Trip Report to North Carolina, USA
August 21 - Sept. 2, 1999.
USAID Grant No. LAG-G-00-97-00002-00
SM-CRSP Project *Decision Aids for Integrated Nutrient Management*

Traveler: Gabriela Soto, University of Costa Rica.
Objectives: Analysis of the data collected in the experiment Residue Decomposition - Nutrient Release Experiment.
Itinerary:

Saturday, Aug. 21	Arrival in Raleigh, NC
Monday, Aug. 23	Introduction to NCSU Soil Science Department personnel; initial discussions with Pedro Luna on data analysis
Tuesday, Aug. 24 to Thursday, Sept. 2	Data analysis with the tutorial help of Pedro Luna, Jot Smyth and Michael Wagger
Thursday, Sept. 2	Description of root scanner program (Rootlaw) by Ivo da Silva
Friday, Sept. 3	Meeting with Michael Wagger and final report preparation
Saturday, Sept. 4	Departure from Raleigh

List of contacts:
Dr. Jot Smyth, SM-CRSP Project Coordinator
Dr. Pedro Luna, Soil Science Research Associate
Dr. Michael Wagger, Soil Science Professor
Mr. Ivo da Silva, Soil Science Graduate student

RESIDUE DECOMPOSITION - NUTRIENT RELEASE ON A HEART OF PALM (*Bactris gasipaes*) PLANTATION IN COSTA RICA

The objective of this visit to North Carolina State University (NCSU) was to analyze all data collected from the biomass study at DEMASA, S.A., Guápiles, Costa Rica. For the analysis of the data I had the support of Pedro Luna, who has been working on this area of research for several years, and the helpful comments of Michael Wagger and Jot Smyth.

Collection of the data at the field is not complete; four sampling dates for the last placement still remain. Consequently, the results presented here will not be final until the new information is collected and analyzed. However, it is expected that the general behavior of nutrient release and decomposition rates will not differ much from that observed to date. With the data analyzed so far, there were no significant differences among the three placement intervals (two rainy seasons - July and September, and the dry season on March, 1999).

Introduction

Heart of palm production area has increased in Costa Rica over the last 5 years from 3926 ha to 10169 ha in 1997 (Alvarado et al., 1998). However, little is known about nutrient cycling within this production system.

Peach palm is known to grow well on a wide range of soils in the humid tropics (Molina, 1997), in areas characterized by abundant rainfall throughout the year (2000-3000 mm), moderately high temperatures (24-28 ºC), and elevations ranging from 5-700 m (Clement, 1989). It will grow well in rich alluvial soils and in nutrient-poor acid soils common to the humid tropics. It is cultivated intensively on highly weathered Oxisols, Andisols, and Ultisols in Brazil, Peru and Costa Rica (Molina, 1997; Clement, 1989; Perez et al., 1987).

In Costa Rica normal plant density is 5000 plants ha^{-1}. Peach palm seeds harvested from trees in the region are germinated in raised nursery beds and grown in the nursery for an additional 2 months. Thereafter, bare-root seedlings are harvested and transplanted in the field the same day. By the end of the second year in the field each plant unit (locally called "cepa") ideally has four stems, each with a 2-3 m height, and 6-8 suckers that eventually will replace harvested stems. At this plantation age stem harvest every two weeks begins from fields for heart-of-palm ("palmito"). Criteria for 'palmito' harvest in Costa Rica used to be stem diameter at the base, but is now shifting to harvesting when the fifth leaf reaches 75% of maximum expansion.

Upon harvesting a stem, in-field processing includes removing all foliage, a 5-6 cm base of the stem, and peeling off the outer layer of the stem. All residues from in-field processing are left in the 2-m area between plant rows at the site of stem harvest (Hue, Smyth, Wagger, 1998). Annual residue production is considerable, while biomass and nutrient exports from the system are relatively small (Deenik et al., 1998). The mature plantation studied by Herrera (1989) was estimated to have 3200 plants ha^{-1} and produced an average of three 'palmitos' $plant^{-1}$ in a year. Relative to the total nutrient accumulation of the aboveground biomass, nutrient export in 'palmito' harvest is relatively small. On one mature peach palm plantation in Costa Rica, for example, only 1.76 t ha^{-1} yr^{-1} of biomass was removed from the field in the form of heart-of-palm (Herrera, 1989). This translates into a nutrient removal of 28, 4.8 and 31 kg ha^{-1} yr^{-1} of N, P, and K in the heart-of-palm (Deenik et al., 1998).

Fertilizers are applied every 1.5 - 2 months in the ranges detailed in Table 1. Current fertilizer recommendations are based primarily on field experience during the last 20 years, rather than actual field experiments to measure yield response (Hue, Smyth and Wagger, 1998).

Table 1. Annual fertilization rates in the Sarapiqui region, Costa Rica. (Source: Alvarado and Salas, 1998)

NUTRIENT	**ANNUAL RATES**
	kg ha^{-1} $year^{-1}$
N	200 - 400
P	22 - 44
K	50 - 125
Mg	18 - 36
S	40 - 80
Calcitic lime	500 - 2000

A compilation of 13 soil samples analyzed in University of Costa Rica labs from peach palm plantations throughout the Atlantic Zone provided a range of soil chemical values described in Table 2. The range in nutrient concentrations of peach palm leaves from plantations in the same region are shown in Table 3.

The general objective of these investigations were to study the nutrient dynamics during decomposition of harvest residues within a heart of palm plantation, under the variable annual climatic conditions of the Sarapiqui region of Costa Rica.

Table 2. Range of soil chemical characteristics for the heart of palm cropping system in the Costa Rican Atlantic Zone. (Compiled by Eloy Molina, UCR-CIA Soils Laboratory)

VARIABLE	RANGE
pH in water	4.1 - 6.0
Exchangeable Ca¶ (cmol l^{-1})	1.1 - 8.5
Exchangeable Mg¶ (cmol l^{-1})	0.2 - 2.3
Exchangeable K§ (cmol l^{-1})	0.1 - 0.6
Exchangeable Al¶ (cmol l^{-1})	0.2 - 4.4
Al saturation (%)	2 - 71
Extractable P§ (mg l^{-1})	4 - 34
Extractable Cu§ (mg l^{-1})	5 - 36
Extractable Fe§ (mg l^{-1})	74 - 2098
Extractable Mn§ (mg l^{-1})	2 - 94
Extractable Zn§ (mg l^{-1})	0.7 - 10.1

¶ 1.0 N KCl extraction.
§ Hunter's Modified Olsen solution.

Table 3. Range of nutrient concentrations for peach palm leaf samples analyzed by UCR labs. (Compiled by Eloy Molina, UCR-CIA Soils Laboratory)

NUTRIENT	RANGE
N (%)	2.5 - 4.0
P (%)	0.15 - 0.30
Ca (%)	0.2 - 0.5
Mg (%)	0.2 - 0.3
K (%)	0.8 - 1.5
Cu (mg kg^{-1})	8 - 15
Fe (mg kg^{-1})	100 - 200
Mn (mg kg^{-1})	50 - 200
Zn (mg kg^{-1})	15 - 25

Methods

The experiment was located in a 16-yr old commercial heart of palm plantation on the DEMASA, S. A. farm at Guápiles, Costa Rica. Mean annual temperature and rainfall are 25.5ºC and 3650 mm, respectively, and altitude is 210 m. Residue decomposition and nutrient release were evaluated for three different placement dates: July 31, 1998 (S1), September 24, 1998 (S2) and March 11, 1999 (S3), to account for the seasonal rainfall variation. During the 2-3 month dry season (S2) in the Sarapiqui region (with 50-75 mm rainfall month^{-1}), 'palmito' production drops by as much as 50%. As can be observed in Figure 1, the placement dates did not correspond with the expected rainfall peaks.

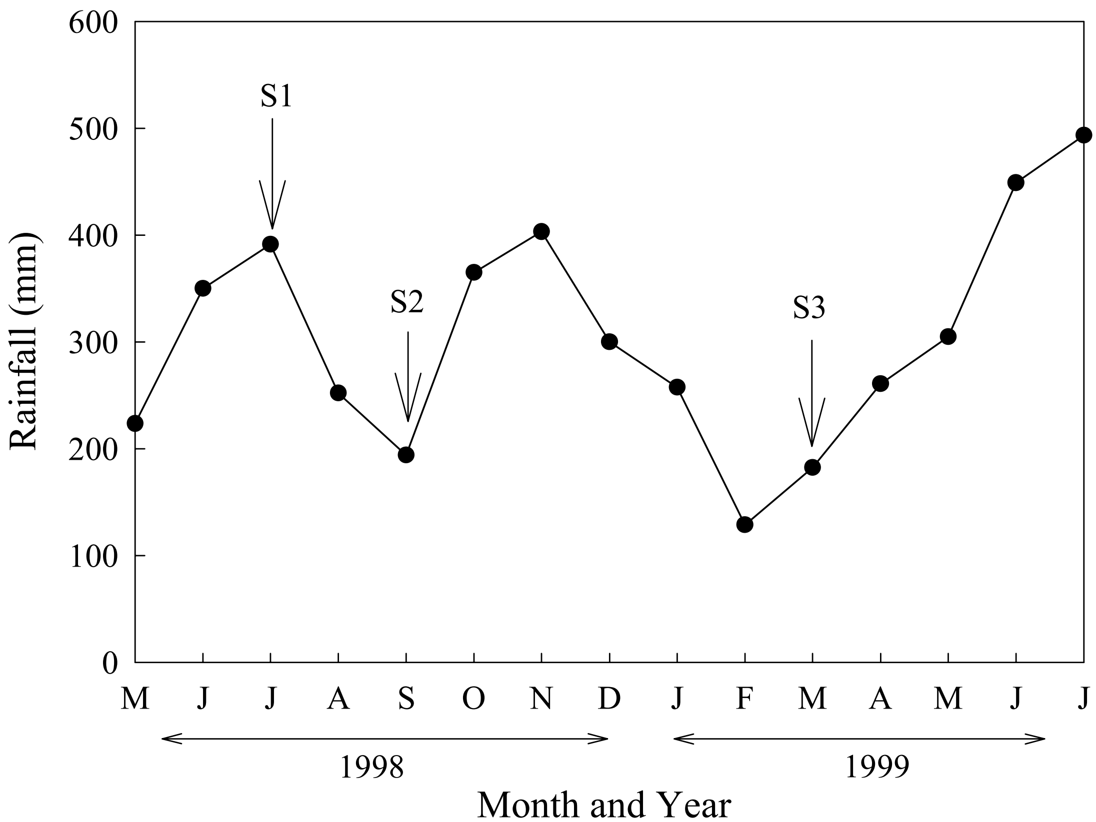

Figure 1. Monthly rainfall distribution during litter decomposition studies at Guapiles, Costa Rica. Arrows indicate times when each placement series was initiated.

To monitor residue decomposition at each seasonal placement, the third leaf of the five leaves cut during harvest was placed in 90 x 45 cm^2 fiber glass mesh bag, placed on the soil surface 2 m apart in the intrarow area. At the same time these samples were collected, 10 additional leaf samples were collected for nutrient (N, P, K, Ca, and Mg) determination. Lignin was also determined on these leaf samples by the acid-detergent method (Van Soest, 1968).

Mesh bags were retrieved 1, 2, 4, 8, 16, 24, 32, 40 and 48 weeks after field placement. A total of 4 replicates were collected at each sampling date. At each retrieval date, the contents of each bag were dried at 70ºC, weighed and analyzed for N, P, K, Ca, and Mg. Dry matter accumulation was calculated on an ash-free weight basis by ashing samples at 550ºC to correct for soil contamination.

Percentage of original dry weight, N, P, K, Ca and Mg remaining at each retrieval date were regressed on time using the NLIN procedure of SAS (1997). The decreases with time generally followed an exponential trend, so the following three models were fit to each response variable: single exponential, double exponential, and asymptotic. A single-exponential model (Eq. 1) assumes that all of the plant tissue or nutrient will decompose or release at the same rate, while the double-exponential model (Eq. 2) attempts to define two rates of decomposition or nutrient release. The asymptotic model (Eq. 3) tends toward a positive constant rather than zero and does not extrapolate beyond the study period. The general forms of the equations are as follows:

$$Y = b_0 * \exp(-k1t), \qquad \text{(Eq. 1)}$$

$$Y = b_0 * \exp(-k1t) + (100-b_0) * \exp(-k2t), \qquad \text{(Eq. 2)}$$

$$Y = b_0 + (100-b_0) * \exp(-k1t), \qquad \text{(Eq. 3)}$$

where,
Y is the percentage dry weight or nutrient remaining at time t;
b_0 is the dry weight or nutrient pool;
k1 and k2 are decomposition or nutrient release rate constants; and
t is time in weeks.

A separate model was fit for each placement period. Selection of the best model for a particular response variable was based on the lower mean square error value. For the purpose of model comparison among placement periods, data from all periods were pooled and a common selected model was fit to test the hypothesis that the curves for the three periods were the same, using an F-test as follows:

$H0 = b_{0\ S1} = b_{0S2} = b_{0S3}$, and $k1_{S1} = k1_{S2} = K1_{S3}$ (Luna-Orea et al, 1996).

Results and Conclusions

Biomass

Analysis of the third leaf cut at harvest during the three placement periods showed no significant variations in dry weight and nutrient content (Table 4). All nutrient concentrations are within the range of values compiled by Molina (Table 3). Lignin content was only determined for the first placement period.

This plantation has been established for 16 years, with an average production per plant of 4 stems per year (personal communication Ing. Félix Castro, farm manager, DEMASA). With a plant density of 5000 plants ha^{-1}, the annual production for this system is around 20,000 palmito stems. Using these plant density and harvest parameters,, an estimated 11.2 t ha^{-1} yr^{-1} of leaf residue remain in the field (Table 5). The nutrient content of this residue is considerable, averaging 276 kg N ha^{-1}, 22 kg P ha^{-1}, 149 kg K ha^{-1}, 43 kg Ca ha^{-1} and 23 kg Mg ha^{-1}.

Table 4. Dry weight and nutrient and lignin content of the third leaf of heart of palm, cut at harvest times coinciding with the three placement periods for mesh bags at Guápiles, Costa Rica.

PLACEMENT PERIOD	DRY WEIGHT	FOLIAR ANALYSIS					
		N	P	K	Ca	Mg	LIGNIN
	g	------------------------------		%		------------------------------	
S1	110	2.18	0.18	1.24	0.29	0.17	6.2
S2	118	2.42	0.20	1.32	0.50	0.25	--
S3	108	2.81	0.22	1.44	0.35	0.18	--
Mean	112	2.47	0.20	1.33	0.38	0.20	--

Table 5. Estimated total foliar biomass and nutrient content added to the field, based on harvesting 5000 plants ha^{-1} four times a year, in a 16-yr old peach palm plantation at Guápiles, Costa Rica.

RAINFALL PERIOD	LEAF DRY WEIGHT		NUTRIENT CONTENT				
	PER PLANT¶	LAND AREA§	N	P	K	Ca	Mg
	g $plant^{-1}$	t ha^{-1} yr^{-1}	---------------		kg ha^{-1} yr^{-1}		---------------
S1	549	11.0	239	20	136	32	19
S2	590	11.8	286	24	156	59	30
S3	538	10.8	302	24	155	38	19
Mean	559	11.2	276	22	149	43	23

¶ Based on 5 leaves at each plant harvest.
§ Based on 5000 plants ha^{-1} and 4 harvests $plant^{-1}$ yr^{-1}.

<u>Nutrient Release</u>

Similar decomposition and nutrient release rates were observed for the three placement periods, thus allowing results for the three periods to be pooled into a single model. This result is not unexpected, even with different rainfall environments, since water availability was not deficient enough to limit decomposition. With the exception of K which was fitted to a single exponential model, an asymptotic model best described residue decomposition and nutrient release (Table 6; Figures 2-7). There was no significant difference between the different seasons studied . The general order for nutrient release was K > N > P > Mg > Ca. These results are similar to the ones observed by Luna-Orea et al. (1996) with two tropical legume cover crops.

Table 6. Nonlinear equations for residue decomposition and nutrient release pooled across three placement intervals, from heart of palm leaves at Guápiles, Costa Rica.

PARAMETER		EQUATION[¶]	$S_{y.x}$[§]	TIME FOR 50% RELEASE
				weeks
Dry matter	Asymptotic	$y=18.2+81.8e^{-0.14t}$	56.3	6.6
N	Asymptotic	$y=18.2+81.9e^{-0.30t}$	77.9	3.2
P	Asymptotic	$y=17.9+82.1e^{-0.18t}$	111.5	5.4
K	Single exp..	$y=105.0e^{-0.28t}$	57.5	2.7
Ca	Asymptotic	$y=20.6+74.0e^{-0.08t}$	531.6	12.2
Mg	Asymptotic	$y=16.4+83.6e^{-0.17t}$	181.7	5.5

[¶] unit for y are % of nutrient or dry weight remaining; units for t are weeks.
[§] $S_{y.x}$ = mean square error.

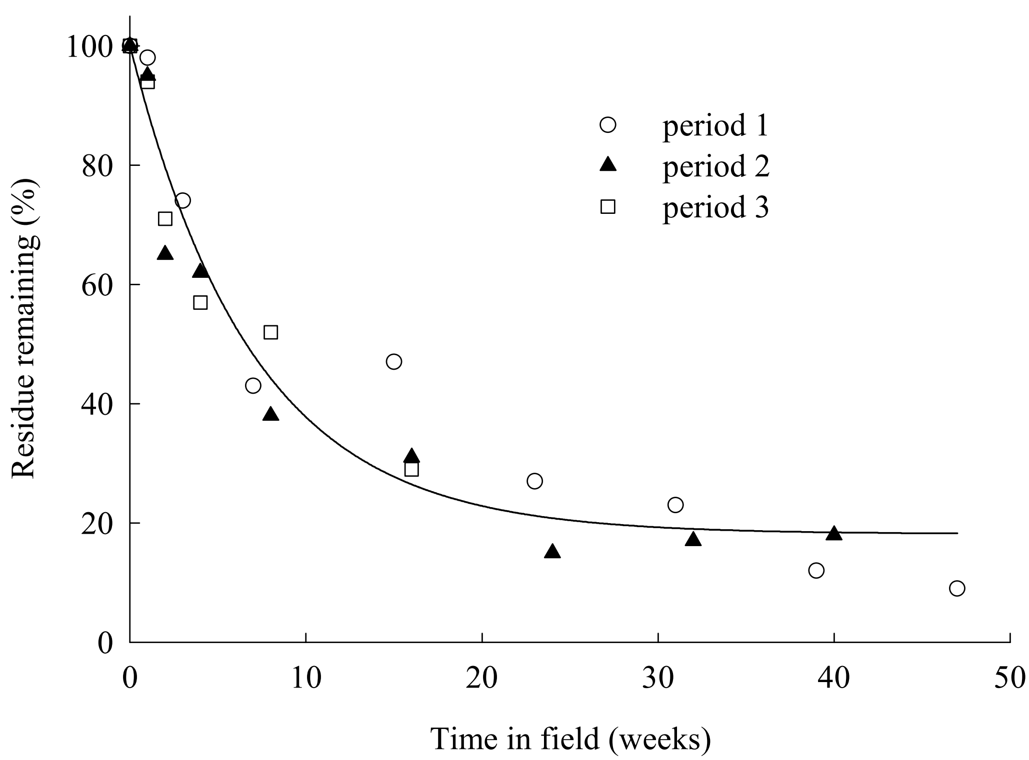

Figure 2. Peach palm leaf dry weight reduction in litter bags during different placement periods at Guapiles, Costa Rica.

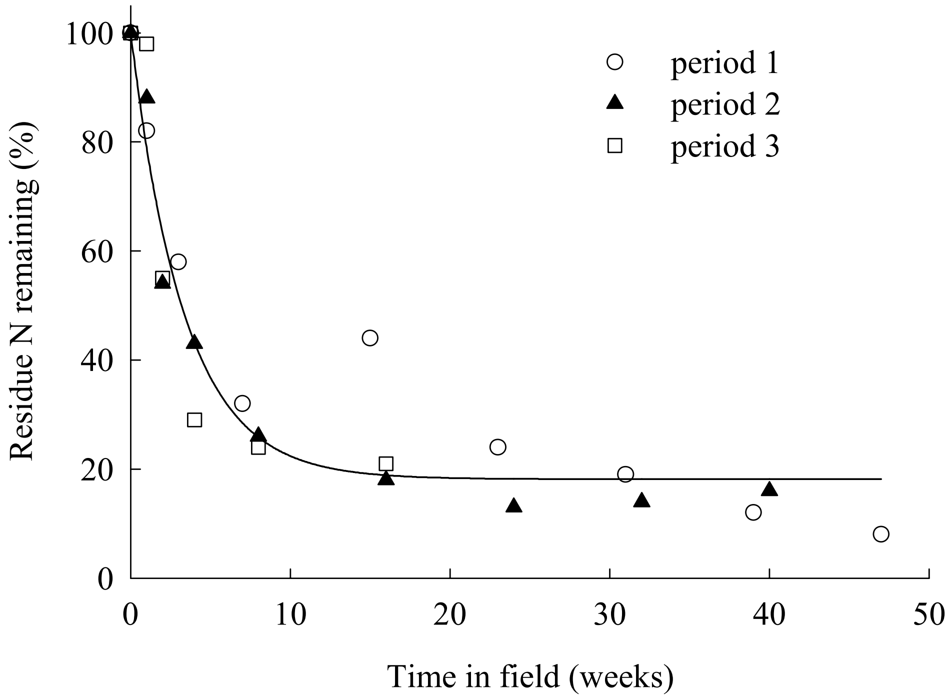

Figure 3. Nitrogen release from peach palm leaf residues during three placement periods at Guapiles, Costa Rica.

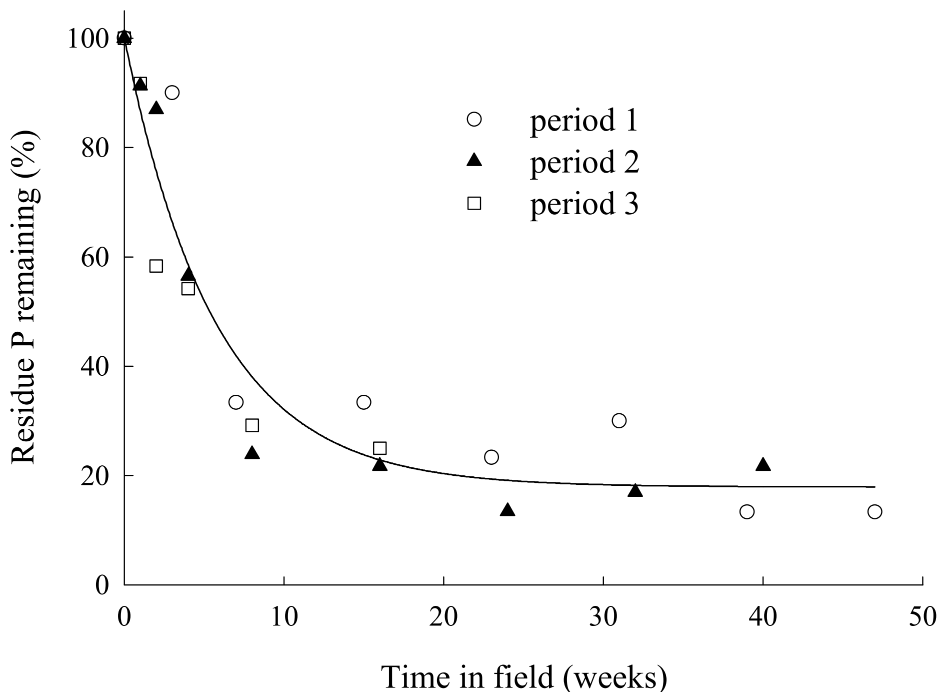

Figure 4. Phosphorus release from peach palm leaf residues during three placement periods at Guapiles, Costa Rica.

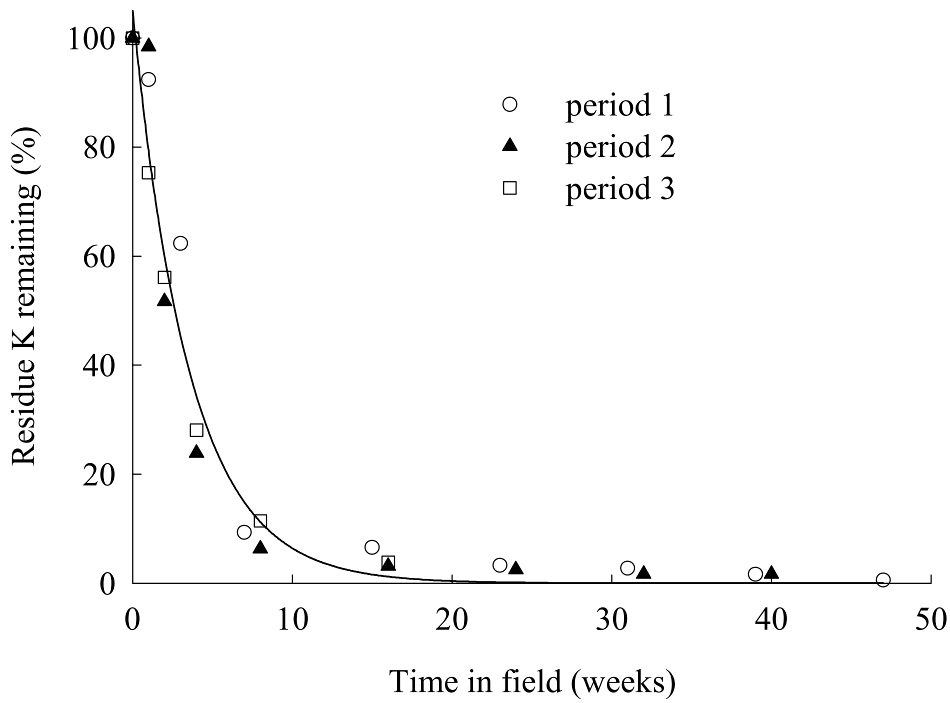

Figure 5. Potassium release from peach palm leaf residues during three placement periods at Guapiles, Costa Rica.

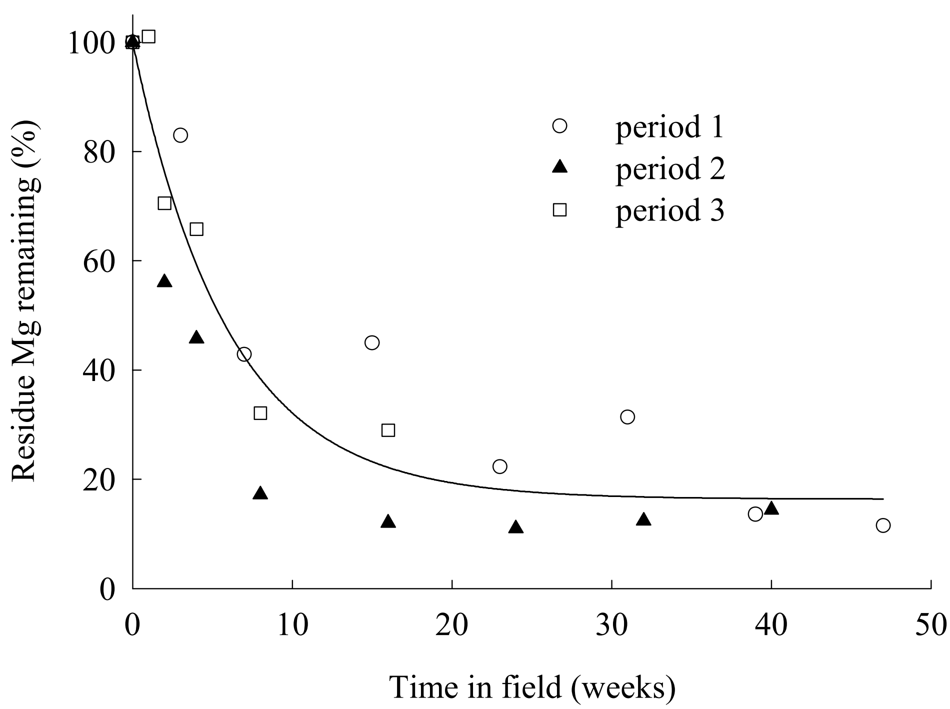

Figure 6. Magnesium release from peach palm leaf residues during threee placement periods at Guapiles, Costa Rica.

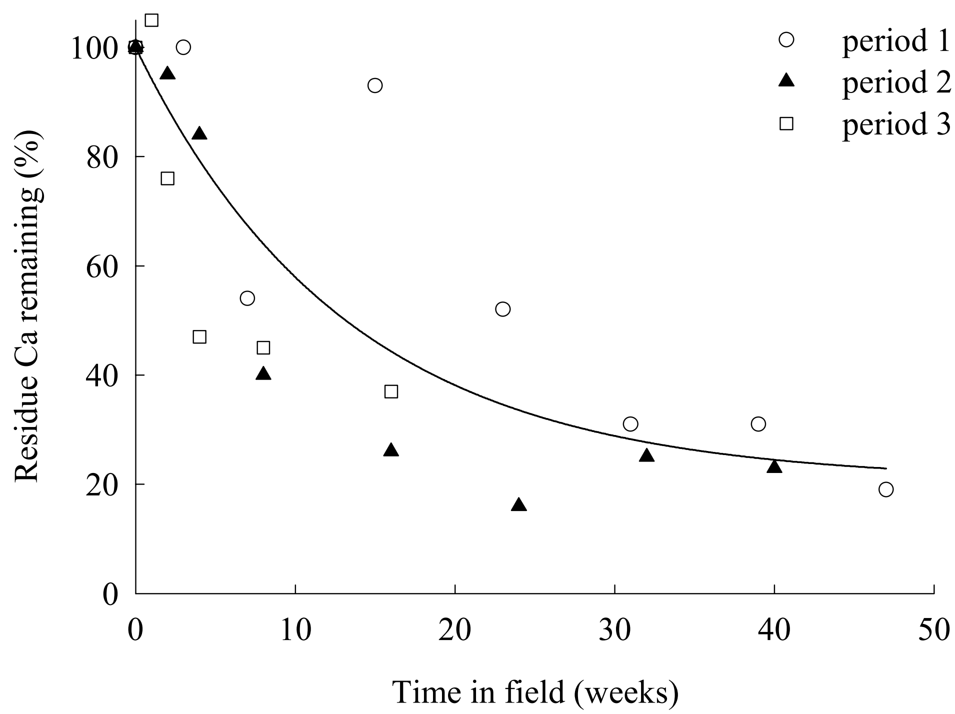

Figure 7. Calcium release from peach palm leaf residues during three placement periods at Guapiles, Costa Rica.

This production system has some unique characteristics with respect to climate conditions and harvesting system. After describing the nutrient release rate when one set of leaves is added to the soil, the effect of repeated additions (every 2 weeks) needs to be considered. The cumulative effect of these additions over one year is shown in Table 7. For example, total annual N added as foliar residue at harvest is 276 kg ha^{-1} yr^{-1}. Using the N release equation described in Table 6 for residue additions every 2 weeks, 78.2% (215 kg ha^{-1} yr^{-1}) of this N is released. In a long term production system such as heart of palm, it could be expected that the weekly N addition as result of periodic harvest will be 4.1 kg ha^{-1} wk^{-1}. It is clear that the nutrient release rate can vary, depending on climate conditions and crop management practices, even though no significant difference in nutrient release rate was observed for the different rainfall conditions in this study. Information on a weekly release of nutrient has implications with respect to the system synchrony between nutrient release and plant demand (Woomer and Swift, 1994), along with any potential requirement of supplemental fertilizer sources.

Table 7. Estimated weekly release of nutrients (N, P and K) in a 16-year old heart of palm production system.

PARAMETER	NUTRIENTS N	P	K
Foliar nutrient added at harvest (kg ha^{-1} yr^{-1})¶	276	22	149
Foliar nutrient added at harvest every two weeks (kg ha^{-1})	10.6	0.9	5.7
Total annual nutrient release from leaves (kg ha^{-1} yr^{-1})	215	17	141
% of nutrient release after 1 year of sequential harvests	78	74	95
Nutrient release per week from sequential harvests (kg ha^{-1})	4.1	0.3	2.7

¶ Based on 5000 plants ha^{-1} and 5 heart of palm harvests $plant^{-1}$ yr^{-1}.

It is important to emphasize that this study was conducted in a 16-year old plantation. Although Herrera (1989)notes that aboveground biomass and 'palmito' production reaches an equilibrium when plantations are 3-4 years old, Bogantes (personal communication) reported only two harvests per year per plant in a five year old system, as compared with 4 harvests a year reported by DEMASA personnel. Additional biomass data currently under collection will help determine the equilibrium point mentioned by Herrera (1989), or the turning point in the exponential curve of plantation biomass production over time. Nutrient release rate of leaf residue from palmito harvests is expected to be similar in the initial years or in an "equilibrium" plantation, but the total derived from these tissue will vary strongly depending upon the harvest frequency.

Future Research Plans

The collection of the data for this experiment is not yet complete. Besides collecting the last sets of litter bags for the third placement, work has begun to collect information on the decomposition rates of the tissue of the palmito stem left in the field at harvest. Also, we would like to examine the effect of any variation in leaf composition (1st leaf, 2nd leaf, etc.) in order to substantiate that the third leaf adequately characterizes the total leaf input. It would also be useful to relate the information of nutrient release to nutrient uptake, the fate of nutrient releases in the system, synchrony between the two processes, and if an equilibrium is eventually reached in plantations as old as this one.

Future trends for heart of palm include the use of spineless peach palm varieties and higher plant populations to initiate production with earlier harvests. These variables may affect the type and amount of biomass added to the field at harvest. New data will need to be collected under these changing conditions.

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