Soil Fertility

Management

in the

Chapare, Bolivia

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General Objectives

The consultancy was carried out between November 29 and December 8, 1999 and had the following objectives:

1. Collect and assess existing information and knowledge on spatial distribution of soil nutrient constraints and management strategies for local adaptation of the targeted crops;

2. Provide familiarity with the Nutrient Management Support System (NuMaSS) software, determine potential for its local use, and define improvements needed to achieve desirable performance;

3. Define pertinent questions, hypotheses and objectives for experiments and on-farm trials to acquire local nutrient management information and knowledge which are needed to sustain crop production and crop expansion goals established by the project.

4. Evaluate the role of Fertility Capability Classification system in future nutrient management.

Assessment of Existing Information on Soil Nutrient Constraints and Management Strategies

Prior to our consulting visit, a survey and assembly of existing information was in progress through DAI employment of Dr. Armando Ferrufino (Ferrufino, 2000). This summary, though incomplete at the time, gave an excellent basis of the following features of the Chapare region:

- Precipitation and temperature.

- Geographic map of the region showing the watersheds, rivers, and roads. A very useful map of the FCC (Fertility Capability Classification) groupings of soil units had been prepared by DAI staff. This map provided a general reference and basis for the assessment of soil and nutrient conditions. The map was based on prior work that included thesis work of S. Monteith (Monteith, 1999) that was directed to a survey of soil characteristics and properties that would likely affect management of the alternative crops.

- Characteristics of representative soils of the region. These were soils data were taken and analyzed during the thesis work and subsequent consultancies with DAI by S. Monteith (Monteith, 1999). These data included largely surface samples with strategically selected analyses with depth. The soils were grouped according to the FCC modifiers (Buol et al, 1973).

- Responses of the alternative crops to fertilization. The DAI summary included previous field results conducted largely at the IBTA stations of La Jota and Chipiriri. Nutrient response data were provided for the major crops to the addition of the macronutrients nitrogen, potassium, and lime. These data were particularly important in providing a basis to interpret the FCC soil units distributed throughout the region. The multiyear experiments summarized in the DAI study were crucial to the assessment of nutrient status and provided the primary basis for the interpretations presented in this report.

- Existing literature on the alternative crops and their probable nutrient requirements and limitations. The DAI report included literature that was especially useful in banana nutrition. Field experiment data from studies of nutrient requirements were also summarized for pineapple, palmito, black pepper, and passion fruit in decreasing number of experiments.

- Selected individual reports and studies were summarized in the DAI study by Ferrufino (Ferrufino, 2000) including:

  - an assessment of lime response by annual crops

  - phosphorus sorption from representative sites

  - characteristics of limestone present in the Chapare region.

The completion of the DAI report should be encouraged as it is a key synthesis of information available to date and a logical beginning for further information needs for the support, maintenance, and problem-solving needs of a viable crop production system. The ongoing support and maintenance needs of productive agricultural systems will be further discussed in the recommendation section of this report.

The second portion of this objective, regarding nutrient constraints and nutrient management strategies, will be organized by each of the individual designated crops in the order banana, palmito and pineapple.

Banana

Fortunately, there have been initial field studies with banana summarized in Ferrufino (2000) and several earlier consultancies regarding banana production (Sierra, 1992). The earlier efforts at the introduction of banana seems to be one of the most successful among the five alternative crops to date according to estimates of the DAI remote-sensing component (Table 1).

Although the management of nutrients in banana may not be the most expensive aspect of management, it is a consistent and recurring requirement for sustained production. Nutrients play an important role in banana production in part because of the large amounts of nutrients, especially of potassium, removed with the crop (Ferrufino, 2000). In our view, the management of nutrients in banana may be best summarized by considering the growth stages of the crop and the particular requirements of each stage. The growth stages that we identify and consider herein include the following: 1) Nursery, 2) Establishment or lag phase, 3) Rapid growth phase or log growth phase, and 4) Mature phase. Of these phases, it is likely that nutrient management during stage 4 or the mature stage will have the greatest impact on success of banana as an alternative crop. Also relatively standard practices exists for the Nursery phase and are likely available for phases 2 and 3. Phase 4, however, is a phase of considerable nutrient removal and thus is a critical stage for nutrient management decisions on the part of the grower. Sustained yields are dependent on nutrient applications and on soil nutrient reserves.

Within the mature phase we recognize several activities that comprise nutrient management, which can be grouped according to the following actions:

- Diagnosis as to whether there is a deficiency or excess of a nutrient,
- Prediction or recommendation of the correction for the diagnosed nutrient deficiency,
- Assessment of the economic viability and alternatives resulting from the prediction of the corrective action, and
- Presentation and communication of this information in a manner appropriate for those managing the cropping system.

Table 1. Estimated area of various crops in the Chapare region based on remotely sensed data provided by Digital Earth Consulting (personal communication, R. Frohn, 1999).

	Land Area		
Crop	**1998**	**1999**[1]	**1999 (field inventories)**
	----------------------------- hectares -----------------------------		
Banana	22,760	20,750	-
Heart of palm	4,876	2,980	2,200
Pineapple	3,952	1,668	-
Citrus	21,621	22,360	-
Others	?	3,803	-
Pepper	61	163	140
Passion fruit	788	158	100
Cassava	6,171	7,920	-
Pasture	25,678	28,232	-
Sum	85,907	88,034	-
Survey Total	105,088	108,504	-

[1] Survey techniques were substantially different between 1998 and 1999 and thus any comparisons of changes in no. of hectares may be due more to methodology change than actual change.

Diagnosis of nutrient adequacy or deficiency is most reliable with an analysis of plant tissue, usually the 3rd leaf (excluding the midrib) at flowering. Critical levels have been reported in Ferrufino (2000) and Lower (1982). Proactive periodic surveys can be useful in ensuring nutrient sufficiency does not limit productivity and stability of production. Several international organizations are seeking to improve banana and plantain management (http://www.iimi.org/ipgri/inibap/Index.htm).

There seem to be a number of less quantitative, but possibly quite useful methods as long as the qualitative nature is remembered. A demonstration experiment is suggested that could also be used to evaluate a yet-to-be-selected set of diagnostic criteria. The set of practical, in-the-field diagnostic possibilities needs the input of experienced banana field experts and growers. Some of these potential indicators to evaluate might include the following:

- Flag leaf turning yellow (more than 50%)? Some banana experts suggest that this sometimes indicates potassium deficiency. It is clear that K deficiency is paramount in banana and this is a key issue in the Chapare with the demonstrated large amounts of K-fixing and K-releasing minerals in the clay and silt-sized soil fractions (Monteith, 1999).

- Related to the first item, severe K deficiency shows up on older leaves. Perhaps this would be useful in identifying severe K deficiency.

- Time since last application of K fertilizer. Given the large K requirement of banana, if no K fertilizer has been applied during the last year, it may be likely that plants are K deficient.

- Certainly tissue levels of nutrients is a possibility, but this is an expensive test that is only likely to be used if serious problems are already identified. Are nutrient levels in the special tissue of 2.6% N, 0.2 % P, and 3.0 % K appropriate critical levels? Are these appropriate levels for diagnosis in all cultivars?

Prediction of nutrient requirements during the mature phase (Phase 4). Estimating the proper amount of nutrients needed to maintain productivity in the various perennial crops was called into question. One farmer, Leo Montaño, told us that he applied 200g of KCl and 200g urea per banana mat 2 times a year at a stand density of 2000 plants/hectare. The calculation results indicate that substantial amounts of fertilizers are being applied and that the costs of these maintenance rates is very high (Table 2).

Table 2. Fertilizer calculation for Leo Montaño’s banana field, Chapare.

		Plant	**Applied**		**Unit**	**Applications/Year**	
Fertilizer	**Quantity**	**Population**	**Fertilizer**	**K or N**	**Cost**	**2**	**3**
	g/mat		---------- kg/ha ----------		$/kg	---------- $/ha ----------	
KCl	200	1500	300	312	25/45	346.67	520.00
Urea	200	2000	400	360	20/45	400.00	600.00

Mr. Montaño says that these amounts are required in order to maintain yields and fruit size. Even with these substantial amounts of K (312 kg ha^{-1}) and N (360 kg ha^{-1}), it is clear that substantial amounts of nutrient K are being supplied by the soil. Calculations performed with yield data and typical contents of K in the fruit suggest that as much as 0.84 to 0.99 $cmol_c$ kg^{-1} may be removed per year on a soil with generally less than 0.14 $cmol_c$ K kg^{-1}. If this estimate is correct it indicates that exchangeable K is not a particularly useful indicator of K supply and also indicates that major quantities of K are flowing out of the soil. This would be in contrast with predictions of widespread K deficiency according to the FCC k modifier. It seems that this uncertainty needs to be clarified with studies, because sustainable production of banana will clearly depend on a consistent supply of K to the plant - be it from the native soil supplies as appears to be the case for banana in the Chapare or be it via expensive fertilizer K, which is largely imported.

We propose experiments to be established in the representative watersheds containing soils with different K minerals as identified in the study of Monteith (Monteith, 1999). These results may indicate different management requirements based on different K supplying minerals in the differing watershed parent materials. It may be that the content and composition of the silt fraction in these soils will be important for management. Often the silt fraction is the one that contains the large amounts of K bearing minerals and also is the fraction that usually contributes the most to pores of the size that hold available water for plant growth. Thus it may be that improved estimates of the silt content of the soils of the Chapare will be important information in their management.

<u>Core experiments</u> - Based on the above considerations a series of experiments is proposed to assess the K supplying power of soils representative of the various watersheds, and consequently of the differing suites of parent minerals and materials throughout the region. In the proposed assessment of Chapare nutrient requirements there would be a core experiment that would be repeated in perhaps 3 separate watersheds on either the low or middle terrace positions within the respective watersheds.

Experimental hypothesis: we would expect that 200 kg N ha^{-1} would provide sufficient N to maintain leaf N status and that 400 kg K ha^{-1} would provide sufficient K to maintain leaf K status within the critical ranges. We would expect that treatments 1 and 2, described below, would soon exhaust the native soil K supply, perhaps with treatment 2 showing decreased yields within a year of the beginning of the experiment.

The core experiment would include the following set of treatments to be replicated within each site:

1. 0 kg K ha^{-1} and 0 kg N ha^{-1} added with only the fruit removed;

2. 0 kg K ha^{-1} and 0 kg N ha^{-1} added both the fruit and the stalk removed (providing maximum stress on the soil K supplying power);

3. 400 kg K ha^{-1} and 200 kg N ha^{-1} added;

4. 800 kg K ha^{-1} and 200 kg N ha^{-1} added;

5. 400 kg K ha^{-1} and 400 kg N ha^{-1}; and

6. 400 kg K ha^{-1} and 0 kg N ha^{-1}.

Measurements

Plant - Yield and foliar concentrations of N, P, K, Ca, Mg, and S, would be measured. Micronutrients would be periodically analysed: Zn, Fe, Cu, Mn, and B. Some estimate of the amounts of nutrients being removed in the fruit and banana stalk would be measured as well to assess the buffering of exchangeable K upon the intensive K removal.

Soil - Soil pH, Ca, Mg, K, acidity, and P should be measured perhaps every six months on all treatments.

Satellite field trials - In support of growers learning and becoming familiar with the importance of nutrient management, a subset of the above treatments could be established at selected locations in growers' fields (rather than selected watersheds or terraces) to demonstrate the effects of fertilizer on banana production and provide a forum for learning and discussion among community farmers and extension agents. These simplified satellite experiments or demonstrations would include only 4 treatments:

1) Check (no N and no K added);

2) 200 kg N ha^{-1} and 0 kg K ha^{-1} added;

3) 0 kg N ha^{-1} and 400 kg K ha^{-1} added; and

4) 200 kg N ha^{-1} and 400 kg K ha^{-1}.

Greenhouse study to assess K fixation and status - Based on the study of Monteith (1999) and a K budget analysis it seems that large amounts of K are likely being supplied from the micaceous minerals in the soils of some of the watersheds. It is likely that there is alternately K fixation and K release, depending on the K status of the soils. A small experiment is proposed to quantify these effects more closely. The experiment would be based on the study of K incubations described in Olk et al., (1995) on micaceous soils of California. The experiment would include samples from all major watersheds and the soils from the sites of the proposed core experiment. The rate of K fixation during relatively wet conditions would be assessed through incubation at controlled water regimes. These rates of fixation could the be used as approximations of the K buffer coefficient, which together with estimates of the amounts of K removed in the crops, may be considered to estimate K fertilizer requirements (see description of *Prediction* as described above).

General Questions on Sustainable Nutrient Management - On the basis of our experiences with nutrient management in other locations throughout the tropics, we also encouraged project members to consider the following key issues. We believe that attention to and preparation for these issues will help avoid production problems in the future.

1. For how many years can 400 kg N ha^{-1} be applied before acidity becomes a yield limitation to banana production? (This is the current rate at which Leon Montaño is applying fertilizers.)

2. How to anticipate future nutrient management problems resulting from current management practices such as:

   - Soil acidification from N fertilization, especially on the sandier soils;

   - Magnesium deficiencies either due to low initial levels, depleted native reserves, or the results of K fertilization;

   - Calcium deficiencies either due to low initial levels or depletion of existing native soil reserves; and

   - Nitrate buildup and contamination of shallow groundwater from increased N application rates.

Palmito

When compared with existing banana production systems in the Chapare, the limited local information and absence of good management practices among growers we visited makes it apparent that peach palm production for heart-of-palm (palmito) is a more recent introduction among the existing alternative crops. The only existing field trial data available was for palmito yields as a function of plant population and fertilizer N rates. Trial data included only one harvest date, wherein the best yield was obtained with 100 kg N ha^{-1} at a density of 6667 plants ha^{-1} . Yields were considerably lower than average palmito production in the Huertar Norte region of Costa Rica (Table 3). It was not clear whether this was a new or established plantation and whether the trial would be continued.

Poor plantation management in farmers' fields was most evident in terms of limited pruning to control number of tillers and, when practiced, fertilizer distribution. When asked about their pruning practices, most growers we visited indicated a concern that they would be eliminating future harvestable palmito. There was little appreciation for the impact of excess tillers on the rate of palmito growth and its quality.

Table 3. Average heart-of-palm (palmito) yields in Costa Rica for different ages of peach palm plantations. (Source: CNP, 1998).

PLANTATION AGE	PALMITO YIELD
Months	Units ha^{-1} yr^{-1}
1 – 7	2500
8 – 24	7000
> 24	11000

Few growers applied fertilizers on a routine basis. Several admitted applying a mixture of N, P and K - either once when the plantation was established several years ago or, when done more frequently, once per year. These local nutrient management practices can be compared with an average application each month of 17 kg N ha^{-1}, 2 kg P ha^{-1} and 12 kg K ha^{-1} to peach palm by growers we surveyed in the Huertar Norte region of Costa Rica (Alvarado et. al., 1998). In general, native nutrient supply of soils in the Chapare region targeted for peach palm are lower than those in Costa Rica. One would therefore expect that nutrient input needs to achieve good palmito production levels in the Chapare, except for P, would at least be similar to those used in Costa Rica.

Another unique characteristic for existing palmito plantations in the Chapare is the origins of the germplasm. It is our understanding that initial seedling production and distribution among growers came from materials collected throughout Latin America. There was little effort to segregate these materials, so that one field may contain a mixture of assessions from Costa Rica, Peru, Ecuador, Brazil and Bolivia. Palmito production areas in most other countries contain limited assessions and often concentrate on the local germplasm (such as Tucurique in Costa Rica and Yurimaguas in Peru). Diversity of germplasm in Chapare plantations would contribute in part to the variability we observed in number of tillers/plant. Diversity of germplasm will also impact selection of improved management practices to promote among growers. In Costa Rica, for example, comparisons between Tucurique and the spineless Yurimaguas accessions indicated that the latter germplasm produces fewer tillers but they are harvestable at an earlier date after plantation establishment (Antonio Bogantes, personal communication, Los Diamantes Experiment Station, Guapiles, Costa Rica). Growers can capitalize on this difference in assession traits by planting the spineless Yurimaguas at a higher density than Tucurique.

Peach palm is a mycorrhizal-dependent plant, meaning that it benefits significantly from the mycorrhizal fungi association with its roots. Presence of mycorrhizal root infection can be particularly important in the plant’s acquisition of immobile elements like phosphorus. In the absence of mycorrhizae, palmito may not be very efficient in acquiring and using soil P; the net result would be to provide supplementary P fertilizers adding additional costs to growers. Good mycorrhizal root infection is normally achieved during the nursery phase of plant growth; once proper inoculation of the fungi is achieved in soil media of seedling nursery beds, this same land area is repeatedly used whenever new seedlings need to be produced. This practice would ensure that peach palm plants distributed to growers in the Chapare would contain the desirable mycorrhizal association.

Based on the description of seedling production procedures used in the Chapare, during the introduction and widespread distribution of peach palm plants to growers, we do not think that it is safe to assume that existing palmito plantations have good mycorrhizal root infection. In fact, this could be one factor contributing to the poor crop growth we observed in the growers' fields. As we understand it, peach palm seeds were germinated in sand beds and transferred to plastic bags with sawdust for distribution among growers. There is no indication that mycorrhizal infection was assessed during this nursery phase.

Our approach to developing good nutrient management practices in palmito is based on many of the same general concepts outlined in this report for banana, including the process of diagnosing whether a nutrient problem exists, recommending corrective measures if a problem exists, and assessing the economic viability of the recommendations. Growth stages of a palmito plantation could also be grouped into the same four phases as banana; based on existing information in Latin America, we suggest the following time intervals for each growth stage:

- Nursery - seedling development, 0 - 6 months before field planting;

- Lag phase - initial slow growth during 0 - 6 months after field planting;

- Rapid growth phase - rapid rate of biomass accumulation by plants during 6 - 24 months after field planting; and

- Mature phase - period where aboveground biomass reaches an equilibrium, usually occurring 24 months after field planting.

In contrast to banana and based on existing information we have collected throughout Latin America, we expect that palmito yields will be limited more by a nitrogen deficiency than by a potassium deficiency. If palmito harvest in the Chapare is practiced in a similar fashion to other regions of Latin America (i.e. exporting only the heart of palm with a protective stem sheath while recycling leaves and other stem residues), nutrients exported from the field are considerably less than with banana.

Given the widespread distribution of K constraints in the region's FCC maps and the tendency to concentrate palmito on the older landscape positions with fewer weatherable minerals, we recommend investing some effort to determine whether palmito yields are limited by low soil K supply. Quite possibly, initial palmito yield response to K fertilizer inputs may be low but long-term maintenance of sustained high crop yields may require supplementary fertilizer K. To this end, a greenhouse study to assess K fixation and status as outlined in the report's section on banana is also of value in determining nutrient management strategies for palmito. As with banana, we propose the following core experiment and satellite field trials for palmito. These trials were developed jointly with project participants and collaborators in the Chapare from DAI, IBTA and FAO.

Core experiments - This experiment seeks to assess the soil's potential to supply N and K for palmito and the extent to which palmito yields are improved and sustained over time when supplemented with fertilizers. It is desirable that this experiment be conducted over multiple years and in 2 or 3 watersheds where palmito production will be concentrated. Repetition of the experiment among several watersheds will provide indications on the extent to which fertilizer N and K needs for economically optimum palmito production would vary among watersheds and their soils. Information as to how soil nutrient supply changes with time of continued palmito production and, thus, the need for adjusting N and K fertilizer supplements is gained in these experiments when they are continued for several years.

Our hypothesis is that 100 kg N ha^{-1} and 75 kg K ha^{-1} would be sufficient for palmito. Treatment 1 provides a measure of the soil's capacity to supply native N and K. Treatment 2 is intended to deplete native soil N and K supplies in a short term; this information enables the development of predictions of sustained crop yields without having to conduct the experiment for too many years.

The set of treatments to be replicated in each site are:

1. 0 kg N ha^{-1} and 0 kg K ha^{-1} added with only harvested palmito removed;
2. 0 kg N ha^{-1} and 0 kg K ha^{-1} added with both palmito and the cut leaves and stem residues removed at each harvest;

3. 100 kg N ha^{-1} and 75 kg K ha^{-1} added;

4. 200 kg N ha^{-1} and 75 kg K ha^{-1} added;

5. 100 kg N ha^{-1} and 0 kg K ha^{-1} added; and

6. 200 kg N ha^{-1} and 75 kg K ha^{-1} added.

Fertilizer amounts correspond to totals applied per year. However, distribution should be in equal split-applications every 2 months during the year.

Once sites are selected and before fertilizer treatments are initiated, the palmito fields need to be subjected to tiller prunings and harvests to bring the plantation up to a good agronomic management status. When implementing similar trials in established fields at other locations, our experience is that this preliminary preparation of the palmito field can take several months.

Measurements

Plant - yields need to be measured on a continuous basis for each treatment and replicate such that the data contains cumulative number and weight of palmitos for each year. Each field should be checked for harvestable palmito (based on stem diameter criteria) once every 4 weeks, and harvested when ready. Pruning of excess tillers could be performed during the same visits to each experiment. Perhaps arrangements could be made with one of the palmito processing plants to evaluate quality of harvested palmito.

Concentrations of N, P, K, Ca, Mg and S would be measured on the 4th and 5th leaves about every 2 months. The existing data base for diagnostic leaf tissues on palmito is quite limited, but our current indications are that one of these two leaves provides the best indication of plant nutrient status. Foliar micronutrient concentrations (Zn, Fe, Cu, Mn and B) should also be measured periodically. Estimates will also be needed (but with less frequent measurements) on the amounts of nutrients removed from the field in harvested palmito and, for treatment 2 only, the crop residues. These estimates are needed and used to calculate the soil's supply of N and K from native reserves.

Soil – Soil pH, Ca, Mg, K, acidity and P should be measured every six months; recommended sampling depths are 0-5 and 5-15 cm.

<u>Satellite field trials</u> - It is our opinion that considerable effort is needed in demonstrating and helping growers to learn the importance of good agronomic management practices for palmito. As a newer crop in the Chapare, extension efforts with growers on palmito production practices have not reached the concerted level of intensity that was used during the introduction of banana. As part of the upcoming extension efforts to demonstrate proper pruning and harvesting practices in selected grower's fields, we proposed the inclusion of a subset of nutrient management practices:

1. Check (no N or K added);

2. 100 kg N ha^{-1} and 75 kg K ha^{-1} added; and

3. Current grower practices.

Treatments 1 and 2 would be conducted with good agronomic practices and fertilizer distributed in equal split-applications every 2 months. Treatment 3 would entail the grower's current practices, including their fertilizer rates and application frequency (if currently used).

<u>Assessment of mycorrhizal root infection across established plantations</u> - We propose a modest effort in determining the extent to which existing grower fields of palmito have roots infected with mycorrhizae. Presence of mycorrhizea in root samples taken from selected fields can be assessed with assistance of personnel in the Pathology Laboratory at IBTA's La Jota Station. This only involves some root staining and microscope evaluations. If mycorrhizae infection is poor among existing plantations, then we would suggest that future productions of

plant seedlings include a strategy to monitor and ensure good inoculation of roots before plants are taken to the field.

Pineapple

There are some general concerns about pineapple's viability as an alternative crop. One of the concerns with the production of pineapple is the narrow window of approximately two months for the primary market in Argentina. This is far too narrow of a window for a crop with such demands of heavy investment both in terms of nutrient requirements (often 400-500 kg N ha^{-1} are required) and the grower's time (crop occupies the land for more than a year). Providing fruit for such a narrow window of opportunity is difficult for any crop. Pineapple, especially if it is to compete for an international market, must be highly industrialized and highly controlled in order to ensure fruit availability and quality at the appropriate time. There appear to be two major problems with the production of the Smooth Cayenne variety.

One concern with the choice of pineapple for an alternative to coca production is the high sensitivity to cold weather both in terms of premature forcing (triggering of the reproductive phase) and in causing various problems such as black heart disease. Existing pineapple producing regions with experience in the effects of cold temperatures on production include Queensland, Australia, Taiwan, and South Africa. Research in these regions shows that low temperatures (even as high as 15^{o}C) may cause premature fruiting by stimulating ethylene production in the stem and D-leaf. Black heart disease is also a typical result of exposure to cold temperatures. Apparently black heart disease is quite common when the fruit are subjected to cool temperatures. The cold temperatures release polyphenol oxidase which causes fruit discoloration and the eventual blackening. A review of minimum temperatures in weather data from 1982 - 1999 at the La Jota Experiment Station shows that low temperatures have occurred between the months April and November (Table 4). Recent research exploring attempts to find alternatives to the loss of quality due to cold weather can be found at the following web site: http://agrss.sherman.hawaii.edu/pineapple/pnews6.htm.

The high risk of such an investment, the high level of management required to ensure that the product is of high quality and is ready at the precise time seems inconsistent with new growers in a region that is just beginning to develop an agricultural support infrastructure.

Table 4. Months with occurrence of minimum temperatures below 15 ^{o}C during the period of 1982- 1991 at La Jota Experiment Station, Chapare, Bolivia. All other months had higher minimum temperatures.

MONTH	**ABSOLUTE MINIMUM TEMPERATURE**
	^{o}C

April	14.4
May	10.0
June	7.8
July	11.1
August	8.3
September	11.1
October	8.9
November	14.4

Introduce and Demonstrate the NuMaSS Software

The NuMaSS software was installed on several local machines and was demonstrated to DAI, IBTA, FAO, and other local scientists. While this software was initially developed for annual crops, diagnostic and predictive information for palmito is being generated at an intensive project site in Costa Rica. It seems that this software would be quite useful for nutrient management in annual crops and in the case of palmito. Although the palmito module is still under development, the NuMaSS system should be useful even during the initial testing phases. For example, we find that the types of questions that need to be answered in developing the system often serve a dual purpose. Local project members can use it to assess current information in the Chapare for its quality and quantity. They could also use it to explore and evaluate potential alternative for proper nutrient management.

Our current efforts in developing the palmito module and data from ongoing field trials on palmito with collaborators in Costa Rica and Brazil can be viewed and downloaded from the following web site:
http://intdss.soil.ncsu.edu/sm-crsp/Download/Download.htm#Trip%20Reports

We expect that involvement of the DAI, IBTA, and FAO staff in the development of the palmito module would provide a clear evaluation of existing information in the Chapare for the purposes of the various steps in nutrient management problem-solving, and decision-making. With such possible benefits from collaborative efforts, a series of questions were posed that are sure to lead to assessment of current information. The answers will probably identify areas that require further investigation. This set of questions is attached in Appendix 3. Additional data and information requirements that would be helpful to nutrient management are listed in the following.

Improved soil database and information system – Fortunately, DAI seems to be developing a highly useful information system to provide communications and information science support for the new crops. While some maps have been developed that show the FCC groupings and distribution, there needs to be continued and expanded effort of this sort. Other Bolivian institutions need access to such information and the benefits that accrue from it.

There are several categories of information support needed including a fairly rapid access to information for problem-solving purposes. An information system of this sort needs to be linked with the various institutions that can generate the data needed for natural resource assessments of the region. For example, efforts for timely and accurate problem-solving of nutrient management requires the ability to collect samples, transport samples to a laboratory, obtain the analysis, and feed the information into decision-aids software to obtain the necessary interpretations. It is unclear at present that such an infrastructure is functional, especially within the short time frames necessary for problem-solving and diagnostic analytical services.

Another somewhat less time-critical type of analysis and information availability is that of having access to the historical soils, cropping, economic, and climate data for the region. This type of information is needed, for example, for the type of consultancy that we have just concluded. Access to rapid, on-line information from previous studies, consultant reports, digital maps, and database information would drastically improve the quality and thoroughness of subsequent consultancies. This type of information is essential in order to adapt NuMaSS and similar decision-aids software to the region. To adapt software of this sort, databases of soils, crops, and weather data are needed for use during their evaluation. While the specific database structure will vary, organizing the information in standard database management structures can dramatically facilitate the outputting to modules of data in the required formats for statistical analysis software, decision-aid software, and GIS or mapping applications.

We would like to acknowledge the efforts of DAI to develop, maintain, and expand their library. This certainly is a critical type of information, albeit one that is relatively costly. We encourage the DAI attention to information access.

Routine diagnostic functions in support of Chapare cropping systems - A locally maintained organization and infrastructure is needed that provides a diagnostic and routine problem-solving function in support of the cropping systems and grower community within the Chapare. This needs to be a technically capable agricultural institution with specialists able to handle information support for growers with insect, disease, nutrient, and other types of information needs. Such an organization differs from traditional research institutions that typically do not respond quickly to grower concerns, questions, and requests for information. Quite often a diagnostic, rapid-service organization may be associated with experiment stations, such as IBTA, but operate independently in order to provide rapid responses to clients with a clear educational, informational mandate. For reasons of access, such a center of information must be centrally located within the Chapare. We suggest that at least rudimentary equipment for soil nutrient management be included in such an organization for measuring pH, acidity and nutrients such as potassium and phosphorus. This would enable analyses to be provided within the period of a week or less.

Questions and Concerns Towards Improved Management and Success of Alternative Crops

The recent history of payment of farmers to not grow coca probably has severely reduced initiative and may be a factor in the generally inadequate level of management apparent for all alternative crops in the region. Past experience has been that providing giveaways in such a manner reduces initiative and often results in an irreversible loss of initiative and motivation. It would seem, therefore, that some activities should be directed towards increasing the motivation, perhaps by increasing the rewards for good management or at least the visibility of good management. Some options may include the following:

Farmer to farmer visits - This technique has been useful in work with farmers less technically qualified than those in the Chapare. There are several principles that the technique seems to put into action: 1) Farmers talking to farmers are likely to communicate much better and convey more information, especially in terms that are likely to be more convincing, than scientists talking to the same farmers. 2) It is an opportunity for the accompanying scientists to reinforce good management and to illustrate and point out scientific principles with concrete examples. 3) It serves the scientists well to learn first hand what issues are faced by the farmers, farmer requests and needs for information.

Public contests to generate interest, attention and recognition for those with the best management (or yield, or product) - In this technique, well-publicized contests are held and the growers most closely achieving the clearly stated goals are rewarded with awards, prizes and extensive public recognition.

Facilitate learning and development of analytical skill by growers - This could involve establishing comparative experiments designed to be easily understood, often understandable from a roadside view without technical explanation. Such experiments must be designed with careful attention to assist in learning how to compare and evaluate. These experiments also differ from the usual experiments not only by being simple and intuitive to understand, but also are usually located in areas of high recognition value. An example might be to locate the experiment next to the weekly market shelter where farmers regularly congregate and converse. An example in the Philippines was to locate an experiment on public land next to the weekly market building. Farmers discussed the visual differences constantly and showed great interest when the field day was announced - over 100 showed up from the small local village when the day was announced. Keeping the learning objective in mind is important because it focuses the conduct and disposition of the experiment towards activities that stimulate, enhance, and reinforce grower learning.

Application of FCC for Nutrient Management of Alternative Crops of the Chapare

It seems important to view the current context of use of the Fertility Capability Classification system within the Chapare. When the FCC was first applied for identification and delineation of possible limiting factors for production of alternative crops in the Chapare, there were few existing surveys or inventories of soil properties available to identify soil mapping units, regions of various soil properties and characteristics that would limit the proposed cropping systems. The Chapare's current FCC system is based on a far smaller set of data than what is normally required for the classic soil surveys as conducted in counties of each of the U.S. states. Certainly, the FCC has served an extremely useful purpose to identify the areal extent and location of important nutrient limitations to growth of the various alternative crops.

Having pointed out the value of the FCC to identify potential problems, it is also important to understand that FCC was not intended to suggest how these problems could be solved. The FCC was not designed to replace the problem-solving techniques of a human expert who would collect the evidence, make a diagnosis and prescribe a solution for the specific crop, field, and economic environment. The later is the role of a nutrient management decision-aid that can develop a field and site-specific fertilizer recommendation. The FCC was not designed to make fertilizer and lime recommendations for specific crops, grower fields, and economic environment. When used in the context in which it was developed the FCC system can be very useful and is a valuable tool to improve the use of natural resources. When used out of context for purposes beyond those for which it was intended, it cannot succeed. For example, use of the FCC to develop fertilizer recommendations or requirements without current, up-to-date soils data is not an appropriate use of the system. Soils data collected for delineation of FCC mapping units were collected at a specific point in time, but nutrient levels and availability will constantly change as the land is cropped and growers either apply fertilizers or deplete the soils native nutrient reserves. The FCC maps of the Chapare are not a substitute for a functional diagnostic laboratory designed to provide site-specific analysis and specific information which decision-aids can use to generate accurate fertilizer recommendations.

Our view of a functional diagnostic laboratory working in tandem with a decision-aids system can be illustrated via the phosphorus module in the NuMaSS software. This module needs to know which crop is to be planted in the field, a measurement of extractable P from the field and an indication of the soil's clay content, possibly available from a soil database. For the economic component of the software the price of the crop, the cost of the fertilizer, and the interest rate are needed. With this information, the decision-aid can estimate the amounts of fertilizer of various types that would be needed, the yield with and without the application of the specified fertilizer, the extractable P level after the crop is grown, whether a profit or loss is likely to occur and how much profit or loss will occur. The decision-aids system will also consider the residual value and calculate a benefit/cost return considering the residual value of the P fertilizer. With a properly validated decision-aid module for palmito, similar estimates should be possible for the Chapare.

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Appendix A. Acronyms

DAI - Development Alternatives Incorporated
IBTA - Instituto Boliviano de Tecnologia Agricultura
NuMaSS - Nutrient Management Support System

Appendix B. Itinerary

Nov. 27, 1999	Leave Honolulu, join Smyth in Miami, travel to Bolivia
Nov. 29	Arrive in Cochabamba and travel to Villa Tunari, Chapare
Nov. 29 - Dec 3	In the Chapare
Dec. 3	Travel Villa Tunari - Cochabamba
Dec. 6	Smyth departs Bolivia
Dec. 8	Yost departs Bolivia

Appendix C. Nutrient Management Questionnaire

Questions for Chapare investigators regarding nutrient management to sustain current gains and lead to further increased productivity and adoption in peach palm and banana. Peach palm will be used as the example. Your replies to these questions will help us shape the NuMaSS palmito module so that it provides good performance in the Chapare.

Nutrient Diagnosis

1. What are the critical soil and plant nutrient levels of N, P, K, Ca, Mg, S in the following phases[1] of peach palm growth?

a. Nursery phase (~0-6mo., before planting)
b. Lag phase (6-12 mo., 0-6 mo. after planting, perhaps initial slow growth?)
c. Grand phase of growth (12-30mo., 6-24mo. after planting, rapid biomass accumulation?)
d. Mature phase (> 30 mo., more than 24 mo. after planting, nearly constant aboveground biomass)

2. We propose using the range in number of tillers/cepa as an indication of level of management using the following scale:

a. 2-4 (indicating good management),
b. 0-5 (indicating either poor management or considerable genetic variability),
c. 0-more than 5, (management is very poor, out of control).

Might this be a useful question to indicate level/quality of management? How would you change this if the population was 10,000 plants/ha rather than the more common 5000 plants/ha?

3. We also propose asking whether there was fertilization within the last year. If not, we would assume poor management. Do you agree?

[1]See Table 5 for a tentative definition of phases according to Ares et al. unpublished

Nutrient Prediction

1. For early stages of plant growth:

   a. Will Phases 1(Nursery) and 2 (Early growth) require relatively similar amounts of N, P, K and micronutrients calculated according to a standard fertilizer requirements for growth irrespective of soils?
   b. What is your estimate of the proper levels for this Standard Fertilizer Requirement?

2. For N and K in phase 3:

   a. How much N and K is accumulated in aboveground biomass, how much is exported in harvests, and what are good values to be used for fertilizer use efficiency?
   b. Can estimates of N & K requirements be based on net uptake during the period’s removals) times an uptake efficiency factor, for both nutrients?

3. For N and K in phase 4:

   a. How much N & K is removed in harvests and are the fertilizer efficiency factors different from those used in phase 3?
   b. Can estimates of N and K requirements be based on removals times an uptake efficiency factor?
   c. Nutrient release/mineralization from peach palm residues has been measured in mature peach palm plantations in the Huertar Norte region of Costa Rica. Can we rely on these estimated values for use in the Chapare? If not how do we adjust these estimates or determine appropriate values for the Chapare?
   d. What is the native soil N & K supply for peach palm during Phase 3 and Phase 4 on the main soils?

4. For Phosphorus Considerations:

   Assuming fertilization can be determined by foliar analysis, can the same soil application be used on all soils to increase tissue plant level from a given tissue level to the critical level? This is a combined soil-plant buffer coefficient that builds on the soil buffer coefficient concept.

5. For Ca and Mg:

   a. What levels of soil Ca and Mg are necessary for good peach palm and banana growth?
   b. Are soil measurements taken at 0-5cm better than measures taken 0-20cm?

General questions on nutrient management

1. Should local soil and plant critical levels and soil buffer coefficients be used for the Chapare soils? If so, would it help to have these incorporated into NuMaSS?

2. Is K fixation in soils of the Chapare a problem, especially those with higher amounts of smectitic clay minerals?

3. What is the native soil N supply to peach palm during grand and mature stage of growth for the major soil types?

4. How many years can 400 kg N ha^{-1} as urea be applied to banana before acidity becomes limiting to production? (This is the rate which Leon Montaño reports applying to his fields in San Marcos.)

6. How might you anticipate and resolve nutrient management problems resulting from current management practices/recommendations such as:

    a. Soil acidification from N fertilization, especially on sandier and weakly buffered soils,
    b. Magnesium deficiencies either due to low initial levels, depleted native soil reserves, or imbalances caused by K fertilization,
    c. Calcium either due to low initial levels, depleted native soil reserves,
    d. Nitrate buildup and contamination of shallow groundwaters from continued application of high fertilizer N rates.

Table 5. Tentative definition of phases in peach palm and types of information to include in nutrient diagnosis modules (Ares et al., unpublished).

Crop	**Location**	**Previous Crop**	**Soil**	**Indicator**	**Analysis**	
Stage		**or Stage**	**Taxonomy**	**Plants**	**Plant**	**Soil**
(1) Nursery 0-6 mo	from quest.	from quest.	from quest.	from quest.	No	Pext, clay, texture, K, Al sat.,pH, N
(2) Lag growth 6-12 mo	from quest.	Pre-plant fertilizer, Plant obs. for S1	from quest.	from quest.	N, P (3rd. leaf), K, Ca, Mg, S	Pext, clay, texture, K, Al sat.,pH, N
(3) Rapid	from	Plant obs.	from quest.	from quest.	N, P (3rd.	Pext, Po, Plit,

Crop	Location	Previous Crop	Soil	Indicator	Analysis	
Stage		**or Stage**	**Taxonomy**	**Plants**	**Plant**	**Soil**
growth 12-30 mo	quest.	for S2 plus yield			leaf), K, Ca, Mg, S	clay, texture, K, Al sat.,pH, N
(4) Maturity > 30 mo	from quest.	Plant obs. for S3 plus yield	from quest.	from quest.	N, P (3rd. leaf), K, Ca, Mg, S	Pext, Po, Plit, clay, texture, K, Al sat.,pH, N