Developing a Nutrient Management Support System for ‘Palmito’

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Introduction

The Nutrient Management Support System (NuMaSS) is a Windows 9x/NT/XP-compatible software that helps in soil acidity, nitrogen and phosphorus management decisions for crops in tropical regions of Africa, Asia and Latin America (Osmond et al., 2004). Software development involved sixteen scientists from four U.S. universities (Cornell, Hawaii, North Carolina State and Texas A&M) and collaboration with investigators from agri-business and national/international institutes throughout tropical regions. Funding was provided by the U.S. Agency for International Development via a project of the Soil Management Collaborative Research Support Program. The current version (2.1) of the public-domain software can be downloaded from the website http://intdss.soil.ncsu.edu/.

User input of pertinent information for a specific site enables the software to provide information about the likelihood of soil nutrient limitations (*Diagnosis*), lime and fertilizer recommendations to correct identified nutrient constraints (*Prediction*) and an economic assessment based on locally available sources and amounts of lime and fertilizer inputs (*Economics*). Details about the overall structure, operation and algorithms of NuMaSS are described in a paper presented at a previous meeting of this Society (Smyth, 2004). The software contains an extensive database assembled from literature for 16 grain, fiber and tuber crops, and forage grasses and legumes which are extensively cultivated in tropical regions. Despite the emphasis on annual crops, a module was also included for tree crops using peach palm (*Bactris gasipaes* Kunth) for heart-of-palm production (palmito) as the test crop.

The purpose of this paper is to describe the approach used to assemble available information and investigate knowledge gaps pertinent to the development of a decision support system for nutrient management of palmito. Most of the field and laboratory investigations were conducted in the Atlantic region of Costa Rica in collaboration with investigators from the Center for Agronomic Investigations at the University of Costa Rica and the ‘Ministerio de Agricultura y Ganaderia’s Los Diamantes’ Experiment Station.

Characteristics of a Palmito Plantation

Peach palm is best suited to areas of high rainfall (2000 - 3000 mm/year) without dry spells, temperatures of 24 - 28° C and elevations up to 700 m (Clement, 1989). It is well adapted to nutrient poor, acid but well drained soils, and has a shallow root system concentrated in the surface 20 cm (Deenik et al., 2000; Salas et al., 2002).

Land area in humid tropical regions of Central and South America under palmito cultivation has increased during recent years in response to growing international and domestic markets. Estimates in 1996 were 24,000 ha of palmito in Bolivia, Brazil, Costa Rica and Ecuador, of which 41% was concentrated mainly among small-scale farmers in the northern and Atlantic regions of Costa Rica (Mora-Urpí et al., 1997). By 1998, land area for palmito production in Costa Rica had expanded by 30% (Mora-Urpí, 1999). Approximately 85% of palmito producers in Costa Rica have plantations that are < 5 ha in size, but they contribute 40% of the country's total production (Smith et al., 2002).

Palmito production, as described by Mora-Urpí et al. (1997), begins at about 18 months after transplanting seedlings from the nursery, with monthly harvests thereafter of offshoots reaching the desired commercial dimension (9 cm diameter at 20-30 cm above the ground for most Costa Rican processing plants). Foliage and outer fibrous leaf sheaths are removed from the stem and left as mulch between plant rows in the field. One or two non-commercial leaf sheaths remain on the stem to protect the palmito from moisture loss and mechanical damage during transport to the processing plant. After the initial harvest, offshoot clusters are pruned at least twice a year to maintain approximately six offshoots of different sizes for subsequent harvests. In plantations with 5000 plants/ha of the Utilis landrace, about 8000 palmitos/ha are harvested in the initial year of production, and 10,000/ha in each subsequent year. The productive lifespan of a palmito plantation remains uncertain but the oldest on record in Costa Rica is over 23 years.

In the newer plantations yields of 20,000 palmitos/ha at 10 months after transplanting and 22,000 palmitos/ha in each subsequent year have been recorded (Mora-Urpí, 2002). The primary factors attributed to increased production are increased stand densities (up to 13,333 plants/ha) and improved varieties.

In a review of existing fertilization practices, Deenik and co-workers (2000) found ranges in annual applications of 110 - 500 kg N ha^{-1}, 0 - 35 kg P ha^{-1}, 17 - 250 kg K ha^{-1}, and less frequent applications of S and B. Symbiotic relations with vesicular-arbuscular mycorrhizae may contribute to the crop's limited growth response to P fertilization. Information on nutrient exports in harvested palmito are limited to single measurements taken on one harvest date. Based on such data, Herrera (1989) estimated an export of 1.76 t ha^{-1} yr^{-1} of palmito biomass from a plantation in Costa Rica and annual removals of 28, 4.8 and 31 kg ha^{-1} yr^{-1} of N, P and K. In Brazil, Bovi (1998) estimated removals of 32, 6.4 and 45 kg ha^{-1} of N, P and K in 2.6 t ha^{-1} of exported biomass. Although significant quantities of residues remain in the field with each harvest, there is limited information on their decomposition rates and nutrient cycling potential (Deenik et al., 2000).

Growth Phases and Biomass and Nutrient Accumulation

Perennial crops have distinct growth phases wherein rates of biomass accumulation in above- and below-ground components and nutrient requirements may differ. Proper identification of growth phases, therefore, are important to determination of nutrient requirements from the initial growth at establishment to a relative equilibrium in biomass at the mature phase.

Ares and co-workers (2002a) evaluated biomass and nutrient accumulation in palmito via destructive sampling of 200-m^2 plots for18 plantations in Ultisols, Andisols and Inceptisols of Costa Rica, ranging in age from 1 - 20 years and plant densities of 3150 - 7250 plants ha^{-1}. Nutrient analysis was performed on sub-samples of stems, leaves and petioles. Biomass accumulation with plantation age was affected by stand density, but not by soil type. As shown in Figure 1, stands with >4200 plants ha^{-1} accumulated dry matter at a faster rate and approached the maximum dry weight of 6.31 t ha^{-1} at an earlier age than stands with <4200 plants ha^{-1}.

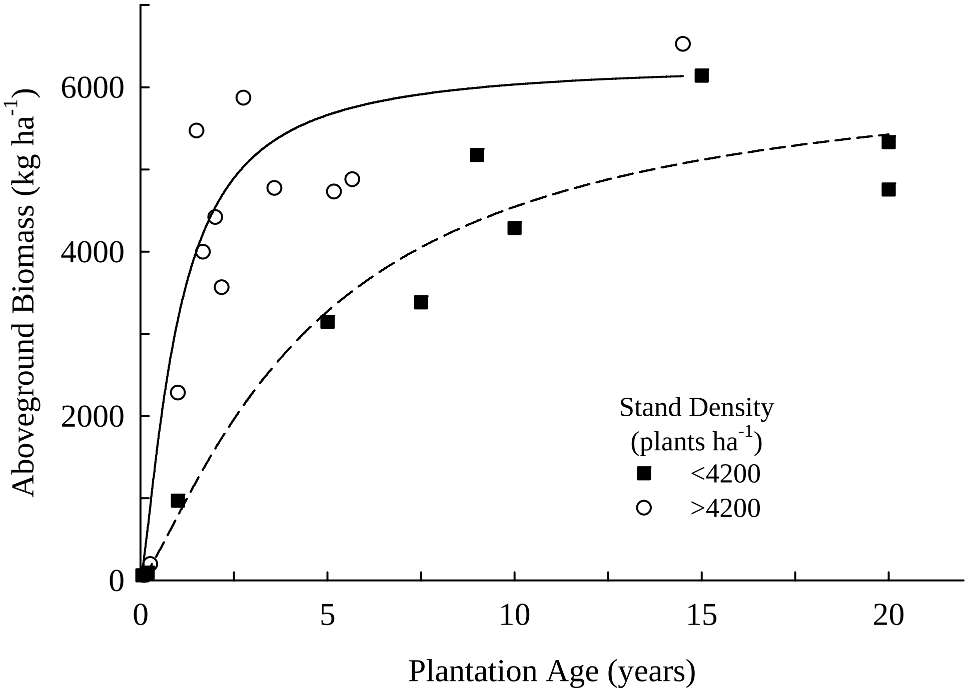


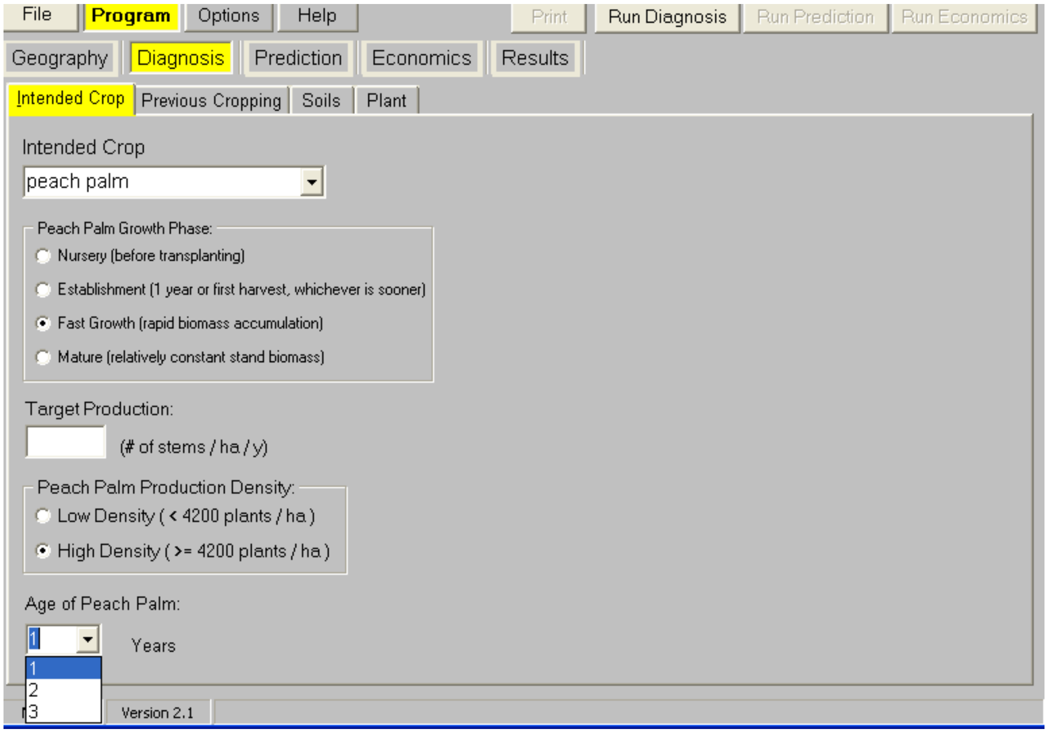
Figure 1. Aboveground biomass accumulation for palmito plantations with different stand densities and ages in the Atlantic region of Costa Rica (Ares et al., 2002a).

The prediction equations were:
$Y = 6310 / (1 + (X / 4.672)^{-1.258})$ for stand densities of <4200 plants ha^{-1} and
$Y = 6310 / (1 + (X / 0.990)^{-1.347})$ for stand densities of >4200 plants ha^{-1}, where Y is kg ha^{-1} of aboveground dry matter and X is in years. Therefore, estimates of aboveground biomass require knowledge of (a) stand density and (b) age of the plantation. Plantations with >4200 plants ha^{-1} achieved 50% of their maximum biomass within one year after seedlings were transplanted from nurseries, whereas it took 4.7 years to achieve the same % of maximum biomass in plantations with lower plant densities.

Based on these trends in biomass accumulation, palmito growth phases were delineated as follows for each class of stand density:

- *Establishment* - 0 - 1 year after seedlings are transplanted to the field from nurseries; a similar period on both stand density classes, wherein no palmitos are generally harvested.
- *Rapid phase* - biomass accumulation increases as does plamito production; 1 -3 years for stands with >4200 plants ha^{-1} and 1-8 years for stands with <4200 plants ha^{-1}.
- *Maturity* - the plantation achieves a stable level of aboveground biomass and palmito production; >3 years for stands with >4200 plants ha^{-1} and >8 years for stands with <4200 plants ha^{-1}.

Information about palmito growth phases is incorporated into the *Intended Crop* page of the *Diagnosis* section of NuMaSS (Figure 2). Therein the user is asked to identify the growth phase and stand density of the palmito plantation. Upon making these selections, the user is then asked to identify the plantations age within the range of years for the chosen growth phase and stand density.



Intended Crop

peach palm

Peach Palm Growth Phase:

○ Nursery (before transplanting)
○ Establishment (1 year or first harvest, whichever is sooner)
● Fast Growth (rapid biomass accumulation)
○ Mature (relatively constant stand biomass)

Target Production: (# of stems / ha / y)

Peach Palm Production Density:

○ Low Density (< 4200 plants / ha)
● High Density (>= 4200 plants / ha)

Age of Peach Palm:

1 Years

1
2
3

Figure 2. Incorporation of growth phases, stand density and age intervals of each phase into the NuMaSS software's *Diagnosis.*

Nutrient accumulation across palmito stands with different ages was more variable than dry matter accumulation and did not differ significantly between stand densities. Nevertheless, data for N accumulation provided information for several components of a N recommendation during the establishment and fast growth phases of a palmito plantation (Figure 3). The intercept for the equation of N with stand age ($Y = 43 + 5.7X$), indicates that 43 kg N ha^{-1} would be accumulated in the above ground biomass during the plantation establishment phase (0 - 1 year). During the fast growth stage, a low-density plantation (<4200 plants ha^{-1}) would accumulate an additional

5.7 kg N ha^{-1} each year from 1 to 8 years. In a high density plantation (>4200 plants ha^{-1}), the fast growth phase only encompasses 3 years and an additional 14.7 kg N ha^{-1} are accumulated in the above ground biomass each year.

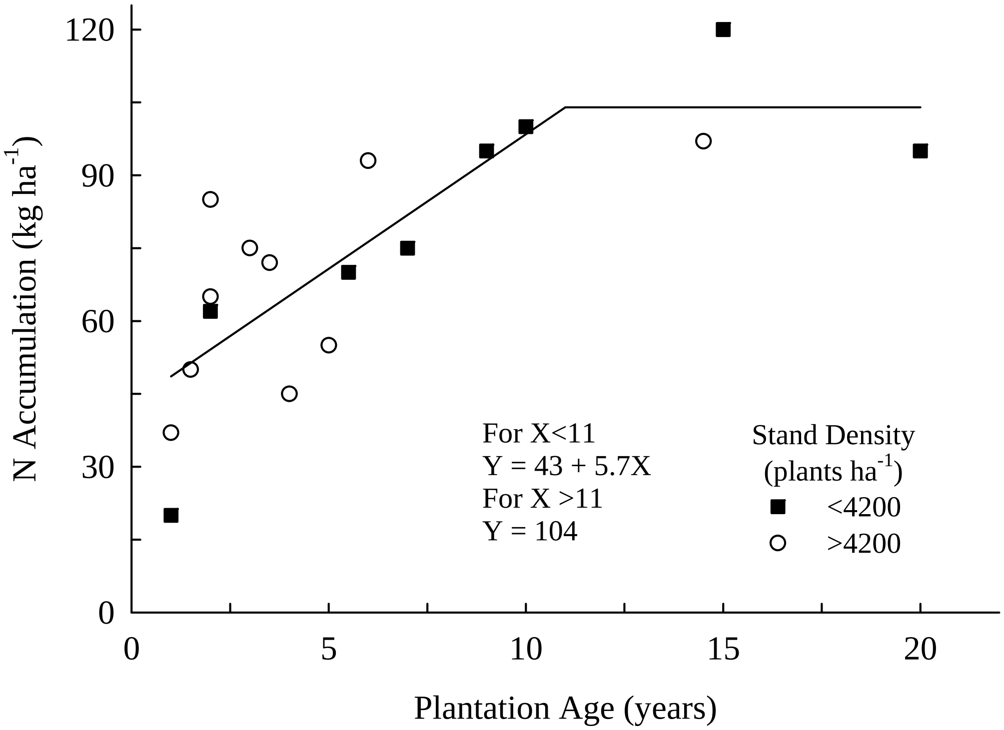


Figure 3. N accumulation in above ground palmito biomass as a function of plantation age and stand density. Adapted from Ares et al., 2002a.

Export and Recycling of Biomass and Nutrients in Harvested Palmitos

Good nutrient management practices need to account for both the nutrients exported through harvests as well as the quantities recycled as residues left in the field. For palmito production systems, residues include both the foliage and outer sheaths of harvested shoots and any excess shoots periodically pruned from each plant to maintain a constant number of stems for future harvests. Dry matter and nutrient content of harvested palmitos and their field residues (leaves, sheaths and pruned shoots) were measured at 4-week intervals throughout an entire year in plantations with 4 and 8 years on Dystrudepts and Hapludands in Guapiles, Costa Rica (Molina et al., 2002a). After the final harvest at 52 weeks, plants in each of the six replicates of each plantation age were destructively sampled to acquire estimates of the above ground live biomass which was not harvested or recycled during the year.

Although distribution of harvested palmitos throughout the year differed between plantations, the total number harvested, and the recycled and live vegetative biomass were similar for both the 4- and 8-year plantations. Mean values of harvested, live and total biomass for the two plantations are shown in Table 1. Of the 20.3 t ha^{-1} of total dry matter in the system, results show that 71% was comprised by stems cut for palmito and pruned shoots. Among the 14.4 t ha^{-1} of dry matter that was cut during the year, only 10% was exported from the field as palmito and protective sheaths. Sixty-eight % of the cut dry matter which was harvested each year consisted of foliage left in the field.

Table 1. Mean total dry matter for 4- and 8-year palmito plantations at Guapiles, Costa Rica and distribution of dry matter among harvested and standing live vegetation components.

	Harvested	**Dry Matter**				
	Palmitos	**Foliage**	**Sheaths**	**Palmitos**	**Prunings**	**Total**
	no. ha^{-1}	----------------------------- kg ha^{-1} -----------------------------				
Harvested	11214	9824	3568	637	416	14445
Vegetative	--	3179	808	276	1619	5882
Total	11214	13003	4376	913	2035	20327

Adapted from Molina et al., 2002a.

There was a highly significant and linear relation across both plantations between the total dry matter of stems harvested every 4 weeks for palmito and the number of stems havested (Figure 4). The slope of the regression predicts that each harvested stem has 1.04 kg of dry matter. Through similar regressions between kg ha^{-1} of nutrients and dry matter for stems harvested every 4 weeks in each plantation, the following values were also determined for nutrient concentrations in the harvested stems: 1.4% N, 0.27% P, 1.6% K, 0.37% Ca and 0.21% Mg. The r^2 values for all these regressions ranged from 0.96 - 0.99 and suggest a fairly constant distribution of dry matter and nutrients among components of harvested stems. However, these estimates of dry matter and nutrient concentration are only representative of plantations which are harvested under the commercial criteria of 9-cm basal diameter stems as used in Costa Rica. Similar studies would be needed to adjust dry matter and nutrient export values for regions where commercial criteria for stem harvests are different.

The mean annual balance across the 4- and 8-year plantations for N, P and K among standing vegetation, and the recycled and exported components of harvested stems are shown in Figure 5. Total accumulation in kg ha^{-1} was 249 for N, 283 for K and 56 for P with a relative ranking of nutrients in the order K > N > Ca > P > Mg. Harvested palmito stems account for 64 - 71% of the total N, P and K, but only 9 - 11% of the total accumulated N, P and K is exported from the field in the palmitos and inner stem sheaths.

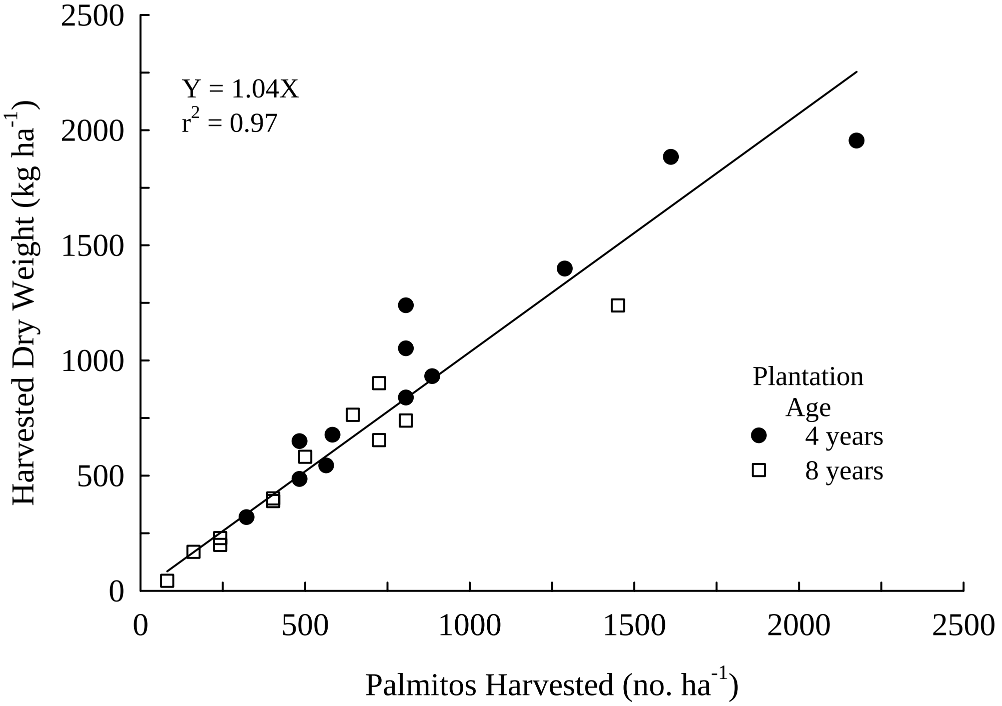


Figure 4. Dry weight of harvested stems as a function of the number of stems havested during 52 weeks in 4- and 8-year palmito plantations at Guápiles, Costa Rica. (Molina et al., 2002a).

These collective data were used to derive an equation for NuMaSS to estimate the quantity of N that is exported from the field with palmito harvests. Protective stem sheaths and each palmito have an average dry weight of 0.13 kg and contain 0.0178 kg of N. Therefore, the N exported during a full year of palmito harvests (N_harvest) can be determined as

$$\text{N\_harvest in kg ha}^{-1} = \text{Target\_yield} * 0.0178 \text{ kg N/palmito}$$

where Target_yield is the number of palmitos/ha to be harvested during the upcoming year.

Replacement of N exported in palmito harvests is one of several components considered in a fertilizer N recommendation by NuMaSS. The N_harvest value is estimated by the equation above, based on the Target Production value (number of stems/ha/year) which the user provides on the *Intended Crop* page of the *Diagnosis* section of NuMaSS (Figure 2).

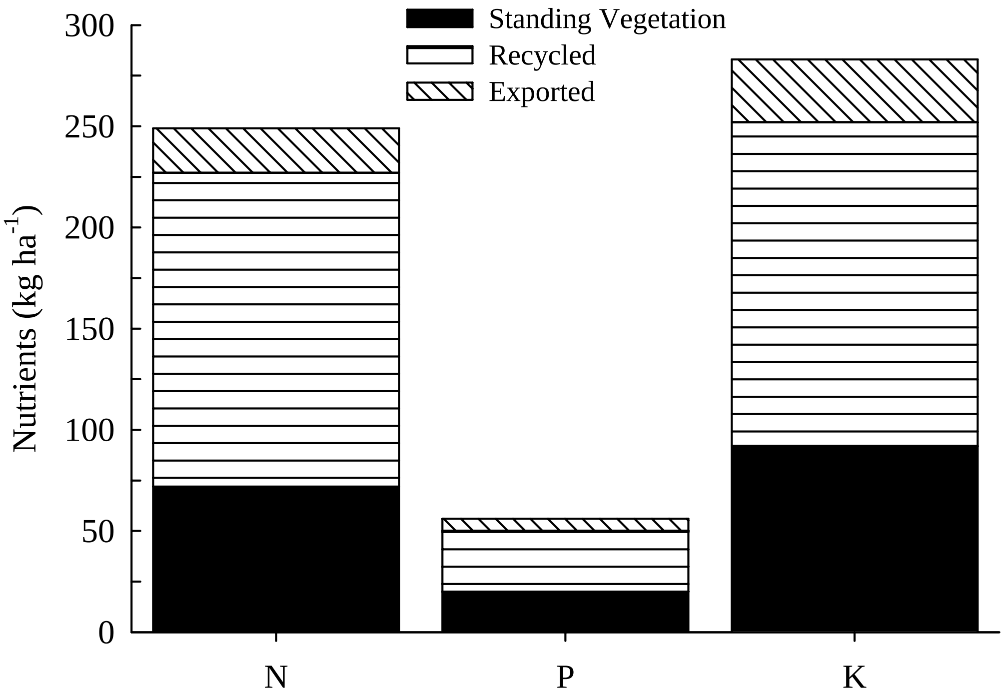


Figure 5. Mean annual balance for N, P and K exported, recycled and in standing vegetation of 4- and 8-year palmito plantations at Guápiles, Costa Rica. (Molina et al., 2002a)

For each harvested palmito, an average of 0.88 kg of foliage litter containing 0.0148 kg of N is left in the field . Upon decomposition of the foliage litter, the N and other nutrients therein are a potential source for recycling nutrients into actively growing plants. Soto and co-workers (2002, 2005) conducted litterbag decomposition studies with palmito foliage in a 16-year plantation at Guápiles, Costa Rica. Quantities and patterns of residue decomposition and nutrient release were determined in three replicated series of 48-week decomposition trials during separate seasonal periods of high and low rainfall. Soil water differences between the decomposition series did not affect residue or nutrient loss over time from the litterbags in this environment where monthly rainfall exceeds 100mm throughout the year.

Residue dry matter loss and nutrient release from litterbags followed an exponential pattern and are illustrated in Figure 6 for dry matter and Figure 7 for N release. Foliage dry matter loss from the bags was 50% after 7 weeks and 70% by 15 weeks. The release of nutrients was similar to that of dry matter loss and in the order of N = K > P > Mg >Ca with rate constant values ranging from 0.282 wk^{-1} for N to 0.164 wk^{-1} for Ca (Soto et al., 2002, 2005).

Palmitos are harvested in Costa Rica at approximately monthly intervals throughout the year. Therefore, at any given point in time, there are various fractions of foliage residue at different stages of decomposition and nutrient release. The integration across time of the nutrient released

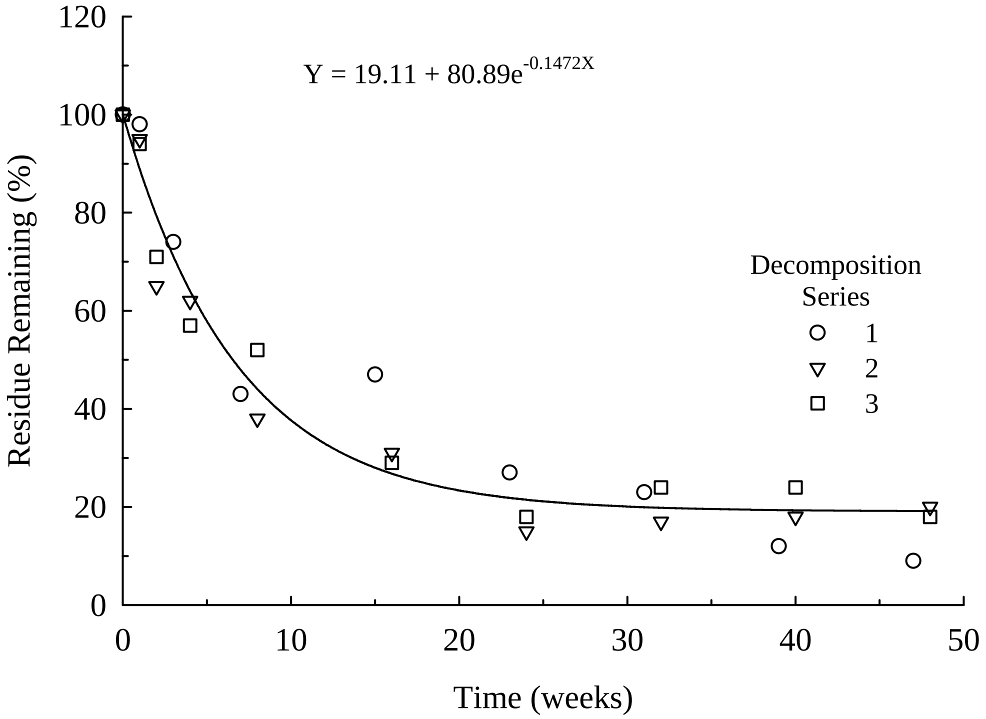


Figure 6. Percentage of initial palmito foliage dry matter remaining in litterbags as a function of time after placement in a 16-year plantation at Guápiles, Costa Rica for three different series of time. (Soto et al. 2002)

by each fraction would, thus, provide an estimate of the pool available for recycling in a palmito plantation.

Molina and co-workers (2002c) evaluated palmito response to 5 rates of fertilizer N for 52 weeks in a 4-year plantation at Guápiles, Costa Rica. With each palmito harvest approximately every 4 weeks, foliage residue dry matter and N content was also determined. Application of the equation in Figure 7 for N release from foliage residue led to estimates of the total amount of N released from decomposing foliage across 52 weeks in each replicated N treatment. Results are illustrated in Figure 8 for the treatment receiving 200 kg N ha^{-1}. A total of 15001 palmitos/ha were harvested during the 52 weeks and a total of 8583 kg ha^{-1} of foliage dry matter residues were left in the field. Of the 280 kg N ha^{-1} in foliage residue, 69% (193 kg N ha^{-1}) was predicted to have been released during foliage decomposition across the 1-year period. Although palmito yields, foliage dry matter and total foliage residue N decreased with less applied fertilizer N (0, 50 and 100 kg ha^{-1}) predictions of total foliage N litter released through decomposition for 1 year averaged 80% for all treatments.

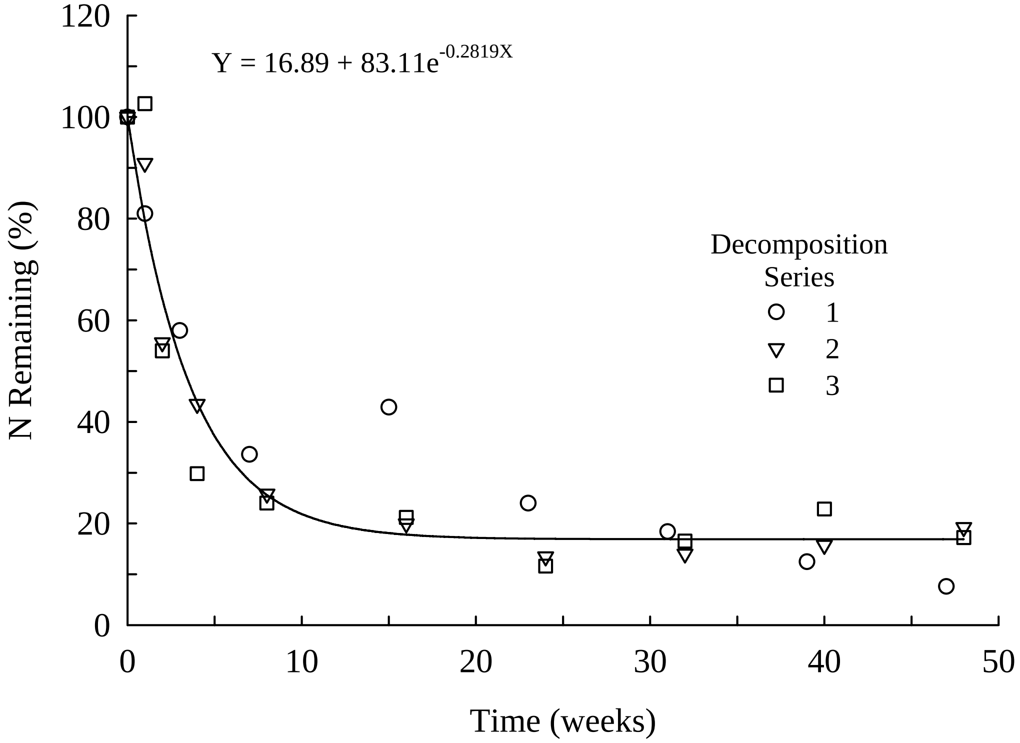


Figure 7. Percentage of initial palmito foliage N remaining in litterbags as a function of time after placement in a 16-year plantation at Guápiles, Costa Rica in three different time series. (Soto et al., 2002)

These results for simulated foliage N release and the previous estimate of 0.0148 kg of N in foliage residues per harvested palmito led to the following equation in NuMaSS to estimate the amount of Recycled_N in a palmito plantation:

$$\text{Recycled\_N in kg ha}^{-1} = \text{Previous\_Yield} * 0.0148 \text{ kg foliage N/ha} * 0.80$$

where Previous_Yield is the number of palmitos/ha harvested during the previous year. This equation for Recycled_N is applied to the value of palmito yield (number of stems/ha/year) that the user provides on the *Previous Crop* page of the *Diagnosis* section (Figure 9). By estimating N release from foliage litter corresponding to palmito yield in the previous year, NuMaSS is making a conservative estimate of the Recycled_N pool which, nevertheless, is valid in the event that the targeted yield for the upcoming year is not achieved.

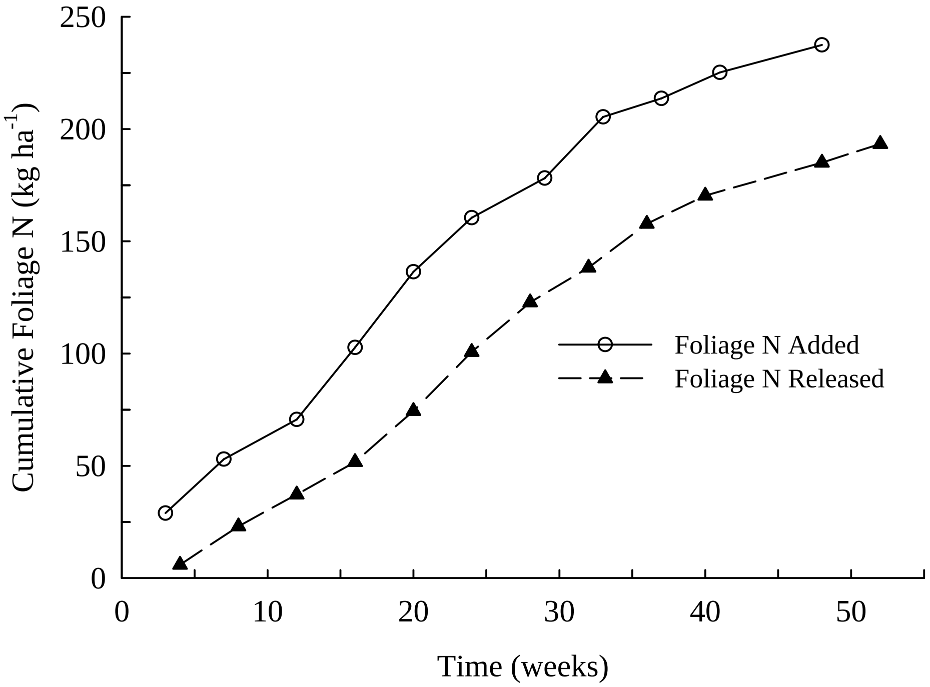
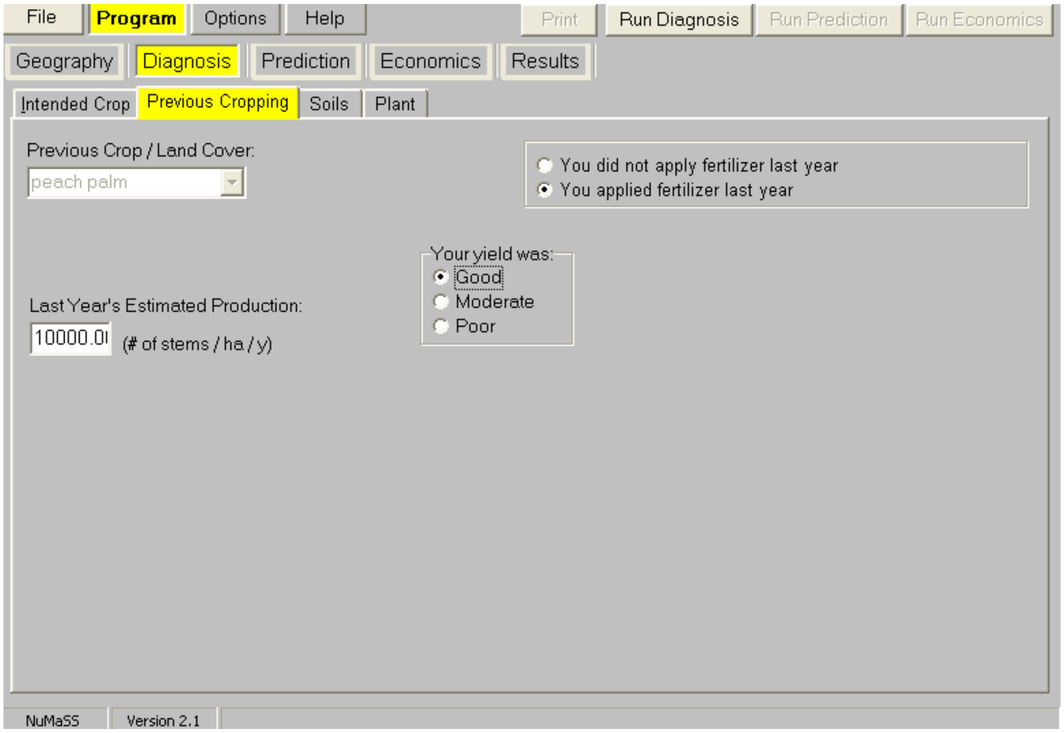


Figure 8. Cumulative N added as foliage litter from palmito harvests and predicted cumulative N released from foliage decomposition during 52 weeks in a 4-year plantation at Guápiles, Costa Rica receiving 200 kg N ha^{-1} yr^{-1} as urea fertilizer. (Adapted from Molina et al., 2002c)

Fertilizer N Use Efficiency and N Recommendations

An important component of a N recommendation is the proportion of applied fertilizer N which is actually taken up by the crop, or fertilizer N use efficiency. In the absence of ^{15}N-labeled fertilizer, the proportion of N accumulation in plants derived from the fertilizer can be assessed via an N balance sheet with the important assumption that the quantity of plant N derived from native soil reserves is constant across all rates of fertilizer N used.

Molina and collaborators (2002bc) evaluated palmito yield response and plant N accumulation with five annual rates of fertilizer N (0, 50 100, 200 and 400 kg ha^{-1}) during two consecutive years in a 5-year stand on an Aquandic Dystrudepts near Guápiles, Costa Rica. Nitrogen fertilizer, as NH_4NO_3, was surface-applied between plant rows in six equal split-applications every 60 days. Palmito stems in each of the four treatment replicates were harvested every 4 weeks throughout the year, sub-divided into harvested components, weighed and analyzed for tissue N concentration. Standing vegetation dry matter and N accumulation was determined each year by destructively sampling two plants in border rows of each plot after the final harvest date in each crop year.



Previous Crop / Land Cover: peach palm

○ You did not apply fertilizer last year
● You applied fertilizer last year

Your yield was:
● Good
○ Moderate
○ Poor

Last Year's Estimated Production: 10000.0 (# of stems / ha / y)

Figure 9. Incorporation of palmito yield from the previous crop year into NuMaSS *Diagnosis*.

Cumulative annual palmito yields across fertilizer N treatments for each of the two years are shown in Figure 10. Yields for all treatments, except 200 kg N ha^{-1}, were greater in the second year. The unusually low yield for 200 kg N ha^{-1} in the second year could not be attributed to outliers among replicates, nor is it supported by plant N accumulation data. Nevertheless, yield responses across the two years place fertilizer N requirements for optimum yield in the range of 193 - 400 kg N ha^{-1} year^{-1}.

Total N accumulation in the harvested palmito biomass, estimates of N released through decomposition of cut foliage litter and N accumulation in the standing biomass are shown in Table 2 for each crop year. Using the assumption that the native soil N supply is constant for all N treatments, the quantity of accumulated N derived from fertilizer N (denoted as “apparent N recovery”) can be estimated by subtracting N accumulated in the zero-N treatment from that for treatments receiving fertilizer N. In a system where the harvested foliage remains as field residues, some of the N released during decomposition originally came from fertilizer N; an adjustment is, therefore, needed to account for fertilizer N in harvested foliage that is released by the foliage litter and could again be recycled into the total N accumulation values. This adjustment on N accumulation in the harvested biomass is achieved by the following calculation:

Apparent Fert. N_Harvested = (Total Fert N_Harvested - Total 0-N_Harvested) -
(Foliage Fert N_Released - Foliage 0-N_Released)

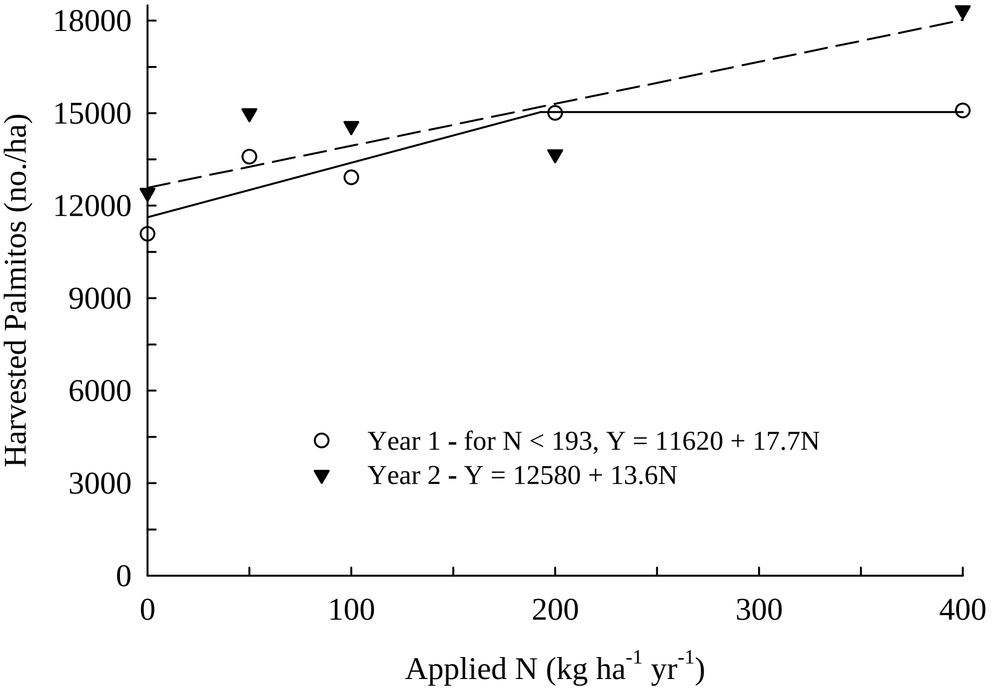


Figure 10. Harvested palmitos as a function of applied N during two consecutive years for a 5-year stand in an Aquandic Dystrudepts at Guápiles, Costa Rica. (Adapted from Molina et al., 2002b).

where “Fert_N” denotes a treatment receiving N fertilization and “0-N” denotes the treatment without N fertilization.

The total apparent N recovery for the palmito system, therefore, is the summation of apparent N recovery values for N accumulation in both the harvested and standing biomass components. The relations between total apparent fertilizer N recovery and rates of applied N are shown in Figure 11 for both crop years. Data for the treatment with 400 kg N ha^{-1} in the first crop year were excluded, because there was no yield response above 200 kg N ha^{-1} (Figure 10). All treatments, except for 200 kg N ha^{-1} in the second crop year, were adequately described by a linear relation with a zero intercept; nevetheless, this outlier was included in the regression. The slope of the equation, kg ha^{-1} of fertilizer N recovered / kg ha^{-1} of applied fertilizer N, provides a mean estimate of 57% for fertilizer N efficiency across agronomically-relevant fertilizer N rates during the two crop years in this palmito stand.

Nitrogen fertilizer recommendations in NuMaSS depend primarily on plant data, and correspond to the difference between the amount of total N accumulated by the crop to achieve the targeted palmito yield and the quantity of accumulated N that can be acquired from the native soil reserves, recycled foliage and manures. The deficit in plant-required N is then adjusted for the fertilizer N use efficiency. As a perennial crop, N recommendations also need to consider differences in growth stages and stand densities.

Table 2. Nitrogen accumulation in harvested palmitos and standing biomass, foliage litter N release and apparent N recovery in harvested and standing biomass in two consecutive years for fertilizer N treatments applied to a 5-year stand at Guápiles, Costa Rica.

Applied	**Harvested Palmitos and Foliage**			**Standing Biomass**	
N	**Total**	**Foliage Release**[a]	**App. N Rec.**[b]	**Total**	**App. N. Rec.**[c]
kg ha^{-1} yr^{-1}	---------------------------------- kg N ha^{-1} ----------------------------------				
Year 1					
0	155	79		93	
50	228	118	34	103	10
100	217	113	28	118	25
200	349	193	80	107	14
400	363	181	–[d]	189	–[d]
Year 2					
0	229	134		82	
50	280	162	23	106	25
100	259	157	7	133	52
200	282	165	22	253	171
400	374	229	50	225	143

[a] N release from foliage litter estimated by applying the equation in Figure 7 to the foliage N harvested with palmitos every 4 weeks.

[b] Apparent N Recovery of N in Harvested Stems = (Total N_Fert - Total N_0-N) -
(N Release_Fert - N Release_0-N)

[c] Apparent N Recovery of N in Standing Biomass = Total N_Fert - Total N_0-N

[d] Treatment excluded from Apparent N Recovery because it exceeded the N rate for optimum palmito yield.

Source: Molina et al., 2002b.

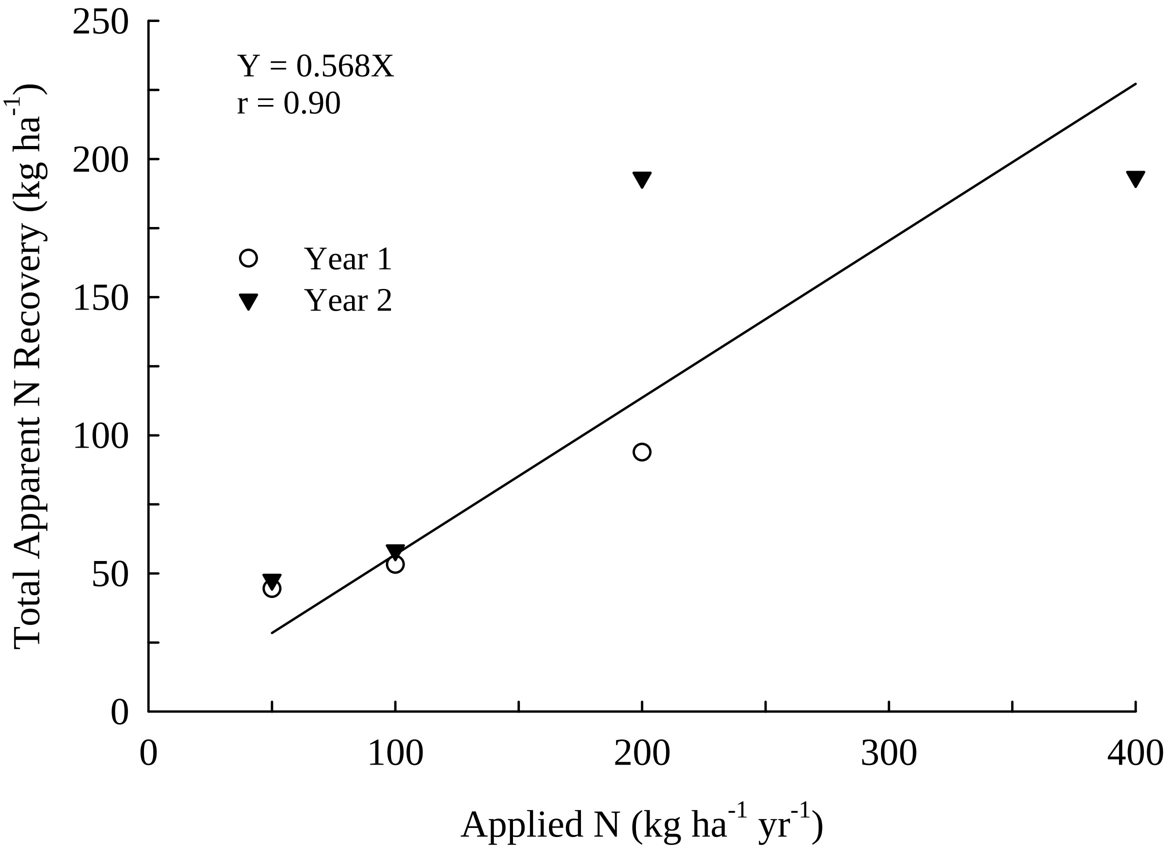


Figure 11. Total apparent N recovery in harvested and standing biomass as a function of annual fertilizer N treatments during two consecutive years in a palmito stand near Guápiles, Costa Rica. (Source: Molina et al., 2002b)

Based on the information previously described in this paper, the following equations were developed to estimate fertilizer N recommendations in each growth stage of a palmito plantation. Establishment - in this first year of growth after seedlings are transplanted from the nursery to the field, approximately 43 kg ha^{-1} are accumulated during plant growth (Figure 3). Therefore,

$$\text{Fertilizer N in kg ha}^{-1} = \text{N\_Growth} / E_f$$

where N_Growth = 43 kg ha^{-1} and E_f = the fertilizer N use efficiency. Since the plant root system is also developing during this growth phase, fertilizer N use efficiency is probably less than that determined in the fast or mature growth phases. NuMaSS recommends an E_f value of 35%, but the user can choose any value.

Rapid Growth - the length of this phase varies with stand density. Plants continue to accumulate biomass, but palmitos are also harvested and foliage litter begins to decompose and re-cycle nutrients. The general expression for fertilizer N, therefore, becomes

$$\text{Fert. N in kg ha}^{-1} = ((\text{N\_Growth} + \text{N\_Harvest}) - (\text{N\_Re-cycled} + \text{N\_Soil})) / E_f$$

where

N_Growth= 5.7 kg ha^{-1} yr^{-1} for stands with <4200 plants/ha, and 14.7 kg ha^{-1} yr^{-1} for stands with >4200 plants/ha;

N_Harvest = targeted_palmito_harvest * 0.0178 kg N/palmito;

N_Re-cycled = previous_year_palmito_harvest * 0.0148 kg N/palmito_foliage * 0.80 foliage_N_release/year; and

N_Soil = is N absorbed by the crop from mineralization of soil organic matter.

As described elsewhere (Smyth, 2004), the value of N_Soil can also be provided from the user's experience at the site, thus over-riding the estimate from soil organic matter mineralization.

Maturity - since the crop has achieved a stable level of aboveground biomass and accumulated nutrients, the N_Growth component is no longer considered. Therefore

$$\text{Fert. N in kg ha}^{-1} = (\text{N\_Harvest} - (\text{N\_Re-cycled} + \text{N\_Soil})) / E_f$$

NuMaSS can adjust the final fertilizer N recommendation for other sources of N inputs like composts and animal manures, using the same algorithms for organic amendments that are used for other crops considered by the software (Smyth, 2004).

P Fertilizer Response and Recommendations

In a review of literature on fertilization practices for palmito Deenik and co-workers (2000) found a broad range of regional fertilizer P recommendations across Brazil and Costa Rica, but concluded that additional investigations were needed to characterize this crop's requirements for and yield response to P at different growth stages. Phosphorus fertilization trials in a greenhouse near Guapiles, Costa Rica and a field trial near Caño Negro, Costa Rica were conducted to evaluate palmito growth response and soil P requirements during the nursery and fast growth stages, respectively (Ares et al., 2002b).

The greenhouse trial evaluated growth response of 30-cm tall palmito seedlings to multiple rates of P fertilizer in surface samples (0-20 cm) of 5 Andisols and 5 Ultisols collected in a transect extending from the northern side of Turrialba volcano to the Los Chiles province in northern Costa Rica. Initial soil P levels with the Modified Olsen extractant ranged from 2 to 8 mg l^{-1} among the soils and soil pH values ranged from 4.2 to 5.7 (Table 3). Ammonium oxalate-extractable Al among the Andisols ranged from 1.9 to 3.2% and clay content, among the Ultisols ranged from 54 to 72%. Six P treatments (including a zero P rate) were applied to each soil, with a targeted Olsen P value of 10 mg l^{-1} at the intermediate level and two additional Olsen P values above and below this level. Quantities of P applied to each soil were based on soil P buffer coefficients (mg Olsen P l^{-1} / mg fertilizer P l^{-1}) pre-determined in laboratory incubations with four rates of applied P (0 to 140 mg l^{-1}).

There was a significant linear response to applied P in plant dry weight for 7 soils (3 Andisols and 4 Ultisols) and in plant height for 5 soils (2 Andisols and 3 Ultisols). As shown in Table 4,

Table 3. Selected characteristics for soils used in the greenhouse experiment.

Soil		**Oxalate**		**Org.**		**Effective**	**Olsen**
Order	**Number**	**Al**	**Clay**	**Matter**	**pH**	**CEC**	**P**
		--------------- %		----------------		cmol$_c$ l^{-1}	mg l^{-1}
Andisol	1	2.1	--	8.6	4.5	5.08	6.0
	2	1.9	--	6.6	4.7	3.53	5.3
	3	1.9	--	7.9	5.3	5.78	4.1
	4	1.9	--	7.6	5.3	5.10	3.0
	5	3.2	--	14.5	5.3	4.62	2.4
Ultisol	6	0.4	54	2.1	4.6	3.20	5.7
	7	0.4	72	2.9	4.7	3.26	3.2
	8	0.3	55	7.4	5.7	17.71	7.3
	9	0.7	72	6.3	4.6	5.67	7.6
	10	0.7	60	7.4	4.2	6.36	4.9

Source: Ares et al., 2002b.

Table 4. Modified Olsen-extractable soil P at harvest and P content of palmito seedlings, averaged across six fertilizer P treatments in 5 Andisols and 5 Ultisols.

Olsen-extractable Soil P	**P in Aboveground Harvested Seedlings**
mg l^{-1}	%
7.7	0.16
10.1	0.14
10.5	0.15
11.7	0.16
12.6	0.17
16.7	0.18

Source: Ares et al., 2002b.

plant P concentration, averaged across soils, increased with Modified Olsen soil P measured at harvest. The plant P concentration of 0.14% at 10.5 mg Olsen soil P l^{-1} approximates the lower limit of P sufficiency Molina (1999) observed for the third leaf in palmito plantations. Despite these evidences of a growth response to P during the nursery stage of palmito, no consistent soil test P critical level was identified either within or across soils investigated.

The P fertilization trial at Caño Negro, Costa Rica was in a high density (10000 plants/ha) 2-year palmito stand on an Inceptisol with ranges of 29 to 56 % clay and 2.5 to 3.1 mg l^{-1} Olsen-extractable P in the surface soil layer (0-5 cm) among the four replications. Six P treatments (0, 4, 8, 14, 21 and 48 kg ha^{-1} yr^{-1}) were surface-applied, during the first year, in two equal applications at a 6-month interval. All plots also received uniform applications of N, K, Mg and S. The same quantities of N, K, Mg and S were applied in the second year, and fertilizer P was re-applied in two equal split applications at rates of 0, 8, 16, 29, 42 and 95 kg ha^{-1} yr^{-1}.

Although P fertilization increased Olsen-extractable soil P (0 - 5 cm depth) to 8.5 mg l^{-1} in the first year and 24.2 mg l^{-1} in the second year, cumulative increments in the fresh weight of palmitos harvested of 1453 kg ha^{-1} in the first year and 1747 kg ha^{-1} in the second year among P treatments were not significantly different (Table 5). Phosphorus concentration in the third leaf increased with P fertilization and with time during the 2 years of the experiment, but there was also considerable fluctuation in mean leaf P values across sampling dates.

Table 5. Mean annual Olsen-extractable soil P (0-5 cm) and cumulative palmito fresh weight yields as a function of P fertilization treatments for two years on an Inceptisol at Caño Negro, Costa Rica.

Applied	**First Year**		**Applied**	**Second Year**	
P	**Olsen P**	**Yield**	**P[a]**	**Olsen P**	**Yield**
kg ha^{-1}	mg l^{-1}	kg ha^{-1}	kg ha^{-1}	mg l^{-1}	kg ha^{-1}
0	5.2	14785	0	7.3	12109
4	4.8	14840	8	7.7	12961
8	5.6	15857	16	8.9	12294
14	5.8	15152	29	11.2	11814
21	6.5	16238	42	14.3	12882
48	8.5	15947	95	24.2	13561

[a] Fertilizer P applied during the second year of the experiment.

Source: Ares et al., 2002b.

Additional evidence of little or no palmito yield response to P fertilizer was obtained in on-farm field trials which Alvarado and co-workers (2002) conducted for 30 weeks on 3 Andisols and 3 Ultisols in the Caribbean region of Costa Rica. Initial characteristics of the plantations and selected soil properties are shown in Table 6. Plantation stands ranged from 2 to 11 years, with stand densities ranging from 4450 to 6975 plants/ha and 3.0 to 12.5 mg l^{-1} of Olsen-extractable soil P.

Table 6. Initial palmito plantation and surface (0-20cm) soil characteristics for on-farm test sites in Costa Rica.

Soil		**Stand**			**Effective**	**Al**	**Organic**	**Olsen**
Order	**Site**	**Age**	**Density**	**pH**	**CEC**	**Sat.**	**Matter**	**P**
		years	plant/ha		$\text{cmol}_c\ \text{kg}^{-1}$	%		mg l^{-1}
Andisol	1	3	6975	5.3	2.7	19	14.0	3.0
	2	4	4450	5.6	7.3	3	9.2	12.5
	3	9	6300	4.5	5.8	25	8.0	7.0
Ultisol	1	3	6800	3.8	3.6	50	4.3	5.4
	2	2	5900	4.0	5.5	29	5.1	5.7
	3	11	5263	3.7	5.3	74	4.8	6.2

Source: Alvarado et al., 2002.

Treatments with 3 replicates at each site consisted of a “control” with no fertilizer added, “N” with 133 kg N ha^{-1} as NH_4NO_3, and “N+P” with the same N rate and 29 kg P ha^{-1} as triple superphosphate. Due to the widespread occurrence of foliar Mg deficiency symptoms, 40 kg Mg ha^{-1} as $MgSO_4$ was also applied to the “N” and “N+P” treatments. All fertilizers were surface applied in four equal fractions on a bi-monthly basis and palmitos were harvested at 7, 12, 17, 21, 25 and 30 weeks after the initial fertilizer application.

There were no significant differences in the cumulative number of harvested stems in 30 weeks among sites within either Andisols or Ultisols. Harvested palmitos, averaged across sites and treatments were 4824 stems/ha in Andisols and 6674 stems/ha in Ultisols. Single-degree-of-freedom contrasts among treatments, averaged across sites and soil orders, indicated that palmito yields for the “control” (4804 stems/ha) were significantly less than for “N” (6297 stems/ha) and “N+P” (6142 stems/ha), but there was no difference between the two fertilizer treatments. Although yield differences among treatments were not significantly different between Andisols and Ultisols, there was a trend for increasing yields when fertilizer N was supplemented with P fertilizer in the Andisols (Table 7). However, the yield response to N alone was greater than that for supplementing N with P.

Table 7. Cumulative yields of palmitos harvested during 30-week on-farm trials evaluating N and P fertilization in Andisols and Ultisols of Costa Rica.

Soil Order	**Site**	**Treatment**			**Site Mean**
		Control	**N**	**N+P**	
		---------- cumulative harvested stems/ha ----------			
Andisol	1	5083	6167	4917	5389
	2	3667	3333	4417	3806
	3	3167	5583	7083	5278
	Mean	3972	5028	5472	
Ultisol	1	7222	10222	9222	8889
	2	3833	4583	6917	5111
	3	5877	7895	4298	6023
	Mean	5644	7567	6812	
Mean Across Soil Orders		4808	6297	6142	

Source: Alvarado et al., 2002.

The marginal responses to fertilizer P in growth at the nursery stage and in palmito harvests during fast growth and mature stages may be related to the symbiotic association formed between peach palm and vesicular-arbuscular mycorrhizae (Janos, 1977; Sudo et al., 1996). Clement and Habte (1994) observed that a minimum soil solution P level was needed for mycorrhizae associations with peach palm seedlings to be effective, and that there was no response to added P in mycorrhizal or non-mycorrhizal treatments above a certain soil solution P level.

In contrast to other annual crops considered in NuMaSS, where the soil P critical level is adjusted according to % clay, the critical level for palmito production systems has been fixed at 12 mg l^{-1} of Olsen-extractable soil P in the establishment growth stage and 8 mg l^{-1} for fast growth and mature stages (Smyth, 2004). The software allows the user, however, to modify these suggested values based on local experience for site-specific conditions.

Soil Acidity and Liming

Since peach palm originates from regions with acid soils (Mora-Urpi et al., 1997) and is considered to be adapted to soils with low pH and high Al saturation (Deenik et al., 2000; Perez et al., 1987), there is little information regarding palmito responses to liming or minimum soil Ca requirements. Nevertheless, several investigators recommend that desirable soil acidity conditions for peach palm plantations are Al saturation values of <50% (Mora-Urpi et al., 1997) and even <30% (Molina, 1999).

Salas and co-workers (2002) evaluated root growth response of peach palm seedlings for various Ca and Mg additions to surface soil samples of an Andisol and Ultisol in Costa Rica. Treatments with 5 replicates consisted of a control without added Ca or Mg, $CaCO_3$ equivalent to twice the soil exchangeable acidity, $MgCO_3$ equivalent to twice the exchangeable acidity, a 50:50 mixture of $CaCO_3$ and $MgCO_3$ equivalent to twice the exchangeable acidity, Ca supplied by a 50:50 mixture of $Ca(NO_3)_2$ and $CaCl_2$ equivalent to that supplied by $CaCO_3$, Ca supplied by $CaSO_4$ equivalent to that supplied by $CaCO_3$, and Mg supplied by $MgSO_4$ equivalent to that supplied by $MgCO_3$. Pre-germinated seedlings were grown in 2.5 l of soil for 8 months, with N, P, K and micronutrients supplied via a watering solution or foliar spray a 0, 2 and 4 months.

Soil analyses at harvest indicated that Al saturation of the control treatment was 49% in the Ultisol and 38% in the Andisol. Calcium and Mg treatments established a range of Al saturation of 4-19% in the Ultisol and 14-32% in the Andisol. When averaged across soils, the range of exchangeable Ca was 0.94-3.91 $cmol_c\ l^{-1}$ and 0.29-2.73 $cmol_c\ l^{-1}$ for exchangeable Mg. Above ground plant dry weight and root length, when averaged across treatments, were greater in the Andisol (24.9 g dry weight and 2071 cm root length/pot) than in the Ultisol (15.4 g dry weight and 795 cm root length/pot), but there was no difference among treatments in plant dry weight. In both soils, none of the Ca-Mg treatments resulted in a significant increase in root length relative to the control treatments (Table 8). When averaged across soils, the largest reduction in root length occurred with the addition of Ca in the form of nitrate and chloride salts. Although responses in root elongation among treatments were not consistent between soils, results suggest that the native soil levels of Ca and Mg were adequate for peach palm seedling root growth.

In the absence of field data providing strong evidence of a palmito yield response upon reduction of soil acidity, NuMaSS recommendations for lime are based on minimum soil levels of exchangeable Ca (0.8 $cmol_c\ l^{-1}$) and Mg (0.15 $cmol_c\ l^{-1}$). Whenever, soil Ca and Mg are below these minimum levels a fixed amount of 1 t ha^{-1} of lime is recommended, with adjustment for $CaCO_3$ equivalence and particle size of the lime material.

Table 8. Peach palm seedling root length after 8 months of growth in different Ca and Mg treatments to an Andisol and Ultisol of Costa Rica.

	Root Length		
Treatment	**Andisol**	**Ultisol**	**Mean**
		cm/pot	
Control	2978	953	1966
$CaCO_3$	2321	329	1325
$MgCO_3$	2343	1319	1831
50:50 Lime	1834	331	1083
$Ca(NO_3)_2:CaCl_2$	559	686	622
$CaSO_4$	2486	1183	1834
$MgSO_4$	1979	764	1371
Mean	2071	795	
$LSD_{0.05}$			
Soil	215		
Treatment			402
Soil x Treatment	569		

Source: Salas et al., 2002

Conclusions

Nutrient management of perennial tree crops requires an understanding of how they grow, accumulate biomass and nutrients, and how residues release nutrients for recycling within the plantation system. Differences in yields, biomass and nutrient accumulation with time of growth help delineate specific phases with distinct nutrient requirements and management.

A notable void in the existing knowledge base for palmito in NuMaSS is the diagnosis and correction of K limitations. Potassium accumulation by palmito matches or exceeds that of N. Likewise, rates of K release from foliage litter is similar to that of N. Thus, if is an important nutrient management consideration for palmito. Recommendations for fertilizer K would need to consider similar factors to those involved with N, namely, crop requirements at different growth stages, quantities left in the field as forage litter, and the balance between crop requirements and recycled K. Unlike N, however, soil test K is a reliable variable to include in recommendation models.

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