

DECISION AIDS FOR INTEGRATED SOIL NUTRIENT MANAGEMENT

A joint project for
the Soil Management Collaborative Research Support Program
by
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University of Hawaii
North Carolina State University
Texas A&M University

PROBLEM DESCRIPTION

Excess acidity or nutrient deficiency limits yields on essentially all tropical soils. Worldwide, 32% of all arable soils are acid and that figure climbs to 50% in the tropics. Crop yields in acid soils are frequently reduced by 50% and can be reduced to zero. Nitrogen limits production on over 50% of the arable soils and almost all soils under food grain production. When limited, N is usually required in the largest quantities, is the most expensive, and is the most difficult nutrient to manage efficiently within the crop cultural system. Phosphorus deficiency exists in 92% of the soils of the tropics and these soils often have high P sorption, thus requiring sizeable P inputs. Often there are no local P sources and importation is expensive.

Soil acidity is a complex syndrome resulting from numerous combinations of Ca deficiency and toxic levels of Al, H and Mn. The most prominent effect of acidity is a reduction in root elongation through limited Ca supply and/or Al and H toxicity. Restricted root growth destabilizes production by limiting the plant's ability to absorb essential nutrients and increasing susceptibility to drought stress. In soils with large sesquioxide contents Mn solubility increases at low pH and physiological disorders occur when plants accumulate excessive amounts of this element in their tissues. Minimum plant Ca requirements and their tolerance levels for Al, H and Mn often differ among species and cultivars within species.

Although subsoils may contain ample water reserves throughout the growing season, limitations in rooting depth as a result of acid subsoils can lead to drought stress and substantial yield reductions. Amelioration of subsoil acidity entails a combination of (a) applying ameliorants to surface layers with subsequent gradual movement of basic cations to lower horizons and (b) selection of crops tolerant to subsoil acidity.

Soil acidity also influences the management of other nutrient constraints. Efficient biological N fixation is often dependent upon an adequate supply of soil Ca, and legume-rhizobia tolerance to soil pH and Al. Aluminum neutralization increases P availability to plants by increasing the volume of soil exploited by roots and decreasing soil P fixation capacity.

Nitrogen sources include soil organic matter, green and animal manures containing biologically fixed N, soil inorganic N, and fertilizers. In humid climates, N may be lost from the soil by plant uptake, leaching, volatilization,

immobilization, and fixation. The efficiency of plant N use depends upon uptake efficiency, rate and timing of mineralization, crop characteristics, and the source, rate and timing of N applications. Unfortunately, there is no effective soil index to measure the quantity of N potentially available to the crop. Thus, N management decisions must be inferred from cropping history, yield potential, climate, soils and N sources. Nitrogen use decisions need to first consider locally available and least expensive N sources, such as biological N fixation (BNF), followed by complementing the N requirement with commercial fertilizer to produce near optimum economic yields based upon local economic conditions.

Decision-makers in developing countries whether they be farmers, extension agents, regional planners, or national and international policy-makers often are not aware of conditions where P limits crop growth or available options to correct P deficiency. Access (either physical or economic) to materials that provide P is limited and they are not aware of the economic and environmental consequences to the use of alternative materials. This lack of knowledge severely limits small farm food and raw material production.

Ironically there also are numerous examples of nutrient over-application in developing countries. Although easily predicted from existing disciplinary knowledge, this information is not readily available to those applying the nutrients. The impacts of nutrient over-application involve both economic loss and serious environmental damage. Misapplication of nutrients can easily occur when site-specific information for characterizing nutrient needs and soil status is not available for use in gauging nutrient applications. The best defense against pollution is to prevent it; otherwise remediation is needed. For most developing countries pollution prevention strategies are appropriate and should be part of the best nutrient management practices.

The knowledge requirements for properly diagnosing the site-specific acidity syndrome and/or nutrient deficiencies and prescribing the best management alternatives for the numerous combinations of crops, social, political, economic and resource conditions that occur throughout the world exceed the capacity of any human expert. If such experts existed their availability at any specific location would be limited and expensive. Scarcity of experts can be alleviated if the required expert knowledge is organized in a manner accessible to inexperienced personnel. The expert system captures the knowledge of experts and makes it available for the agriculturalist to make the most appropriate management

decisions in combination with local data and observations.

Investigators for this proposal have contributed to the development of separate decision support systems on acidity (ADSS), N (NDSS) and P (PDSS). These separate computer-based expert systems allow users to diagnose acidity, N and P problems and evaluate different solutions. Based on user replies to questions about soils, crops, available nutrient supplying materials and input-output prices, the programs evaluate the data through the same logic and problem-solving methods of experts and recommend the best management strategies. Users can make informed decisions and choose the most desirable management strategy for their conditions after evaluation of costs and returns for various soil, crop and management alternatives.

Feedback from researchers, extension agents and other decision makers using these single nutrient constraint systems have identified weaknesses in the knowledge assemblies and information gaps in the knowledge base. The diagnosis process needs to consider quality and accuracy of different soils information and the recommendation process needs to provide a hierarchy of solutions based on the amount and type of available site information. Outreach activities have been identified that would complement such computer programs and maximize their dissemination and use in diagnosing and solving the farmers' location-specific acidity and nutrient problems.

Existing knowledge gaps for acidity management include the ameliorative and detrimental effects of organic inputs on soil acidity, how long a corrective amendment will last before needing replenishment, and estimates of the time required for cation leaching from surface amendments to alleviate subsoil acidity constraints. Nitrogen management needs to be adapted to consider a broader number of crops, multiple cropping cycles per year, and the contribution of BNF on N cycling and crop yields. The current knowledge base on P management has not been fully tested in independent field trials, diagnostic information is incomplete for many food crops and agroforestry species, and recommendations need to consider the use of rock phosphate.

Although these individual systems have not been integrated, they do illustrate that an Integrated Nutrient Management Decision Support System is feasible. However integration entails new levels of agronomic considerations that often have not been studied, such as how much nitrogen is required when P is available at only 50% of the optimum or the soil is still too acid for roots to access water reserves in the subsoil.

Although an integrated nutrient management system will enable users without an extensive soil fertility background to perform a logical diagnosis and evaluate remedial alternatives, most agriculturalists will only be concerned with the relevance and application of such tools at a regional level. Many targeted users will also have limited access to computers. With user participation, however, estimates can be developed for the regional extent of the major factors contributing to the soil acidity and nutrient constraints. In conjunction with the global knowledge base in an integrated

nutrient management decision support program, reliable and practical guides can be produced to indicate the economic consequences of potential management alternatives for the prevailing cropping systems, cultivars, lime and fertilizer materials, and soil conditions in a given region.

OBJECTIVES

The goal of this project is to integrate and disseminate decision aid tools that will reduce acidity and nutrient limitations to food production and quality by facilitating the process of diagnosing the soil constraints, and selecting the appropriate management practices for location-specific conditions. Project objectives are as follows:

- Improve the diagnosis and recommendations for acidity and nutrient problems by identifying and resolving knowledge gaps through extensive literature reviews and, when necessary, developmental research.
- Develop an integrated computerized knowledge base for global use in diagnosing and recommending practical solutions to soil acidity and nutrient problems, which considers differences in resource availability and soil, climate, crop and management factors contributing to location-specific acidity and nutrient constraints.
- Develop auxiliary tools to the integrated knowledge base to enable local agriculturalists to diagnose and solve soil acidity and nutrient problems that predominate within the social, economic and agronomic characteristics of their regional domains.

Constraints addressed by project: soil acidity and plant access to soil water reserves, nitrogen deficiency, phosphorus deficiency, and their interactions under location-specific multiple constraint conditions.

Justification in terms of USAID goals and strategic objectives:

Food Security: Excessive soil acidity and nutrient deficiencies limit crop yields in most under developed countries. The consequences of the poor yields are food insecurity or economic hardship. Unfavorable weather, even for one growing season, can lead to famine in areas of limited agricultural productivity. Increased production of food and raw products, that contribute to income, provide more options to limited-resource farmers. Once the soil has been improved, new cropping alternatives are possible and there are more alternatives for crop products and associated services. The information that will be contained in this project's Integrated Nutrient Management Decision Support System can result in increased crop yields and income.

Improved natural resource base: Under most itinerant cultivation practices nutrients for crop growth are obtained by continuously clearing more land. With poor crop yields soil exposure is increased and the potential for erosion and downstream pollution increases. An improved soil nutrient status and management provides greater choices of plant materials to control erosion, minimizes off-site nutrient transport, optimizes animal habitat and contributes to esthetic value.

STRATEGY

Our strategy is to develop globally applicable, largely computer-assisted, integrated decision aids that will both diagnose nutrient constraints to food production and quality and prescribe appropriate solutions to the constraints. A range of decision aids, varying from guides to assist in nutrient management at a regional level to those that provide site-specific nutrient diagnoses and prescriptions will be available for users to select as applicable to their local conditions. Prior to final release, the capability of these integrated decision aids will be tested, refined, and retested with the assistance of user groups. Users will apply the decision aids, usually the electronic integrated nutrient management system, to diagnose and prescribe management solutions to identified nutritional constraints.

Project activities will be conducted by a multi-disciplinary team of 16 scientists from four U.S. universities in close collaboration with overseas investigators from national agricultural research and extension systems (NARES), international agricultural research centers (IARCs), and selected members of private volunteer organizations (PVOs), nongovernmental organizations (NGOs), agribusiness and other CRSP projects. Project activities are distributed among two levels of collaborative effort: *intensive testing areas* and an *extensive evaluation network*.

Intensive testing areas are a selected representative region in each of three agroecological zones (semi-arid, wet-dry, and humid tropical) where there is significant potential for products developed by this project to alleviate soil acidity, N and P constraints to food production and to promote environmental security. Each area should be large enough to constitute a political entity. It can be as small as a farming community but not exceeding a county or province. Testing areas provide real life situations where all developmental research by U.S. team scientists will be conducted in conjunction with collaborators in each area. Testing area activities will begin with a baseline assessment of social, economic and cultural conditions, infrastructure, and nutrient needs. This initial assessment will be conducted by multi-disciplinary teams of U.S. scientists and local collaborators. It will include extensive contacts with farmers, extension agents, planners and decision-makers. Based on the team's determination of potential remedial actions and approaches, subsequent activities in developmental research and outreach will be tailored to address the needs of the testing area. Products developed by the project will be tested in these areas and refined to provide satisfactory performance. Similar assessments in the third and fifth years will be used to document project impact.

The second type of collaborative effort, *extensive evaluation*, will focus on a network of collaborators to evaluate refined products under a variety of global conditions. Although extensive evaluation will be concentrated towards the end of the 5-year project, a modest level of interaction with collaborators in this effort is also planned for the initial years of the project. Early and continued contact with these collaborators will help clarify the global

extent of knowledge gaps and potential adjustments needed for application of products beyond the testing areas.

The integrated nutrient management decision support system is the core knowledge base from which information is extracted to build auxiliary tools that facilitate use of this knowledge for different purposes and/or groups. We perceive the process of developing the integrated nutrient management decision support system and its auxiliary tools as a continuous feedback loop among developmental research and outreach activities. Upon the synthesis of existing knowledge the team will gather to formulate options and refine developmental research needs. Prototypes will be assembled and tested, and the team of U.S. scientists and collaborators will critique/discuss/improve the prototypes. With each repetition of this cycle the product approaches desirable performance.

IMPLEMENTATION PLAN

Proposed activities in developmental research and outreach, described in the following sections, are based on collaborative efforts in both the testing areas and evaluation network.

Developmental Research

Research activities in this category include tasks to a) merge the single-constraint decision support systems into an integrated nutrient management DSS; b) synthesize, analyze and assemble knowledge required to overcome recognized information gaps in the current acidity, N and P information base; c) test and refine the integrated nutrient decision support system; and d) develop auxiliary tools to facilitate use of the integrated knowledge base by a variety of users. Tasks for each category are described in the following.

DSS Integration

The integrated nutrient management DSS will be designed primarily for agriculturalists in NARES, PVOs and NGOs. The primary challenge in achieving an integrated DSS will be how to address interactions among nutrients when prescribing management solutions to the location-specific combination of acidity, N and P constraints. Our previous single-component software addresses an individual nutrient constraints under the assumption that other nutrients are not limiting. In real life situations, however, lime or N and P fertilizers may not be available or economically feasible. The integrated DSS needs to adjust for such conditions by revising yield expectations and consequent nutrient needs and offering alternative cropping sequences that would best suit the continuing nutrient limitations. Many of these issues are not well defined from the agronomic and economic standpoints. Our initial integration will, thus, focus on algorithms for multiple iterations.

Nutrient interaction problems are of such complexity that they need to be addressed simultaneously to activities focusing on knowledge gaps associated with individual nutrient constraints. Consequently, we propose an intensive effort to develop an integrated DSS prototype by the end of the first year of the project, using the existing knowledge base assembled in ADSS, NDSS and PDSS. The initial

prototype will be used in the intensive testing areas and distributed among a select group of individual collaborators for evaluation with location-specific data sets. Feedback from this testing and selective evaluation will be used to identify weaknesses in the DSS integration process and plan refinements. An early appraisal of the integration strategy will also help identify whether adjustments should be made in ongoing developmental research for individual nutrient components.

Intermediate prototype releases are planned for the second and third project years, and will consist of incorporating planned refinements in the integration process plus the addition of new information synthesized from developmental research on acidity, N and P components. The process of evaluation in testing areas and off-site evaluation by a select group of collaborators will be repeated with each prototype release. The final version of the integrated nutrient management DSS, with incorporation of all developmental research, is planned for the end of the fifth project year.

Integrated soil nutrient management DSS software will be accompanied by auxiliary tools to facilitate use of the knowledge base at the local level under conditions where computers are not readily accessible and/or user interest is in a summary of potential recommended management alternatives and economic analyses for the prevailing cropping systems, cultivars, lime and fertilizer materials, and soil conditions within a given region. Auxiliary tools can also provide instructional information on the process of diagnosing and solving nutrient management problems, and the effective use of lime and fertilizer inputs. Depending on user needs and their available resources, format for these tools can include printed materials, decision-making structures, map overlays, coupled-GIS, or spreadsheet templates. Feedback from our collaborators in the intensive testing areas and the extensive evaluation network, upon evaluation of different auxiliary tool prototypes, will determine the most desirable format to be used.

Developmental research for several information gaps in nutrient management will be addressed in conjunction with DSS integration tasks, because they are common to two or more of the individual nutrient constraints. Organic soil amendments can produce various biochemicals, some of which are effective chelators of trace metals and Al. Consequently, organic materials can have lime equivalence values which may last for different periods of time depending on quality of the materials and the nature of the soil acidity constraint. We propose to initially estimate lime equivalence and residual effects of different organic materials through greenhouse and laboratory incubation studies. Subsequent field evaluations in project testing areas will be used to verify and refine algorithms based on laboratory findings. Organic amendments can increase soil P availability by a) direct contribution through mineralization, b) reduced soil P sorption, and c) organic complexation of cations that limit P solubility. Conversely, organic materials may reduce P availability by inhibiting the crystallization of sesquioxides or dissolving soil minerals that increase soil P sorption

(Bennoah and Acquaye, 1989; Sanyal and De Datta, 1991). A similar sequence of greenhouse-laboratory-field testing activities will be conducted to fill this information gap.

Prediction of residual management effects have important economic consequences on both lime and P recommendations. How long will lime and fertilizer P applications last and can they be estimated by soil factors and cropping systems practices? What is the economic value of the improved crop rooting zone as lime reaction products move into the subsoil? Predictions from the nutrient leaching investigations, as described below in activities for the acidity component, may provide solutions to such questions about liming.

Nutrient pollution of surface water resources is caused primarily by eutrophication and habitat degradation from N and P runoff and erosion of suspended soil particles. At sufficiently high levels, $\text{NO}_3\text{-N}$ can contaminate groundwater. Conway and Pretty (1988) found that 20-50% of the wells tested in Africa and India had more than 50 mg $\text{NO}_3\text{-N}$ L^{-1} , but most of this contamination came from animal and human waste rather than agricultural fields. There are, however, certain locations in developing countries (e.g. Java, some coffee and vegetable producing regions, the Cerrados) where excess P fertilization could lead to nutrient pollution. The best defense against pollution is prevention; otherwise remediation is necessary.

The project's integrated nutrient management decision support system and auxiliary tools will minimize N and P pollution by recommending nutrient applications in the range that maximizes plant uptake and use. The ability to diagnose conditions of excess soil P will be incorporated to the integrated DSS. Agricultural remediation practices will also be recommended with a focus on maintaining P on site by increasing P recovery, and reducing runoff and erosion. At any location, several practices involving placement, timing and number of fertilizer applications, vegetative barriers and fertilizer sources should be jointly recommended to minimize nutrient pollution and maximize crop yields.

Acidity Component

The current knowledge base does not predict the rate of movement of basic cations into acid subsoils from surface-applied liming materials. This knowledge gap limits our ability to recommend management strategies for alleviating acidity constraints below the depth of lime incorporation. An accurate description of the soil-plant-atmosphere water balance and leaching patterns will be essential for predicting movement of lime reaction products. The relationships between soluble Al, solid phase Al, other cations, and anion sorption will also be critical. We propose to address this knowledge gap through the application of models developed at Cornell University to existing field data sets from long-term lime trials at various locations. The multiple ion uptake model (Bouldin, 1989) imposes electrical neutrality conditions to soil and soil solution ionic composition. Subroutines from GAPS (Buttler and Riha, 1987) will be incorporated for prediction of soil water movement. The model will be tested

and refined using known data sets (from Brazil, Costa Rica, and Puerto Rico) and others yet to be identified by comparing predictions with known observations in pH change and cation movement. Through this procedure, parameters will be identified to develop a mechanistic prediction of leaching for acid soils.

Although soil acidity is a major limitation to crop production in the African Sahel (Scott-Wendt et al., 1988; Takow et al., 1991; Wilding and Hossner, 1989) much of the data on surface and subsurface acidity is either in the gray literature or in European libraries. We will work towards capturing information that is available and pertinent, but anticipate a paucity of suitable data relating to long-term liming trials. A major consideration for the productive use of these acid, sandy soils is the introduction of basic cations, namely Ca and Mg, and their movement into the acid subsoils. Due to time and cost limitations, we propose to acquire this information through field lysimeter studies and complementary laboratory leaching studies in representative West African soils. A sufficient number of small, intact soil lysimeters will be prepared to allow destructive sampling for movement of applied Ca and/or Mg salts as a function of time and water movement. Data generated in controlled laboratory experiments will be used to corroborate and predict solute movement under field conditions.

The acidity knowledge base will also be expanded to evaluate soil conditions with limited Ca and/or excess Mn. The consequences of using lime materials with low Mg contents on soil Mg availability and recommendations for solving this potential problem need to be added to the integrated decision support system. We propose to address these information gaps through an extensive review and assembly of existing knowledge in the literature. Particular attention will be given to the experiences and recommended practices among our network of collaborators for extensive evaluation of products.

There is considerable variability in the tolerance of sorghum genotypes and cultivars on Paleustalfts of West Africa (Doumbia et al., 1993). Local cultivars used by farmers seem less affected by soil acidity problems than introduced cultivars. Ongoing variety tests in West Africa, conducted by scientists at national centers in association with the INSORMIL CRSP, seek to determine the susceptibility of sorghum and millet cultivars to acid soil conditions. A modest project effort to characterize the nature of the soil acidity complex (Al and H toxicity, Ca and Mg deficiency) will enrich the knowledge base with respect to cultivar differences to soil acidity constraints. This collaboration with a commodity research team, resulting from linkages developed by the Texas A&M team members, illustrates the mutually beneficial process by which the knowledge on species and cultivar tolerances to soil acidity can be improved. We will explore similar opportunities with commodity research teams at IARCS and other CRSPs.

Nitrogen Component

Current N recommendations use the crop's constant internal N requirement, as proposed by Stanford (1966), and

the total above ground dry matter production to determine total plant N requirements. This concept can be used for monocots with high N requirements. The amount of nitrogen that must be supplied for any given yield can then be computed by the equation:

$$N \text{ needed} = \frac{[Plant \ N - (Soil \ N + Manure \ N + Atmospheric \ N - N \ loss)]}{N \ uptake \ efficiency}$$

There is no unifying concept that allows an evaluation of the efficiency and mineralization transfer coefficients with changes in soils and climate. Therefore, each coefficient must be calibrated for each new set of conditions. Local calibrations are achieved by comparing the new condition with the soils and climate for known calibrations. Adjustments can then be made to the model based on inputs from local agronomists through a series of questions and local observations. Existing calibrations in the literature will be assembled in a N database for the integrated DSS. Much of the published information on maize yield response to N was summarized by Osmond (1991). One of the first tasks will be to develop similar calibration coefficients for other important crops using the data in the literature. However, results from experiments needed for the calibrations often are not in published literature. Collaborators involved in the extensive evaluation phase of this project are an important source of unpublished and/or 'grey literature'. Given the size of this task, acquisition and refinement of these coefficients will be an ongoing process throughout the entire project. These coefficients will be verified in both the intensive testing areas as well and in the extensive evaluation network.

Biologically fixed N is an important contribution to the total N requirement, especially for economically distressed growers. This potential contribution must be evaluated, not only by examining the current crop grown, but evaluating the possibility of introducing additional legumes into crop rotations. In many situations a food crop cannot be sacrificed to produce N, but edible leguminous crops may replace nonleguminous crops within the rotation or may be planted between nonleguminous crops within the rotation (Burle, 1992). In drier climates such as West Africa the potential for BNF has not been thoroughly investigated. One of the first tasks will be to summarize the existing literature data on some important legumes such as cowpea, especially with respect to acidity, P and Rhizobia constraints. Close collaboration with NifTAL, other CRSPs and NARES will be necessary to maximize the efforts within this area and to capture the 'grey literature'. Available data will be categorized by organic source, C constituents, plant age and soil conditions (including temperature and moisture regime) to determine their influence on N transfer coefficients. The N recovery by important crop species will also be studied. Based on the existing data, critical information gaps will be identified and ranked for their absolute need in the development of the integrated DSS. Missing critical transfer coefficients for specific crops or legumes will be obtained by

direct experimentation either in testing areas or within the laboratory.

Efficient use of BNF requires that the legume be properly managed within the cropping system and the proper strain of Rhizobia is present. Both the legume crop and its organic residue must be considered within the cropping scheme if the use of BNF is to be optimized. As agronomists we most often think of the problems associated with growing the legume, such as the soil pH, P requirements, and inoculation. However, timing, quantity and how the legume is incorporated relative to the following crop is critical when there is excessive rainfall between legume senescence and the start of the N requiring crop. Evaluations of as many of these legume management factors as possible, during the initial baseline assessment, will help identify specific needs for each of the intensive testing areas. For example, on-site evaluation of availability of inoculant will be conducted by determining the kinds of inoculant, their species, carrier use and effectiveness. At some locations, it may be necessary to demonstrate inoculant use in collaboration with the local NARES as part of the outreach activities. If so, materials from NifTAL can be localized for use. We will depend upon the collaborators to provide this information within the extensive evaluation network.

Estimates of crop N requirements assumes that soil N losses are accounted for within the transfer coefficients or within the uptake efficiency factors. Losses can often be predicted and should be incorporated into the integrated DSS. There are a number complex models which estimate N losses. Within the decision support system, the N loss estimates may be simpler, but strategies need to be developed to predict the quantity which is lost. Alternatively, a measure of the soil or plant N must be able to recommend N additions needed to replace N lost through large rainfall events, denitrifying conditions, or volatilization. An example of this type of recommendation is the PreSidedress Nitrogen Test used in the Northeastern U.S. for corn. Other examples of loss that should be evaluated are those resulting from plowing legumes followed by delayed planting of the next crop or N volatilized from organic matter or fertilizer applied to the soil surface.

Phosphorus Component

Rock phosphate often exists in local deposits. When of high quality and applied to acid soils or perennial crops, it can be as effective as soluble fertilizer P (Pushparajah et al., 1974, 1976; Charoy, 1980; Yost et al., 1982). In other cropping systems rock phosphate is clearly not an optimum alternative (Kochhann et al. 1980; Chien and Friesen, 1990). Consequently, the integrated DSS needs to advise nutrient managers of conditions appropriate for the use of rock phosphate. Existing literature will be thoroughly gleaned for information that may assist in diagnosing situations where rock P is preferable to other P-containing materials. To enable users to compare benefits upon choosing rock P, their effectiveness in supplying nutrient P must be evaluated and algorithms generated that will either replicate practical experience or predict performance based on data and

information available to the intended users.

Additional effects of rock P on other soil properties will also be noted, where significant, to account for interactions with the diagnoses and prescriptions for acidity and N constraints. The addition of lime, for example, usually reduces the effectiveness of rock P. Depending on the acid tolerance of the crop, the extended use of acidifying N fertilizers could increase rock P dissolution and its effectiveness by lowering soil pH. Only the interactions of major, practical significance, as revealed by field testing, will be included in the integrated DSS. Sites and locations among the extensive evaluation network having experience with rock P as an adopted practice will be identified. Information and early DSS prototypes will be tested against diagnostic information from systems in which this soil P management technology is in practice.

Our current ability to diagnose and accurately prescribe P requirements for perennial species in agroforestry systems is limited. Present methods of plant P diagnosis and prescription are intended primarily for annual crops. Usually P concentrations are measured in specific tissues, such as young fully expanded leaves, known to be indicative of plant nutrient status. The "critical level concept" assumes that plant growth with less than the critical leaf concentration results in a dilution and reduction of leaf P concentration. In some species and plant tissues there seems to be either little growth below the critical concentration or such a narrow range of observed tissue concentrations that the difference between deficiency and sufficiency is narrower than existing sampling and measuring technology can reliably detect. In addition, determining how much P should be applied, once diagnosed as deficient, can differ for perennial species. This occurs because perennial species can often recycle up to 70% of their total nutrient P content (Herbert 1995). Existing literature will be gleaned for first approximations of critical levels for agroforestry species applicable to establishment phases of tree growth. Plant critical P levels during the mature phase will be obtained from collaborator sites in the extensive evaluation network where practical experience has been developed for agroforestry species. Improved estimates of critical levels may require field testing with extensive evaluation collaborators at selected locations. Alternative diagnostic methods for mature stands, such as spot applications of P, will be tested as an alternative to the critical level. Estimates of P recommendations will be based on the buffer coefficient approach used for annual crops. Early decision-aid prototypes will be tested against diagnostic and prescriptive information from established agroforestry systems.

Phosphorus decision aids are in a younger stage of development than the modules for acidity and N. For many situations, predicted P requirements are uncertain or undetermined. Existing coefficients for P need to be improved and expanded over more soil and crop conditions before predictions become reliable. The present algorithm for resolving a soil P constraint requires three coefficients and two measurements. The coefficients are a) the P added to the soil that remains available, as measured by extractable P (buffer

coefficient); b) the critical extractable soil P above which no nutrient response is expected for the crop under consideration; and c) the rate of decline in extractable P with time. The required measurements are the current level of extractable P in the soil and soil texture (clay content). Our recent research has indicated that the buffer coefficient and the critical level are the least well quantified (Chen et al., 1996).

There is a paucity of field data to quantify the buffer coefficient, and data from incubation studies or other quick tests may be needed. The validity of such data will be determined by adding P to soils and subjecting samples to a drying cycle or an incubation period, then determining extractable P. Other soil properties will be measured to develop relationship between buffer coefficients determined in the field and the laboratory.

The influence of soil clay content on predicted P requirement is based primarily on research with Ultisols and Oxisols. Although similar relationships have been noted with Alfisols and some Inceptisols, the actual breadth of this interpretation has not been determined. Presumably, clay content would not be applicable to Histosols or Andisols, because there is no meaningful particle size fractionation for these orders. If P is precipitated by free lime, as would occur in some Aridisols, then free CaCO₃ content of these soils would likely be more important than clay content. The limits on the current interpretation based on clay content will be determined by reviewing current data from around the world, conducting incubation studies, and seeking the collaboration of personnel in the extensive evaluation network from areas with soils which have these boundary conditions. In cases where the current interpretation does not apply, other logical approaches will be developed and submitted for evaluation.

Various solutions are used to measure available soil P and relationships among these extractants remain unclear. As we assembled the existing P knowledge base, data were collected primarily from sources using the Bray-1, Mehlich-1, Mehlich-3, Olsen, and Modified Olsen solutions. If the integrated DSS is to have widespread application, this relationship needs to be improved to represent a greater number of soil conditions. Laboratory data from other tasks and data from collaborators in the evaluation network will be used to improve the existing relationships among extractants.

Outreach Activities

Intensive Testing Areas

As previously described, these areas provide real life situations where developmental research will be concentrated, thus allowing a joint team effort in assembling knowledge for information gaps, testing and refining products, and interacting with the ultimate beneficiaries of our project activities. Consequently, many of our activities on developmental research will be blended into the outreach activities in these selected areas.

Testing areas were selected based on a combination of criteria. Testing areas need to be representative of the major ecosystems in the tropics, as well as the different social, political, economic and cultural conditions where our

products will be used. These areas also need to provide the soil and climatic conditions suitable for conducting the developmental research to fill existing knowledge gaps in the decision support systems. Testing areas need to be in regions that are acceptable to the donor agency and, if possible, should be matched with other CRSP projects to maximize the use of limited funds. Additional considerations included accessibility to the potential testing area and the institutional capacity of the on-site collaborators. The three intensive testing sites for this project are a) a humid tropical environment with andic soil properties in Costa Rica, b) a wet-dry environment in the Phillipines, and c) a semi-arid area in Mali.

The initial baseline assessment will begin at each testing area once detailed plans for all project activities are developed in conjunction with on-site collaborators. As stated previously, the initial assessment will be conducted by multi-disciplinary teams of U.S. scientists and local collaborators and will include appraisals of social, economic and cultural conditions, infrastructure, soil resources and nutrient needs. Many of the initial tasks described in the various developmental research components reflect the expectation by U.S. team-members that they will participate in this baseline assessment activity. Upon completion of the initial assessments at each site, a document will be produced based on collective team input, summarizing initial conditions at each site, identifying potential remedial actions for overcoming nutrient constraints, and a plan for tailoring activities in developmental research and outreach to address the testing area needs. Similar assessments in years three and five will be undertaken to measure impacts of project activities in overcoming nutrient problems in each testing area.

Extensive Evaluation

Outreach activities in this category focus primarily on the evaluation of products under a variety of user conditions, once suitable tool performance is achieved in project testing areas. Within this group of collaborators we envisage a) individuals with knowledge that should be incorporated into products, b) individuals with field and laboratory data sets that could be used to evaluate products at location-specific conditions, and c) established networks who would be interested and would benefit from using our products in their programs. Although major efforts in product evaluation will occur towards the end of the 5-year project, early and continued contact with collaborators in this outreach effort would help ensure global relevance in product design and knowledge assembly. Therefore, we propose a series of four meetings to be held in project years 1, 2, 4 and 5. Collaborators at project testing sites would also be involved in these meetings.

The initial workshop will serve as a coordination and planning meeting with collaborators. The summary document on baseline assessment of testing areas would be presented in conjunction with the plans for product development. Collaborators would be asked to consider whether planned products would be relevant to their local needs and suggest potential modifications or additions. During this

meeting we would also seek to identify if collaborators had any information from their respective regions that would contribute to filling existing knowledge gaps to be addressed by developmental research activities. Workshops in years two, four and five would focus on obtaining their feedback on evaluations of the integrated DSS prototype and auxiliary tools when applied to their local conditions. Collaborators would receive instructions on using the software and auxiliary tools as well as desirable contents of local data sets to be used in evaluating these products.

Project Timeline, Leadership, and Coordination

Table 1 shows the timeline for research and outreach activities as described in the sections above. The leadership for this project will be integrated throughout the participating institutions in order to provide maximum communication, coordination and cooperation between team scientists. Overall project leadership will be the responsibility of Jot Smyth (NCSU). Each combination of related tasks in the project has a coordinator and an assigned team of scientists from the four participating universities. Coordinators and

Table 1. Timeline for project activities during the 5-year period.

| PROJECT | | YEAR | | | | |
|---------------------------------|---------------------------------------|------|---|---|---|---|
| CATEGORY | TASKS | 1 | 2 | 3 | 4 | 5 |
| Developmental | DSS Integration | X | X | X | X | X |
| Research | <i>Initial prototype</i> | X | | | | |
| | <i>Intermediate releases</i> | | X | X | | |
| | <i>Final release</i> | | | | | X |
| | <i>Predicting residual management</i> | | | X | X | |
| | <i>Predicting organic effects</i> | | | X | X | X |
| | <i>Predicting nutrient pollution</i> | | | | X | X |
| | Acidity Component | X | X | X | | |
| | <i>Lime movement</i> | X | X | | | |
| | <i>Ca, Mg and Mn</i> | | X | X | | |
| | Nitrogen Component | X | X | X | X | X |
| <i>Calibrating coefficients</i> | X | X | X | X | X | |
| <i>Predicting N losses</i> | | X | X | | | |
| <i>Legume management</i> | | | X | X | X | |
| <i>BNF contribution</i> | | | | X | X | |
| Phosphorus Component | X | X | X | X | X | |
| <i>Tree crops</i> | X | X | X | | | |
| <i>Refining coefficients</i> | | X | X | | | |
| <i>Predicting placement</i> | | | X | | | |
| <i>Rock P</i> | | | | X | X | |
| Outreach | Intensive Testing Areas | X | X | X | X | X |
| | <i>Selection</i> | X | | | | |
| | <i>Baseline assessment</i> | X | | | | |
| | <i>Impact assessment</i> | | X | X | X | X |
| | Extensive Evaluation | X | X | | X | X |
| | <i>Initial contact meeting</i> | X | | | | |
| | <i>Workshops</i> | | X | | X | X |

U.S.-team members are listed in Table 2. A complete list of project team-members and their institutional affiliations is given in Table 3. We expect the list of overseas collaborators in the intensive testing areas and the extensive evaluation network to increase once the project becomes operational.

Baseline information is essential not only for impact assessment but for at least two additional activities related to developmental research. These include but are not limited to:

- assessment of user requirements to shape and adapt product interfaces for simplicity and stimulation of

Table 2. Coordination and group composition for tasks in developmental research and outreach activities

| CATEGORY | TASK | COORDINATOR | U.S. TEAM-MEMBERS |
|---------------|--------------------|----------------|---|
| Developmental | DSS Integration | Osmond | Hue, Reid, Smyth, Yost, others as needed |
| Research | Acidity | Smyth | Bouldin, Hossner, Juo, Onken, Reid, Yost |
| | Nitrogen | Reid | Fownes, Hossner, Israel, Osmond, Wagger, Wollum, Yost |
| | Phosphorus | Yost | Cox, Fownes, Hossner, Onken, Reid, Smyth |
| Outreach | Int. Testing Areas | UH, NCSU, TAMU | all |
| | Ext. Evaluation | Tsuji | all |

In order to assure progress towards the products for this project, communication management tools will be used on a regular basis. When necessary, phone conferences will also be used by the coordinators and project leader to ensure adequate communication among participants. Task coordinators, in conjunction with U.S. team scientists and their collaborators will prepare progress reports for their assigned tasks on a bi-annual basis. These reports will consist of work completed during the preceding period and work planned for the succeeding period. Based on these reports the project leader and coordinators will assemble annual progress reports describing completed and planned work, and listings of papers, presentations and contacts prepared or made during the year.

PROGRAM OUTPUT AND IMPACT

Biological and social scientists will work in teams with NARES, IARCs, Agro-Industry, University, NGO and PVO participants for the interrelated activities of constraints evaluation, product development, knowledge generation and impact evaluation. The best practices and principles of evaluation research will be used to assess project impact (Valadez, 1994). Reliability and validity will be assured by appropriate design and analysis.

The constraints evaluation at intensive testing areas will result in a documentation of baseline conditions, as described by multi-disciplinary teams, including the following measurable indicators:

- agricultural practices, production levels, factor and product prices, and environmental quality;
- methods of planning, diagnosis and decision making relating to land use, infrastructure development, market liberalization, regulation, and related factors;
- levels of participation of target groups; and
- levels of integration of diverse information types for decision making at all levels.

learning knowledge applied to resolve nutritional constraints; and

- inter-disciplinary assessment of user-identified weaknesses in the nutrient management scenarios that project decision aid tools must directly address and resolve.

Impact assessments in intensive testing areas will measure changes in relation to each of the baseline measures, highlight salient constraints, and suggest adjustments in product design, development, implementation and related matters. Impact evaluations will be based on systematic follow-up assessments during the third and fifth years of project implementation. Impact at the testing sites will reveal the value added by decision support systems in farm-based production, policy improvement, planning and investment activities, and food security and access.

Based on their experiences with the decision tools, users and target beneficiaries will render their judgement on the value of the decision tools and provide testimony to whether the tools have improved operations and generated both private and social benefits. Measurable indicators of impact at the intensive testing areas will include:

- awareness and familiarity with the various products within the target groups;
- the capacities of users to use the tools to simulate different agronomic, social and economic conditions; and
- changes in farming practices, policies, diagnosis, and planning methods.

Site impact information will provide critical feedback to help adjust and improve the decision tools prior to release for widespread distribution. Impact evaluation at these intensive testing areas will fortify fundamental assumptions about the agronomic, social and economic relationships controlling the decision support system. Validation of the products and methods in these testing areas will provide the experience base for widespread dissemination.

Interactions with collaborators in the extensive evalua-

Table 3. Project team-members and their institutional affiliations.

| COUNTRY | INSTITUTION | TEAM-MEMBER |
|-------------|--------------------------|--|
| U.S. | Cornell University | David Bouldin, Shaw Reid |
| | University of Hawaii | Jim Fownes, Nguyen Hue, GordonTsuji, Russell Yost |
| | N.C. State University | Fred Cox, Danny Israel, Deanna Osmond, Frank Smith, Jot Smyth, Mike Wagger, Art Wollum |
| | Texas A&M University | Lloyd Hossner, Anthony Juo, Art Onken |
| | IFDC | Philip Thornton |
| Bolivia | IBTA | Armando Ferrufino |
| Brazil | EMBRAPA | Manoel Cravo |
| | University of Viçosa | Roberto Novais |
| Colombia | IFDC/CIAT | Dennis Friesen |
| Costa Rica | University of Costa Rica | Alfredo Alvarado, Floria Bertsch, Carlos Henriques, Eloy Molina, Rafael Salas |
| Guatemala | CIMMYT-PRM | Jorge Bolanos, Elio Duron |
| Indonesia | ICRAF | Dennis Garrity |
| Mali | IER | Mamadou Doumbia, Aminata Sidibé |
| Philippines | Philrice/IRRI | Santiago Obien |
| Senegal | ISRA | Aminata Badiane, Jean-Pierra Ndiaye |
| Thailand | IBSRAM | Eric Craswell |

tion network will assess the global dissemination and utility of knowledge, products and activities of the project. Using existing global network technology, stakeholders and users will provide critical information on product utility and impact (Harasim, 1993). These assessments will show how target users are using the innovative tools for nutrient management, how use affects decision making, and how productivity and yield stability change as a result. Analysis of widespread impact will also identify areas of resistance or constraints and provide valuable insights and recommendations for future special action for global promotion of product awareness and use.

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