VII[th] Symposium of the International Society for Tropical Root Crops,
Gosier (Guadeloupe), 1-6 July 1985, Ed. INRA, Paris, 1988.

USING LEAF DRY BIOMASS TO IMPROVE TARO (COLOCASIA ESCULENTA) PRODUCTION SYSTEM

(Utilisation de la biomasse sèche de la feuille pour améliorer le système de production du Taro (Colocasia esculenta)

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SUMMARY

Taro (*Colocasia esculenta*) leaf information was used to determine how evapotranspiration (ET) varied with growth stage and to predict foliage (i.e., lamina and petiole) dry biomass production. The ET study was conducted during 1981 and 1982, and the foliage study was conducted during 1982 and 1983. Both studies were conducted on a flooded Pahokee muck (*Lithic mediasaprist*) organic soil. Leaf area index (LAI) increased gradually from April to July, rapidly from July to September and remained relatively constant thereafter. Taro ET was strongly dependent upon the plant growth stage, specifically the LAI. Taro ET was estimated from the available standard pan evaporation (SPE), and the ET/SPE ratio. The ET/SPE ratio was closely related to LAI, being between 0.9 and 1.0 when LAI was less than 1.0 and between 0.73 and 0.75 when LAI was greater than 1.0.

Foliage harvests to two to four month intervals were better for sustained maximum production than monthly harvests. Leaf lamina constituted an increasingly greater proportion of the total foliage as harvest interval increased. Harvesting economics may dictate that the longer harvest interval (3 or 4 months) is preferable.

RESUME

Une information sur la feuille de taro (Colocasia esculenta) a été utilisée pour déterminer comment l'évapotranspiration (ET) varie avec le stade de croissance pour prédire la production de biomasse sèche (limbe et pétiole). L'étude de ET a été conduite en 1981 et 1982, et celle du feuillage en 1982 et 1983. Les deux études ont été conduites sur sol submergé riche en matière organique. L'index de surface foliaire (LAI) s'accroit progressivement d'avril à juillet, rapidement de juillet *à septembre et demeure relativement stable après. ET dépend étroitement du stade de croissance du taro, particulièrement le LAI. ET a été estimé à partir du bac standard d'évaporation (SPE) et du rapport ET/SPE. Ce rapport était très lié au LAI, avec 0,9 et 1,0 pour un LAI inférieur à 1,0 et 0,73 et 0,75 pour LAI supérieur à 1,0.*

La récolte du feuillage à intervalles de deux à quatre mois convenait davantage à une production soutenue que la récolte mensuelle. La proportion de limbe foliaire s'accroissait dans le total du feuillage avec la réduction de l'intervalle de récolte. L'intervalle de 3-4 mois pourrait le mieux répondre aux données économiques de la récolte.

INTRODUCTION

Wetlands are common features of humid regions covering over 230 million hectares world wide (Angle and Wolseley, 1982). Generally these sites are among the last to be cultivated in a region, even though their potential for crop production often is recognized. In almost all cases drainage is the first step in developing wetlands for agricultural use. However many now recognize that wetlands play a useful and important role in the environment. They are sites for water storage, aquifer recharge, water purification, and provide habitat for many types of wildlife (BROWDER et al., 1975). Permanent drainage largely eradicates the beneficial aspects of wetlands. In most cases drainage requires very large capital outlays at the outset, and high operating expense for maintenance of the system and fuel charges for pumping.

Utilization of flood-tolerant crop plants would allow production on wetland sites without imposing continuous drainage. The ideal crop would be one that can tolerate flooding, but that does not absolutely require it. This would be particularly useful in a region like the Florida Everglades, which has fairly distinct wet and dry seasons. Taro (*Colocasia esculenta*) is a wetland crop cultivated in many tropical and subtropical areas of the world where it is particularly important as a staple food (CHAPMAN, 1964 ; F.A.O., 1974). Taro foliage can be utilized for silage (STEINKE et al., 1982) and the entire plant can be utilized for biomass conversion into various energy forms. In most locations, taro has a number of advantages as a biofuel relative to other aquatic crops such as rice (*Oryza sativa*). Taro has fewer pest problems, total biomass production probably is greater, and much of this in the form of easily convertible materials. Several drawbacks to taro include an 8 to 10 month minimal growing season, the necessity for vegetative propagation, and the paucity of production information.

Leaf area index (LAI) is often used as an indicator of plant growth and for evaluating assimilation and transpiration rates in plant physiological studies. This parameter is frequently used to study dry biomass production (AASE, 1978 ; ASHLEY et al., 1965 ; CHAPMAN, 1964 ; EZUMAH, 1972 ;

HODGES and KANEMASU, 1977 ; PEARCE et al., 1965 ; REDDY et al., 1968 ; RHOADS and BLOODWORTH, 1964 ; SHIH and GASCHO, 1980 ; SHIH et al., 1981 ; SHIH and SNYDER, 1984a ; and ZURST, 1974), and has also been used to study evapotranspiration (SHIH and RAHI, 1983 ; and SHIH and SNYDER, 1984b, 1985). Furthermore, the prediction of biomass production is important for scheduling harvest and conversion operations. The objectives of this study were two-fold : (1) to illustrate how taro evapotranspiration (ET) varies with LAI changes ; and (2) to study foliage biomass production as related to the harvest intervals and leaf dry biomass.

MATERIALS AND METHODS

Evapotranspiration Experiment

Two-year (1981-1982) lysimeter investigations were conducted to study taro ET in relation to pan evaporation and LAI. The lysimeters were placed in a Pahokee muck (*Lithic mediasaprist*) flooded field. The field was located in the interior of the Everglades Agricultural production. The lysimeters consisted of metal drums 57 cm in diameter and 46 cm deep that were buried about 25 cm into the ground. The drums were filled with Pahokee muck to about 18 cm below the rim. The bulk density of the soil was about 0.25 to 0.30 g cm^{-3}.

In 1981, four lysimeters were installed within a plot (5 m x 5 m, 10 rows of 10 plants in each row). The plot was surrounded by a one-tenth hectare of the flooded taro plants. In 1982, eight lysimeters were installed within the same plot as used in 1981.

The standard Class A national Weather Service Evaporation Pan located at the University of Florida's Everglades Research and Education Center (EREC) at Belle Glade was used to measure the standard pan evaporation (SPE). The weather station, about 1.2 km from the lysimeter site, was grassed with St. Augustinegrass (*Stenothaphrum secundatum*).

Two crops of taro were raised. The 1981 and 1982 crops were designated as first and second crops, respectively. A popular Hawaiian clone called'Lehua maoli' was planted in the lysimeters and surrounding plot on March 1, 1981, and March 15, 1982 for the first and second crops, respectively. One cutting, consisting of the upper 1 cm or so of the corm or cormels with 20 to 25 cm of the petiole attached (PLUCKNETT and DE LA PENA, 1971), was planted in each lysimeter. The surrounding plants were planted at a spacing of 50 cm between plants.

The amount of water supplied to the taro plant was separated into two periods ; 1) the establishment period and 2) the flooding period in accordance with the flooding after transplanting. The establishment period includes the time when small quantities of water were added for inducing establishment. The establishment periods were from the second crop. During this establishment period, the plants were irrigated four times for the first crop and three times for the second crop. The amount of water applied each time was 7 mm, or 28 mm and 21 mm for the first and second crops, respectively. The flooding periods were from 3 April, 1981 to 14 January, 1982 for the first crop and from 2 April, 1982 to 10 February, 1983 for the second crop. Taro, both in the lysimeters and field, was maintained at a water depth of 8-10 cm. The water level within the lysimeter was manually maintained and the amount of water added or removed was recorded. The water level within the surrounding taro field was controlled by an inflow system for pumping the water from a canal into the field and also controlled by an outflow gate for releasing the excess water above the 10 cm depth. The first and second crops were harvested on 15 January, 1982, 320 days after planting (DAP), and 11 February, 1983, (333 DAP), respectively.

Evapotranspirations from lysimeters were monitored by measuring changes in the water level at 8:00 a.m. twice a week (Tuesday and Friday). The standard pan evaporation data were obtained daily at 8:00 a.m. in the EREC Weather Station. Weekly data were calculated on a Friday through Thursday week basis. The ET from each lysimeter unit was determined based on the water budget method.

The leaf area index was estimated by multiplying the average leaf area per leaf by the total number of leaves per unit area. According to the study reported by SHIH and SNYDER (1984a), the leaf are (hereafter, the leaf area refers to the area of the lamina) of taro can be determined from the leaf dry biomass, i.e.

$$LA = 223\ LDB \qquad (r^2 = 0.91) \qquad (2)$$

where LA = leaf area, cm^2 ; and

LDB = leaf dry biomass, gram.

Thus, the leaf area index of taro can be determined from the leaf dry biomass and the leaf number.

Unfortunately, the leaf dry biomass estimation is a destructive sampling procedure. In order to maintain an undestructive growth condition within the plot, leaf samples used to determine the variation in leaf dry biomass and leaf number over time were taken from the surrounding field. For the 1981 crop, six plants were randomly selected during the first week of each month from April, 1981 through January, 1982. In the 1982 crop, during the middle of the months of May, July, September, November, 1982, and January, 1983, six plants were randomly selected. In both years sampling, the six sample plants were always surrounded by other plants, the leaves of each plant were counted, and the leaf dry biomass was determined after drying at 70°C.

Foliage Biomass Experiment

Foliage from an established stand of *C. esculenta* var. 'aquatilis' (a stoloniferous type) growing in flooded Pahokee muck was harvested on 1, 2, 3, and 4-month intervals beginning March, 1983. There were two treatment, with and without fertilizer application, with three replications utilizing plots 1.5 meter square. The experiment was repeated in 1984 using separate plots in the same established stand. However, this time it was limited to the fertilizer treatment with four replications. Foliage from the center $1m^2$ of each plot was separated into leaf lamina and petioles for fresh and dry biomass determination. The foliage was harvested as close to the 15th day of the month as possible and dry biomass was determined following oven drying at 70°C. Fertilization in 1983 (kg ha^{-1}) was P-52 and K-162 in May, and N-100 and K-100 in August. In 1984 fertilization was P-100 and K-100 in May, and N-100 and K-100 in July.

A linear regression model was proposed in this study to analyse the relationship of the petiole dry biomass (PDB) and foliage dry biomass (FDB) to the leaf dry biomass (LDB). The model is

For petiole dry biomass

$$PDB = a_0 + a_1 \; LDB \qquad (1)$$

For foliage dry biomass

$$FDB = b_0 + b_1 \; LDB \qquad (2)$$

where a_0, a_1, b_0, b_1 are coefficient which were estimated from experimental data by using regression analysis.

RESULTS AND DISCUSSION

Evapotranspiration Varied With Leaf Area Index

The average daily ET and SPE in a given week (ADW) were compiled. The variation in ADW values with time are also plotted in Fig. 1 and 2 for the 1981 and 1982 crops, respectively. Several features can be drawn from these figures.

ET and SPE values were closer before August than during the rest of the growth season. It was also prior to August that the LAI was less than 1.0 as the leaf canopy was developing. Since the taro had not formed a full canopy before August, evaporation from the water surface under the taro canopy was similar to open pan evaporation without shading.

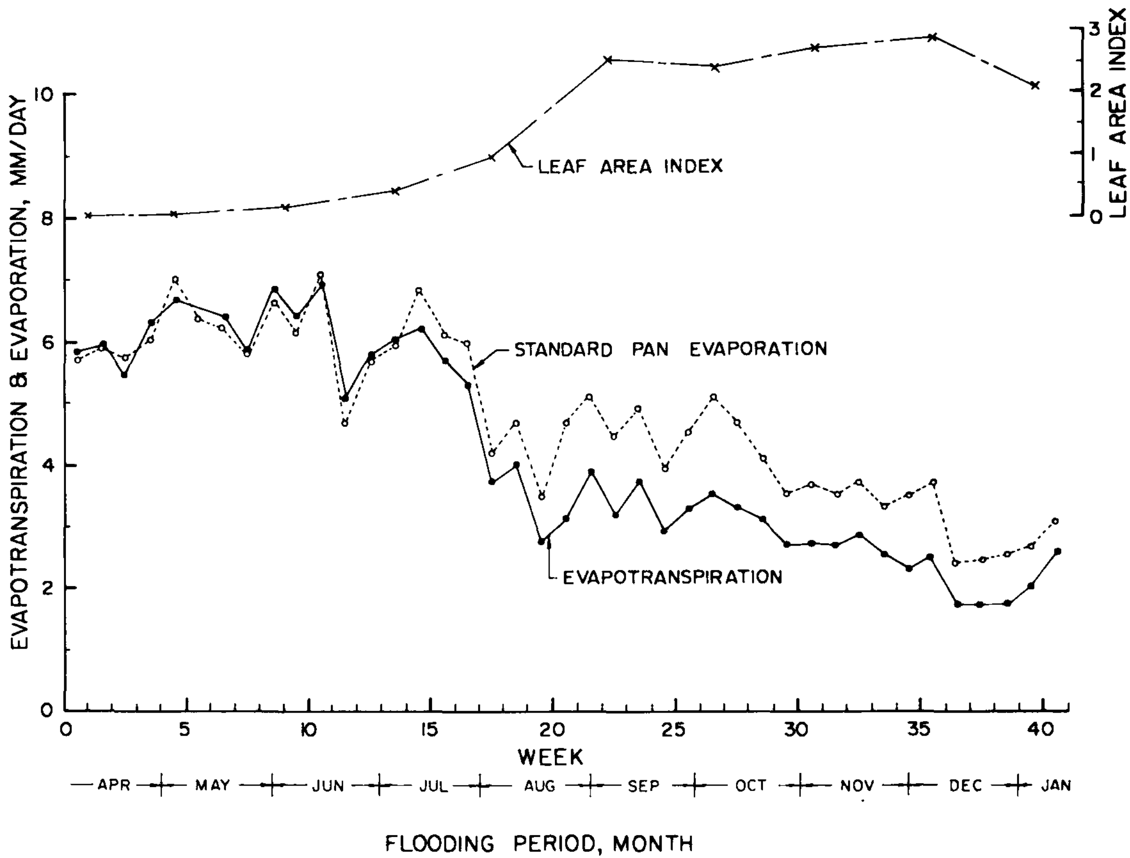

Fig. 1. Average daily evapotranspiration and standard pan evaporation in each week, and monthly leaf area index as related to time for 1981 taro crop.

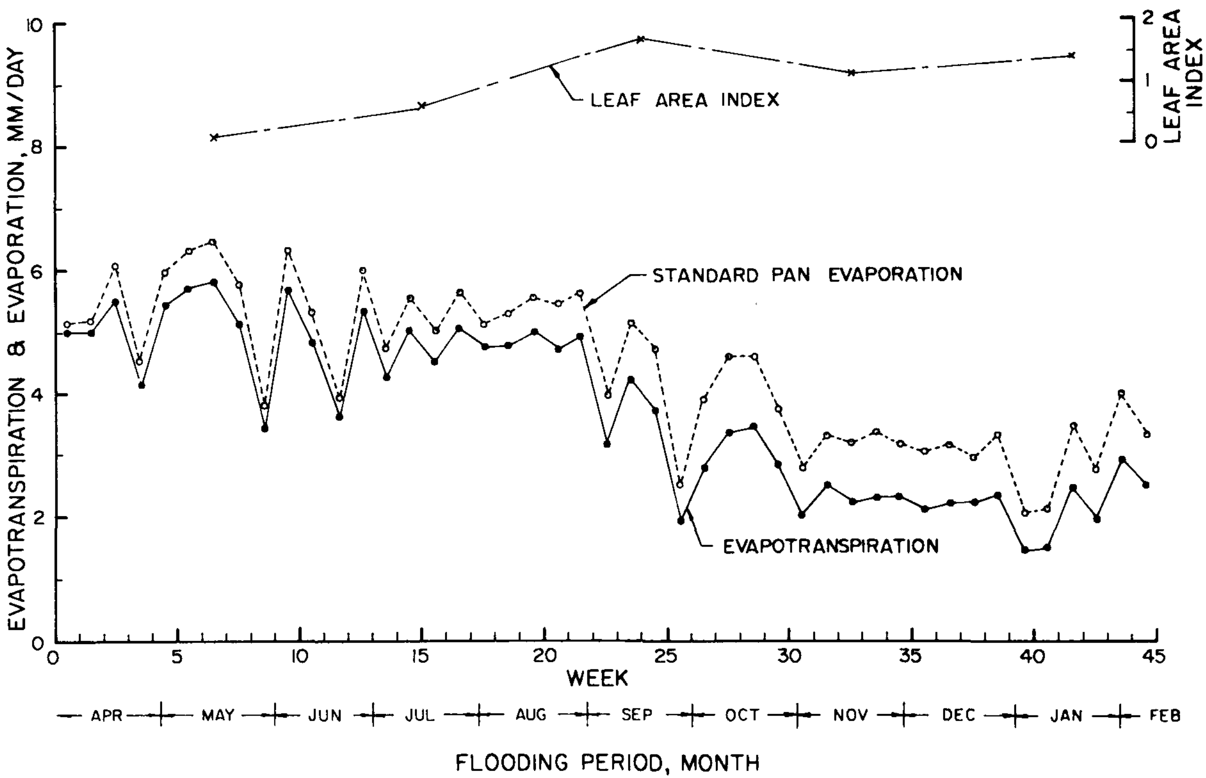

Fig. 2. Average daily evapotranspiration and standard pan evaporation in each week, and monthly leaf area index as related to time for 1982 taro crop.

Several factors may be accounted for the decrease in ET, relative to SPE, that was observed during August in both years. Full canopy closure probably reduced evaporation from the water surface below the taro canopy.

Monthly ET and SPE data for the flooding period were compiled. The average daily ET and SPE in a given month (ADM), standard deviation of ET in a given month (SDM), and the ratio between ET and SPE in a given month (ESM) were computed. The results of ADM, SDM, ESM, and LAI for the 1981 and 1982 crops are plotted in Figs 3 and 4. First both ET and SPE decreases with time as the seasonal weather changed from July in 1981 and August in 1982 to the end of growth season. Second, LAI increased gradually from April to July (insignificant canopy stage), rapidily from July to September (developing canopy), and remained relatively constant near 2.5 in the 1981 crop and 1.5 in the 1982 crop from September to the end of growth season (full canopy). The ratio of ET to SPE followed these LAI changes very closely, since they were near 1.0 in the 1981 crop and 0.9 in the 1982 crop from April to July, and then dropped abruptly from July to September, and remained near 0.75 in the 1981 crop and 0.73 in the 1982 crop from September to the end of growth season.

It needs to be noted that the ratio between ET and SPE in the 1981 crop was slightly higher than that in the 1982 crop, particularly at the early stage of growth (i.e. LAI < 1). This could have been due to weather differences which may affect microclimate conditions. For instance, the incoming solar radiation at the EREC Weather Station during the months of April, May, June, and July in 1981 was about 10 per cent (i.e., 5400 cal cm^{-2}) higher than that in 1982.

The data in Figs. 3 and 4 show that ET of a taro crop system is both strongly dependent upon climate conditions and upon stage of plant growth, specifically LAI. The crop LAI effects are superimposed upon the seasonal weather effects. The seasonal weather effects would be similar for other crops, and not unique for taro.

Unlike non-flooded crops, ET was reduced being more affected by shading as the crop canopy developed more than by the additional leaf area, which increase ET.

Foliage Production Related To harvest Interval

The results of the relationship between petiole dry biomass and lamina dry biomass as presented in Equation (1) are shown in Table 1. Several important features can be observed from Table 1. First, the correlation coefficients were all greater than 0.78 except for the 4-month harvest interval in the unfertilized treatment which was only 0.67. Second, the intercept terms, a_0, in the fertilized treatment for both years were inversely related to the harvest interval

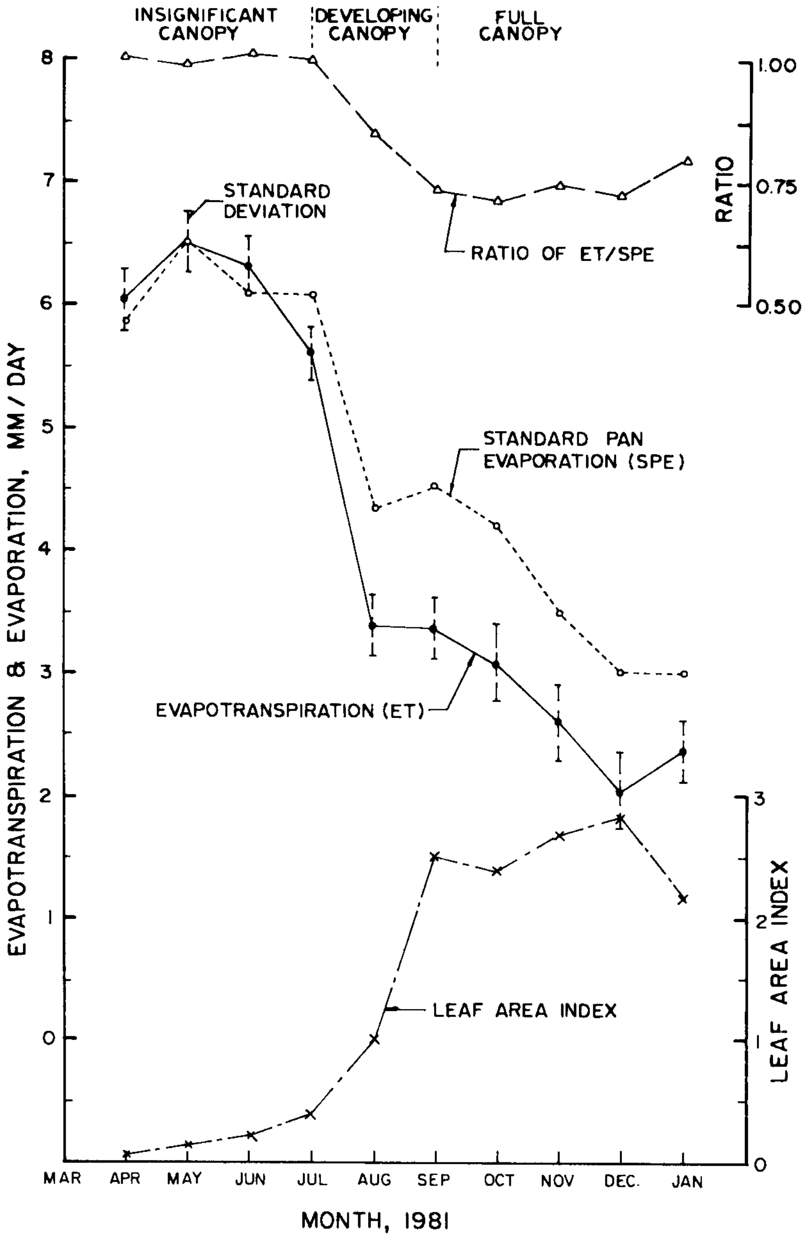

Fig. 3. Evapotranspiration (ET), standard pan evaporation (SPE), and ET/SPE ratio as related to the leaf area index for 1981 taro crop.

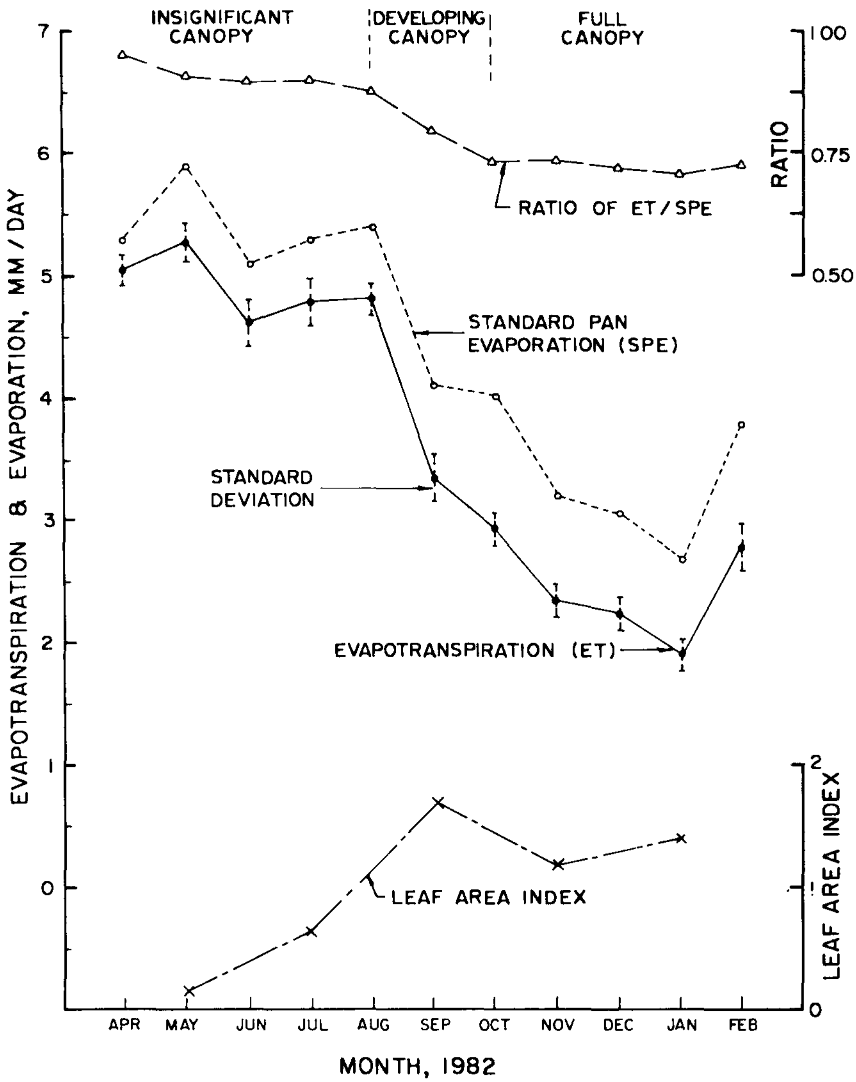

Fig. 4. Evapotranspiration (ET), standard pan evaporation (SPE), and ET/SPE ratio as related to the leaf area index for 1982 taro crop.

TABLE 1 : Statistical coefficients of the regression analysis between lamina and petiole dry biomass

Harvest interval	1983 crop unfertilized treatment a_0	a_1	r	1983 crop fertilized treatment a_0	a_1	r	1984 crop Fertilized treatment a_0	a_1	r
--month--									
1	-0.16	1.16	0.78	-19.97	1.63	0.89	-1.90	1.47	0.96
2	-141.55	2.83	0.86	-36.27	1.95	0.78	-75.42	3.03	0.94
3	-120.88	3.00	0.97	-51.47	2.60	0.96	-272.76	4.40	0.88
4	66.98	0.97	0.67	-216.15	3.35	0.98	-549.22	5.20	0.91

TABLE 2 : Statistical coefficients of the regression analysis between lamina and foliage dry biomass

Harvest interval	1983 crop unfertilized treatment b_0	b_1	r	1983 crop fertilized treatment b_0	b_1	r	1984 crop Fertilized treatment b_0	b_1	r
--month--									
1	-0.16	2.16	0.92	-19.97	2.63	0.95	-1.90	2.47	0.98
2	-141.55	3.83	0.92	-36.27	2.95	0.86	-75.42	4.03	0.97
3	-120.88	4.00	0.98	-51.47	3.60	0.98	-272.76	5.40	0.92
4	66.98	1.97	0.88	-216.15	4.35	0.99	-549.22	6.20	0.93

increase, but not in the unfertilized treatment. The negative sign of a_0 implies that the lamina must reach to a certain size before the petiole is visible. Third, the slope term a_0, in the fertilized treatment for both years was directly related to the harvest interval increase. In other words, there is more lamina in proportion to petiole as harvest interval is increased. These three features imply that not only can the petiole dry biomass be predicted based on the lamina dry biomass, but also the lamina dry biomass of the fertilized treatment can be used to predict the petiole dry biomass as related to the increase in harvest interval. The fertilized plot data had more consistent statistical characteristics than the data gathered from the unfertilized treatment. Thus, a further study is needed to test those treatment differences.

The results of the relationship between foliage dry biomass and lamina dry biomass as given in Equation (2) are shown in Table 2. The correlation coefficients were all greater than 0.85. This implies that the foliage dry biomass can be predicted utilizing measurements of the lamina dry biomass. The intercept term, b_0, and slope term, b_1, in the fertilized treatment had a similar trend in relationship with the harvest interval increase as was observed when the lamina and petiole dry biomass were compared in the a_0, and a_1, in Table 1, i.e., the b_0 was inversely related to the harvest interval increase, and the b_1 was directly related. This implies that using the lamina dry biomass data of the fertilized treatment to predict the foliage dry biomass production as related to the harvest interval increase had more consistent statistical characteristics than that using the data gathered from the unfertilized treatment. Thus, a further study is needed to test those differences between the two treatments.

The results of the number of leaf, dry biomass of lamina petiole, and foliage for 1983 crop and 1984 crop are shown in Tables 3 and 4, respectively. The leaf numbers were not only significantly different among the four harvest intervals but also inversely related to the harvest interval increase, with the exception that there was no difference between the 2-month and the 3-month intervals in the 1984 crop. This implies that the shorter harvest interval resulted in a smaller leaf size, since the foliage biomass was not directly related to the harvest interval increase. The foliage dry biomass using the 3-month harvest interval was consistantly greater than other harvest intervals in both years. With monthly harvests there was a severe reduction in plant vigor. This is shown by the general reduction in yield observed for each successive monthly harvest. Althouh part if this reduction, no doubt, was caused by the shorter day length and cooler temperatures that occured by the end of the growing period.

TABLEAU 3 : Number of leaf, dry biomass of lamina and petiole differences among four harvest intervals for 1983 crops

		Unfertilized treatment				Fertilized treatment			
Harvest		Leaf	Dry Biomass			Leaf	Dry Biomass		
interval	Rep.	NO	Lamina	Petiole	Foliage	NO	Lamina	Petiole	Foliage
--month--			g/m²				g/m²		
	1	1643	391	449	840	1770	451	520	971
	2	1429	362	579	941	1888	486	614	1100
1	3	2008	549	478	1027	1843	502	666	1168
	Avg.	1693a*	434a	502b	936b	1834a	480a	720a	1080a
	1	1131	497	833	1330	864	386	630	1016
	2	1022	507	884	1391	793	408	582	990
2	3	912	430	593	1023	770	398	673	1071
	Avg.	1022b	478a	770a	1248a	809b	397b	628a	1057a
	1	719	377	729	1106	669	356	732	1088
	2	586	435	933	1368	616	350	835	1185
3	3	739	424	956	1380	520	303	594	897
	Avg.	680c	412c	873a	1285a	602c	336c	600a	1026ab
	1	400	314	396	710	385	289	538	827
	2	435	355	456	811	321	287	505	792
4	3	411	244	438	682	423	313	640	953
	Avg.	415d	304d	430b	734b	376d	296c	561a	857b

* Values within a column followed by the same letter are not different ($p < 0.05$) by duncan's Multiple Range Test.

TABLEAU 4 : Number of leaf, dry biomass of lamina and petiole differences among four harvest intervals for 1984 crop

Harvest interval	Rep	Leaf No	Lamina	Dry Biomass Petiole	Foliage
			--------------gm²---------------		
	1	1973	469	677	1146
	2	2158	457	628	1085
1	3	2309	602	864	1467
	4	2263	599	910	1509
	Avg.	2176a*	532a	770c	1302c
	1	999	464	1104	1569
	2	1116	425	949	1374
2	3	1141	544	1347	1892
	4	954	495	1226	1721
	Avg.	1053b	501a	1157b	1639b
	1	898	557	1490	2047
	2	988	517	1348	1866
3	3	825	396	1205	1601
	4	884	509	1385	1894
	Avg	899b	495a	1357ab	1852ab
	1	488	533	1678	2211
	2	658	488	1286	1773
4	3	524	498	1633	2132
	4	434	485	1430	1914
	Avg.	526c	482a	1507a	2007a

* Values within a column followed by the same letter are not different ($p < 0.05$) by Duncan's Multiple Range Test.

Practical Applications

Two practical implementations of this study can be mentioned as follows. First, taro growers or water managers can estimate the taro ET requirement for irrigation scheduling or fo water resources planning and management in accordance with available SPE data, and the ET/SPE ratio. The ET/SPE ratio is dependent upon the LAI condition (i.e. stage of canopy closure). According to the results drawn in this study, a ratio between 0.9 and 1.0 is appropriate when leaf area index is less than 1.0 (i.e., before canopy closure), and is between 0.73 and 0.75 when leaf area index is greater than 1.0 (i.e., after canopy closure). Second, in terms of total foliage yield during a growing season, there appears to be little difference among harvest intervals of 2-months or more. Therefore, the choice may center more on the economics of harvesting or the need for a steady supply of biomass feedstock. Harvesting economics may dictate that the longer harvest interval (3 or 4 months) is preferable, since a similar amount of biomass can be obtained with fewer harvests.

ACKNOWLEDGMENT

A grant from the Gas research Institute, administered by the Center for Biomass Energy System, IFAS, University of Florida, in partial support of this study is gratefully acknowledged.

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