Table 1. Measured and predicted photosynthetic rates and photosynthetic efficiencies of apple leaves under continuous and alternating light.

Light conditions	Photosynthetic rate ($mg\ CO_2/dm^2 \cdot hr$)	Photosynthetic rate Relative (%)	Photosynthetic efficiency $mg\ CO_2$/einstein	Photosynthetic efficiency Relative (%)	Predicted photosynthetic rates ($mg\ CO_2\ dm^{-2}h^{-1}$) McCree/Loomis method	Predicted photosynthetic rates ($mg\ CO_2\ dm^{-2}h^{-1}$) Mean light value method
High[z] continuous	20.8 ± 1.5	100	578 ± 41	100	–	–
Alternating	17.8 ± 1.3	85	901 ± 67	154	12.2	18.0
Low[z] continuous	3.5 ± 1.8	16	967 ± 493	161	–	–

[z]High and low light refer to 1000 and 100 $\mu Em^{-2}s^{-1}$ PAR respectively.

tinue to fix CO_2 using these intermediates. Under conditions of continuous high light the dark reactions are limiting and photosynthetic efficiencies are relatively low because the light reaction cannot utilize all the available light (1, 6).

Prediction of photosynthetic rates under short term alternating light conditions can be done by two methods. McCree and Loomis (4) suggest that photosynthetic rates could be predicted by calculating the mean of the photosynthetic rates measured in high and low light. This method underestimates photosynthetic rates under our short term alternating light conditions (Table 1).

An alternate method which was found to give more accurate estimates of photosynthetic rates was to calculate the mean of the two PAR levels used (550 $\mu Em^{-2}\ s^{-1}$ in this case) and obtain the predicted rate from a photosynthetic light response curve and a maximum photosynthetic rate appropriate for that crop. For the apple leaves in this study, a light response was determined and described by the hyperbolic equation: $P_n = P_{max} - k/PAR$ with $P_{max} = 21.3$ mg $CO_2\ dm^{-2}h^{-1}$ and k = 1791 mg $CO_2\ dm^{-2}h^{-1}\ \mu Em^{-2}s^{-1}$. Using this equation and 550 $\mu Em^{-2}s^{-1}$ mean PAR value, the predicted photosynthetic rate was very close to the rate measured (Table 1).

The discrepancy between the results of McCree and Loomis and those reported here appears to be due to the differences in alternating light periods. The durations of high and low light levels in these experiments were 0.5 sec whereas the durations used by McCree and Loomis were either greater than 3 sec or 0.014 sec. Apparently, intermittent light of the latter frequencies is not utilized as efficiently as frequencies in the range of 0.03 to 1 sec (1). For long light durations (greater than 3 sec) the photosynthetic mechanism can fully respond to the new light conditions, while 0.014 sec appears to be too short for the completion of the dark reaction (1). Intermediate times, as used in this study, allow for the completion of the dark reaction, therefore increasing the efficiency of light use.

Note, however, that only 1 of 3 types of light conditions exists within a tree canopy at a given time: a) long term sunflecks when sunny and calm b) short term sunflecks when sunny and windy or c) no sunflecks when overcast.

During a sunny, calm day with long term sunflecks, photosynthetic estimates as described by McCree and Loomis (4) would probably give accurate predictions. However, for the short term fluctuations that are found on sunny, windy days, an increased leaf photosynthetic efficiency would be expected, with photosynthetic rates being close to those obtained under conditions of high intensity continuous light. Under these conditions, mean light values should be used to estimate photosynthetic rates.

Literature Cited

1. Emerson, R. and W. Arnold. 1932. A separation of the reactions in photosynthesis by means of intermittent light. *J. Gen. Physiol.* 15:391-420.
2. Kerr, J. P., G. W. Thurtell, and C. B. Tanner. 1967. An integrating pyranometer for climatological observer stations and mesoscale networks. *J. Appl. Meteorol.* 6:688-694.
3. Kriedemann, P. E., E. Torokfalvy, and R. E. Smart. 1973. Natural occurrence and photosynthetic utilisation of sunflecks by grapevine leaves. *Photosynthetica* 7:18-27.
4. McCree, K. J., and R. S. Loomis. 1969. Photosynthesis in fluctuating light. *Ecology* 50:422-428.
5. Rabinowitch, E. I. 1956. Photosynthesis and related processes. Vol. II, Part 2. Interscience Publ., New York. p. 1433.
6. Zelitch, I. 1971. Photosynthesis, photorespiration, and plant productivity. Academic Press, New York. p. 64.

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Sink Strength and Cassava Productivity [1]

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Additional index words. Leaf area index, net assimilation rate, *Manihot esculenta*

Abstract. **Primary productivity in cassava (*Manihot esculenta* Crantz) was greater as planting density and leaf area index decreased. This is a result of a control of net assimilation rate in the leaves by sink strength of the roots, for productivity was a direct function of root system weight.**

Very little is known about the physiology of cassava, in spite of its intensive use as a staple food in the diet of a large part of the population in many tropical countries.

Establishment of an optimum leaf area index (LAI) for maximum productivity in cassava has been the aim of the work carried out by CIAT (International Center of Tropical Agriculture, Cali, Colombia) scientists (1). They advocate LAI values around 3 to 4 during tuber formation for maximum yield. Williams (4), however, has observed differences in productivity of 3 cassava cultivars were not associated with LAI, leaf disposal, or stomatal behavior but with the sink capacity of the cultivar.

An experiment was carried out in Urucuca, Bahia, Brazil (14° 36' S) in which 'Mamão' cassava was cultivated at 4 densities. An attempt was made to determine whether LAI or sink strength, was more closely related to yield in cassava. Accumulation of dry matter decreased both in the plant as a whole and in the roots, when the number of plants per unit surface area increased (Fig. 1). The shoot:root ratio, however, was consistently higher as population density increased, maximum productivity being obtained in treatments where the root systems drained the major part of the assimilates. This fact provides clear evidence that productivity

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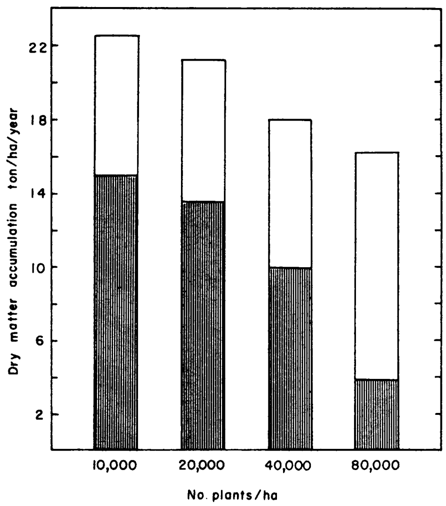

Fig. 1. Dry matter accumulation in cassava as affected by planting density. (Root dry wt represented by hatched columns; differences shown are significant at the 1% level).

in cassava is basically controlled by the sink capacity of the roots.

Variations in LAI and in net assimilation rate (E) during the course of the experimental period, are shown in Fig. 2. It can be observed in comparing Fig. 1 and 2 that E was positively correlated with primary production, while LAI was found to be inversely related to it for most of the growth period. LAI values above 3, the optimum reported by CIAT, were not found until the plants reached the age of 160 to 200 days. It is noteworthy such values were associated with low yield treatments in this study.

Rate of dry matter production was found to be a linear function of LAI up to the age of 80 days (Fig. 3). Thereafter, it was clearly associated with E until the final harvest at 280 days. Thus, productivity in cassava is a function of LAI in the initial stages of development. It depends on E, which in turn is controlled by the sink strength, after some time, however, possibly when tuber formation initiates. Control of the rate of photosynthesis in the leaves (source) by sinks is already well established (3). The sink expressed its full strength through a more efficient competition with the shoot at lower planting densities, where more space was available to the tubers. Consequently, the average absolute rates of dry matter production for the whole growth period, as defined by Richards (2), were 6.25, 5.92, 5.01 and 4.53 g m^{-2} day^{-1} in the treatments 10,000, 20,000, 40,000 and 80,000 plants per hectare, respectively.

Present results give support to the hypothesis sink capacity is a more important parameter to assess productivity in cassava and possibly in other tuberous crops than total leaf area. Thus, the ability to produce abundant foliage is not the primary character in selecting cassava cultivars for tuber production.

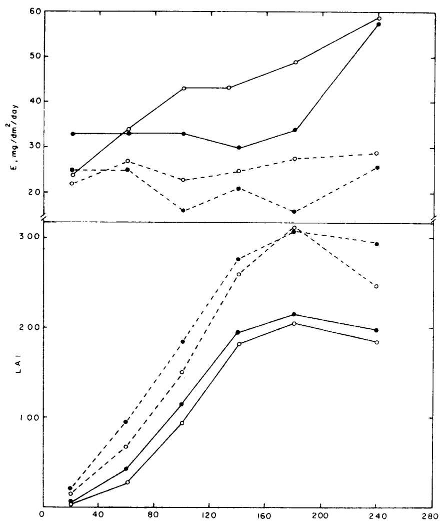

Fig. 2. Variations in leaf area index (*LAI*) and in net assimilation rate (*E*) during the growth cycle of cassava in different planting densities: 10,000 (O——O), 20,000 (●——●), 40,000 (O-----O), and 80,000 (●-----●) plants per ha. (Differences are significant at the 1% level.)

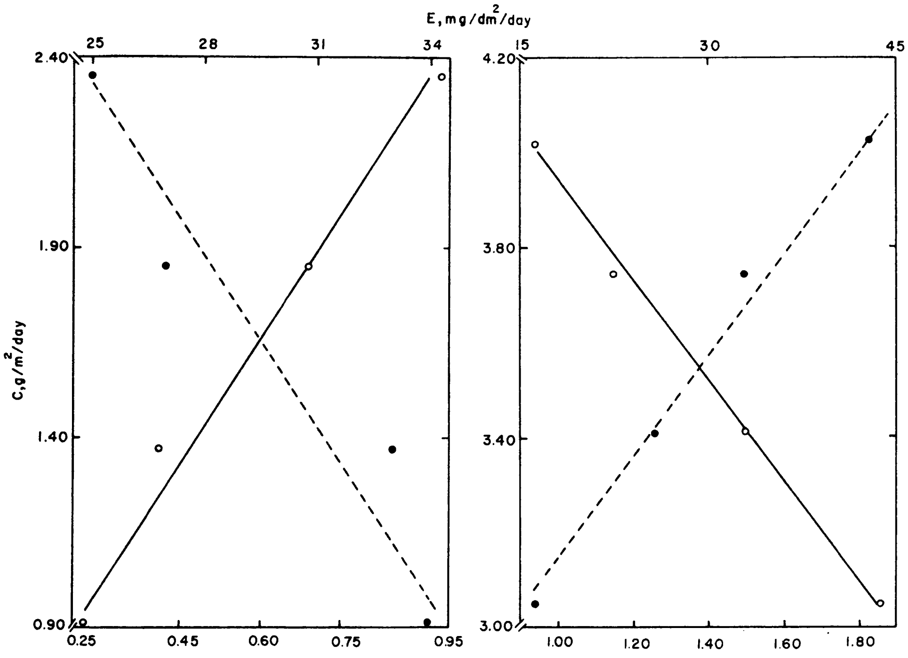

Fig. 3. Values assumed by dry matter production (*C*), net assimilation rate (*E*: ●-----●) and leaf area index (LAI: O——O) at 2 stage of the growth period (40 to 80 days, left, and 80 to 120 days, right). (Differences are significant at the 1% level.

Literature Cited

1. CIAT, 1975. Cassava production systems. p. 9-15. CIAT Annu. Rpt.
2. Richards, F. J. 1969. The quantitative analysis of growth. Vol. VA, p. 3-76. *In* F. C. Steward (ed.) Plant physiology, a treatise, Academic Press, N.Y.
3. Stoy, V. 1969. Interrelationships among photosynthesis, respiration, and movement of carbon in developing crops. p. 185-206. *In* J. D. Eastin, F. A. Haskins, C. Y. Sullivan and C. H. M. van Bavel (eds.) Physiological aspects of crop yield. American Society of Agronomy and Crop Science Society of America, Madison, Wis.
4. Williams, C. N. 1972. Growth and productivity of tapioca (*Manihot utilissima*). III. Crop ratio, spacing and yield. *Exp. Agr.* 8:15-23.