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Nitrogen, Shading Duration, Gas Exchange, and Growth of Cassava

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Abstract. The effects of applied N and shading duration on net gas exchange and growth of two southern Florida cassava (*Manihot esculenta* Crantz.) cultivars grown in containers were determined. Both cultivars responded similarly to shading and N with respect to the measured variables. There were no interactions between shading duration and N application rate for any of the variables measured. Tissue dry weights, total leaf N and chlorophyll concentrations, net CO₂ assimilation (A), transpiration (E), water-use efficiency (WUE), and stomatal conductance (g_s) were quadratically related to the concentration of N applied to the soil. The optimum N application rate for maximum growth of both cultivars was 60 mg/plant per day. Increased shading duration reduced A, E, g_s, WUE, storage root number, and weight and increased the shoot : root ratio.

Cassava is traditionally cultivated in association with other crops in many developing countries (Okigbo and Greenland, 1976). Reduced light interception by cassava when associated with over-story crops can depress yield (IITA, 1981). Bhagsari and Harmon (1982) suggested that crop yield is largely determined by net photosynthetic potential and partitioning of photosynthates to the harvested portion of the plant. Some studies have suggested that the effect of reduced solar input on cassava depends on the plant's growth stage (Fukai et al., 1984).

Nitrogen utilization is conditioned by the light environment in which plants develop. Evans (1989) observed that species that flourish in the shade have lower net CO₂ assimilation (A) per unit of N. Leaf N has been positively correlated with A (Evans, 1989; Sage and Percy, 1987). Excess N accumulates as proteins and nitrates in some

species and accounts for excess top growth at the expense of root growth. In cassava, excess N results in accumulation of cyanogenic glucoside (Bruijn, 1971).

Shading duration may affect the photosynthetic efficiency, growth, and yield of cassava, as well as N utilization. Therefore, determining the optimum N application rate for cassava grown with various shading durations may assist in designing intercropping systems that efficiently use this crop. The purpose of this study was to determine the effects of N application rate and shading duration on leaf gas exchange and growth of cassava.

Cuttings (25 cm in length) of 'Manti-queira' cassava, a profusely branching cultivar, and 'Senorita', a cultivar with an upright growth habit and little branching, were planted in 1 sand : 1 vermiculite (v/v) in 7.6-liter plastic pots. The experiments were conducted in Homestead, Fla., from Feb. to Aug. 1989.

Nitrogen application (Expt. 1). This experiment was designed to determine the optimum N application rate for A and growth. Plants were divided into four N treatments: 0, 60, 120, or 180 mg of NH₄NO₃/plant per day applied to the soil. This corresponded to

a total of ≈0, 50, 100, and 150 kg N/ha available to the plant during the growth period. Plants were fertilized twice weekly with the appropriate amount of N, along with an N-free nutrient solution previously described by O'Hair (1979). The experimental design was a randomized complete block with four replications and three single-plant samples per replication per cultivar.

Nitrogen and shading (Expt. 2). This experiment was designed to test the effects of N and shading duration on gas exchange and growth of cassava. Four 6.1 × 1.5 × 1.5-m metal frames were constructed and covered with woven polyethylene cloth, blocking 30% of the incoming radiation [maximum photosynthetic photon flux (PPF) 1300 μmol·m⁻²·s⁻¹, as determined with a 190SA quantum sensor (LI-COR, Lincoln, Neb.)]. Plants were arranged in a split plot design, with shading duration as the main plot and N application rate and cultivar as subplots. The treatments were the same as in Expt. 1 with the addition of shading. The four shading durations were 0, 1, 2, and 3 months beginning at time of planting. At the end of

Table 1. Effect of N application on number of storage roots per plant and root dry weight of cassava 90 DAP (Expt. 2).

Nitrogen (mg/plant per day)	Roots (no.)	Root wt (g)
0	0.1	0.5
60	4.4	55.4
120	4.8	50.2
180	2.9	24.3
Contrast		
Linear	NS	NS
Quadratic	**	**

**, NS Significant at $P < 0.01$ or nonsignificant, respectively, according to orthogonal contrast analysis.

Table 2. Effect of shading duration on number of storage roots per plant, root dry weight, and shoot : root ratio (dry-weight basis) 90 DAP (Expt. 2).

Shading duration (days)	Roots (no.)	Root wt (g)	Shoot : root ratio*
0	4.5	56.5	1.42
30	3.3	33.2	1.90
60	2.5	24.8	2.10
90	1.8	14.3	2.81
Contrast			
Linear	*	*	**
Quadratic	NS	NS	NS

*Shoot : root ratio calculated as shoot dry weight/total root dry weight.

*, **, NS Significant at $P < 0.05$ or 0.01 or nonsignificant, respectively, according to orthogonal contrast analysis.

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Fig. 1. Dry weights of cassava as affected by N application rate (a) 90 DAP and (b) 90 or 120 DAP (Expt. 1). Symbols represent means of eight plants. All variables showed significant quadratic responses according to orthogonal contrast analyses ($P < 0.01$). The regression equations are: (a) leaf dry weight, $y = 4.36 + 0.64x - 0.003x^2$, $R^2 = 0.88$; petiole dry weight, $y = 2.52 + 0.13x - 0.001x^2$, $R^2 = 0.85$; stem dry weight, $y = 5.94 + 0.63x - 0.003x^2$, $R^2 = 0.78$; root dry weight, $y = 2.95 + 0.47x - 0.002x^2$, $R^2 = 0.35$; (b) plant dry weight 90 DAP, $y = 16.36 + 1.9x - 0.01x^2$, $R^2 = 0.76$; plant dry weight 120 DAP, $y = 25.5 + 4.5x - 0.02x^2$, $R^2 = 0.86$.

Fig. 2. Effect of N application rate on (a) net CO₂ assimilation (A) and (b) water-use efficiency (WUE). Symbols represent means of eight plants 90 DAP (Expt. 2). The variables showed significant quadratic responses according to orthogonal contrast analysis ($P < 0.01$).

each shading period, plants were transferred to full sun. There were four, two-plant rep-

lications per treatment for each of the two cultivars. All plants were irrigated at ≈ 3 -day

intervals to maintain soil near container capacity.

In Expt. 1, four single-plant replications per cultivar were randomly selected from each treatment 90 and 120 days after planting (DAP), and leaf laminae, petioles, stems, and roots were harvested separately, dried at 70°C, and the dry weight of each tissue was determined. Tissue dry weights were determined only 90 DAP in Expt. 2. Portions of roots >0.5 cm in diameter were considered to be storage roots (Mahon et al., 1976). Leaf chlorophyll concentrations were determined as described by Marini and Marini (1983). Total leaf N concentration was determined colorimetrically as described by Wolf (1982).

Net CO₂ assimilation, stomatal conductance for CO₂ (g_s), transpiration (E), and water-use efficiency (WUE) were determined for the first fully expanded leaf below the apex of one plant per replication 90 DAP with a portable CO₂ analyzer (Analytical Development Co., Hoddeson, Herts., England) as described by Schaffer and O'Hair (1987). All gas exchange determinations were determined at PPF > 1000 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ using solar radiation as the light source after plants were allowed to equilibrate at that light level for 10 min. Data were analyzed by analysis of variance, single degree-of-freedom orthogonal contrasts, and regression analyses of nontransformed data.

There were no significant interactions between cultivar and N application rate for any of the variables measured in either experiment ($P < 0.05$). Dry weights of all plant tissues 90 DAP responded quadratically to N application rate, with the greatest biomass in the stem, followed by leaf lamina, root, and petiole for plants receiving 0 and 60 mg N/plant per day in Expt. 1 (Fig. 1a). Plants that received 120 or 180 mg N had greater dry weights in the leaf laminae than in the stem. This could be exploited in areas where cassava is grown principally for its high-protein leaves (Eggum, 1970). Total plant dry weight at 90 DAP was greatest for plants in the 60 and 120 mg N/plant per day treatments, respectively, in Expt. 1 (Fig. 1b) and 138 and 129 g/plant, respectively, in Expt. 2 (data not shown). Less biomass accumulation at 90 DAP was observed for plants in the 0 and 180 mg N/plant per day treatments, with 11.8 and 57.7 g, respectively, in Expt. 1 (Fig. 1b) and 14.5 and 98.4 g/plant, respectively, in Expt. 2 (data not shown).

Net CO₂ assimilation and WUE responded quadratically to the amount of N applied in Expt. 1, with the highest values for plants in the 60 and 120 mg N/plant per day treatments (data not shown). Similar responses were observed in Expt. 2 (Fig. 2). In Expt. 1, A ranged from 6.5 for plants receiving 0 mg N to 14.9 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ for plants receiving 60 mg N/plant per day (data not shown); a similar trend was observed in Expt. 2 (Fig. 2a).

Leaf N concentration was quadratically

Fig. 3. Effect of N application rate on leaf (a) N and (b) chlorophyll concentration of cassava 90 DAP (Expt. 1). Symbols represent means of eight plants. The variables showed significant quadratic responses according to orthogonal contrast analyses ($P < 0.01$).

related to N application rate in both experiments, with the greatest concentration observed for plants in the 120 and 180 mg N treatments. Leaf N ranged from 2.0% dry weight for plants receiving 0 mg N to 5.0% dry weight for plants receiving 120 mg N/plant per day in Expt. 1 (Fig. 3a). A similar trend (although with lower concentrations) was observed in Expt. 2 (data not shown). Leaf chlorophyll concentration responded quadratically to N application rate in Expt. 1. The greatest leaf chlorophyll concentrations were found for plants in the 60 through 180 mg N treatments and the lowest concentrations for plants in the 0 mg N/plant per day treatments (Fig. 3b). Total chlorophyll concentration in the leaves ranged from 340 to 830 mg·m⁻² in Expt. 1. A similar trend was observed in Expt. 2 (data not shown).

In Expt. 2, there were no interactions between cultivar or N application rate and shading duration for any of the variables studied. The effect of the N application on the variables studied were the same as observed in Expt. 1, with the greatest values observed for plants fertilized with 60 and 120 mg N. The greatest number of storage roots and highest dry weights were produced by plants in the 60 and 120 mg N/plant per day treatments (Table 1). In addition, the length of the shading period was negatively correlated with A and WUE ($R^2 = 0.50$, $P < 0.01$ for shading vs. both A and WUE). There was also a trend of decreased E and g_s with increased shading duration (data not shown).

The greatest number of storage roots and dry weights were observed for the nonshaded treatment. The number of roots and root dry weight decreased linearly with increasing

shading duration (Table 2). The shoot : root ratio increased with increased shading duration (Table 2), while leaf chlorophyll, leaf N, and biomass accumulation were not affected by the shading treatments (data not shown).

The application of high N rates (180 mg N/plant per day) resulted in excessive leaf abscission and partial decomposition of the roots, which may have impeded nutrient uptake. Barker (1989) suggested that while many factors influence the efficient use of nutrients, young plants generally exhibit lower N-use efficiencies than mature plants, and efficiencies decline as N fertilization increases.

Sixty to 120 mg N/plant appeared to be optimal for maximum growth of the two cassava cultivars studied. This optimum N concentration resulted in optimum A, as well as the greatest leaf chlorophyll and N concentrations. Nitrogen at 60 and 120 mg/plant yielded the greatest increase in plant growth between 90 and 120 DAP, the time that coincides with storage root formation (Ramanujam, 1985).

Maximum A rates for cassava observed in this study were lower than those reported by other workers. Rates as high as 26 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ have been reported for cassava (El-Sharkaway and Cock, 1984). This high rate has been attributed to the fact that the photosynthetic pathway of cassava is reportedly intermediate between the C₃ and C₄ pathway, since it possesses the enzymes of the C₄ pathway but lacks the typical Kranz anatomy (Cock et al., 1986). Pereira et al. (1986) suggested that the variability in net CO₂ assimilation of cassava could be due to differences in cultivars, age of the leaves, or

environmental conditions in which they were grown. While some cassava cultivars exhibited greater A rates in the younger leaves, other cultivars showed an increase in A of leaves as they mature (Pereira et al., 1986). Boardman (1977) reported that maximum A of shade-grown plants was lower than that of sun-grown plants for several species. Similar results were obtained in this study, where increasing shading duration resulted in decreased A. This trend was not related to the temperature at which the plants were grown, since periodic measurement of soil and air temperatures for plants in and out of the shade structures showed no significant differences (data not shown). Pereira et al. (1986) observed that chlorophyll concentration in the leaves of cassava depends on developmental PPF, nutritional status, age of the tissue, and genetics. However, in the present study, shading duration did not affect leaf chlorophyll content.

Kasele et al. (1983) observed a decrease in dry weight of cassava with a 30% light reduction up to 180 DAP. However, in Expt. 2 of our study, a 30% reduction in light produced no significant differences in total dry matter accumulation by 90 DAP. The discrepancy between Kasele's results and ours may be attributed to the length of time in which the plants were left in the shade, since 90 DAP was the maximum shading duration in our study. In agreement with our observations, Kasele et al. (1983) also observed that 30% shade delayed storage root formation. Hunt et al. (1977) found that shade inhibited the partitioning of dry matter to the roots and lowered productivity. We also found that by increasing shading duration, the shoot : root ratio was increased. Similar results were reported by Fortwin and Omta (1980) for *Solanum nigrum* and by Fukai et al. (1984) for cassava.

Increased shading duration lead to reduced storage root production and gas exchange of cassava. Others have suggested that a 5% to 10% increase in light intensity reaching cassava when intercropped with maize could result in a cassava yield increase of $\approx 32\%$ (IITA, 1982). Our results suggest that intercropping systems using cassava should be designed to minimize the shading duration from the overstorey crop. The effect of other climatic factors that affect the performance of cassava in intercropping systems also need to be evaluated to efficiently use cassava in multicropping systems.

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Assessing Multidisciplinary Team Training for Integrating Horticulture and Nutrition

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Abstract. Twenty students from six disciplines in a farming systems course and in a human nutrition course were organized into four interdisciplinary teams during a joint laboratory. Through lectures, videotapes, and actual interviews of farm families, students were trained to work as a team collecting and processing information from informal interviews. Most students (63%) found the joint laboratory "very useful," but 41% considered the overall work load excessive. Students rated achievement of team-related objectives significantly higher than course-related objectives. The actual interviewing of farm families was rated the most useful training technique. Student contributions to the team were more discipline-based than integrative, with 63% of the students contributing knowledge and skills from their own discipline. Students' gains from the team were more integrative, with 94% gaining from the team process, knowledge from other disciplines, and integration of disciplines, but only 31% gaining new knowledge or skills in their own disciplines.

The issues that research and extension professionals must address increasingly cross traditional discipline boundaries. Achieving effective solutions to agricultural develop-

ment problems often requires a systems approach and interdisciplinary teamwork. This is true both in developed and developing countries (Anderson, 1979; Axinn, 1986; Dillon, 1976; Futures Task Force to the Extension Committee on Organization and Policy, 1987; Schuh, 1984). While there is a need for interdisciplinary teams of professionals to analyze and solve complex agricultural development problems, few have experience and/or formal training in interdisciplinary work. There is little information on how to incorporate training for interdisciplinary work into the academic education of future professionals (Chubin et al., 1979),

although beginning the training early in academic programs and extending it beyond the involvement of an outside graduate committee member has been recommended (Mitchell, 1977).

Farming systems research/extension (FSR/E) is one method for organizing interdisciplinary work. FSR/E uses interdisciplinary teams to set priorities for on-farm agricultural production experiments. It is widely used in developing countries and has been applied in several states in the United States (French and Waugh, 1988; Shaner, 1982).

Assessment of food consumption and human nutritional status can provide valuable information to a FSR/E team, both in setting priorities for on-farm experiments and in evaluating the potential nutritional impact of experimental results on farm households. Consideration of food consumption can clarify links between food production and household use. Assessment of human nutrition is especially important when horticultural crops are a part of the farming system (Bittenbender, 1983).

In spite of the need to consider food consumption and nutrition together, examples of this approach in FSR/E are few (Frankenberger, 1985; Frankenberger et al., 1986; Prehm, 1987). There are several possible explanations for this situation. FSR/E makes extensive use of informal survey techniques, derived in part from anthropological methods, in setting priorities for on-farm experiments (Beebe, 1985; Rhoades, 1982). Comparable informal techniques for assessing human nutrition are less developed. Traditional nutrition assessment measures, such as 24-hr dietary recalls and multiple anthropometric measurements, are time consuming. Project resources often are too limited for the team to include nutritionists who could develop simplified methods for assessing human nutrition.

In Fall 1986, students from a farming sys-

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