Improving Efficiency in Calcium Acquisition and Utilization by Forage Grasses and Legumes

A Proposal for: Der Bundesminister für Wirtschaftliche Zusammenarbeit (BMZ)

Executing Agency: CIAT

Collaborating Partner: University of Hohenheim, Stuttgart, Germany

January 1995
IMPROVING EFFICIENCY IN CALCIUM ACQUISITION AND UTILIZATION BY FORAGE GRASSES AND LEGUMES

A Proposal for: BMZ

Executing Agency: International Center for Tropical Agriculture
Centro Internacional de Agricultura Tropical

Collaborating Partner: - Institute of Plant Nutrition, University of Hohenheim, Stugart, Germany

January 1995
January 5, 1995

Dr. J. de Haas
Head, Agriculture and Rural Development Division
Federal Ministry for Economic Cooperation and Development (BMZ)
Friedrich-Ebert-Allee 114-116
D-53113 Bonn
Federal Republic of Germany

Ref.: Proposals for Special Projects

Dear Dr. Haas:

We are pleased to identify for your consideration three special projects involving cooperation between CIAT, German partners and NARS:

(1) Sustainable Animal Production for the Agropastoral Systems of the Brazilian Cerrados

This proposal was submitted in August 1994 and the peer review committee considered it to be in principle worthwhile for funding. We have revised the proposal and have addressed the three issues raised in your previous letter. As per your instructions, we have forwarded copies of the revised proposal directly to ATSAF and GTZ.

(2) Dynamics and Sustainability of Farming and Regional Systems in the South American Savannas

This proposal was submitted in August 1994, but arrived too late to be considered during the last Special Project Competition. We would appreciate if it would be now considered for the current competition. We understand from the BMZ fax of December 21, 1994 that there is no need to submit additional copies of the proposal at this stage since there have been no changes to the document submitted last August.
Improving Efficiency in Calcium Acquisition and Utilization by Forage Grasses and Legumes

Copies of this proposal have been forwarded directly to ATSAF and GTZ.

We look forward to continued support for our research cooperation with German universities and NARS and we would like to thank you for consideration of our new requests.

Yours sincerely,

ROBERT D. HAVENER
Interim Director General

Attachments

cc: Dr. E. Kurschner, ATSAF
    Dr. J. Friedrichsen, Head of Division, Plant Production, Plant Protection and Agricultural Research, GTZ
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<td><strong>BMZ</strong></td>
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<td><strong>CIAT</strong></td>
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<tr>
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<td>Gesselschaft für Technische Zusammenarbeit, Germany (German Agency for Technical Cooperation)</td>
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<td><strong>NARS</strong></td>
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1.0 Summary

Title: Improving Efficiency in Calcium Acquisition and Utilization by Forage Grasses and Legumes

Short Title: Calcium Nutrition of Tropical Forages

Objective of Research:

To identify plant attributes that contribute to improved efficiency in acquisition and utilization of calcium in *Brachiaria* and *Arachis* species in order to develop screening procedures to evaluate forage germplasm for efficiency in calcium acquisition and utilization.

Abstract:

The goal of the Tropical Forages Program at CIAT is to develop forage components for farming systems on acid infertile soils of the humid and sub-humid tropics which will contribute to increased and more efficient meat and milk production, soil improvement and erosion and weed control.

Inadequate nutrition is the main constraint in ruminant productivity throughout most tropical regions. Development of improved forage systems of high nutritive value is the key to increased and sustainable livestock productivity. Forage species can improve soil fertility, physical structure, and biological activity, protect soil against erosion, reduce the need for herbicide used in weed control and sequester large amounts of carbon deep in the soil, thus contributing to minimizing the greenhouse effect of increasing atmospheric CO₂.
In low fertility acid soils of the tropics, root growth (and particularly root penetration into subsoils) is limited by the availability of calcium. Forage species differ in both requirement in calcium supply to the roots and calcium demand per unit tissue weight. Inter-and intraspecific differences in calcium efficiency may be related to a higher efficiency in utilization within the plant, or a higher efficiency in acquisition of calcium by the roots. Furthermore, intracellular compartmentation and concentration of calcium in forage tissue affects feed value and animal intake.

The proposed research to be carried out in Colombia and Germany will test two hypotheses: (i) inter- and intraspecific differences in calcium acquisition are related to their root architecture, cation exchange capacity and binding of calcium to root cell walls; and (ii) lower concentrations of calcium in the shoot dry matter results in lower forage quality. Results from this research will help to identify plant attributes that contribute to greater acquisition and utilization of calcium in forages. Identification of plant attributes will contribute to the development of prototype screening procedures for tropical forage evaluation/improvement.

**Cooperating Partners:**

(1) Tropical Forages Program, Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia

(2) Institute of Plant Nutrition, University of Hohenheim, Stuttgart, Germany

**Names of Principal Scientists:**

**CIAT**
- Dr. I. M. Rao, Project Leader
- Dr. C. E. Lascano
- Dr. J. W. Miles
- Dr. P. C. Kerridge

**University of Hohenheim**
- Prof. H. Marschner, Project Co-leader
Staff to be Financed:

* University of Hohenheim
  - 1 doctoral student (3 years)

* CIAT
  - 1 technician (2 years)
  - 1 field worker (3 years)

Budget Total and Breakdown by Activities and Year (Current US$):

*The total budget is US$250,520, broken down as follows:*

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| GRAND TOTAL          | 88,100 | 94,920 | 67,500 | 250,520|
| ALL PARTNERS         |        |        |        |        |
2.0 Background and Justification

2.1 Introduction

The availability and, particularly, the quality of feed is the main constraint to increased and more efficient animal production in the tropics of Latin America, Asia and Africa. Forage grasses and legumes can play a role in alleviating this feed shortage in the majority of production systems (Kerridge, 1994). Further it has been demonstrated that they have a major role in contributing to more sustainable agricultural systems (Vera et al., 1992). The combination of nitrogen fixing forage legumes with deep-rooted grass can increase nutrient cycling, greatly improve animal production, markedly increase soil biological activity, and store significant amounts of organic carbon deep in the soil (Thomas et al., 1994; Rao et al., 1994; Fisher et al., 1994).

Low nutrient supply is a major limitation of forage adaptation and production in acid soils of the tropics. The use of forages adapted to low fertility acid soils is one of the most effective means of managing these soils. Considerable achievements have been made in identifying legumes and grasses well adapted to these soils but little is known about the mechanisms for adaptation (Rao et al., 1993). Widespread adoption of forage cultivars depends on efficient acquisition of nutrients from the soil and utilization for growth.

Continued progress in the selection and genetic improvement of forages will depend upon the development of rapid and reliable techniques which facilitate screening of large numbers of genotypes for tolerance to low fertility acid soils.
2.2 The target species

The genus Brachiaria is the source of a number of widely used tropical forage grasses. Together, several Brachiaria species are undoubtedly the most widely sown forages in tropical America, with 40-50 million hectares sown in Brazil alone. An important germplasm collection was assembled at CIAT and regional evaluation of this collection is essentially complete. A genetic enhancement project is in progress at CIAT which utilizes new techniques in exploiting apomixis to create synthetic gene pools with resistance to major pests (spittlebug and leaf cutter ants), high feed quality and good persistence on acid, low fertility soils.

*Arachis pintoi* is unique among tropical forage legumes in the humid tropics in its ability to form stable grass-legume associations with vigorous grasses like the Brachiarias. It is persistent and even increases under heavy and continuous grazing pressure. Nutritive quality is high. However, the present widely used cultivar CIAT 17434 is slow in establishment and is not tolerant of dry conditions. Research efforts are directed towards increasing the range of adaptation.

2.3 The problem

In many tropical soils, low calcium (Ca) may be a greater limitation to plant growth than high aluminum (Al) but has received much less attention. In highly weathered tropical soils (Oxisols and Ultisols), plant growth is often limited by Al toxicity and phosphorus and Ca deficiency (Marschner, 1991). In the subsoil, the Ca content is often very low. Many subsoils have less than 4 mg Ca kg$^{-1}$ of soil (Ritchey et al., 1987). Because Ca is not mobile in the phloem it does not move downwards in the roots towards the root tips where it is required for growth (Hanson, 1984). Thus, apical root zones (root tips) have to cover their Ca demand for growth by direct uptake from their immediate environment. In acid mineral soils, root growth is therefore often severely limited, particularly root penetration into the subsoil (Pearson et
An important aspect of calcium nutrition of tropical forages is the effect of calcium concentration on forage quality.

Plant species differ in their ability to acquire and utilize calcium from soils.

BACKGROUND AND JUSTIFICATION

al., 1973) and, correspondingly, utilization of nutrients and water from the subsoil (Howard and Adams, 1965). Low Ca activity in the subsoil may be a greater limitation to plant growth than high Al (Bruce et al., 1988).

Another very important aspect of Ca nutrition is the effect of Ca concentration on feed value and animal intake. Calcium fed as a supplement is not as effective as higher Ca in the plant tissue in improving forage quality (Minson, 1990). Therefore we need to identify forage species and ecotypes that can grow and efficiently acquire Ca from soils very low in the nutrient.

Calcium nutrition is different to other nutrients (Marschner, 1974). Because of its phloem-immobility there is no re-distribution of Ca. In root to shoot transport and distribution within the shoot, Ca is confined to the xylem and, thus, is closely related to the transpiration stream. The Ca transport into low transpiring tissues such as shoot apices and young leaves is therefore low. In addition, Ca binding to pectates in cell walls or precipitation as oxalate along the transport pathway further limit Ca supply to the sites of demand for growth. Furthermore, the common route for recycling nutrients in the phloem from mature leaves to new growth is not available for Ca (Ho and Adams, 1989). In vigorous growing tropical forage grasses and legumes, unless the import of Ca via xylem matches the demand during the accelerated expansion growth for new leaves, plant growth will be limited by Ca supply. Recent field experiments with tropical forage grasses (Brachiaria species) on Oxisols in Carimagua (Colombia) support this view of Ca limitation. Increase in shoot dry matter production was similar with Ca application in form of lime or gypsum, although soil pH was only increased with lime (K. Haussler, unpublished results).

There is variation between plants in their ability to grow on low Ca soils. Plant species differ in both requirement in Ca supply to the roots and Ca demand per unit tissue weight. As a rule, the required supply (i.e., soil content or concentration in the soil solution) of Ca and the Ca content in the tissue are higher in
Differences in calcium efficiency may be related to acquisition by roots, or utilization for plant growth

The higher efficiency in calcium acquisition was related to higher root branching

dicotyledonous species (e.g., legumes) than in monocotyledonous species such as forage grasses (Loneragan et al., 1968; Loneragan and Snowball, 1969; Islam et al., 1987). But also between species of grasses and dicots as well as between cultivars or ecotypes of a given species considerable differences exist in the apparent requirement and demand of Ca. According to these differences the terms “calcium-efficiency” and “calcium-inefficiency” have been introduced. From the agronomical or breeding point of view, for adaptation to acid mineral soils a high calcium-efficiency is achieved, i.e., genotypes which acquire greater amounts of Ca and produce a high yield in a soil low in available Ca.

Calcium efficiency may be related to a higher efficiency in utilization within the plant, or a higher efficiency in acquisition of Ca by the roots (Figure 1). Examples for a more efficient utilization of Ca within the shoot have been given for a Ca-efficient tomato cultivar (English and Barker, 1987) or cowpea cultivar (Horst et al., 1992), or by a higher proportion of Ca translocated to the shoot apex in a Ca-efficient tomato cultivar (Behling et al., 1989). Differences in efficiency in Ca acquisition between species and genotypes within a species are well documented and demonstrated by differences in Ca concentrations in the shoots of plants grown in the same solution (Loneragan et al., 1968; Islam et al., 1987) or the same soil.

Inter- and intraspecific variation in Ca efficiency has been demonstrated in several acid soil-adapted tropical forage grasses and legumes in field experiments conducted on an Oxisol of Carimaguá (Colombia) (Tropical Pastures Program Annual Report, 1981). Among the grasses, Brachiaria humidicola CIAT 679 was the most Ca-efficient one, it had the lowest requirement for Ca supply (125 kg CaCO₃ ha⁻¹) and also the lowest internal Ca concentration (0.22% Ca in the dry matter). Glasshouse studies using acid soils of contrasting texture have indicated marked interspecific variation in Ca acquisition and internal utilization among 7 grasses and 12 forage legumes (Table 1; I.M. Rao et al., unpublished data). Recent work, supported in a BMZ project,
Figure 1
Components of calcium efficiency in plants

**Calcium Efficiency**
- Low demand of calcium at cellular level
- Maintenance of high concentrations of soluble calcium

**Efficiency in Utilization**

**Efficiency in Acquisition**
- High root-to-shoot transport of calcium
- Preferential transport of calcium to the shoot apex and young leaves

**Root morphology**
- Large surface area
- Abundant root tips

**Root physiology**
- High affinity uptake system for calcium
- Root exudates (complexation of aluminum)
demonstrated higher Ca acquisition in *Brachiaria ruziziensis* compared to *Brachiaria dictyoneura*, leading to much higher Ca concentrations in the shoot dry matter and uptake of Ca in the above-ground biomass of *B. ruziziensis* (K. Haussler, GTZ Report, 1994). The higher efficiency in Ca acquisition in *B. ruziziensis* was related not to a higher root length but higher branching, i.e., more root tips which are the main sites of Ca uptake along the root axis (Marschner and Richter, 1974; Haussling et al., 1988).

Much of the 50 million hectares planted to *Brachiaria* species pastures in tropical America are now in a state of degradation owing to nutrient depletion. There is good evidence that inclusion of legumes can assist in reversing pasture degradation. *Arachis pintoi* forms stable grass-legume associations with the *Brachiaria* species. But there is no information on differences in Ca acquisition and utilization among different *A. pintoi* ecotypes now available. *A. pintoi* is better adapted to clay loam than sandy loam Oxisols which may be related to better water and Ca availability in the clay loam.

The Ca concentration per unit shoot dry weight is much higher in *A. pintoi* (dicot) compared to the forage grasses. In preliminary experiments with *A. pintoi* grown in two Oxisols (sandy loam, clay loam) the Ca concentration in the shoot dry matter was about 15 mg g⁻¹ dry matter (Milz, unpublished). So far only a few data are available on Ca acquisition and internal utilization in a single ecotype, CIAT 17434, of *A. pintoi* (See Table 1; I.M. Rao et al., unpublished results). Shoot Ca uptake, at high Ca supply, was greater with clay loam than sandy loam soil.

Agronomic evaluation of thirty-three ecotypes of *A. pintoi* in the Cerrados of Brazil indicated ecotypic differences in tolerance to soil water deficits. Based on green leaf retention in the dry season, the performance of CIAT 22160 was markedly superior to CIAT 17434 (E. izarro, unpublished results). But there is no information on differences in Ca acquisition and utilization among *A. pintoi* ecotypes.
Table 1
Differences in shoot calcium uptake and calcium use efficiency in *Brachiaria* and *Arachis* species grown in low fertility sandy loam acid soil.

<table>
<thead>
<tr>
<th>Species and Ecotype</th>
<th>Shoot Ca uptake (mg/pot)</th>
<th>Ca use efficiency (g/g)*</th>
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<td><em>Brachiaria decumbens</em></td>
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<td>CIAT 606</td>
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<td><em>Brachiaria brizantha</em></td>
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<td>CIAT 6780</td>
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<td>170</td>
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<td><em>Brachiaria dictyoneura</em></td>
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<tr>
<td>CIAT 6333</td>
<td>11.5</td>
<td>187</td>
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<tr>
<td><em>Brachiaria humidicola</em></td>
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<td>CIAT 6369</td>
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<td><em>Arachis pintoi</em></td>
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<tr>
<td>CIAT 17434</td>
<td>60.5</td>
<td>34</td>
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</table>

* grams of forage produced per gram of total Ca uptake from soil
2.4 Project outline

We intend to test two hypotheses:

1. That differences in Ca acquisition among and within *Brachiaria* and *Arachis* species and ecotypes are related to their root architecture, cation exchange capacity and binding of Ca to root cell walls.

2. That lower Ca concentrations in the shoot dry matter affect forage quality.

By testing these hypotheses and identifying plant attributes that contribute to greater acquisition and utilization of Ca, we should be able to develop improved screening procedures for tropical forage evaluation/improvement. Higher Ca acquisition will enhance recycling of Ca in tropical pastures and reduce Ca losses from the system by leaching.

Grasses and legumes are known to contribute not only to animal production but also to soil fertility in tropical farming systems. Thus they are essential components of sustainability.

What is desirable from an animal nutrition point of view is the greater efficiency in acquisition of Ca by roots and translocation to the shoots. There is a need to relate the efficiency of Ca acquisition to Ca activity in soil solution. This project will contribute to selection of high quality forages and will also have an additional spin-off on fertilizer management for pastures on low fertility acid soils. By relating Ca acquisition to soil Ca it will provide important information to growth of other crops on acid soils.
2.5 **Ability of organization and individuals to undertake the research.**

The project's principal CIAT scientists Drs. I. M. Rao (Project leader), C. E. Lascano, J. W. Miles, and P. C. Kerridge have long-term experience in the development of tropical forage germplasm, namely in the areas of plant nutrition/physiology, forage quality/animal nutrition, forage genetics/breeding, and soil fertility/agronomy, respectively. They will be able to provide the required local supervision to the German doctoral student and the eventual B. Sc. students.

For the past 3 years, the CIAT Tropical Forages Program has been cooperating closely with the German project partner (Prof. H. Marschner) with special project funding from BMZ in a project entitled “Study of phosphorus dynamics in the rhizosphere of various grass and legume species growing in acid soils of Latin America”.

2.6 **Agricultural development and ecology implications of the project**

Development of calcium efficient forages that combine productivity and quality with adaptation to low fertility acid soils of the tropics, will contribute to sustainable livestock production.

In addition, the calcium efficient forages will enhance recycling of calcium in agropastoral systems, reduce calcium losses from the system by leaching, and contribute to sustainable land use systems in the humid and subhumid tropics.
3.0 Project Objectives

The project has a clear goal, which complements and integrates into the research of the CIAT Tropical Forages Program

The expected outputs will help to identify calcium efficient tropical forage grasses and legumes

Goal

To develop tropical forages with improved efficiency in acquisition and utilization of calcium from low fertility acid soils.

Project Purpose

To identify plant attributes that contribute to improved efficiency in acquisition and utilization of calcium in Brachiaria and Arachis in order to develop screening procedures to evaluate forage germplasm for efficiency in calcium acquisition and utilization.

Project outputs

The expected outputs from the above objectives are:

- Identification of Brachiaria and Arachis species and ecotypes with greater ability to acquire and utilize calcium.
- Identification of plant attributes that contribute to calcium efficiency in Brachiaria and Arachis.
- Selection of superior Brachiaria genepools (using new screening methodology).

Benefits for Developing Countries and NARS

The results from the project will be presented at regional conferences organized by regional networks such as RIEPT and Agropastoral Network. Furthermore, final results of the project will be discussed in a 2-day workshop at CIAT.

The outputs of this project will contribute towards the development of forage components for farming systems on acid infertile soils of the humid and sub-humid tropics which is the broader goal of the Tropical Forages Program at CIAT.
The principal activities and subactivities of the project as they relate to the project’s outputs are illustrated in Figure 2. The project organization concerning technical reporting and financial management is shown in Figure 3. Figure 4 shows the implementation schedule with the commencement and duration of each main activity.

The execution of the project in Palmira and Carimagua, Colombia will require three years. The project will be coordinated by Dr. I. M. Rao, Tropical Forages Program, CIAT, with assistance from other scientists from CIAT and Prof. H. Marschner from the University of Hohenheim, Germany.

The research will be carried out by a Ph. D. student and staff of German University and CIAT scientists (see also 5.0 Training).

Figure 2 shows the breakdown of the project structure with descriptions of the goal, purpose, outputs and activities.
Figure 2

Project Description
Structure Linking Project Activities to Project Outputs

Program Goal
To develop tropical forages with improved efficiency in acquisition and utilization of calcium from low fertility acid soils.

Project Purpose
To identify plant attributes that contribute to improved efficiency in acquisition and utilization of calcium in Brachiaria and Arachis in order to develop screening procedures to evaluate forage germplasm for efficiency in calcium acquisition and utilization.

Identification of Brachiaria and Arachis species and ecotypes with greater ability to acquire and utilize calcium
- Select contrasting genotypes of Brachiaria and Arachis from agronomic evaluation experiments.
- Establish an experiment on a calcium deficient sandy loam acid subsoil with different levels of Ca supply as lime and gypsum.
- Determine dry matter partitioning among plant parts and leaf area production (three times during growing season), concentration of Ca and another mineral elements in the dry matter.
- Determine root biomass and root length distribution across the soil profile (up to 80 cm soil depth).
- Determine partitioning of nitrogen among soluble and total protein in leaves of different maturities.
- Identify Ca-efficient Brachiaria and Arachis ecotypes.

Identification of plant attributes that contribute to calcium efficiency in Brachiaria and Arachis
- Select contrasting genotypes of Brachiaria and Arachis from agronomic evaluation.
- Conduct a glasshouse experiment with sandy loam acid subsoil supplied with different levels and forms (lime, gypsum) of Ca, determine root architecture using minihizotrons and measure Ca concentrations in root and shoots.
- Use of labelled isotope ($^{45}$Ca) technique for measurement of Ca uptake in different root zones (mature, elongating, tip) of primary and secondary roots, and of Ca transport to the shoots and young levels in particular.
- Determine short-term uptake of calcium ($^{45}$Ca) in roots exposed to solutions of different pH and concentrations of aluminum (water and sand culture experiments).
- Determine cation exchange capacity of the cell walls in roots and cell wall constituents and digestibility of leaf and stem tissue.
- Determine intracellular compartmentation and binding forms of Ca in leaves of different age.
- Determine cell wall constituents and digestibility of leaf and stem tissues.
- Relate compartmentation and binding forms of Ca with forage quality attributes.
- Develop a new screening procedure to evaluate Ca-efficiency.
- Relate Ca acquisition to Ca activity in soil solution.

Selection of superior Brachiaria genepools (using new screening methodology)
- Grow out gene pools (advanced lines) from Brachiaria improvement program.
- Undertake restricted set of measurements on plant attributes as would be used by a Geneticist screening material.
- Validate laboratory findings with restricted set of animal feeding trials.
- Select Ca efficient Brachiaria gene pools.

Project management and dissemination of results
- Revise proposal together with donor.
- Provide progress, technical and financial reports.
- Report progress at Regional Network meetings.
- Publish results.
- Conduct a workshop at CIAT.
- Provide final report.
### Figura 4
**Project Implementation Schedule of Activities by Quarter**

<table>
<thead>
<tr>
<th>Activities</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
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<td><img src="image" alt="Activities Schedule" /></td>
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**Identification of Ecotypes**
- Selection of ecotypes
- Establishment of field experiment
- Evaluation of shoot and root production
- Determination of Ca efficiency
- Identification of Ca efficient ecotypes

**Identification of Plant Attributes**
- Select contrasting ecotypes
- Establish glasshouse experiments
- Isotope studies on Ca acquisition
- Studies on forage quality and Ca compartmentation
- Screening procedure for Ca efficiency

**Selection of Brachiaria Gene Pools**
- Establish field trial
- Test screening procedures

**Project Management**
- Workshop
- Publication of results
5.0 Training and Workshops

A German doctoral student from the University of Hohenheim will carry out the proposed research. He will work under the supervision of the project leaders, Dr. I. M. Rao (CIAT) and Prof. H. Marschner (University of Hohenheim).

The project will also provide the opportunity for two Colombian undergraduate students from the University at Palmira (Universidad Nacional), Colombia. According to its gender policy, CIAT will take care that both female and male students will participate in the project if they are equally talented.

A two-day workshop will be conducted at CIAT at the end of the project to discuss final results and their implications for future research on the development of forage components for sustainable agropastoral systems on low fertility acid soils of the humid and sub-humid tropics.
6.0 Expected Patentable Research Results

CIAT endorses the principle of free access to research results. It supports this through publication of research findings in international journals and in-house documents.

There are no patentable results anticipated in this project.
7.0 Funding Requirements

7.1 Budget

The budgets for CIAT and the University of Hohenheim appear in Table 2. The CIAT budget will be administered by CIAT.

7.2 Budget notes

Personnel

The two positions (1 technician and 1 worker) budgeted for CIAT refer to assistance needed for one technician at CIAT-Carimagua for field research and one worker at CIAT-Palmira for glasshouse research.

The German doctoral student will carry out the proposed research with the help of a technician and a worker at CIAT (18 months) and at the University of Hohenheim (18 months). The doctoral student will be supported by two Colombian undergraduate students.

Research and operational expenses

As the project includes field and glasshouse research, there are substantial costs involved in the establishment of experiments, purchase of chemicals including radioisotopes, processing of samples and mineral analysis of samples.

Research results from the project will be published in three languages (English, German and Spanish).
Training and Workshops (CIAT budget)

- Provision is made in the project for training up to two B.Sc. students from a Colombian University who will receive a small allowance to do undergraduate thesis research.

- The workshop budgeted refer to a short (two-day) meeting at CIAT with the participation of CIAT scientists, the German doctoral student, and the scientists from NARS at the end of the project, in order to discuss final results and their implications for future research.

Travel (Hohenheim budget)

The amount budgeted for local travel refers to an absolute minimum necessary for the doctoral student to move between CIAT-Palmira and CIAT-Carimagua.

The international travel for the doctoral student and supervisors includes a provision for an eventual participation in an international congress. The German supervisor will travel to Colombia during Year 1 to visit field and glasshouse experiments and to discuss the project with CIAT scientists. The CIAT supervisor will travel to Germany at the end of Year 2 to discuss the progress made.
Table 2

CENTRO INTERNACIONAL DE AGRICULTURA TROPICAL – CIAT
BMZ – Improving efficiency in calcium acquisition and utilization by forage grasses and legumes

Proposed Budget

(IN US$ )

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<th>INSTITUTION/LINE ITEM</th>
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<th>Year 2</th>
<th>Year 3</th>
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Juan A. Garafulic
Financial Controller
8.0 References


Idupulapati M. Rao

Research Coordinator, Plant Nutritionist/Physiologist.

Centro Internacional de Agricultura Tropical (CIAT)
Cali, Colombia (1989- present)
Plant Nutritionist/Physiologist, Tropical Forages Program
Responsible for identifying adaptive attributes of tropical forage species to low fertility acid soils; developing reliable screening indices for plant evaluation and plant improvement; investigating plant-soil interrelationships with respect to recycling of nutrients in pasture-based production systems.

University of California, Berkeley, California, USA (1984-89)
Assistant Specialist, Department of Plant and Soil Biology
Research on mechanisms of plant adaptation to low nutrient supply in sugar beet and soybean; use of light scattering and chlorophyll fluorescence techniques for mineral deficiency diagnosis; role of phosphorous in photosynthesis, carbon partitioning and carbon export; limiting factors in photosynthesis.

University of Illinois
Urbana-Champaign, Illinois, USA (1982-83)
Research Associate, Department of Plant Biology
Research on mechanisms of plant adaptation to water stress in sunflower; leaf nutrient status (particularly magnesium and potassium) and photosynthetic response to low leaf water potentials.

Cornell University, Ithaca, New York, USA (April-May, 1982)
Boyce Thompson Institute for Plant Research
Visiting Scientist, Environmental Biology
Research on effects of sulfur dioxide (SO2) pollution on photosynthesis, leaf conductance and stomatal metabolism of peas.
Appendix A-1
CV - I.M. Rao

University of Illinois at Chicago
Chicago, Illinois, USA (1981-82)
Research Associate, Department of Biological Sciences

*Research on the role of light modulation of enzymes in the mechanisms of stomatal movement; effects of sulfite and arsenite on stomatal metabolism.*

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Patancheru, Andhra Pradesh, India (1979-81)
Plant Physiologist, Pulse Physiology

*Research on development of field screening techniques to evaluate pigeonpea genotypes for their tolerance to abiotic stresses, particularly salinity and waterlogging; growth analysis of pigeonpea hybrids and their parents; response of pigeonpeas to environment and cultural practices such as spacing, plant population, irrigation and nutrients.*

Supervisory Experience:
Supervision of Ph.D. (3) and Undergraduate degree (3) thesis projects for students registered in the Universities from USA, Germany and Colombia.

Areas of Specialization:
Plant traits and mechanisms for adaptation to low fertility acid soils; nutrient acquisition and nutrient cycling in pasture-based production systems; physiological responses of plants to edaphic and climatic stresses.

Professional Memberships:
- American Society for Plant Physiology
- American Society of Agronomy
- Crop Science Society of America
- Soil Science Society of America

Education:
Ph.D. Plant Physiology
*Sri Venkateswara University*, India (1978)
*Dissertation Title:* Carbon metabolism and water relations of six woody weeds and their modification by paraquat and 2,4,5-T.

M.S. Botany, Plant Physiology
*Bhopal University*, India (1973)

B.S. Botany, Chemistry, Zoology
*Andhra University*, India (1971)
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Horst J. Marschner

Position in Project:

German Project Coordinator

International Research Experience:

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<tr>
<th>Position</th>
<th>Institution/University</th>
<th>Dates</th>
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<tr>
<td>Member of the Deutsche Akademie der Naturforscher - Leopoldina</td>
<td></td>
<td>1993</td>
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<tr>
<td>University Hannover</td>
<td>Dr. rer hort. honoris causa, Faculty of Horticulture</td>
<td>1989</td>
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<tr>
<td>University of Hohenheim</td>
<td>Professor of Plant Nutrition</td>
<td>Since 1977</td>
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<tr>
<td>Commonwealth Scientific and Industrial Research Organization (CSIRO), Adelaide, Australia</td>
<td>Division of Horticultural Research</td>
<td>1973-1974</td>
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<tr>
<td>Technical University of Berlin</td>
<td>Institutie of Plant Nutrition</td>
<td>1966-1976</td>
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<tr>
<td>University of California, Berkely, USA</td>
<td>Full Professor and Director</td>
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<td>University of Hohenheim</td>
<td>Department of Soil Science and Plant Nutrition</td>
<td>1965-1966</td>
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<td>German Academy of Sciences, Berlin</td>
<td>Research fellow</td>
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<tr>
<td>University of Jena</td>
<td>Institute of Agricultural Chemistry</td>
<td>1955-1958</td>
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### Education:

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<tr>
<td>Study of Agriculture and Chemistry</td>
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<th>Ph.D., University of Jena</th>
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### Main Research Interests:

- Mineral metabolism of plants (uptake, translocation, function of mineral elements).
- Genotypical differences in mineral metabolism of crop plants (deficiency, toxicity).
- Adaptation of plants to adverse soil conditions (acid or alkaline soils, salinity, water logging).
- Yield formation ("source-sink-relationship").
- Environmental aspects of fertilizer application (nitrogen, heavy metals).
- Plant-microbial symbiosis: Endo- and ectomycorrhizae, Rhizobium.

Joint research projects on plant nutrition and crop production, Universities and Research Institutions, e.g. in the P.R. of China (increase in efficiency of fertilizer application), Israel (iron acquisition; drought stress tolerance), Niger (increase in nutrient use efficiency), Syria (phosphorus efficiency), Turkey (micro-nutrient supply in citrus and cotton, zinc efficiency), and Colombia (phosphorus efficiency of pasture legumes and grasses).

### Languages:

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### Citizenship:

German

### Country of Residency:

Germany
Appendix A-2
CV - Horst Marschner

Publications:

Relevant Publications
119 publications for the past 5 years


Dr. P. Kerridge
Leader of the Tropical Forages Program
CIAT
A.A. 6713
Cali, COLOMBIA

Dear Dr. Kerridge,

I am writing to confirm my commitment and that of the Institute of Plant Nutrition of this University, to the special project entitled

"Calcium acquisition and utilization by forage grasses and legumes"

which will be proposed to BMZ.

Yours sincerely,

[Signature]

Appendix B
Partner Confirmation Letter

Fruwirthstr. 20
70599 Stuttgart
den
11.1.1995
CIAT has in-house facilities for the production of high-quality training materials and video programs for scientific and extension agricultural activities.

This proposal was produced and published, using CIAT’s computer layout and graphic composition facilities and outside low-cost copying services.