Traveler:
Adrián Ares - University of Hawaii

Objectives:
The objectives of this trip were:

In Brazil:
1. Collect soil and tissue samples from existing factorial experiments of P application to peach palm (*Bactris gasipaes* Kunth.) for P diagnosis and prediction purposes, and discuss soil and foliar analyses with Brazilian collaborators.
2. Compare results on peach palm response to P additions, and P release/recycling in experiments carried out by researchers at Instituto Nacional de Pesquisas da Amazônia (INPA) with data from previous experiments and from those underway in Costa Rica.
3. Explain and demonstrate the current PDSS2 system to the collaborators and illustrate how the peach palm data and information will eventually be used.

In Costa Rica:
4. Discuss and assist CIA (Centro de Investigaciones Agronómicas-Universidad de Costa Rica) scientists in installing a P experiment on a recently located low-P site.
5. Discuss and assist CIA scientists in implementing the nutrient and biomass accumulation experiment previously discussed.

Itinerary:

Saturday, March 13  
Arrival to Manaus

Sunday, March 14  
Holiday

Monday, March 15  
Meeting with O. Menezes Fonseca, director of INPA to discuss collaborative activities to be carried out at the Institute with INPA personnel. Meeting with N. Falcão to examine data from experiments with peach palm and plan field sampling in subsequent days. Tour of INPA labs and greenhouse, and meeting with E. Chaves and M. Sarrazin to discuss appropriate methods for soil P extraction and determination. Meeting with C. Clement to discuss topics on peach palm research. Field sampling of a fertilization experiment on peach palm at Rieda farm (about 8 km from Manaus) with N. Falcão and S. Morais.
Tuesday, March 16  Meeting with C. Bueno, Coordinator of extension and diffusion activities of INPA. Seminar on PDSS2 and demonstration of the software. The seminar was attended by about 30 people who also participated in an exercise on PDSS2 application after the talk.

Wednesday, March 17  Field sampling in two peach palm experiments at Yuricam farm (about 100 km from Manaus) with N. Falcão and S. Morais. The protocol for sampling was the same than that followed during field work on Monday, March 15. Visit to experiments on chicken manure application to a peach palm stand within Mr. Miyamoto’s farm.

Thursday, March 18  New discussion about performing soil P analysis by the Mehlich I and III, and the modified Olsen methods with E. Chaves and M. Sarrazin at the INPA laboratory. Meeting with J. van Leeuwen to discuss perennial crops and agroforestry systems with potential for the Amazon region. Visit to EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária) research station and meeting with M.Cravo and J. Macêdo, to discuss P diagnostic methods in peach palm and other perennial crops such as guarana (Paullinia cupana), oil palm (Elaeis guineensis), and coconut (Cocos nucifera). Demonstration of PDSS2 software to EMBRAPA collaborators.

Friday, March 19  Meetings with L. de Oliveira and S. Alfaia to discuss topics on mycorrhizae, soil enzymes, growth-promoting bacteria, nitrogen and phosphorus nutrition as related to soils and crops of the Amazonian region. Meeting with K. Yuyama to discuss management, weather and mineral nutrition effects on peach palm. Discussion and photograph taking in three greenhouse experiments carried out by N. Falcão and students on 1) peach palm response to liming and potassium; 2) phosphorus additions and mycorrhizae inoculation to three peach palm genotypes and, 3) identification of symptoms of deficiency by using the technique of the absent element. Visit to Bosque da Ciência, a demonstration area within INPA station. Final meeting with N. Falcão and C. Clement.

Saturday, March 20  Departure for Costa Rica

Sunday, March 21  Holiday
Monday, March 22  
Meeting with R. Salas to discuss progress of experiments on peach palm carried out at CIA. Discussion of ongoing greenhouse experiments with L. Uribe and J. Quesada.

Tuesday, March 23  
Meeting with E. Molina to discuss available soil and foliar data from the site for the experiment on P diagnosis and P response prediction in peach palm, and plan a new preliminary sampling. Bibliographical search on nutrition of perennial tree crops at CIA library.

Wednesday, March 24  
Field work in a peach palm stand located at Caño Negro, San Carlos (about 3 and a half hours from San José) with J. Quesada and E. Molina. Preliminary soil sampling was performed on each experimental block within the experiment.

Thursday, March 25  
Visit to agriculture production systems in the region around Poas Volcano.

Friday, March 26  
Visit to the experiment on peach palm litter decomposition within DEMASA farm with J. Quesada. Visit to the Agricultural Research Station “Los Diamantes” to observe four and eight-year old peach pam stands for the experiment on biomass and nutrient accumulation with time of establishment. Discussions with A. Bogantes, director of the station, on research activities carried out at the station.

Saturday  
Departure for the U.S.

General characteristics of INPA and field work in experiments on peach palm

The Instituto Nacional de Pesquisas da Amazônia (INPA) was created in 1954 as a regional research center for environmental conservation and sustainable development. INPA has three campuses in the city of Manaus that comprise more than 35 ha and also manages five natural reserve areas, four experimental stations and two floating laboratories. The education program at INPA offers both Master and Doctoral degrees. Among the six research programs administered by INPA, one is in Rural Production Systems with the objective to provide knowledge for the rural development on the Amazon region with reduced environmental impact. In addition to the studies on peach palm, research has been conducted in several topics such as soil microbiology, plant pathology, agroforestry and soil and plant nutrition.

Some of the research carried out by INPA scientists has involved the use of nutrient isotope tracers. A study with $^{15}$N urea and $^{15}$N ammonium sulfate, showed that 60% of the nitrogen added to an Oxisol and an Ultisol was recovered as $\text{NH}_4$ after 2-month lab incubations while 50% of the applied nitrogen was nitrified in a low-humic gley soil. The proportion of nitrogen incorporated to organic matter in the Oxisol and Ultisol soils varied between 7 to 19% and reached 30% in the gley soil (Alfaia et al., 1995). Another study with $^{15}$N indicated that 60-70% of urea and 44-49% of ammonium sulphate was absorbed by Lolium multiflorum plants growing on an Oxisol and an Ultisol from the Amazon region (Alfaia, 1997a). Microbial nitrogen
immobilization was higher in the presence of urea while losses, probably in gaseous form, where higher for ammonium sulfate. Also, the incorporation of cowpea (*Vigna unguiculata*) green manure to an Oxisol and an Ultisol increased the rate of organic nitrogen mineralization suggesting the occurrence of the “priming effect or added nitrogen interaction” (Alfaia, 1997b).

Three field experiments on peach palm carried out by INPA researchers were visited and sampled. One experiment was located at Rieda farm about 8 km from Manaus on BR-174, and two experiments were at Yuricam Farm, Rio Preto da Eva, on AM-10, about 100 km from Manaus. The experiment at Rieda farm was started on March 1996 with the objective of determining the best levels of N, P and K and the effect of liming, animal manure and micro nutrients on peach palm for heart-of-palm production. Twenty treatments were set up in a replicated experiment on a “terra firme” Oxisol. The “terra firme” area is of Tertiary age and, therefore, older than the “várzea” or food plains of Quaternary age. The “terra firme” soils known as “latossolo amarelo” in Brazil are common under peach palm and have high clay and moderate organic carbon contents (Falcão et al., 1998). The doses of urea, TSP and KCl ranged between 0 and 180 kg ha$^{-1}$, 0 and 90 kg ha$^{-1}$ and 0 and 240 kg ha$^{-1}$, respectively. Peach palm appeared to respond to P additions six months after fertilization as shown by increased plant stem diameter and plant height (Yuyama, 1997). We sampled soil at 0-5 cm and 5-20 cm and the third and 6th leaf of peach palm plants. Two out of three blocks were sampled. The experiment is currently 3 years old.

The other two experiments were located at Yuricam Farm, about 100 km from Manaus also on an Oxisol. Experiment I was set up in 1996 to study the effect of NPK levels, spacing and trunk numbers on heart-of-palm production. The experiment is a 3 x 5 factorial with three spacings (1 m x 1 m, 1 m x 2 m, and 1.5 m x 2 m) and 5 different NPK levels. Doses of N, P$_2$O$_5$ and K$_2$O ranged between 0 and 225 kg ha$^{-1}$, 12.5 and 90 kg ha$^{-1}$ and 90 and 270 kg ha$^{-1}$, respectively. A randomized complete block design with three reps was followed. We sampled the plots with plants at the 2 m by 1 m spacing within two blocks out of three. Results at six months after fertilization have indicated a response to P additions for the 2 x 2.5 m spacing treatment (Yuyama, 1997). Also, recent measurements showed that P additions (90 vs 25 kg ha$^{-1}$ P$_2$O$_5$) increased the number of harvested stems which, in turn, positively correlated to stem diameter, plant height and number of stems (Yuyama, personal communication). During “El Niño” period, there was a reduction in stem diameter for the treatments containing 5,000 and 10,000 plants per ha, and for those with lower fertilization additions. The number of leaves per plant decreased in all the treatments and the recovery in the number of leaves after “El Niño” was lower in the treatments with high stem density and without fertilization.

Experiment II within Yuricam Farm was set up in 1996 to determine the effect of increasing levels of NPK on fruit production. There are 10 treatments with P$_2$O$_5$ amounts ranging from 0 to 135 kg ha$^{-1}$ and K$_2$O doses varying between 0 and 270 kg ha$^{-1}$. The experiment followed a completely randomized design with three replications. At 26 months after planting, stem diameter and height for peach palm plants under all fertilization treatments were higher than those for the control but there were no differences among the treatments with nutrient additions (Chávez Flores et al., 1997).

Soil and foliar sampling for experiments I and II at Yuricam farm was performed as at Rieda farm. In experiment II, an older leaf (determined as the total number of leaves divided by two)
has been sampled recently and foliar nutrient data from this tissue will be compared to those from the 3rd and 6th leaves.

No data on soil and foliar P levels are available for these experiments so far. Peach palm tissues of different age and soil P values obtained by different methods (e.g. modified Olsen, Mehlich I and III) and for different depths should be compared to select the best method of P diagnosis. Sampling will be probably repeated during the dry season. Number of leaves and stem diameter of peach palm are reduced because of drought effects (K. Yuyama, personal communication). An analysis on soil and tissue sensitivity to P additions and yield response will be run as follows:

<table>
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<tr>
<th>Fertilization Levels</th>
<th>Yield Response</th>
<th>Symptoms of Deficiency</th>
<th>Response Found in 3rd leaf</th>
<th>Response Found in 6th leaf</th>
<th>Soil P Levels 0-5 cm</th>
<th>Soil P Levels 5-20 cm</th>
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</table>

**Observations from INPA greenhouse experiments**

Three experiments with peach palm were being carried out at INPA greenhouse by undergraduate students R. Simões, A. Portela and M. da Costa under the guidance of N. Falcão. In experiment I, the effect of four levels of P on three peach palm genotypes with and without mycorrhizae inoculation were examined. Preliminary results confirmed that responses to mycorrhizae inoculations in peach palm were genotype-dependent. In experiment II, symptoms of deficiency were studied by using the method of the absent element (all macro and micronutrients are applied at one time except one). Some of the observed symptoms were: a) reduced growth and development, and generalized chlorosis for N deficiency, b) chlorosis and subsequent necrosis of the tips of old leaves for K deficiency, c) interveinal chlorosis in leaves for Mn deficiency, d) dark green-colored leaves for Ca deficiency and e) chlorosis of young leaves in S deficiency plants. Some of the symptoms (e.g., for K deficiency) were similar to those reported in a previous experiment (Falcão et al., 1998).

In the third experiment, the effects of five levels of dolomitic lime and four doses of K are being examined. Growth of peach palm seedlings appeared to be greater under the treatment with two tonne ha⁻¹ of dolomitic lime and 100 kg ha⁻¹ of KCl. Growth was reduced at high doses of lime especially at 6 and 8 tonnes ha⁻¹.

**Potential for perennial fruit crops**

There is increasing interest in growing fruit crops in the Amazon region. In the Yuricam farm, there was an orchard of camu-camu (*Myrciaria dubia*, Mirtaceae) and seeds and seedlings of this species were being sold by the farm. Camu-camu naturally grows in “várzea” areas of the states of Pará, Amazonas, Rondônia and Roraima. Its fruits are very rich in vitamin C and are used for juice, ice-cream, liquors, jellies, cake flavors and deserts. This a promising fruit crop together with acerola (*Malpighia glabra*, Malpighiaceae), cupuacu (*Theobroma grandiflorum*), and araça-boi (*Eugenia stipitata*, Myrtaceae). Guarana (*Paullinia cupana*, Sapindaceae), a more established fruit crop, currently comprises some 20,000 ha in Brazil. EMBRAPA researchers are
investigating mineral nutrition of guarana in view of the general lack of information about nutrient requirement diagnosis and prediction as well as on nutrient recycling. There is still interest in more traditional crops such as rubber (Hevea brasiliensis), oil palm and coconut.

**Ongoing and planned experiments in Costa Rica.**

The experiment on residue decomposition and nutrient release is underway at DEMASA farm since August 1998. Results so far demonstrated rapid biomass decomposition and nutrient release under the high rainfall and temperature environment and management conditions (fertilization, frequent harvest for heart-of-palm production) prevalent in the region. The experiment to evaluate changes in chemical properties and nutrient availability of Andisols after adding peach palm mulch has just started in PVC columns in the greenhouse. Seedlings are also being acclimated to the conditions of the greenhouse for an incoming experiment on the effect of different liming materials on peach palm growth. The experiment on biomass and nutrient accumulation with time of peach palm plantation establishment (as described in a previous report) will be carried out at “Los Diamantes’ Experimental Station under the “Ministerio de Agricultura y Ganadería” of Costa Rica, in Guápiles town.

The site for the on-farm diagnostic experiment on fertilizer P response and P diagnostic methods is located within the farm “Agropecuaria Río Frijoles” in Caño Negro, San Carlos, at about 200 m elevation. Mean annual rainfall is about 4000 mm. The soil is probably an Aquic Dystrudepts with clay contents ranging between 29 to 57 % (Table 1). Soil pH ranged between 4.2 and 4.4. Soil extractable P by the modified Olsen method averaged 2.72 mg kg$^{-1}$ at 0-5 cm depth and 1.65 mg kg$^{-1}$ at 5-20 cm depth. In addition to low P values, the soil analysis showed that K and Zn contents were below the sufficiency levels determined for the provisional norms for peach palm in Costa Rica. A preliminary survey showed that foliar P levels were also low (0.15% for “healthy” plants and 0.13% for plants with symptoms of deficiency). Although other elements may be also deficient, there is a good probability of P deficiency. The proposed experiment is as follows:

**Field experiment on fertilizer P response and P diagnostic methods in peach palm**

*Principal Investigators:*
UCR - Eloy Molina, José P. Quesada, Rafael Salas
U.S. - Adrián Ares, Russell Yost

*Location:* Near Caño Negro, San Carlos, Costa Rica, 3 and ½ hours from San José. Field with approximately 2.5 mg kg$^{-1}$ Modified Olsen P at 0-5 cm soil depth. Three-year old peach palm stand on an Ultisol.

*Objectives:*  
1. Evaluate alternative methods of detecting P sufficiency by comparing sampling tissue, time effects and soil measurements in detecting changes in P concentration after imposing nutrient differentials on a mature peach palm production system.
2. Predict yield response of peach palm to changes in foliar, litter and soil P.

*Tentative hypotheses:*  
1. Soil P critical level for established peach palm stands is approximately 10 mg kg$^{-1}$ P (Modified Olsen).
2. Soil and foliar P levels in the peach palm stand can be maintained by adding the crop nutrient maintenance rates.
3. The 6th leaf may be a better tissue than that of the 3rd leaf for P diagnosis in peach palm managed for hearts-of-palm production.

Procedure:
- Laboratory incubation of soil from the field with a series of P levels: To indicate the soil P buffer coefficient (kg P to raise the soil test P by one mg kg⁻¹) and subsequently the amount of P needed to reach certain level. This parameter estimate permits extrapolating the experimental results to roughly all soils of this series within the range of clay percentage.
- Treatments (9): control (no P added), P additions to raise soil P levels to 5, 10, and 20 mg kg⁻¹ (soil-base treatments) and P additions to supply crop requirements assuming 75 and 25 % of nutrient uptake efficiency (system-base treatments). Phosphorus doses will be split in two applications. P will be applied as DAP. Nitrogen (about 250 kg ha⁻¹; applications will balance the amount of N applied to all P treatments as DAP), potassium (124 kg of P), magnesium (36 kg ha⁻¹ of MgO) and sulfur (60 kg ha⁻¹) will be also applied throughout the experimental site. Potassium, magnesium and sulfur will be applied as K-Mag or Sol Po Mag (0-0-22-18-22) fertilizer. The experimental site has been already limed to approximately pH 4.3.
- Experimental set-up: 24 rectangular plots (4 reps x 6 treatments) with 100 plants per plot at 2 m x 0.5 m spacing. Measurements will be taken in interior plants of each plot. A randomized complete block design will be followed.
- Measurements:
  * Foliar P at 0 (before fertilizer), 3, 6, 9, 12, 15, 18 and 24 months in a) 3rd pinnate (adult) leaf and (c) 6th leaf. Litter P content will be determined in selected samplings. Symptoms of P deficiency, if any, will be recorded. Roots may also be sampled occasionally for nutrient and mycorrhizae analysis depending on fund availability. Rainfall and other weather data from nearby stations will be recorded.
  * Soil P at 0 (before fertilizer), 3, 6, 9, 12, 15, 18 and 24 months at 0-5 cm and 5-20 cm depth by the modified Olsen and Mehlich-III methods. Labile, moderately labile and moderately resistant organic P will also be determined by extractions with 0.5 M NaHCO₃, 1.0 M H₂SO₄ and 0.5 M NaOH to determine the diagnostic value of these pools.
  * Stem basal diameter, height, number of leaves and yield of heart of palm will be determined monthly.
- Data analysis: Plant tissue and soil P extractant diagnostic performance for evaluation of deficiencies and sufficiencies will be tested using coefficients of determination and indices such as Kappa’s efficiency coefficient (Cai et al., 1997) and the coefficient of variation. P-effects on peach palm growth and yield will be tested by using both ANOVA and regression analysis methods.

References:


**List of Contacts:**

**INPA, Manaus**

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Agropecuaria Río Frijoles
Eng. Enrique Berrocal, Farm Owner
Mr. Martín Sanchez, Farm Supervisor
Agricultural Research Station “Los Diamantes”
Eng. Antonio Bogantes, Station Director
Table 1. Baseline soil data for the proposed experimental site at San Carlos, Costa Rica.

<table>
<thead>
<tr>
<th>Block</th>
<th>Depth</th>
<th>pH</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
<th>Al+H</th>
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<th>P</th>
<th>Cu</th>
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<tr>
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<td>cmol (+) L⁻¹</td>
<td>mg L⁻¹</td>
<td>g L⁻¹</td>
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Extraction with KCl was used to measure Ca, Mg and exchangeable acidity, and the Modified Olsen method for P, K and micronutrients.