70
Total plant (%)[y]	100.00	100.00
	Period 2	
Leaf, petiole, and stem (%)	33.39	2.97
New shoot (%)	0.00	43.88
Fibrous root (%)	59.02	37.79
Storage root (%)	7.60	15.36
Total plant (%)[y]	100.00	100.00
	Period 3	
Leaf, petiole, and stem (%)	11.28	0.99
New shoot (%)	29.81	21.60
Fibrous root (%)	11.69	11.58
Storage root (%)	47.21	65.83
Total plant (%)[y]	100.00	100.00

[z] Period 1 : 7 to 28 DAP;
Period 2 : 28 to 49 DAP;
Period 3 : 49 to 70 (first experiment) or 79 (second experiment) DAP.

[y] Totals of plant organ percentages may not add to exactly 100% due to rounding.

APPENDIX D

Table 1. Effect of cultivar on growth parameters at 8 days after planting sweet potato single-leaf cuttings in experiment I.

Growth parameter	Cultivar[z]			Statistical[y] significance		
	Cen	Jew	Nem	CJN[x]	CJ vs N[w]	C vs J[v]
Leaf area (mm^2)	7190	3958	4093	**	+	**
Leaf weight (mg)	246	136	127	**	**	**
Petiole weight (mg)	69	53	31	**	**	NS
Stem weight (mg)	44	51	29	**	**	*
Root weight (mg)	26	11	30	**	*	**
Total weight (mg)	385	252	217	**	**	**

[z] Cen : Centennial; Jew: Jewel; Nem: Nemagold.

[y] Significance at 1% (**), 5% (*), or 10% (+) levels, or non-significant (NS).

[x] Overall comparison with 2 degrees of freedom among cultivars 'Centennial,' 'Jewel,' and 'Nemagold.'

[w] Single degree-of-freedom comparison between cultivars 'Centennial' and 'Jewel' vs 'Nemagold.'

[v] Single degree-of-freedom comparison between cultivars 'Centennial' vs 'Jewel.'

Table 2. Effect of cultivar on growth parameters at 21 days after planting sweet potato single-leaf cuttings in experiment I.

Growth parameter	Cultivar[z]			Statistical significance[y]		
	Cen	Jew	Nem	CJN[x]	CJ vs N[w]	C vs J[v]
Leaf area (mm^2)	7691	5488	4238	**	**	*
Leaf weight (mg)	333	199	172	**	**	**
Petiole weight (mg)	101	106	75	NS	NS	NS
Stem weight (mg)	60	83	46	**	**	**
Root weight (mg)	200	112	99	**	**	**
Total weight (mg)	692	500	392	**	**	**

[z] Cen : Centennial; Jew: Jewel; Nem: Nemagold.

[y] Significance at 1% (**) or 5% (*) levels, or non-significant (NS).

[x] Overall comparison with 2 degrees of freedom among cultivars 'Centennial,' 'Jewel,' and 'Nemagold.'

[w] Single degree-of-freedom comparison between cultivars 'Centennial' and 'Jewel' vs 'Nemagold.'

[v] Single degree-of-freedom comparison between cultivars 'Centennial' vs 'Jewel.'

Table 3. Effect of mean leaf position on growth parameters at 8 days after planting sweet potato single-leaf cuttings in experiment I.

Growth parameter	Mean leaf position[z]			Statistical[y] significance	
	2	5	8	L	Q
Leaf area (mm^2)	2673	5901	6668	**	NS
Leaf weight (mg)	83	198	228	**	+
Petiole weight (mg)	20	60	73	**	NS
Stem weight (mg)	21	46	56	**	**
Root weight (mg)	19	28	21	NS	+
Total weight (mg)	144	332	377	**	*

[z] 2: Leaf position 1 to 3 from the terminal bud;
5: Leaf position 4 to 6 from the terminal bud;
8: Leaf position 7 to 9 from the terminal bud.

[y] L : Linear effect;
Q : Quadratic effect.
**: Significance at 1% level;
* : Significance at 5% level;
+ : Significance at 10% level;
NS: Non-significant.

Table 4. Effect of mean leaf position on growth parameters at 21 days after planting sweet potato single-leaf cuttings in experiment I.

Growth parameter	Mean leaf position[z]			Statistical[y] significance	
	2	5	8	L	Q
Leaf area (mm^2)	4880	6386	6152	NS	NS
Leaf weight (mg)	188	254	262	*	NS
Petiole weight (mg)	80	93	109	NS	NS
Stem weight (mg)	41	69	78	**	NS
Root weight (mg)	132	183	95	+	**
Total weight (mg)	441	600	543	NS	+

[z] 2: Leaf position 1 to 3 from the terminal bud;
5: Leaf position 4 to 6 from the terminal bud;
8: Leaf position 7 to 9 from the terminal bud.

[y] L : Linear effect;
Q : Quadratic effect.
**: Significance at 1% level;
* : Significance at 5% level;
+ : Significance at 10% level;
NS: Non-significant.

Table 5. Effect of cultivar on mean net assimilation and relative growth rates of plant organs between 8 and 21 days after planting sweet potato single-leaf cuttings in experiment I.

		RGR (%)[y]				
Cultivar	NAR[z] ($mg \cdot mm^{-1} \cdot day^{-1}$)	Leaf	Petiole	Stem	Root	Total
Centennial	0.0032	2.31	2.90	2.37	15.63	4.51
Jewel	0.0041	2.93	5.29	3.79	17.58	5.29
Nemagold	0.0032	2.34	6.91	3.61	9.07	4.56

[z] Mean net assimilation rate.

[y] Mean relative growth rate ($mg \cdot mg^{-1} \cdot day^{-1}$).

Table 6. Effect of mean leaf position on mean net assimilation and relative growth rates of plant organs between 8 and 21 days after planting sweet potato single-leaf cuttings in experiment I.

		RGR (%)[x]				
Mean[z] leaf position	NAR[y] ($mg \cdot mm^{-1} \cdot day^{-1}$)	Leaf	Petiole	Stem	Root	Total
2	0.0062	6.28	10.54	5.22	14.80	8.64
5	0.0034	1.93	3.41	3.07	14.40	4.55
8	0.0020	1.05	3.09	2.55	11.80	2.80

[z] 2 : Leaf position 1 to 3 from the terminal bud;
5 : Leaf position 4 to 6 from the terminal bud;
8 : Leaf position 7 to 9 from the terminal bud.

[y] Mean net assimilation rate.

[x] Mean relative growth rate ($mg \cdot mg^{-1} \cdot day^{-1}$).

Table 7. Effects of covering on dry weight of plant organs on four sampling days in the first experiment (Winter, 1986).

Organ	Covering[z] Full	Half	Statistical[y] significance
	7 DAP[x]		
Leaf (mg)	129.7	117.6	NS
Petiole (mg)	41.4	35.5	+
Stem (mg)	37.4	35.6	NS
Fibrous root (mg)	13.9	20.2	NS
Total plant (mg)	222.3	209.0	NS
	28 DAP		
Leaf (mg)	285.4	190.6	**
Petiole (mg)	87.7	60.9	**
Stem (mg)	106.9	82.6	**
New shoot (mg)	75.8	75.0	NS
Fibrous root (mg)	345.6	202.3	**
Total plant (mg)	901.5	611.4	**

Table 7 continued.

	49 DAP		
Leaf (mg)	329.1	226.3	**
Petiole (mg)	111.4	75.8	**
Stem (mg)	131.0	101.0	**
New shoot (mg)	433.4	558.4	NS
Fibrous root (mg)	439.9	279.4	**
Storage root (mg)	505.7	0.0	**
Total plant (mg)	1950.5	1240.8	*
	70 DAP		
Leaf (mg)	347.2	266.5	**
Petiole (mg)	103.2	89.3	NS
Stem (mg)	125.4	105.2	*
New shoot (mg)	1067.8	1060.3	NS
Fibrous root (mg)	325.8	230.8	**
Storage root (mg)	759.2	546.7	+
Total plant (mg)	2728.6	2298.7	NS

[z] Full : full leaf uncovered;
Half : half leaf covered.

[y] Statistical significance at the 1% (**), 5% (*), or 10% (+) levels, or non-significant (NS).

[x] DAP : days after planting.

Table 8. Variation in covered area and percentage of total area covered at constant lengths of covering and at constant numbers of squares uncovered at 7 and 28 days after planting (DAP) in experiment III.

Covering technique[z]	Leaf area covered (mm^2), ±SE[y]		Leaf area uncovered (mm^2)		Percentage covered (%)	
	7 DAP	28 DAP	7 DAP	28 DAP	7 DAP	28 DAP
Half	1039±119	950± 77	1033	1513	50	39
Full	0 -	0 -	2149	2544	0	0
L15	1788±299	1488±141	167	228	91	87
L30	1609±273	1326±222	351	388	82	77
L45	1158±175	1425±375	700	1113	62	56
S4	1604±165	1852±196	400	400	80	82
S8	1338±123	1253±196	800	800	63	61
S12	1179±260	1505±240	1200	1200	50	55

[z] Half: half leaf covered;
Full: full leaf uncovered;
L15: 15 mm from leaf tip left uncovered and rest covered;
L30: 30 mm from leaf tip left uncovered and rest covered;
L45: 45 mm from leaf tip left uncovered and rest covered;
S4 : 4 squares (400 mm^2) left uncovered and the rest of the leaf covered;
S8 : 8 squares (800 mm^2) left uncovered and the rest of the leaf covered;
S12: 12 squares (1200 mm^2) left uncovered and the rest of the leaf covered.

[y] SE : standard error.

Table 9. Effect of covering techniques on mean relative growth rate of each plant organ and mean net assimilation rate in experiment III.

Covering technique[z]	RGR					NAR
	Leaf	Petiole	Stem	Root	Total	($mg \cdot mm^{-2} \cdot day^{-1}$)
Half	0.24	1.00	1.75	10.66	3.64	0.52
Full	1.10	2.50	3.88	14.74	4.88	0.52
L15	-0.82	0.67	1.20	1.79	0.29	0.14
L30	-1.67	0.67	0.58	9.34	1.11	0.36
L45	-1.05	1.04	1.60	10.20	2.42	0.39
S4	-0.53	2.25	1.69	5.47	1.49	0.00
S8	-0.90	0.00	1.98	8.27	2.42	0.00
S12	-0.22	1.04	2.36	9.77	3.09	0.00

[z] Half: half leaf covered;
Full: full leaf uncovered;
L15: 15 mm from leaf tip left uncovered and rest covered;
L30: 30 mm from leaf tip left uncovered and rest covered;
L45: 45 mm from leaf tip left uncovered and rest covered;
S4 : 4 squares (400 mm^2) left uncovered and the rest of the leaf covered;
S8 : 8 squares (800 mm^2) left uncovered and the rest of the leaf covered;
S12: 12 squares (1200 mm^2) left uncovered and the rest of the leaf covered.

[y] Mean relative growth rate ($mg \cdot mg^{-1} \cdot day^{-1}$).

[x] Mean net assimilation rate.

APPENDIX E

Culture of Stock Plants

Sweet potato roots of cultivars 'Centennial,' 'Jewel,' and 'Nemagold' were obtained from the Department of Horticulture North Carolina State University, Raleigh. The roots were planted in steam-sterilized sand in January 1984. The temperature of the sand was maintained at 80°F in a hotbed nursery in greenhouse. Sprouts were pulled from the roots in the nursery and planted in clay pots (13 cm tall x 15 cm diameter) filled with steam-sterilized sand in summer 1985. Half strength nutrient solution (made from soluble 20-20-20 NPK fertilizer) was applied daily. The sprouts were grown to the 9 leaf stage before use. Both primary and secondary shoots were used as cuttings for experiments I, II, III, and IV. After cuttings were taken from stock plants, they were not used again.

APPENDIX F

Calculation of Day Lengths

Day lengths were calculated from times shown in the table of sunrise and sunset at Roanoke, Virginia, in : E. W. Woolard and C. G. Christie 1959. Nautical almanac, Government Printing Office, Washington, D. C. The times shown may be used with any year of the twentieth century. The times shown have a possible error normally less than ± 1 minute and no more than ± 2 minutes at Roanoke, Virginia. There is an additional error of no more than ± 1 minute for each 9 miles from the site of observation at Roanoke, Virginia. Hence, the additional possible error for Blacksburg, Virginia, located approximately 25 miles southwest from Roanoke, Virginia, can be estimated as no more than ± 3 minutes.

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