Sweet Potato Canopy Architecture: Branching Pattern

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Abstract. The effect of the plant density (15, 30, 45 × 96-cm spacing) on the branching pattern 'Jewel' sweet potato [*Ipomoea batatas* (L.) Lam.] was determined bi-weekly for 18 weeks. Plant density effects were significant for the number of branches formed and timing of branch formation. Plant density did not affect the type of branches formed (e.g., primary, secondary, and tertiary), but did alter the timing of induction during the growing season. By the end of the growing period, the ratios for the number of primary to secondary branches were 1.5:1, 1.3:1, and 0.6:1 at the 15-, 30-, and 45-cm spacing, respectively. Few tertiary branches were formed, but were present on some plants at each spacing. Tertiary branches most commonly occurred on plants at the widest spacing. While the number of branches per plant was highly plastic and inversely related to plant density, nodes per branch and internode length were not significantly affected. Average internode length per branch decreased with descending branch hierarchy (i.e., main stem < primary branch < secondary branch). 'Jewel' sweet potato responded to increased space available largely through production of additional branches with the modification of branching pattern increasing as the season progressed.

Sweet potato is an extremely important staple crop worldwide due to its high yield and widespread adaptation (Bouwkamp, 1985; Edmond and Ammerman, 1971; Harlan 1976; Jones, 1970). Among food crops, the sweet potato ranks fifth in both economic importance and contribution to the calorie and protein intake in developing countries, which produce the major portion of this crop (FAO, 1985).

When compared to other food crops, little is known about the morphology of above-ground portion of the sweet potato plant. Most studies have focused on factors affecting storage root yield, morphology, quality, and processing (Bouwkamp, 1985). Little is known about the above-ground structure of the plant and its relationship to yield (Kays, 1985). Existing reports on the canopy of the sweet potato describe genetic variation in individual plant characteristics (e.g., leaf or petiole length) (Yen, 1974) or attributes that are integrated on a unit-land-area basis [e.g., leaf area index (Austin et al., 1970; Kays, 1985)]. Minimal information is available on canopy morphology or the ef-

fects of environmental and production factors on it (Austin et al., 1970). Plant density has a pronounced effect on the growth of the plant (Austin and Aung, 1973); however, its effects on the spatial arrangement of canopy components have not been assessed. Information on canopy development would contribute to the overall understanding of plant growth and possible factors limiting yield. This information could be of value in altering existing cultural practices and in developing new cultivars.

We present in this paper a precise quantitative analysis of the branching pattern of the 'Jewel' sweet potato over time and the effects of plant density on changes in branching.

Materials and Methods

Transplants of 'Jewel' sweet potato were grown on a Cecil sandy clay loam soil at the Univ. of Georgia horticulture farm, located near Watkinsville. Each transplant, with five to eight fully expanded leaves, consisted of a single shoot. The plants were grown according to the normal commercial production practices with regard to the cultivation, fertilization (28N-25P-70K, kg-ha⁻¹), and irrigation (Barker et al., 1986). The soil was plowed, disked, and ridged in rows 30 cm high and 60 cm wide, with 96 cm between rows. Transplants were hand-planted

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on 19 May and grown until 19 Oct. During the early growing season, the plots were hand-weeded twice and irrigated as needed.

Plants were grown in a randomized complete-block design with treatments replicated seven times. Each replication (plot) consisted of three rows 7.3 m long with 0.96 m between rows. Transplants were randomly assigned to the plots and were planted at in-row spacings of 15, 30, or 45 cm. The middle row in each plot was used for data collection and was bordered by two guard rows at the same spacings.

One plant per plot was harvested bi-weekly for 18 weeks, starting on the planting day. Between the first five consecutive harvests, at least 10 plants were skipped on the row. The subsequent harvests were made from individual plots.

The sampled plants were dug and handled carefully to avoid leaf loss or branch breakage. The entangled branches of neighboring plants were separated at harvest. Losses of branches due to harvest were insignificant. The aerial portion of the plant was severed from the roots at the ground line. The position of each canopy part was determined using a successive ranking, i.e., position of each primary branch on the main stem, secondary branch on the primary branch, etc. The branches were sequentially severed from the bearing branch and the location of each branch and leaf was identified by the node rank on each branch. The number of branch types and nodes per branch, and individual internode and branch lengths, were measured on each plant. These measurements were executed sequentially from the base to the apex of the branch. In addition, the two-dimensional orientation of the branches was measured on randomly selected plants 1 week before the final harvest.

The Statistical Analysis System (SAS) program for data manipulation was used to sort the data by harvest date, spacing treatment, replication (single plant), and primary, secondary, and tertiary branch type. A Mean Procedure Analysis (SAS, 1982) was used to compile the mean for each variable. Data were tested by the General Linear Models procedure and regression analysis.

Results and Discussion

The efficiency of plants in fixing carbon is influenced by their rate of development and the morphology of the canopy. Canopy morphology is a function of number, length, and orientation of individual branches, and number, size, and position of individual leaves within the canopy.

Timing of branch formation and branch number. Branching of the sweet potato is known to be cultivar-dependent (Yen, 1974), varying not only in number but also in the distance the branches grow outward from the crown of the plant. Three types of branches—primary, secondary, and tertiary—were produced at different chronological stages of the growth of the plant at all plant densities. The time of initiation of these branches and the rate of branching were modified by the plant density (Fig. 1). The total number of branches per plant was inversely related to plant density. The total number of branches stabilized at 6, 8, and 16 weeks after planting (WAP) and 15-, 30-, and 45-cm spacings, respectively. Fewer branches were produced by plants grown at 15- and 30-cm spacings than at 45 cm (Fig. 1A). This relationship indicates that branch formation in the sweet potato plant is highly plastic, responding to space available during the growing season.

The initial period of primary branch formation was between the 2nd and the 4th WAP, regardless of spacing. By the 6th week, however, plant density induced changes in the rate of branch formation (Fig. 1A). The number of primary branches

Fig. 1. Effect of plant population (15, 30, 45 $\times$ 96 cm) on: (A) Total number of branches per plant [15 cm, $0.30 + 1.25X - 0.12X^2 + 0.004X^3$ ($R^2 = 0.97$); 30 cm, $0.12 + 1.08X - 0.02X^2 - 0.0002X^3$ ($R^2 = 0.97$); 45 cm, $0.51 - 0.40X + 0.44X^2 - 0.02X^3$ ($R^2 = 0.99$)]; (B) total number of primary branches per plant [15 cm, $-3.71 + 2.33X - 0.20X^2 + 0.01X^3$ ($R^2 = 0.94$); 30 cm, $-10.97 + 4.79X - 0.41X^2 + 0.01X^3$ ($R^2 = 0.92$); 45 cm, $-8.04 + 3.97X - 0.31X^2 + 0.01X^3$ ($R^2 = 0.94$)]; (C) total number of secondary branches per plant [15 cm, $92.91 - 21.19X^2 + 1.56X^2 - 0.04X^3$ ($R^2 = 1.00$); 30 cm, $-10.92 + 3.03X - 0.24X^2 + 0.01X^3$ ($R^2 = 0.96$); 45 cm, $-54.73 + 14.24X - 0.94X^2 + 0.02X^3$ ($R^2 = 0.96$); 45 cm, $-54.73 + 14.24X - 0.94X^2 + 0.02X^3$ ($R^2 = 0.99$)] at 2-week intervals throughout the growing season.

was inversely related to plant density, with the higher densities plateauing earlier in the growing season (i.e., 6 to 8 weeks) (Fig. 1B). At the lowest density, primary branches continued to be produced throughout the season. By separating the total number of branches into primary, secondary, and tertiary branches, a better understanding of the effect of plant density could be obtained.

Major increases in branch number in the latter half of the growing season were due primarily to the formation of the sec-

Fig. 2. Effect of plant population (15, 30, 45 $\times$ 96 cm) on the length of: (A) total branches per plant [15 cm, $28.65 - 31.19X + 6.75X^2 - 0.11X^3$ ($R^2 = 0.99$); 30 cm, $6.68 - 16.09X + 6.67X^2 - 0.09X^3$ ($R^2 = 0.99$); 45 cm, $85.84 - 119.45X + 22.15X^2 - 0.19X^3$ ($R^2 = 0.99$)]; (B) total primary branches per plant [15 cm, $38.79 - 32.42X + 6.66X^2 - 0.17X^3$ ($R^2 = 0.99$); 30 cm, $-84.48 + 6.30X + 3.77X^2 - 0.05X^3$ ($R^2 = 0.99$); 45 cm, $454.91 - 209.63X + 28.24X^2 - 0.69X^3$ ($R^2 = 0.99$)]; (C) total secondary branches per plant [15 cm, $4822 - 1044X + 74.41X^2 - 1.69X^3$ ($R^2 = 1.00$); 30 cm, $2526 - 631X + 50.88X^2 - 1.26X^3$ ($R^2 = 0.99$); 45 cm, $5131 - 1132X + 83.68X^2 - 1.70X^3$ ($R^2 = 0.99$)]; (D) the mean stem $^2[14.75 - 5.79X + 1.37X^2 - 0.03X^3$ ($R^2 = 0.97$)], (E) individual primary branches per plant $^2[-6.67 - 2.31X + 1.22X^2 - 0.04X^3$ ($R^2 = 0.97$)], and (F) individual secondary branches per plant $^2[328 - 71.16X + 5.29X^2 - 0.12X^3$ ($R^2 = 0.78$)] at 2-week intervals throughout the growing season.

²Pooled equation for all spacings.

ondary branches (Fig. 1C). While secondary branches were typically found on all plants, the number of branches formed, rate of formation, and timing of the onset of formation were affected by plant density. The lower the plant density, the earlier secondary branches were formed, the greater their rate of formation and final number by the end of the growing season. Major increases in branch growth after mid-season (i.e., 8 to 10 weeks) at the lowest plant density were due to the growth of secondary branches. By the end of the growing period, the ratios for the number of primary to secondary branches were 1.5:1, 1.3:1, and 0.6:1 at 15-, 30-, and 45-cm spacings, respectively. After 12 weeks, no additional secondary branches were formed; however, a few tertiary branches had begun to develop on some plants at each spacing (data not shown).

Node number. The number of nodes per plant increased as the season progressed at a rate that varied with plant density (Fig. 2A). Differences due to plant spacings increased signifi-

cantly from 8 to 18 WAP, when the growth of the plants at the lowest density increased relatively to plants grown at 30- and 15-cm spacings.

While the number of nodes on primary branches continued to increase throughout the growing period, the plants at closer spacings (15 and 30 cm) had fewer nodes on primary and secondary branches than at the widest spacing (Fig. 2 B and C). The primary branches accounted for about two-thirds of the total number of nodes per plant grown at closer spacings (15 and 30 cm), but only one-half of the total number of nodes per plant grown at the 45-cm spacing. Plant densities had no significant effect on the number of nodes per main stem and individual primary branches at any harvest date (Fig. 2 D and E). Although the ratios for total number of nodes on primary to that on secondary branches depended on the plant density, fewer nodes were formed per individual secondary than primary branches during the season (Fig. 2 E and F).

Branch orientation. The combined effects of differences in the number and types of branches produced and the length of these branches at varying plant populations resulted in plants with distinctly different branching patterns and orientations (Fig. 3). The density of branches was inversely related to plant density. The lowest plant density (45 cm) produced a large number of branches, some of which extended outward from the plant crossing as many as two adjacent rows (i.e. $\approx$ 2m). This was sharply contrasted by plants at the closest spacing. Here, very few branches were formed, and they seldom extended for more than one row from the base of the plant.

Although not quantified, the branches typically extended out-

Fig. 3. Branching and branching pattern of representative sweet potato plants at three different plant populations (15, 30, 45 $\times$ 96 cm) 17 weeks after planting.

ward from the row, rather than down the row in which they originated (Fig. 3). Most branches grew more or less straight in keeping with their initial orientation outward from the plant, seldom displaying a greater deviation than 90° from their initial direction. This may have been due to the slope of the sides of the beds initially influencing the orientation of the main stem and/or a perpendicular orientation from the row was stimulated by areas of maximum sunlight availability.

Branch length. The branches elongated progressively throughout season (Fig. 4A). Differences in total length of primary and secondary branches due to plant densities increased from 8 to 18 WAP, when the growth of the plants at the widest spacing increased relatively to plants grown at closer spacings (Fig. 4 B and C). Secondary branches accounted for one-third and slightly more than one-half of the total length of branches per plant grown at 15- and 30-cm, and 45-cm, spacings, respectively. In contrast, plant densities had no significant effect on the average length of main stem, and individual primary and secondary branches, or main stem (Fig. 4 D-F).

Internode length. During the first 4 WAP, the mean internode length at all spacings decreased during the period when the plants were recovering from transplanting and producing shorter internodes (Fig. 5A). Subsequently, the internode length increased steadily until 16 WAP at all plant densities. Thereafter, the average internode length declined slightly, possibly due to cooler temperatures and lower growth rates in early fall. Similar trends were found for the length of internodes on main stems (Fig. 5B). Although some positive trends occurred toward the end of the season, plant density had very little effect on the length of internodes on primary branches (Fig. 5C). However, the internode length on secondary branches was inversely related to plant density during the period between 14 and 16 WAP (Fig. 5D).

Plant density significantly modified the branching system of the sweet potato; this effect increased as the growing season progressed. The effect of plant density was more pronounced on the number of branches formed and their number of nodes than on internode and branch length.

One can infer that differences in sweet potato branch growth varied with the intensity of competition for light, moisture, nutrients, etc. Based on the continuous production of branches and nodes (Figs. 1 and 2) and a progressive increase in branch length (Fig. 4), 'Jewel' sweet potato can be characterized as having an indeterminate growth habit if the essential requisites for growth are adequate. The growth rate of each type of branch was not fixed during the growing season and was higher at the wider plant density (45 cm) than at the closer plant densities (15 and 30 cm). The average number of nodes per individual primary branches was $\approx$ 30 and 39 for the highest (15 cm) and the lower plant densities (30 and 45 cm), respectively (Fig. 2E); the maximum average total branch length per plant at 18 WAP varied between 10 and 40 m, depending on plant density (Fig. 4A). Internode length seldom exceeded 4 cm, regardless of the plant spacing during the growing period (Fig. 5).

In the earlier stages of development, internode length and branch length were relatively short at all plant densities. As the branches began to develop, the internode length increased substantially until the latter half of the growing season, when plant growth rate declined.

Canopy morphology of 'Jewel' sweet potato was significantly influenced by the number, length, and orientation of individual branches. These canopy components depended on the plant density and the growth stage of the plant. Based on the extended

Fig. 4. Effect of plant population (15, 30, 45 $\times$ 96 cm) on the number of: (A) total nodes per plant [15 cm, $5.68 - 2.07X + 1.53X^2 - 0.03X^3$ ($R^2 = 0.99$); 30 cm, $-2.99 + 3.52X + 1.50X^2 - 0.04X^3$ ($R^2 = 0.99$); 45 cm, $21.89 - 35.21X + 8.72X^2 - 0.22X^3$ ($R^2 = 0.99$)]; (B) total nodes on primary branches per plant [15 cm, $2.59 - 5.17X + 1.91X^2 - 0.06X^3$ ($R^2 = 0.99$); 30 cm, $-86.20 + 25.59X - 0.94X^2 + 0.02X^3$ ($R^2 = 0.99$); 45 cm, $27.75 - 23.33X + 5.34X^2 - 0.16X^3$ ($R^2 = 0.99$)]; (C) total nodes on secondary branches per plant [15 cm, $65.14 - 12.18X + 0.46X^2 + 0.01X^3$ ($R^2 = 1.00$); 30 cm, $-217 + 52.60X - 4.10X^2 + 0.11X^3$ ($R^2 = 0.94$); 45 cm, $1038 - 220X + 16.77X^2 - 0.36X^3$ ($R^2 = 0.99$)]; (D) nodes on the main stem per plant $^2[5.66 + 0.15X + 0.30X^2 - 0.01X^3$ ($R^2 = 0.96$)]]; (E) nodes per individual primary branches per plant $^2[-10.89 + 3.58X - 0.04X^2 - 0.001X^3$ ($R^2 = 0.96$)]]; and (F) nodes per individual secondary branches per plant $^2[19.61 - 0.28X^2 - 0.20X^3$ ($R^2 = 0.69$)] at 2-week intervals throughout the growing season.

²Pooled equation for all spacings.

production of branches and nodes and a progressive increase in branch length, the canopy of 'Jewel' grew relatively continuously throughout the season. We did not find a distinctive decline in canopy growth that could be construed as a shift between vegetative and reproductive growth. This does not, however, preclude the occurrence of a shift in photosynthate allocation pattern under other conditions.

While a small degree of variation in absolute number for individual characteristics will no doubt occur between locations and years, these typically will be relatively minor under similar production conditions when contrasted to the effect of plant density. In a limited test of the effect of year, we measured selected canopy characters on 'Jewel' plants grown at a 30 $\times$

96-cm spacing in 1987 and found relatively minor variation around the means at corresponding harvest dates. Based on previous work, other factors such as cultivar and production practices (e.g., fertilizer and irrigation levels) should have a much more pronounced effect on canopy morphology.

Understanding the morphology of the canopy and allocation patterns of carbon within the sweet potato is an essential requisite for ascertaining plant characteristics essential for the selection of new higher-yielding cultivars. An ideal sweet potato may be one that allocates a major portion of its photosynthate into the production of the leaves and branches early in the season and little thereafter, thus minimizing losses due to the shedding of excess leaves.

Fig. 5. Effect of plant population (15, 30, 45 × 96 cm) on the average length of: (A) internode per plant $^2[2.25 - 0.45X + 0.07X^2 - 0.002X^3]$ ($R^2 = 0.95$); (B) internode on the main stem per plant $^2[2.37 - 0.51X + 0.07X^2 - 0.002X^3]$ ($R^2 = 0.93$); (C) internode on primary branches per plant $^2[-2.18 + 0.87X - 0.04X^2 + 0.001X^3]$ ($R^2 = 0.97$); and (D) internode length on secondary branches per plant $^2[71.80 - 16.16X + 1.24X^2 - 0.04X^3]$ ($R^2 = 0.85$) at 2-week intervals throughout the growing season.

²Pooled equation for all spacings

Literature Cited

- Austin, M. E., L.H. Aung, and B. Graves. 1970. Some observations on the growth and development of sweet potato (*Ipomoea batatas*). J. Hort. Sci. 45:257-264.
- Austin, M.E. and L.H. Aung. 1973. Patterns of dry matter distribution during development of sweet potato (*Ipomoea batatas*) J. Hort. Sci. 48:11-17.
- Baker, J. M., P. Colditz, and W. J. McLaurin. 1986. Commercial sweet potato production. Univ. of Georgia Coop. Ext. Circ. 677.
- Bouwkamp, J.C. (ed.). 1985. Sweet potato products: A natural resource for the tropics, CRC Press, Boca Raton, Fla.
- Edmond, J.B. and G.R. Ammerman. 1971. Sweet potatoes: Production, processing and marketing. AVI, Westport, Conn.
- FAO. 1985. FAO production yearbook. vol. 38. Food and Agr. Org., Rome.
- Harlan, J.R. 1976. The plants and animals that nourish man. Scientific Amer. 235:89-97.
- Jones, A. 1970. The sweet potato: today and tomorrow. Proc. Food Intl. Symp. Trop. Root and Tuber Crops 1:3-6.
- Kays, S.J. 1985. The physiology of yield in the sweet potato, p. 79-132. In: J.C. Bouwkamp (ed.). Sweet potato products: A natural resource for the tropics. CRC Press, Boca Raton, Fla.
- SAS Institute. 1982. SAS user's guide: Basics. SAS Institute, Inc. Cary, N.C.
- Yen, D.E. 1974. The sweet potato and Oceania. Bishop Museum Press, Honolulu.