Journal of Agriculture and Rural Development in the Tropics and Subtropics

DITSL

Vol. 109 No. 2 2008

kassel university press

Journal of Agriculture
and Rural Development in
the Tropics and Subtropics

Volume 109, No. 2, 2008

Journal of Agriculture and Rural Development in the Tropics and Subtropics

formerly:
Der Tropenlandwirt. Beiträge zur tropischen Landwirtschaft und Veterinärmedizin,
Journal of Agriculture in the Tropics and Subtropics

ISSN 1612-9830

Publisher

German Institute f. Tropical and Subtropical Agriculture (DITSL GmbH), Witzenhausen
Association for Sustainable Development (GNE mbH), Witzenhausen
Institute for tropical Agriculture e.V., Leipzig
University of Kassel, Faculty of Organic Agricultural Sciences, Witzenhausen
Association of Agronomists in the Tropics and Subtropics Witzenhausen, e. V., (VTW)

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Subscription

The *Journal of Agriculture and Rural Development in the Tropics and Subtropics* is published twice a year (April and October). It may be subscribed by a price of €30,– + shipping. The subscription is for at least one year and is automatically extended unless otherwise stated by the subscriber till the end of the year. Single copies may be purchased for €20,– + shipping. Orders may be placed at Kassel University Press, Diagonale 10, D-34127 Kassel (www.upress.uni-kassel.de), Fon ++49 (0)561 804 2159, Fax ++49 (0)561 804 3429 or at any bookstore.

Publishing House

kassel university press GmbH
www.upress.uni-kassel.de

Composition and Layout

Bierwirth & Gabele Softwaredesign GbR, Steinstr. 19, Postfach 1128,
D - 37201 Witzenhausen, http://www.bg-softwaredesign.de

Cover layout: Jochen Roth, Melchior v. Wallenberg, Kassel
Printed by: Uniprinter University of Kassel

Journal of Agriculture and Rural Development in the Tropics and Subtropics
Volume 109, No. 2, 2008, pages 113–121

Investigation of *Imperata* sp. as a Primary Feedstock for Compost Production in Ucayali region, Peru

J. Banout [*1], **B. Lojka** [2], **N. Matouskova** [1], **Z. Polesny** [2] and **J. Lojkova** [1]

Abstract
Five compost piles with different initial C : N ratios have been investigated in this study. As a primary feedstock *Imperata* sp. was used. The primary feedstock was mixed with poultry litter and vegetable refuse in order to obtain different C : N ratio. The results show that during 64 days of well managed composting under tropical conditions the initial C : N ratio between 30:1 and 50:1 decreased to ratio 11:1 to 15:1, respectively. Results of bioassay tests expressed as the germination index (GI) indicate particular compost phytotoxicity. The value of GI was 51.4%, 48.6%, 47.8%, 46.7% and 40.0% for samples from the compost with initial C : N ratios of 30:1, 37:1, 40:1, 44:1 and 50:1, respectively.

Keywords: Composting, *Imperata* sp., allelopathy, Peruvian Amazon, compost phytotoxicity

1 Introduction

The earth contains 4.5 billion ha of forests, of which 43% are in the tropics. Tropical forest area is decreasing at the rate of 13.5 million ha/year, mainly due to the clearing for agricultural purposes (Kobayashi, 2004). Peru contains about 12% of tropical rain forests located in the Amazon Basin (Goulding *et al.*, 2003). One of the most important and less developed regions in Peruvian Amazon is the Ucayali region which includes 1.3 million ha of tropical forests and the deforestation is proceeding at 30,787 ha/year (Kobayashi, 2004).

Farmer-settlers in the Ucayali region have traditionally practiced slash-and-burn agriculture to produce annual crops. This farming system results among others to high infestation of large areas by *Imperata* sp. (known as Cogongrass or locally as Cashaucsha) together with high soil degradation. Cogongrass (*Imperata* spp.) is one of the most troublesome aggressive perennial weed grasses in degraded soils of the humid tropics.

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Cogongrass (Imperata cylindrica) is the most varied and cosmopolitan species in the genus, which also includes *I. conferta*, *I. contracta*, *I. brevifolia*, *I. brasiliensis*, *I. tenius*, *I. cheesemanii*, *I. condensata*, and *I. minutiflora* (MacDonald, 2004). Based on results of a study that was conducted among farmer-settlers near Pucallpa, the capital city of Ucayali region, more than 50% of respondents named *I. brasiliensis* as the worst weed followed by *Rottboellia cochinchinensis* (Fujisaka *et al.*, 2000).

The soils in non-flooded areas in Ucayali region are degraded, acid, and high in aluminium ultisols with poor organic matter (OM) and physical properties (Fujisaka and White, 1998). Arresting the decline of soil OM is the most potent weapon in fighting against soil degradation and threatened sustainability of agriculture in the region. Improving soil OM is, therefore, crucial in the sustenance of soil quality and future agricultural productivity (Katyal *et al.*, 2001). Composting is the biological decomposition of organic matter under controlled aerobic conditions leading to the improvement of soil OM content and fertility trough application of stable and mature compost (Epstein, 1997; Rynk, 1992).

Since *Imperata* sp. has a large prevalence in the region and at the same time there is lack of suitable raw material for compost production on non-flooded areas mainly due to low livestock production (Fujisaka and White, 1998), the main objective of this study was to investigate the possibility of using *Imperata* as a prime matter for compost production in the Ucayali region.

2 Materials and Methods

2.1 Raw materials and procedure

As a predominant composting material the dry leaves and stalks of *Imperata* sp. were used. Aerial parts of *Imperata* sp. were collected from the agricultural areas in Antonio Raymondi village 25 km west from Pucallpa city. As an amendments mixed with the primary feedstock to balance the $\mathrm{C:N}$ ratio and moisture content, two year old deep poultry litter and vegetable refuse were used. The deep poultry litter was purchased from the local poultry farm located on the main road 19 km west from Pucallpa city. The vegetable refuse was collected from the local vegetable market Bellavista in Pucallpa.

Nitrogen and carbon content, moisture content and bulk density were determined for each raw material before composting. Nitrogen content was evaluated by Kjeldahl method, OM content by weight loss on ignition at 540°C for 16 h. Total carbon content (TCC) was estimated by the following equation proposed by Guerra-Rodríguez *et al.* (2000).

$$TCC = (TOMC - 9,33)/1.745 \qquad (1)$$

where $TOMC$ is the total organic matter content. Moisture was determined by the oven method (105°C for 24 h). The initial chemical and physicochemical properties of composted raw materials are presented in Table 1. The experimental composting was done at the National University of Ucayali in Pucallpa. The experiments were carried out in five wooden bins (width 1m x length 1m x height 1.5m) as batch aerobic runs. Each bin was loaded by a mixture of shredded organic feedstock (*Imperata* sp., poultry litter and vegetable refuse) with different initial $\mathrm{C:N}$ ratio reaching 1m3 of volume. The experimental bins were labeled C-30, C-37, C-40, C-44 and C-50 with initial $\mathrm{C:N}$ ratios 30:1, 37:1, 40:1, 44:1 and 50:1, respectively. The compost bin C-30 with an optimal $\mathrm{C:N}$ ratio of 30:1 was used as a control. A percentage content of *Imperata* sp. was 57%, 67%, 72%, 76% and 81 %; the content of deep poultry litter was 25%, 20%, 18%, 15% and 11%; the content of vegetable refuse was 18%, 13%, 10%, 9% and 8% for compost C-30, C-37, C-40, C-44 and C-50, respectively. During the composting process a feed material in each bin was turned weekly and after 14 days once every two weeks to ensure the aeration. Also water was added each week to the composts to maintain the desired moisture content between 50% and 60%.

Table 1: Chemical and physical characteristics of compost feed materials

Characteristics	*Deep poultry litter*	*Imperata sp.*	*Vegetable refuse*
Moisture content (% w.b.)	18.58	3.29	80
Total nitrogen (% d. b.)	0.62	0.49	1.70
Total carbon (% d. b.)	7.81	50.6	46.3
Bulk density (kg.m^{-3})	690	66	800
$\mathrm{C:N}$ ratio	12.6	103	27.2

w.b. - wet basis
d.b. - dry basis

2.2 Monitoring the composting process

During the experimental runs the composting process in each bin was monitored. Monitoring was mainly focused on temperature, moisture content and pH. Other conditions like change in color of the compost components and rate of shrinkage was monitored as well. The temperature was measured daily at 11:00 a.m. by mercurial thermometers in three different parts of each compost pile. The data were averaged to give a representative temperature value. Samples of 20g were taken every three days during the composting to assess the pH. The moisture of compost samples was determined by the oven method. The pH was determined from an aqueous extract of 5 g aliquot of sample with distilled water at a solid : water ratio of 1:25 (w/v) (Guerra-Rodríguez *et al.*, 2000).

2.3 Evaluation of mature composts

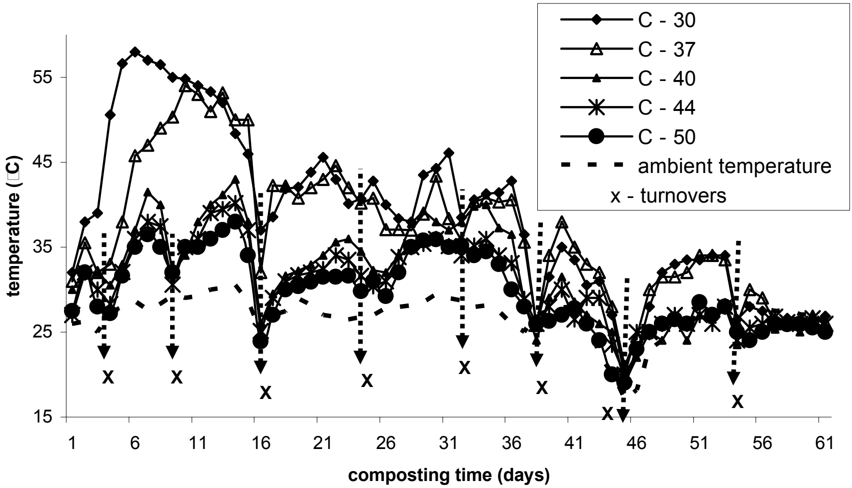
After nine weeks of composting ten 30 g subsamples of compost were taken at the random from each compost bins. Compost subsamples were then homogenized, air-dried (air-drying was done after compost moisture estimation) and labeled C-30, C-37, C-40, C-44, C-50 according to the compost bins. All samples were kept in dark plastic bottles at 4°C, then chemical analyses and bioassay tests were carried out. The pH was determined in the aqueous extract of 5 g aliquot of sample with distilled water at a solid:water ratio of 1:25 (w/v). Moisture was determined by the oven method (105°C for 24h) and organic matter (OM) content by weight loss on ignition at 540°C for 16 h. Total carbon content (TCC) was estimated by the expression proposed by GUERRA-RODRÍGUEZ *et al.* (2000). Total nitrogen content was determined by Kjeldahl method. Available phosphorus was extracted with 0.5 M CO_3HNa and measured by UV-VIS spectrophotometry (VILLAR *et al.*, 1993). Available nutrients (Ca, Na, K and Mg) in dry matter were estimated by Flame Atomic Emission Spectroscopy (FAES) (SOLANO *et al.*, 2001). Heavy metal (Cu, Zn, Cd, Pb, Cr, Ni, Hg, As, Mo) content of the compost samples was measured using atomic absorption as expressed by HASSOUNEH *et al.* (1999). The bioassay tests for phytotoxicity evaluation were based on germination index method on cress seed of *Lepidium sativum* (ZUCCONI *et al.*, 1981). In this biological method the influence of compost sample leach on cress seed germination was examined. The germination index was obtained by multiplying the percentage of germination by the percentage of root growth as related to the control. Each result in the study is the mean of three replicates.

3 Results and Discussion

3.1 The composting process

Temperature has been widely recognized as one of the most important parameters in the composting process (TIQUIA *et al.*, 2002). The temperature profiles for all compost piles together with ambient temperature are presented in Figure 1. During the composting period, the ambient temperature fluctuated between 26°C and 28°C. The temperature of all treatments increased rapidly from the first day of composting, however the optimal temperature patterns are represented by compost C-30 and C-37. Reference to Figure 1 shows that in case of compost C-30 and C-37, the temperature was in the range of 26-50°C within the first three days, which is well close to the optimum range of 15-40°C for mesophilic bacteria which colonize the compost during this period (MBULIGWE *et al.*, 2002). From day 3 to day 25 the temperature range was 40-60°C, which is close to the range for thermophilic bacteria and fungi to colonize and degrade the organic compounds. From day 30 to day 64, the temperature was in the range of 28-38°C, which is predominantly within the range which is favorable for actinomycetes and fungi to colonize the compost. It is also evident that during the last week the temperatures inside the heaps were close to the ambient temperatures due to low microbial activity and compost maturity. The temperature curves of compost C-40, C-44 and C-50 corresponded to C-30 and C-37 but with lower temperature values mainly in mesophilic and thermophilic periods. It is also evident that lowest temperature patterns from 24°C to 38°C during the whole composting process are referring to compost C-50. These conditions were caused by the inappropriate initial $C:N$ ratio, leading to an insufficient content of nitrogen in the pile. Figure 1 also shows that only in case of compost C-30 the temperature exceeded 55°C for several days which is important for pathogen reduction (EPSTEIN, 1997). The turnovers during the composting are well perceptible from Figure 1. The moisture content during the whole process varied between 40% and 60% in all compost piles.

Figure 1: The ambient and composting temperature patterns



The variations of pH during all experiments were in ranges described by many authors as optimal (Epstein, 1997; Haug, 1993; Rynk, 1992). At the beginning the pH was slightly acid (5.5 - 5.7) and during the termophilic period raised to alkaline values up to 8.3. Then during compost curing the pH decreased to neutral values from 6.8 to 7.6.

During the first two weeks of composting a 52%, 54%, 53%, 52% and 51% of volume reduction was achieved in compost C-30, C-37, C-40, C-44 and C-50, respectively. After the first two weeks the shrinkage with time slowed down and at the end of composting process stopped at values of 65%, 64%, 71%, 73% and 73% for compost C-30, C-37, C-40, C-44 and C-50, respectively. High shrinkage can be explained by the high rate of primary feedstock dry grass *Imperata* (bulky material), mainly in composts C-40, C-44, and C-50. Changes in the color of the compost materials during the composting process indicate the degree of stability. The initial color of tested composts in this study was almost brown-whitish with some green parts. After 21 days, the compost C-30 had a dark-brown color, the compost C-37, C-40 and C-44, C-50 had brown and auburn color, respectively. At the end of the composting process (after 64 days) the composts had the following colors: compost C-30 and C-37 black, compost C-40 dark-brown and compost C-44 and C-50 brown. In case of compost color it is evident that color changes between each compost heap depend on the amount of *Imperata* in the compost mixture. The compost with the highest share of *Imperata* C-50 had the lightest color.

3.2 Evaluation of finished compost

The physical and chemical characteristics of all compost samples are presented in Table 2. Final moisture content (MC) of all tested samples was within the recommended range from 40% to 60% (Epstein, 1997). The lowest bulk density was observed in

compost C-50, which corresponded to the highest content of *Imperata*. The C : N ratio usually decreased during the composting process and its end to initial values was one of compost stability indicators. Referring to Table 2, the final C : N ratio of all analyzed composts was between 11 and 15 hence well below 20 which is the upper limit for stable compost (JIMENEZ and GARCIA, 1989; EPSTEIN, 1997). Further a significant C : N ratio decreasing rate is evident in all composts, even compost C-40, C-44 and C-50 have been prepared as composts with a high initial C : N ratio. The OM contents ranged between 20.0% and 29.3% (d.b.) in all tested composts, which is near the minimum of 25% in d.b. required for compost by EC specifications (GUERRA-RODRÍGUEZ *et al.*, 2000). The low OM content could be explained by very low TCC of deep poultry litter (7.8% d.b.), which is evident from the OM content of compost C-30 with the highest content of this compost feed material. The final pH of all tested composts was between the recommended ranges 6 – 8.
Total macro-nutrient contents in all compost samples are presented in Table 3. The macro-nutrient values in all composts are well above the minimal values required by EC regulations and are within the range reported by other authors (VILLAR *et al.*, 1993).

Table 2: Chemical and physical properties of final composts.

Compost sample	*Moisture Content (% w. b.)*	*Bulk density (kg m^{-3})*	*pH*	*Organic Matter (% d.b.)*	*Total C (% d.b.)*	*Total N (% d.b.)*	C : N *ratio*
C-30	50.50	780	7.8	20.00	10.68	0.98	11:1
C-37	41.22	705	8.0	25.00	13.23	1.12	13:1
C-40	40.75	660	7.3	25.10	13.28	0.98	14:1
C-44	46.64	612	8.0	29.26	15.40	1.13	14:1
C-50	40.66	552	7.7	28.62	15.08	1.01	15:1

Table 3: Macro nutrient contents of final composts.

Compost sample	K	Ca	Mg *mg kg^{-1}*	P	Na
C-30	10.187	73.843	5.869	15.179	1.963
C-37	9.176	85.036	5.292	15.963	1.636
C-40	8.137	72.606	7.496	13.214	1.365
C-44	8.593	81.393	5.441	15.394	1.437
C-50	7.155	69.730	4.422	13.726	1.243

Table 4 shows the heavy metal contents in all tested composts. Referring to this table it is evident that concentrations of all heavy metals in all tested composts are well below the required limits (COMPOST COUNCIL OF CANADA, 1999; HEGBERG *et al.*, 1991) except the concentrations of zinc. The concentration of Zn may not complete some very rigorous regulations, for instance EEC Organic Rule 2092/91 where a value of 200 mg kg^{-1} of Zn is considered as maximum (BIDLINGMAIER and BARTH, 1993). From Table 4 it is also evident that there is no relationship between the content of *Imperata* in compost piles and the content of various heavy metals. Results of bioassay tests expressed as the germination index (GI) were 51.4%, 48.6%, 47.8%, 46.7% and 40.0% for sample C-30, C-37, C-40, C-44 and C-50, respectively. According to ZUCCONI *et al.* (1981), GI values greater than 50% indicate a phytotoxic-free compost which is only the case of sample C-30. The majority of literature sources reported germination over 80% as essential for mature and phytotoxic-free compost (GUERRA-RODRÍGUEZ *et al.*, 2000; BREWER and SULLIVAN, 2001). However, the GI results can indicate a compost immaturity in all tested samples, the final $C:N$ ratios indicate that all tested composts may be considered as mature. Further Table 4 confirmed that the compost phytotoxicity predicted by the bioassay tests is not a result of redundant heavy metal content.

Table 4: Heavy metal contents of final composts.

Compost sample	Cu	Zn	Cd	Pb	Cr	Ni	Hg	As	Mo
					mg.kg⁻¹ → $mg.kg^{-1}$				
C-30	29.31	303.1	0.191	4.458	32.57	5.831	0.0316	7.681	2.401
C-37	39.33	336.1	0.304	6.860	32.23	6.595	0.0338	7.935	2.568
C-40	30.01	283.2	0.208	4.036	30.84	4.792	0.0300	6.829	1.935
C-44	30.63	321.3	0.224	2.667	32.30	6.994	0.0377	6.161	2.284
C-50	26.40	275.1	0.195	2.963	29.83	5.632	0.0300	6.598	1.761

The relatively low GI values may be explained by phytotoxic effect of the major compost feedstock *Imperata*. It was reported that *Imperata* sp. contains phenolic compounds which significantly inhibit germination and growth of other plants and cause an allelopathic effect (INDERJIT and DAKSHINI, 1991; HONG *et al.*, 2003). The bioassay tests show a decline of GI from sample C-30 to C-50 which corresponds to an increasing content of *Imperata* sp. in these composts. The direct effect of *Imperata* on the final compost phytotoxicity has not been verified in this study; however some particular relationships have been described. Hence further tests to verify a relationship between the allelopathic effects of *Imperata* sp. and final compost phytotoxicity are strongly encouraged.

4 Conclusions

(1) In all tests a considerable $C:N$ ratio reduction was achieved during 64 days of well managed composting under tropical climatic conditions.

(2) Composts prepared with *Imperata* sp. as a prime feedstock were found as convenient in terms of physical and chemical properties.

(3) No over limits of heavy metal concentrations have been observed in the tested composts.

(4) A particular compost phytotoxicty, which may be caused by the allelopathic effect of the main component *Imperata* sp. has been observed in this study.

Acknowledgements

The financial support of the Ministry of Agriculture of the Czech Republic, Project No. 80/03-06/MZe/B and the foundation Nadani Josefa, Marie a Zdenky Hlavkovych are gratefully acknowledged.

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Journal of Agriculture and Rural Development in the Tropics and Subtropics
Volume 109, No. 2, 2008, pages 123–137

Green Gram Rotation Effects on Maize Growth Parameters and Soil Quality in Myanmar

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Abstract

At present maize–green gram crop rotations are not widely practiced among farmers in Myanmar. However, this cropping system might become more popular in the future given raising prices for green gram and maize grain and scarcity of mineral nitrogen (N) fertilizers in this Asian country. The results of a cropping systems experiment with continuous maize versus a green gram-maize rotation, manure application (0 and 2 t ha^{-1}) and phosphorus (P) fertilization (0 and 15 kg P ha^{-1}) in each of five consecutive seasons revealed a strong decline in total dry matter and grains yields for both crops irrespective of the treatment. Treatment effects on yield components, nutrient concentrations, mycorrhizal infection and nematode infestation were small or negligible. The data show that in addition to manure used at 2 t ha^{-1}, application of mineral N fertilizers is essential to maintain particularly maize yields. A comparison of different green gram cultivars did not indicate genotype specific effects on maize growth. The incorporation of legume residues, unless they are used as animal feed, is recommended to increase the recycling of N and to balance N fluxes when green gram is cultivated for seed.

Keywords: Maize, Green gram, Rotation, Manure, Nitrogen, Phosphorus, Myanmar

1 Introduction

Among the 60 different crop species grown in Myanmar, maize (*Zea mays* L.), grown for domestic use and export, is the second most important cereal after rice (*Oryza sativa* L.). In 2003, the total maize area in Myanmar was 300,000 ha with an average grain yield of 2,500 kg ha^{-1} (FAO, 2004). Given favourable terms of trade on export markets, maize cultivation is becoming increasingly popular and farmers are using more and more hybrid varieties. However, soil fertility in continuously cropped maize fields is deteriorating rapidly leading to declining yields during the rainy (May-September) and dry (October-December) season (MOAI, 2005). To supply nitrogen (N) to the crop, farmers often use mineral fertilizers at rates of up to 100 kg N ha^{-1} rather than legume

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rotations. However, imports of mineral fertilizers are severely hampered by shortages of foreign exchange and therefore their use is low. Similarly, manure application is restricted due to scarcity-induced high prices.

With productive farmland facing increased pressure from a growing population, cereal-legume rotations have been proposed as an effective means to increase the productivity of nutrient-depleted soils in low-external input systems (BUERKERT *et al.*, 2001a,b). On acid sandy soils of semi-arid West Africa where crop yields are strongly limited by P availability (BATIONO *et al.*, 1992), cereal/legume rotations based on maize, sorghum (*Sorghum bicolor* L. Moench), cowpea (Vigna unguiculata L.) and groundnut (*Arachis hypogaea* L.) have been shown to cause large increases in cereal yields (BAGAYOKO *et al.*, 2000a,c).

Similarly, soil productivity in SE Asia including Myanmar is limited by low pH, low CEC, low base saturation and high P-fixation capacity (PUSHPARAJAH and BACHIK, 1987). Highly weathered tropical soils (Oxisols, Ultisols) are typically characterized by low total and available P and an often high P retention capacity (FRIESEN *et al.*, 1997). Moreover, P use efficiency is usually low and rarely exceeds 20% of applied P in the year of application depending on the nature of the soils and crops concerned (SUBBA RAO *et al.*, 1995). However, when manure and fertilizer P are applied together, synergistic effects often lead to available P being higher than expected from the sum of both amendments alone (REDDY *et al.*, 1999). While the addition of animal manure may improve P-availability, it is unlikely to have much impact on other yield limiting factors such as pests and diseases, which are favoured by continuous cropping, but it may slow down the deterioration of soil structure. While yield increases in cereals following rotation with legumes have been reported from Myanmar (HAN *et al.*, 2001), solid experimental data from cropping systems experiments are necessary to substantiate these reports. So far, the few available data refer to rice-based systems and were collected on acid Vertisols (FARIS, 1992).

Given the scarcity of data on legume rotation effects for maize in Myanmar, the objectives of this study were to examine to what degree an expected N-related yield decline in a maize monocropping system under the low external input conditions of local farmers could be slowed down by a rotation with green gram and to explore the causes of possible yield-enhancing effects of green gram on maize. The following research hypotheses were therefore tested in field experiments: (i) rotation with green gram (*Vigna radiata*), farm yard manure and P fertilizer will slow down the expected yield decline in a continuous maize system, (ii) incorporation of green gram shoot residues will further enhance maize growth. Different green gram cultivars were used to determine possible cultivar-system interactions.

2 Methodology

2.1 Experimental details

The experiment was conducted from 2002 to 2004 on a Gleysol soil with pH_{water} of 5.6; 50 mg total N kg^{-1} soil and 6.8 mg Bray-1 P kg^{-1} soil at the farm of Yezin

Agricultural University (191°38' N latitude, 96°50' E longitude, 102 m altitude). The layout consisted of a split-split plot design with four replications. Treatment factors were two cropping systems as main plots. The subplot factor was manure application at 0 and 2 t ha^{-1} cattle compost, with N concentrations of 1.15, 0.78, 0.67, 1.01 and 0.89% and P concentrations of 0.51, 0.97, 1.15, 0.91 and 0.78% for the five experimental seasons, respectively. The sub-sub plot factors consisted of 0 and 15 kg P ha^{-1} as basal triple-super phosphate (TSP with 21% P). In the first season, three introduced green gram cultivars (V-3726, VC-5205 and Kanti) and one maize cultivar (Yezin Hybrid-3) were used. In season two and three, the three green gram cultivars V-3726, Kanti and the landrace Pakhoku were grown. Because of its high yield, V-3726 was also chosen for the 4th and 5th season.

Annual rainfall, distributed bimodally between May and November, totalled 1369 mm in 2002, 727 mm in 2003 and 1279 mm in 2004. Land preparation was done once by an animal-drawn plough followed by two harrowing operations. Plant spacing was 0.5 m between and 0.1 m within rows for green gram and 0.5 m between and within rows with one plant per hill for maize. Weed and pest control was done as necessary. To examine the effects of legume residue management, treatments of shoot incorporation and removal were added in the 5th season as a further split of legume plots.

2.2 Plant sampling and analysis

At flowering samples for tissue analysis of both crops were taken, dried at 70°C to weight constancy and analysed for N and P at the Agricultural Chemistry Division Laboratory, Department of Agricultural Research in Yezin and at the Institute of Crop Science Laboratory, University of Kassel, Germany. Total N was determined with a Macro-N-Analyser (Heraeus, Bremen, Germany). For P analysis, shoot and seed samples were ashed for 4 hrs in a muffle furnace at 500°C and the ash was dissolved in 1:30 (v/v) HCl. Phosphorus was determined calorimetrically (Hitachi U-2000 spectrophotometer). At final harvest total dry matter (TDM, kg ha^{-1}) was measured and the Harvest Index (HI) was determined. For root analyses soil samples (0 to 0.2 m) were collected at five locations within each plot in all blocks at flowering. All samples were washed over a 0.5 mm sieve to remove adherent soil and analysed for root length density according to TENNANT (1975) in a 10 mm grid line petri dish with a binocular at 40×. After counting, root samples were dried at 60°C for 12 h. Dry weight, total root length (TRL), specific root length (SRL) and root length density (RLD) were determined using the following equations:

$$SRL = \frac{Z * mesh\,(cm) * 11/14}{X\,(g)} \tag{1}$$

$$TRL = SRL * y\,(g) \tag{2}$$

where:
$Z =$ total numbers of intersects; $X =$ dry weight of counted sample;
$y =$ dry weight of entire root; and

$$RLD = \frac{TRL(cm)}{soil\ volume\,(cm^3)} \tag{3}$$

2.3 Measurements of mycorrhizae and nematodes

Mycorrhiza and nematode incidence were assessed in the 4th and 5th growing season. For measurement of mycorrhizae, 100 g of washed maize roots were cut into segments of 10-20 mm and cleared with 10% KOH at 60°C for 1 h. Subsequently, roots were rinsed three times in deionized water and acidified for 30 minutes in 2 N HCl. Then, roots were stained with 0.05% trypan blue in lactic acid over night followed by destaining in lactic acid. Percent mycorrhiza colonization of roots was determined by the line intersection method (Kormanik and McGraw, 1982). A modified Baerman funnel method as described by Hooper (1984) was used for the extraction of nematodes from 200 g soil and root samples prior to counting.

2.4 Data analysis

Data of TDM, grain yield and nutrient concentrations were analysed for all seasons together whereby treatments were split into seasons and subsequently analysed for each season separately by Analysis of Variance (ANOVA) using the Restricted Maximum Likelihood procedure (REML) and time series analysis of GENSTAT (Lawes Agricultural Trust, 2000). Seasonal data of grain yield and plant nutrient concentrations were also subjected to ANOVA. The data of nematode populations obtained in the final season was transformed as log base 10 and analysed as above.

3 Results

3.1 Green gram

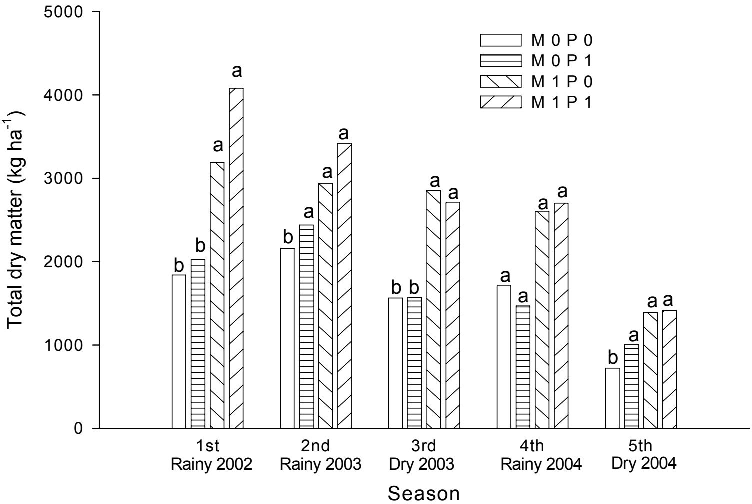
Regardless of the treatment level TDM and grain yield of green gram decreased over the course of the experiment by an average of 41% and 52% (Fig. 1 and 2). Across seasons manure application led to consistently higher TDM whereas P application was only enhancing growth in season 2 and 5 without manure (Fig. 1). Significant effects of manure on grain yield were noted in season 4 and 5 (Fig. 2).

Effects of manure and P on grain yield varied greatly with the season. No effects were observed in season 1, whereas in season 2 P and manure addition resulted in significant yield increases with no synergistic effects being observed between both types of amendments (Table 1).

While mean grain yield declined by about half over the duration of the experiments (from 600 kg ha^{-1} in season 1 to 310 kg ha^{-1} in season 5) during the same period, RLD was reduced by 75% (from 4.5 cm cm^{-3} to 0.9 cm cm^{-3}). The LAI of green gram was also reduced by 59% across seasons (from 3.3 to 1.9), but the HI remained with values of 0.182 and 0.183 unchanged. Pod numbers per plant declined from 12.9 to 12.3 over the course of the experiment. Of the cultivars tested in some, but not all seasons grain yields were highest for cultivar V-3726 which is very popular in Myanmar because of its large grain size and subsequent high market price.

Although not significant, N and P concentrations in green gram shoots of all treatments increased over the duration of the experiment from around 23 to 42 mg g^{-1} and from 2.2 to 3.6 mg g^{-1}, respectively (Table 2). In untreated controls shoot N concentration was higher than with manure and shoot P increased from 3.9 to 4.6 mg P g^{-1}. No correlations were found between N and P concentrations and green gram grain yield (r = 0.37, r = 0.34).

Figure 1: Effects of manure and phosphorus (P) application on total dry matter of green gram (cv. V-3726) in a field trial in Myanmar (2002-2004).



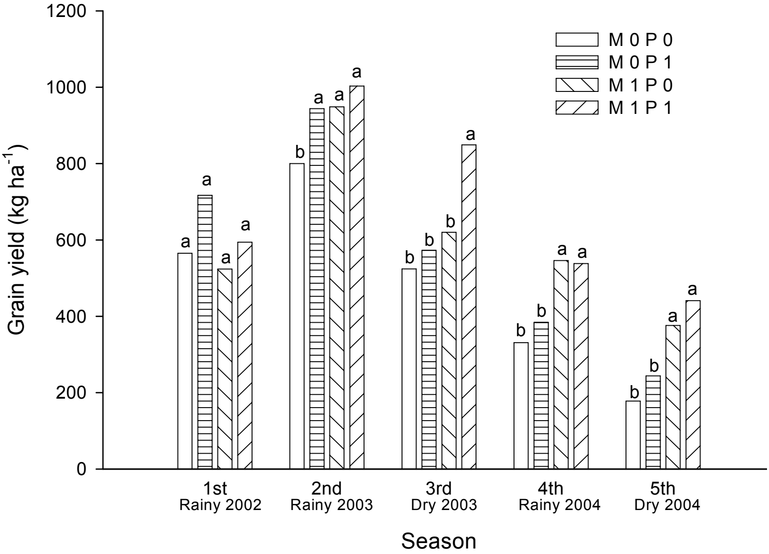
M0P0 = no manure, no mineral P; M0P1 = no manure, 15 kg P ha^{-1}; M1P0 = 2 t ha^{-1} manure, no mineral P; M1P1 = 2 t ha^{-1} manure, 15 kg P ha^{-1}. The lsd0.05 values across treatments are 1650, 1208, 720, 1175 and 480, in season 1-5, respectively. Columns within season marked with different letters are significantly different at $P < 0.05$.

Table 1: Combined analysis of variance (ANOVA) of manure (M) and phosphorus (P) application effects in green gram grown in a cropping systems (CS) experiment with continuous maize and maize in rotation with green gram at Yezin, Myanmar (five seasons from 2002-2004).

Source of variation	*Pr > F* *		
Parameter	*Total dry matter* (kg ha^{-1})	*Grain yield* (kg ha^{-1})	*RLD* † (cm cm^{-1})
Season ‡	0.001	0.001	0.001
Manure	0.001	0.003	0.801
Season × Manure	0.443	0.077	0.825
P	0.274	0.002	0.055
Season × P	0.709	0.652	0.798
Manure × P	0.623	0.837	0.216
Season × Manure × P	0.895	0.435	0.062

* Probability of a treatment effect (significance level), † Root length density,
‡ 2002 rainy, 2003 rainy, 2003 dry, 2004 rainy, 2004 dry

Figure 2: Effects of manure and phosphorus (P) application on grain yield of green gram (cv. V-3726) in a field trial at Yezin, Myanmar (2002-2004).



M0P0 = no manure, no mineral P; M0P1 = no manure, 15 kg P ha^{-1}; M1P0 = 2 t ha^{-1} manure, no mineral P; M1P1 = 2 t ha^{-1} manure, 15 kg P ha^{-1}. The lsd0.05 values are 201, 143, 199, 95 and 80, in season 1-5, respectively. Columns within seasons marked with different letters are significantly different at $P < 0.05$.

Table 2: Nitrogen (N) and phosphorus (P) concentrations in green gram and maize shoots in a cropping system field experiment at Yezin, Myanmar across five seasons (2002-2004). Data show treatments means.

	Concentration (mg g^{-1}*) in Season*				
	1	*2*	*3*	*4*	*5*
Green gram					
Shoot N	n.a.	23.2	28.4	41.6	41.9
Shoot P	n.a.	2.16	3.52	4.01	3.57
Maize					
Shoot N	n.a.	18.6	16.9	19.2	12.6
Shoot P	n.a.	1.6	3.0	3.5	4.6

n.a. – not available

3.2 Maize

With 93% and 97% the respective decline of maize TDM and grain yield over the duration of the experiment was larger than similar effects in green gram (Fig. 3 and 4). The overall ANOVA showed significant F-value for season, cropping system, manure and P application (Table 3). For individual years, F-values did not show significant rotation effects from season 2 onwards, although yields from rotation plots tended to be higher than those from continuous maize plots. Root length density decreased over time and there were only marginal effects of P fertilizer and no effects of rotation on RLD. Although across years rotation effects on maize growth were inconsistent, crop rotation increased TDM, grain yield, RLD and the number of ears per plant compared to continuous maize in seasons 2, 3 and 4.

Manure application led to increased leaf area, plant height, TDM and grain yield. Phosphorus application also increased LAI and plant height, thereby contributing to increased TDM and grain yield. In season 5, incorporation of legume residues significantly enhanced grain yield relative to residue removal only without P application (Fig. 5). However, compared to maize growth in previous seasons, grain yield and TDM of maize in all treatments sharply declined.

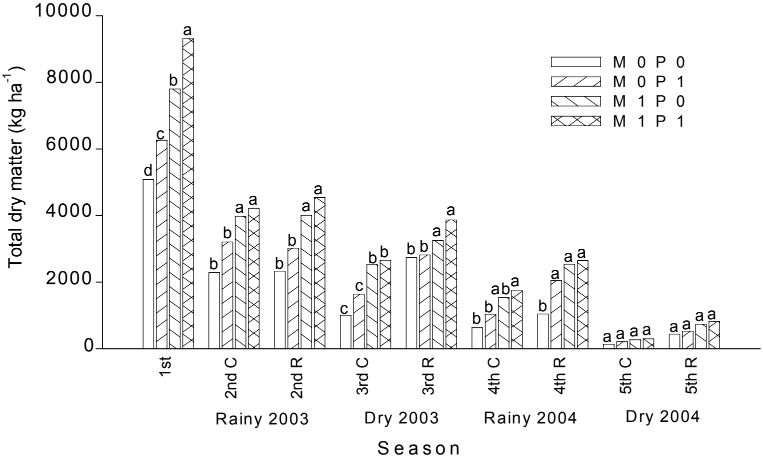
By season 3, legume rotation-induced increases in maize growth were larger than those caused by manure- and P-application (Fig. 4). From season 2 onwards, rotation effects were little affected by manure and P application. In the 4^{th} and 5^{th} cropping season manure application tended to increase mycorrhizal infection but effects on plant-parasitic nematodes were inconsistent across cropping systems (Fig. 6 and 7). The average LAI of maize decreased from 4.0 to 0.3 and there was no significant effect of manure and P application on ear number per plot.

Manure increased ear numbers from 12 to 15. From season 2 to 5 plant height and stem diameter declined from 143 and 5.7 cm to 48 and 3.9 cm. Across seasons, the HI remained almost constant. Recycling / incorporation of legume straw led to substantial yield increases but was not enough to alleviate N constraints.

Over seasons the rapid yield decline overtime was reflected in a strong decrease of N concentrations in maize shoots from 19 to 13 mg g^{-1} and a concomitant increase in P concentrations from 1.6 to 4.6 mg g^{-1} (Table 2). In the 5^{th} season incorporation of legume residues led to a slight increase in maize N concentration. From season one to season five, N removal of the maize field declined from 54 kg N to 30 kg N.

The soil mineral N concentration in the top 15 cm of the profile tended to be higher in rotation plots with residue incorporation up to six weeks after planting compared to rotation plots with legume residue removal or continuous maize cultivation. However, these differences were not statistically significant.

Figure 3: Effects of cropping system, manure and phosphorus (P) application on total dry matter of maize in a field trial at Yezin, Myanmar (2002-2004).



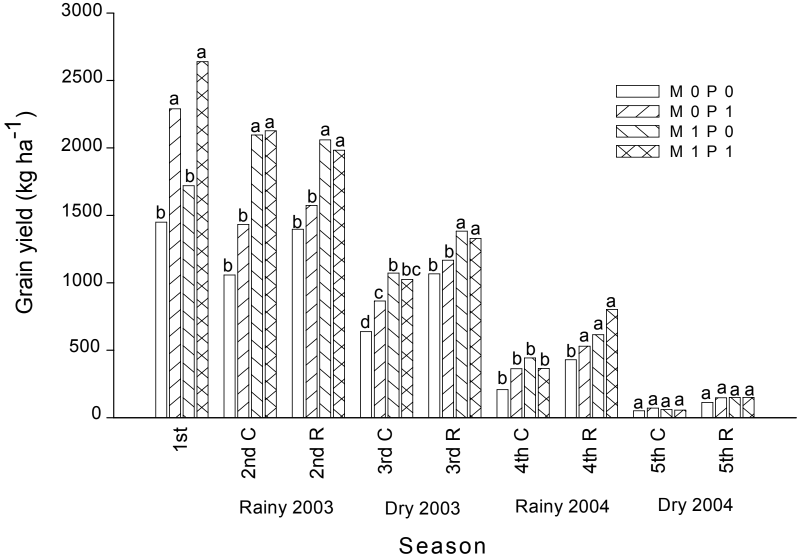
C = continuous maize, R = maize-green gram rotation, M0P0 = no manure, no mineral P; M0P1 = no manure, 15 kg P ha^{-1}; M1P0 = 2 t ha^{-1} manure, no mineral P; M1P1 = 2 t ha^{-1} manure, 15 kg P ha^{-1}. The lsd0.05 values are 1040, 503, 643, 582 and 107, respectively. Columns within seasons marked with different letters are significantly different at $P < 0.05$.

Table 3: Analysis of variance (ANOVA) for the time dependent effects (five seasons from 2002-2004) of cropping system (continuous maize versus green gram-maize rotation), manure application (0 and 2000 kg ha^{-1}) and banded phosphorus (P) fertilization (0 and 15 kg P ha^{-1}) on total dry matter (TDM), grain yield and root length density (RLD) of maize (*Zea mays* L.) at Yezin, Myanmar.

Source of variation	*Pr > F* *		
Parameter	*Total dry matter* (kg ha^{-1})	*Grain yield* (kg ha^{-1})	*RLD* † (cm cm^{-1})
Season ‡	0.001	0.001	0.003
System	0.001	0.007	0.102
Season × System	0.104	0.750	0.838
Manure	0.001	0.001	0.247
Season × Manure	0.001	0.001	0.739
System × Manure	0.305	0.436	0.164
Season × System × Manure	0.971	0.055	0.112
P	0.001	0.015	0.047
Season × P	0.081	0.356	0.913
System × P	0.157	0.122	0.591
Manure × P	0.485	0.434	0.882
Season × System × P	0.697	0.450	0.868
Season × Manure × P	0.390	0.657	0.979
System × Manure × P	0.899	0.535	0.103
Season × System × Manure × P	0.713	0.827	0.634

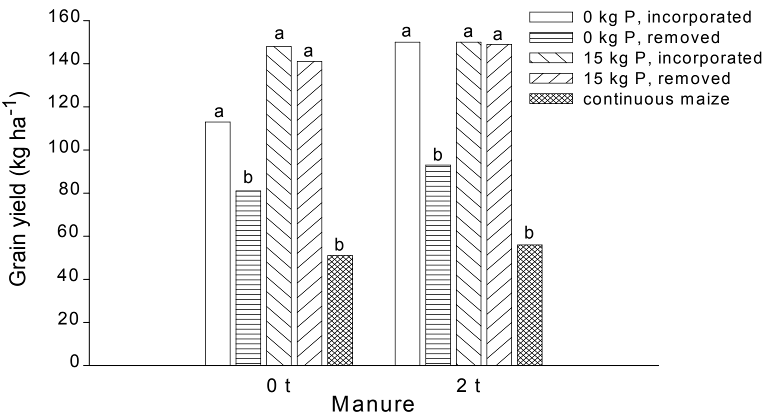
* Probability of a treatment effect (significance level), † Root length density,
‡ 2002 rainy, 2003 rainy, 2003 dry, 2004 rainy, 2004 dry

Figure 4: Effects of cropping system, manure and phosphorus (P) application on grain yield of maize in a field trial at Yezin, Myanmar (2002-2004).



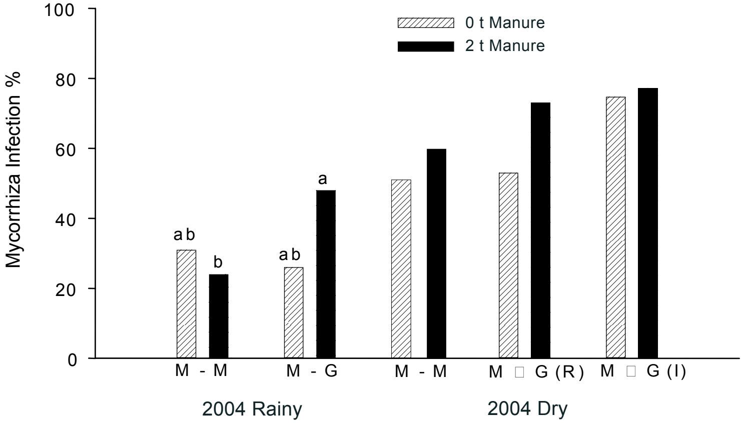
C = continuous maize, R = maize-green gram rotation, M0P0 = no manure, no mineral P; M0P1 = no manure, 15 kg P ha^{-1}; M1P0 = 2 t ha^{-1} manure, no mineral P; M1P1 = 2 t ha^{-1} manure, 15 kg P ha^{-1}. The lsd0.05 values are 450, 568, 743, 477 and 106, respectively. Columns within seasons marked with different letters are significantly different at P $<$ 0.05

Figure 5: Effect of phosphorus (P) application (kg ha^{-1}) and legume residue management (removal versus incorporation) on grain yield of maize in the 5th season at Yezin, Myanmar (2004 dry season).



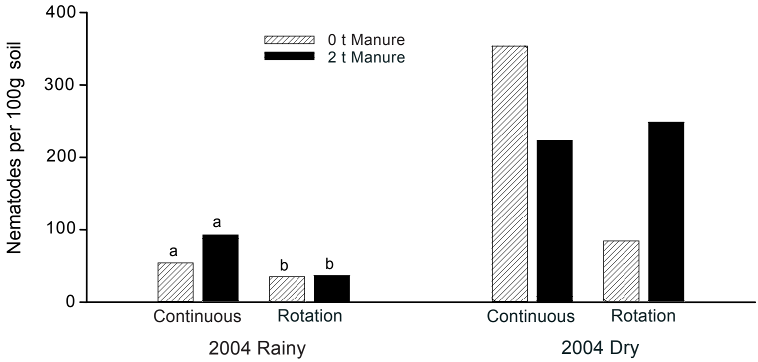
The lsd0.05 value was 42. Columns within seasons marked with different letters are significantly different at P $<$ 0.05.

Figure 6: Effects of cropping system and manure application on mycorrhizal infection of maize in the 2004 rainy and dry season at Yezin, Myanmar (2004).



M-M = continuous maize, M-G = maize-green gram rotation; R = legume straw removed; I = legume straw incorporated. The lsd0.05 values 22.6 and 31.0, in season 4 and 5, respectively. Columns within seasons marked with different letters are significantly different at P $<$ 0.05.

Figure 7: Effect of cropping system and manure application on plant-parasitic nematodes in soils of a maize cropping systems experiment in the 4th and 5th season at Yezin, Myanmar (2004).



The data are back transformend after log-transformation for statistical analysis; lsd0.05 values of transformed values are 0.26 and 0.64, respectively. Columns within season marked with different letters are significantly different at P $<$ 0.05.

4 Discussion

4.1 Green gram

Over the five cropping seasons green gram TDM and grain yield steeply declined which likely reflected effects of N deficiency for as evidenced by the decline of N concentrations over time. During the first seasons V-3726 consistently showed highest TDM and grain yield which was also reflected in its high LAI and number of pods per plant.

Although not significant except for the 1st season, P application tended to increase RLD in all seasons, which likely reflected P effects on shoot growth. AHMAD *et al.* (2001) reported total N concentration in green gram ranging from 26 to 36 mg g^{-1}, whereas LAWN and AHN (1985) showed N concentrations of 6 – 16 mg g^{-1} and P concentrations of 2 – 2.9 g kg^{-1}.

4.2 Maize

The results clearly showed that regardless of the treatment maize growth was strongly limited by N supply which also led to the dramatic decline in yields over time and the decline in shoot N concentrations to 68% of the value measured in the second season. Similar results were found by CHERUIYOT *et al.* (2001) who reported that growing continuous maize resulted in a strong growth decline following limited soil N. The data did not show any alleviation of this yield decline or a significant difference in shoot N concentration in plots with green gram rotation. Further studies using acetylene reduction assays or ^{15}N analysis would have been needed to determine the level of N_2 -fixation by green gram in this study. The absence of a difference in the N-status of maize grown in the two cropping systems indicates that under the conditions of this experiment N_2-fixation of green gram may have been severely hampered despite the strong presence of reddish nodules on roots.

At this level of N supply soil P was apparently not limiting despite its low availability (6.8 mg Bray-1 P kg^{-1} in the initial soil). Only this would explain the small response of maize growth to regular P applications in organic form (manure) and as mineral fertilizer. Lacking rotation effects on maize growth in the 2nd season are likely due to the erroneous fallow phase following the first cropping season in 2002. The increase in RLD with P application is in agreement with earlier findings on P-poor sandy soils from West Africa which showed increased root biomass, root to shoot ratio and lateral root length after P addition (MARSCHNER *et al.*, 2004).

Higher TDM yield of maize due to manure were observed in season 2, which may also be linked to the observed increase in pH from 5.6 to 6.8 after five seasons in plots with and without manure application. Similar manure-induced pH increases were observed previously by HARRIS (2002) and CHETTRI *et al.* (2003).

WADDINGTON and KARIGWINDI (2001) reported that on on-farm grain yields from continuous maize (one season per year) without fertilizer ranged from 0.5-0.8 t ha^{-1} over five years. In contrast, in the 5th season of this experiment maize grain yield was < 0.5 t ha^{-1}. MCDONAGH and HILLYER (2003) also reported that for moderate millet grain yield (1000 kg ha^{-1}) in Africa, 20-30 kg N ha^{-1} and 10-15 kg P ha^{-1} mineral fertilizer were essential. KWABIAH *et al.* (2003) observed that application of 5 t dry matter ha^{-1} of *Tithonia* and *Croton* was similar to the effects of 120 kg N ha^{-1} and 50 kg P ha^{-1} of inorganic fertilizers in enhancing on maize grain yield. In this experiment only 10-20 kg N was added annually through the application of manure. This was too low to sustain maize yields at average N removals of 70, 74, 43, 32, 4 kg ha^{-1} per season.

GILLER and CADISCH (1995) reported that the removal of legume stover at harvest frequently leads to a net removal of N from the soil. Therefore the recycling of residues to the soil is essential for the N-balance in grain legumes. Nevertheless, food legumes such as cowpea, green gram and pigeon pea were found to increase yields of subsequent cereal crops in semi-arid India by an equivalent of 30-40 kg N ha^{-1} (KUMAR RAO *et al.*, 1988). Similar results were found by REGO and RAO (2000) in sorghum–pigeon pea intercropping on a Vertisol in India (2000). For maize HERRMANN and TAUBE (2005) reported a critical shoot N concentration of 10.5 g N kg^{-1} TDM.

CHETTRI *et al.* (2003) reported that the application of 7 t ha^{-1} manure to rice and wheat crops over eight years had no beneficial effect on yields. But HARRIS (2002) showed manure-induced yield increases due to the improvement of N, P, K and micronutrients and of soil physical properties. In contrast to the latter results, manure effects on crop yield were very small in this experiment. This might have been due to the application rate of only 2 t ha^{-1}.

The slightly (from 19.05 to 19.35 mg N g^{-1}; from 3.24 to 3.73 mg P g^{-1}) increased N and P concentration of rotation maize compared to continuous maize might have been due to a small (though statistical not significant) increase in mycorrhizal infection. Without manure, however, mycorrhizal infection rates were not affected by cropping system. For nematodes, a small, though significant decrease in numbers was observed with green gram rotation in the rainy season of 2004, but differences were insignificant in the following dry season. The compared to the results of BAGAYOKO *et al.* (2000b) missing consistent rotation-induced decline in nematodes may be due to the fact that in all treatments overall infestation levels were small and unlikely to cause much harm to plant roots.

5 Conclusions

In the absence of mineral N fertilizers and with only moderate amounts of applied cattle manure the green gram rotation failed to increase maize yields compared to the monoculture maize system. The results indicate that under the conditions of this five-season experiment, N_2-fixation of green gram might have been severely hampered and the crop's effects on the N balance negative when seeds and stalks were removed. The absence of significant effects of green gram on mycorrhizal infection and nematodes in subsequent maize may further explain lacking legume-rotation effects on this crop. The results strongly suggest that apart from 2 t ha^{-1} manure, application of mineral N fertilizer is needed to maintain growth and grain yield of maize irrespective of the rotation with different green gram cultivars.

Acknowledgements

The authors are grateful to the German Academic Exchange Service (DAAD) for a scholarship to the first author and to the technical assistance of Claudia Thieme, Eva Wiegard and Burkhard Heiligtag.

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Journal of Agriculture and Rural Development in the Tropics and Subtropics
Volume 109, No. 2, 2008, pages 139–149

Phosphate Sorption Characteristics and External P Requirements of Selected South African Soils

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Abstract

The Transkei is the largest consolidated area in South Africa where land is held by smallholder farmers but little is known about the extent of phosphate fixation in the region. This study was conducted to determine the phosphate sorption properties and external P requirements (EPR) of selected soils from the Transkei region, South Africa and to relate derived sorption values to selected soil parameters. The P sorption maxima and EPR values varied widely ranging from 192.3 to 909.1 mg P kg^{-1} and from 2 to 123 mg P kg^{-1} soil, respectively. Citrate dithionite bicarbonate-extractable aluminum explained most of the observed variations in P sorption. About 43% of the soils were found to be moderate P fixers and may need management interventions to ensure adequate P availability to crops. The single point sorption index accurately predicted the EPR of the soils obviating the need to use multiple point sorption isotherms. The results suggested that the use of blanket phosphate fertilizer recommendations may not be a good strategy for the region as it may lead to under-application or over-application of P in some areas.

Keywords: External P requirement, P-sorption, Single point sorption test, Citrate dithionite bicarbonate-extractable aluminum, South Africa

1 Introduction

The sorption of phosphate by oxides of iron and aluminum, and amorphous materials in soils is a major contributing factor to reduced effectiveness of added phosphates necessitating larger applications of fertilizer P to achieve good crop yields (Warren, 1994). Phosphate sorption studies on soils from KwaZulu-Natal and Mpumalanga provinces, South Africa have shown that highly weathered soils have high sorption capacities ranging from 500 to 1197 mg P kg^{-1} soil (Bainbridge *et al.*, 1995; Henry and Smith, 2002). The highest P fixers were weathered red or yellow-brown clays with high oxalate (amorphous) aluminum content, and especially those with a humic-horizon. The Transkei is the largest consolidated area (4, 365, 263 ha) in South Africa where land is held by smallholder farmers (van Averbeke *et al.*, 2008). Little is, however, known

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on the extent of P retention by soils in this region of South Africa despite the common occurrence in the region of soils with potential for high P fixation (BÜHMANN *et al.*, 2006a).

Phosphorus sorption relationships are commonly used in the determination of the external phosphorus requirement (EPR) of crops. According to FOX (1981) EPR is the concentration of P in solution that is non-limiting to plant growth. For most crops, the amount of P in equilibrium with 0.2 mg P l^{-1} ($P_{0.2}$) has been shown to be the threshold over which no response to P is observed (BECKWITH, 1965; IYAMUREMYE *et al.*, 1996; NZIGUHEBA *et al.*, 1998). The P requirements, estimated in this manner aim at building up the status of soil phosphorus by a single application to a level which, thereafter, only requires maintenance application to replenish losses owing to plant uptake, removal by erosion or continuing slow reactions between phosphate and soil (HENRY and SMITH, 2003). No information could be found on the EPR of soils in the Eastern Cape Province, South Africa. Such information is, however, necessary to guide P fertilizer recommendations to ensure that crop yields are not compromised due to under-fertilization and that ground water is not polluted with P transported from over-fertilized soils.

Though phosphorus sorption relationships have been used successfully to assess the preliminary fertilizer requirements, the labour and time involved in constructing P sorption curves make it too expensive for routine soil testing laboratories. HENRY and SMITH (2003) proposed a single point sorption test procedure for obtaining an index of the P requirement in soils that avoids the need for constructing multiple point sorption isotherms. It was, therefore of interest to determine if the single point sorption procedure could be used as an index for estimating the P requirements of soils in the Eastern Cape. The objectives of this study were, therefore: (i) to quantify and compare the P sorption characteristics of selected soils from the Transkei region of the Eastern Cape, South Africa, and (ii) to relate the P sorption characteristics of the soils determined from Langmuir adsorption equations with single point sorption test values and other soil parameters.

2 Materials and Methods

2.1 Soil preparation

Surface soil samples (0-15 cm) were collected from cultivated farmers' fields from four districts (Elliotdale, Mthata, Lusikisiki and Mt. Fletcher) in Transkei, South Africa (Table 1). The districts were selected to represent low (0-600 meters above sea level (masl)), medium (700-1100 masl) and high (1500-3000 masl) altitudes. The soils were air dried and ground to pass through a 2mm sieve.

2.2 Soil characterization

Soil pH was measured in water and 1.0 M KCl (soil: solution ratio of 1:2.5) using a pH meter with a glass and reference calomel electrode (Model pH 330 SET-1, 82362) after the soil suspensions were shaken for 30 minutes and left standing for 1 hour. Electrical conductivity was measured in water (1:2.5 soil:water ratio) using a conductivity meter (Model Cond.330i/SET 82362). Organic C and N were determined by dry combustion

Table 1: Selected chemical properties of soils used in the study.

	Sampling Sites and Grid References						
Properties	*Ntlonyana* 31°46'27"S 28°38'16"E	*Ncihane* 32°00'04"S 28°42'33"E	*Qweqwe* 31°41'42"S 28°42'09"E	*Qunu* 31°46'27"S 28°38'16"E	*Chevy Chase* 30°50'54"S 28°32'12"E	*Bethania* 30°39'41"S 28°16'45"E	*Flagstaff* ND ‡
pH H_2O	5.0	4.9	5.6	5.5	4.6	5.6	4.7
pH KCl	4.3	4.1	4.9	4.9	3.9	4.9	4.0
Total P (g kg^{-1})	0.18	0.18	0.21	0.14	0.17	0.18	0.42
Total N (g kg^{-1})	1.93	0.87	0.81	0.70	0.83	0.16	1.30
Organic C (g kg^{-1})	25.7	11.3	12.3	10.4	15.4	3.97	21.9
Bulk density (kg m^{-3})	1351	1449	1471	1492	1515	1698	1429
Exchang. acidity (cmol (+) kg^{-1})	0.93	0.83	0.07	0.10	1.27	0.10	1.73
CEC (cmol (+) kg^{-1})	16.5	11.3	15.8	7.4	6.3	4.6	16.2
% sand	21.1	39.0	53.2	40.6	74.7	54.7	21.8
% silt	56.4	45.2	30.3	38.5	12.8	28.0	45.2
% clay	22.5	15.8	16.5	20.9	12.5	17.3	33.0
Soil Form *	Klapmuts	Cartref	Glenrosa	Westleigh	Hutton	Hutton	Inanda
Corresponding WRB Soil units†	Planosol	Luvisol	Cambisol	Acrisol	Ferralsol	Ferralsol	Ferralsol

* : South Africa Soil Classification Working Group (1991); † : World Reference Base (2006); ‡ : data not available.

using a LECO TRUSPEC C/N auto-analyzer (LECO CORPORATION, 2003). Total P was estimated following wet digestion with H_2O_2/H_2SO_4 (OKALEBO *et al.*, 2002). Exchangeable Ca^{2+}, Mg^{2+}, K^+, and Na^+ were extracted with 1.0 M ammonium acetate at pH 7 (OKALEBO *et al.*, 2002) and determined by atomic absorption spectrophotometer. Exchangeable acidity ($Al^{3+} + H^+$) was extracted with 1.0 M KCl and titrated with 0.05 M $NaOH$ (OKALEBO *et al.*, 2002). Cation exchange capacity was estimated by the summation of exchangeable cations and exchangeable acidity.

Amorphous Fe and Al (Fe_{ox} and Al_{ox}) were determined in 0.2 M acidified ammonium oxalate adjusted to pH 3.0 with oxalic acid (WARREN, 1994). Dithionite citrate bicarbonate-extractable Fe and Al (Fe_{CDB} and Al_{CDB}) were determined by the method of MEHRA and JACKSON (1960) as cited by AGBENIN (2003). Exchangeable Al and Fe (Al_{KCl} and Fe_{KCl}) were extracted with 1.0 M KCl as outlined by OKALEBO *et al.* (2002). The extracts were separated by centrifuging at 3000 rev min^{-1} for 10 min and filtered with Whatman No.42 filter paper to get a clear solution. Al and Fe in all the extracts were measured by atomic absorption spectrophotometer (table 2). All analyses were done in triplicate. Particle size analysis was done by the pipette method as described by KETTLER *et al.* (2001).

Table 2: Forms of Al and Fe in soils used in the study.

Site	Soil form		Exchangeable		Oxalate		Dithionite		Crystaline Al
	South African Soil Classification*	World Ref. Base†	Al (mg kg^{-1})	Fe	Al (g kg^{-1})	Fe	Al (g kg^{-1})	Fe	(g kg^{-1})
Ntlonyana	Klapmuts	Planosol	12.50	11.00	0.41	3.47	2.28	9.24	1.87
Ncihane	Cartref	Luvisol	19.03	9.70	0.42	3.49	1.68	10.12	1.26
Qweqwe	Glenrosa	Cambisol	0.00	3.63	0.11	0.33	0.51	5.55	0.40
Qunu	Westleigh	Acrisol	0.77	3.47	0.12	0.27	1.31	9.91	1.19
Chevy chase	Hutton	Ferralsol	48.73	10.40	0.77	0.66	3.00	12.73	2.23
Bethania	Hutton	Ferralsol	0.00	3.30	0.18	0.69	1.56	13.20	1.38
Flagstaff	Inanda	Ferralsol	76.27	3.20	3.54	3.94	5.70	50.50	2.16

*: South African Soil Classification Working Group (1991); †: World Reference Base (2006)

2.3 Phosphate sorption isotherms

Three replicate 3.0 g, air-dried and milled (<2 mm), soil samples were weighed into 50 ml centrifuge tubes and suspended in 30 ml of 0.01 M $CaCl_2$ of supporting electrolyte containing 0 to 100 mg P l^{-1} as KH_2PO_4 with increments of 10 mg P l^{-1} . Three drops of toluene were added to each container to inhibit microbial activity. The tubes were then stoppered and shaken on an end-to-end shaker for 24 hours at a constant temperature of 25 $\pm$ 1°C at 100 oscillations per minute. Following equilibration, the soil suspensions were centrifuged at 3000 rev min^{-1} for 10 minutes and filtered through Whatman No. 42 filter paper to obtain a clear solution. Phosphorus in the supernatant was then determined by the molybdate-ascorbic acid method (Murphy and Riley, 1962). The amount of P sorbed was calculated as the difference between the amount of P added and that remaining in solution (Fox and Kamprath, 1970). The sorption data were then fitted to the linearized form of the Langmuir equation viz:

$$\frac{C}{S} = \frac{1}{S_{max} \times b} + \frac{C}{S_{max}} \qquad (1)$$

where C is the equilibrium P concentration (mg L^{-1}), S is the total amount of P sorbed (mg kg^{-1}), b is a constant related to the binding energy (L mg^{-1}) and S_{max} is the adsorption maximum (mg kg^{-1}).

Soil external P requirements were determined by substituting the desired P concentration into the fitted Langmuir equations (Dodor and Oya, 2000).

2.4 Single point sorption test

The single point sorption test (SI) was determined as described by Henry and Smith (2006). Simply, 50 ml of solution containing 10 mg P l^{-1} as KH_2PO_4, in 0.002 M $CaCl_2$, and three drops of toluene were added to 2 g of air dried soil (< 2 mm). The suspensions were shaken for 24 hours on an end-to-end shaker, rotating continuously at 100 oscillations per minute. Following equilibration the suspension was centrifuged at 5000 rev min^{-1} for 10 minutes and then filtered through Whatman paper No 42. Phosphorus in the clear supernatant was determined colorimetrically by the molybdenum blue method (Murphy and Riley, 1962). The amount of P sorbed was calculated as the difference between the amount of P added and that remaining in solution. The single point sorption index was calculated as the amount of P sorbed expressed as a percentage of the added P (Henry and Smith, 2003).

2.5 Statistical analysis

Relationships between P sorption parameters, and P sorbed at equilibrium with 0.2 mg P L^{-1} ($P_{0.2}$), with selected soil chemical properties were done with simple regression and correlations and tested for significance at p = 0.05 using the GenStat statistical software (Lawes Agricultural Trust, 2005). The contribution of soil properties to sorption parameters were examined using the maximum r^2 improvement stepwise model-building procedure (SAS Institute Inc., 2001).

3 Results

3.1 Phosphate sorption

Sorption behavior was adequately described by the linearized Langmuir sorption equation with coefficients of determination (r^2) values > 0.95 observed for all the soils studied. Sorption isotherms for the seven soils showed that the soils differed considerably in sorption characteristics (Table 3). Sorption maxima ranged from 192.3 to 909.1 mg P kg^{-1} and sorption affinity constant ranged from 0.051 to 0.786 l mg^{-1}. The amount of P required to maintain a soil solution concentration of 0.2 mg P l^{-1} ($P_{0.2}$) ranged from 2 to 123 mg P kg^{-1} soil (Table 3) and as expected the trend was similar to that of the sorption maxima. Values for the single point sorption test (SI) expressed in percentage ranged from 9.5 to 86.5% (Table 3) and were highly and significantly correlated with S_{max} (r = 0.92), sorption affinity constant (r = 0.812), and external P requirement (r= 0.93).

Table 3: Phosphate sorption parameters of the different soils used in the study.

Site	*Soil form*		*Linearized Langmuir equation* $S = S_{max}bC/(1 + bC)$					
	*South African Soil Classification**	*World Ref. Base*†	S_{max}	b	R^2	*SI*	*EPR* ($P_{0.2}$)	*EPR* ($P_{1.0}$)
Ntlonyana	Klapmuts	Planosol	526.3	0.247	0.978	49.4	25	104
Ncihane	Cartref	Luvisol	476.2	0.158	0.965	48.1	15	65
Qweqwe	Glenrosa	Cambisol	204.1	0.051	0.959	9.5	2	10
Qunu	Westleigh	Acrisol	192.3	0.122	0.985	25.5	5	21
Chevy Chase	Hutton	Ferralsol	555.6	0.269	0.974	79.2	28	118
Bethania	Hutton	Ferralsol	285.7	0.095	0.965	33.5	5	25
Flagstaff	Inanda	Ferralsol	909.1	0.786	0.983	86.5	123	400

S = Total sorbed P (mg kg^{-1}), S_{max} = sorption maxima (mg P kg^{-1}), b = sorption affinity constant (L mg^{-1}), C = equilibrium P concentration (mg L^{-1}), SI = Single point sorption test (%), EPR = external phosphate requirement (mg P kg^{-1})
*: South African Soil Classification Working Group (1991); †: World Reference Base (2006)

3.2 Relationship between phosphate sorption parameters with soil properties

The regression of P sorption maxima on selected individual soil properties showed that Al_{CDB}, Fe_{CDB}, Al_{KCl}, pH, Al_{crys} and Fe_{crys} explained 89%, 69.8%, 83.9%, 79.7%, 62.8%, and 40.5%, respectively of the variations in S_{max} (Table 4). Using the stepwise multiple regression procedure (p = 0.05), a combination of organic carbon, Al_{KCl}, Al_{CDB} and Al_{ox} explained 93.2% of the variation in S_{max} of which 87.8% of the variation was explained by Al_{CDB} alone. These results suggested that the different forms of Al were primarily responsible for P sorption in the soils. The addition of soil organic carbon to the Al_{CDB} model only marginally increased the variation in S_{max} explained by the two parameters to 91.1%. The functions best fitting the data were:

$$S_{max} = 85.87 + 150\,Al_{CDB} \quad (R^2 = 0.878)$$

$$S_{max} = 46.73 + 128\,Al_{CDB} + 78.73\,C \quad (R^2 = 0.911)$$

where; S_{max} = Adsorption maximum, CDB = citrate dithionate bicarbonate, C = organic carbon.

Table 4: Relationships of sorption maxima (S_{max}) with selected soil variables.

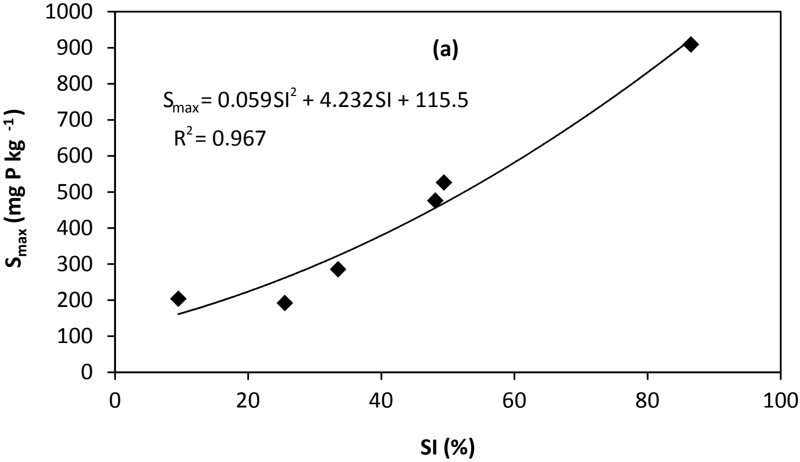
Variable (x)	*Functions best fitting data*	R^2
pH_{water} (1 : 2.5)	$Y = 195560^{e-1210lx}$	0.797
Al_{KCl}	$Y = -0.04x^2 + 10.99x + 257.91$	0.839
Al_{ox}	$Y = 117.75x^2 + 627.34x + 164.93$	0.855
Fe_{ox}	$Y = 44.03x^2–67.60x + 316.33$	0.607
Al_{CDB}	$Y = -23.04x^2 + 310.05x–115.20$	0.894
Fe_{CDB}	$Y = -0.26x^2 + 28.96x + 107.95$	0.698
Al_{crys}	$Y = 95.87^{e0.8836x}$	0.628
Fe_{crys}	$Y = 275.13^{e0.025lx}$	0.405

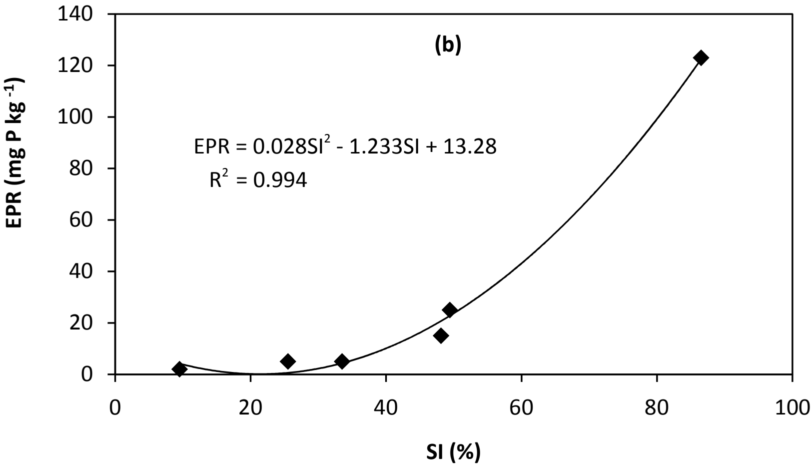
Y = sorption maxima, KCl = potassium chloride, ox = ammonium oxalate, CDB = citrate dithionate bicarbonate, crys = crystalline

3.3 Relationship between single point sorption tests (SI) with adsorption maxima (S_{max}) and external P requirement (EPR) $P_{0.2}$

The single point sorption test (SI) values were closely related to the adsorption maxima (S_{max}) and external P requirements (EPR) (Figure 1a and b) with R^2 values > 0.90. The functions best fitting the data were: $S_{max} = 0.059\,SI^2 + 4.232\,SI + 115.5$ (R^2 = 0.967) and EPR = $0.028\,SI^2 - 1.233\,SI + 13.28$ ($R^2 = 0.994$).

Figure 1: Relationships between the single point sorption test (SI) and Langmuir adsorption maxima (S_{max}) (a), and the external P requirements (EPR) (b) for the soils studied.





4 Discussion

The soils varied widely in their extent of P sorption as reflected by the ranges in adsorption maxima (S_{max}) and sorption index (SI) (Table 3). Soils collected from Qweqwe, Qunu, Ncihane and Bethania had low P sorption values and thus could be categorised as low P sorbers whereas soils from Ntlonyana, Chevy Chase and Flagstaff are moderate sorbers based on the scale of phosphate sorption of Juo and Fox (1977). Soils from Chevy Chase, Bethania, and Flagstaff were all classified as Ferralsols but they differed substantially in the extent to which they fixed phosphorus indicating that soils belonging to the same form will not necessarily fix P to the same extent or have similar P fertilizer requirements. BÜHMANN *et al.* (2006b) observed similar P sorption trends for soils of the Lusikisiki area, Eastern Cape Province, South Africa and suggested that for optimum P recommendations soil P fertilization assessments need to be made at field scale level.

The observed differences in sorption parameters were largely explained by the variations in the amounts of Al in the soils. However, as revealed by stepwise multiple regression analysis most of the variation in S_{max} (87.8%) was explained by Al_{CDB} alone with only a marginal increase of 3.3% when soil organic C was included in the model. Our findings are in agreement with those of AGBENIN (2003); HENRY and SMITH (2002) and DUFFERA and ROBARGE (1999) who also observed that Al_{CDB} had greater influence on P retention than other Al forms in the tropical soils they studied. The observed dependence of P sorption on Al_{CDB} suggested that citrate dithionite bicarbonate extractable Al is the single most important soil parameter that could be used for indicating the potential for soil P sorption in the area. The equation: $S_{max} = 85.87 + 150\ Al_{CDB}$ could therefore be used for estimating P sorption in the region after validation using a wider range of soils. Organic C was not significantly correlated with any of the P sorption parameters but together with Al_{CDB} explained 91 % of the variations in S_{max}. This suggested possible active participation of organic matter in governing P sorption in the experimental soils, possibly through Al-organo complexes as suggested by HAYNES and SWIFT (1989).

The amounts of added P required to maintain a concentration of 0.2 mg P L^{-1} ($P_{0.2}$) in solution (EPR) were generally lower than ranges reported in other studies (WARREN, 1994; IYAMUREMYE *et al.*, 1996; MEHADI and TAYLOR, 1988; DODOR and OYA, 2000). DUFFERA and ROBARGE (1999) for example reported values ranging from 50 to 201 mg P kg^{-1} for surface samples from non-cultivated and non-fertilized areas in Ethiopia. Only Flagstaff soil with an EPR of 123 mg P kg^{-1} fell within this range while others such as Qweqwe, Qunu and Bethania had very low EPR values indicating possible early P saturation for these soils following repeated applications of P fertilizers. This could lead to elevated P levels in the soil solution which in time could contribute to the eutrophication of freshwater bodies. For purposes of water quality protection, the United States Environmental Protection Agency (USEPA) has recommended a maximum level of 1 mg P L^{-1} in surface runoff (US ENVIRONMENTAL PROTECTION AGENCY, 1986). External P requirements (EPR) calculated based on this criterion for the different soils ranged from 10 to 400 mg P kg^{-1} equivalent to 20 to 800 kg P ha^{-1} (Table 3). Given the low usage of fertilizers in sub Saharan Africa estimated at 8 kg nutrients ha^{-1} (MORRIS *et al.*, 2007), these results suggest that unless rates of fertilizer use increase substantially, it will take some time before the application of fertilizer poses a significant threat to water quality in the region. Therefore, in the short term emphasis should be placed on ways of minimizing P fixation so as to increase P use efficiency, especially for soils such as Flagstaff, Chevy Chase and Ntlonyana with relatively high P fixing capacities.

The close association between SI with EPR ($R^2 = 0.994$) suggested that the SI function ($EPR = 0.028SI^2 - 1.233SI + 13.28$) could be used to predict the external P requirement ($P_{0.2}$) for soils in the region most of which seem to have low to moderate P sorbing capacities. Henry and Smith (2003) also found high coefficients of determination ($R^2 = 0.98$) in the relationship between SI and $P_{0.11}$ for low to moderate sorbing soils of the tobacco growing areas of Kwa-Zulu Natal. They also concluded that SI can be used advantageously as a time saving measure to obtain an index of the external P requirement of soils instead of having to produce full P isotherms.

5 Conclusions

The seven soils studied varied widely in their capacities to sorb P with four of the soils classified as low P fixing and the remaining three (43%) as moderate P fixers. The latter category may need management interventions to ensure that P availability to crops is not compromised. The contrasting differences in the P fixing capacities of the soils suggested that the use of blanket phosphate fertilizer recommendations may not be a good strategy for the region as it may lead to under-application or over-application of P in some areas with the attendant consequences of compromised crop yields or freshwater quality. The differences in P sorption observed between the different soils were largely explained by variations in their citrate dithionite bicarbonate-extractable aluminum contents indicating that this parameter could be used for indicating the potential soil P sorption in the area. The results further showed that the single point test function could successfully be used to predict the external P requirements for the soils in the area obviating the need to use multiple point sorption isotherms.

Acknowledgements
The authors are grateful to the University of Fort Hare and the National Research Foundation (NRF) of South Africa for funding the study. We also acknowledge with gratitude, The Director, Kenya Agricultural Research Institute (KARI) for granting study leave to the first author. The views expressed in this paper are those of the authors and do not in any way reflect the views of the NRF, the University of Fort Hare, or KARI.

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Journal of Agriculture and Rural Development in the Tropics and Subtropics
Volume 109, No. 2, 2008, pages 151–168

A Survey of Myanmar Rice Production and Constraints

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Abstract

Although modern high yielding varieties were introduced into Myanmar in the early 1980s, the national average of rice grain yield has stagnated at 3.2-3.4 t ha^{-1}. To identify yield constraints, input intensities and the general practices of rice cultivation in Myanmar, a survey was conducted during the wet seasons of 2001 and 2002. A total of 98 farmers from five townships in Upper Myanmar and 16 in Lower Myanmar representing the most important areas of rice production were questioned on their management practices, yields, and perceived yield constraints over the previous four years. There was a recent decrease in the overall average rate of fertilizer application, an increase in the prevalence of rice-legume cropping systems, and only localized insect pest or disease problems. Additionally, rice yields were found to be higher in Upper Myanmar, likely the results of more suitable weather conditions, better irrigation, and ready market access. Furthermore, a number of critical factors affecting production are identified and possible solutions discussed.

Keywords: Myanmar, Burma, rice diseases

1 Introduction

Agriculture in Myanmar, dominated by paddy rice cultivation, generates a direct or indirect economic livelihood for over 75% of the population. Rice is grown throughout the country by resource poor rural farmers and landless agricultural labourers on small farms averaging only 2.3 ha in size (Okamoto, 2004). Although a shift to high yielding rice varieties (HYVs) in the 1980s was meant to increase production, average grain yields have stagnated at around 3.0 t ha^{-1}. With an annual population growth rate of 2%, an increase in rice yield has become vital to both matching the rising caloric demand for this staple and to contributing to the income of the rural poor. Before production can be improved, the most critical factors affecting that production must be revealed. There exists only one recent comprehensive survey in the literature on rice production in Myanmar (Garcia *et al.*, 1998), but little is known about the actual inputs used

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and the overall constraints limiting rice productivity. Therefore, a survey was conducted in the two major rice-growing regions of Myanmar during the rainy seasons of 2001 and 2002 to provide a comprehensive overview of rice production and to understand its shortcomings. The cropping systems practiced by local farmers were examined to determine the yield variability among different rice growing regions, explain the effects of climate and crop management on rice yields, understand how disease and pest incidence is related to crop management and environmental conditions, identify yield constraints of rice production, and define possible approaches to remove those constraints. This in turn has multifaceted practical applications, as improved yields would benefit the nutrition and living standards of the predominantly rural population of Myanmar.

This paper is structurally divided into six sections. Section two explores the previously published literature to provide an overview of the recent history of rice production in Myanmar. Section three outlines the research design for the data collected. Section four draws on the data to present the key current cropping systems, seed sources, diseases and pests, and the status quo of agrochemical use to tease out yield constraining relationships. The final sections of this paper discuss yield constraints and possible solutions.

2 Rice Production in Myanmar: An Overview

At 676,552 km^2 the Union of Myanmar is the largest country in Southeast Asia. Due to its geographic size, Myanmar varies considerably both topographically and meteorologically. Annual precipitation and monthly mean maximum/minimum temperatures also show considerable variation over time and space, and are particularly affected by the summer monsoons. In general, the climate is cooler in the mountainous north and warmer in the southern Delta areas of the Ayeyarwady River, with monthly mean maximum temperatures from 24.1°C to 38.2°C in May, and monthly mean minimum temperatures from 2.3°C to 20.8°C in December. Most major rice growing areas, such as the Ayeyarwady, Yangon and Bago Divisions, are naturally provided with fertile deltaic alluvial soil and abundant monsoon rainfall.

Myanmar has a long tradition of rice production. In the years immediately prior to World War II it was the largest rice-producing nation in the world, and it continues to be one of the ten largest rice-producing countries in terms of total yield (IRRI, 2002). Traditionally, rice production occurred only as a monsoon crop in the rainy season (from the end of May through November). This changed during the late 1970s and early 80s with the government-sponsored Whole Township Paddy Production Program that introduced modern high yielding varieties (HYVs) of rice and thereby enhanced production possibilities.

Since that time over 60 HYVs, usually of the semi-dwarf type, have been introduced, and now comprise 70% of the total lowland rice area (Nguyen and Tran, 2002). Many of these can accommodate closer spacing, heavy nitrogen (N) fertilization, continuous cropping and/or are photoperiod insensitive. Overall, this adaptation of HYVs and the improvement of irrigation systems in some areas of the country has allowed for the cultivation of rice in the dry summer season and for double cropping. In particular, IR50 and IR 13240-108-2-2-3 now occupy 80% of the country's dry land cultivation area (Kaushik, 2001). By 2001/02, the total overall area sown with rice was roughly 7.3 Mio ha with 5.7 Mio ha under monsoon paddy and 1.6 Mio ha under irrigated summer paddy in rotation (MOAI, 2003).

Nonetheless, despite the cultivation of HYVs in many parts of the country, the expected increases in yield did not happen during the last decade (IRRI, 2002). Rather, the average rice yield has remained relatively stagnant at 3.2 t ha^{-1} in 1994, 3.3 t ha^{-1} in 2000, and 3.4 t ha^{-1} in 2002 (MOAI, 2003). In view of this, the purpose of this study was to examine biotic and abiotic constraints to production through an in-depth survey of the country's main rice growing regions.

3 Materials and Methods

Qualitative data were collected through 107 semi-structured interviews with farmers over a span of two years in the two main agroecological zones of rice production, that is in Lower and Upper Myanmar (Fig. 1). In the rainy season of 2001, 52 respondents in ten townships located in Lower Myanmar and in three townships in Upper Myanmar were interviewed. In 2002, 55 respondents from nine townships in Lower Myanmar and three townships in Upper Myanmar were interviewed. Among the farmers, four from Upper Myanmar (Pyinmana) and five from Lower Myanmar (Nyaungdon) were interviewed in both years to check the reliability of the survey data over time.

Respondents were chosen from townships incorporating rainfed and/or irrigated lowland rice production areas, as these regimes comprise approximately 90% of the country's rice production (Garcia *et al.*, 1998). In each township, a maximum of five respondents were selected. Criteria employed in this selection were that they cultivated the popular Manawthukha rice variety in relatively accessible fields.

The interview schedule was designed to obtain the following types of information:

(a) Field description: farm size, soil type, source of water supply,

(b) History of farm cropping systems over the last four years,

(c) Amount and type of organic and inorganic fertilizer applied over the last four years,

(d) Rice yields over the last three to four years,

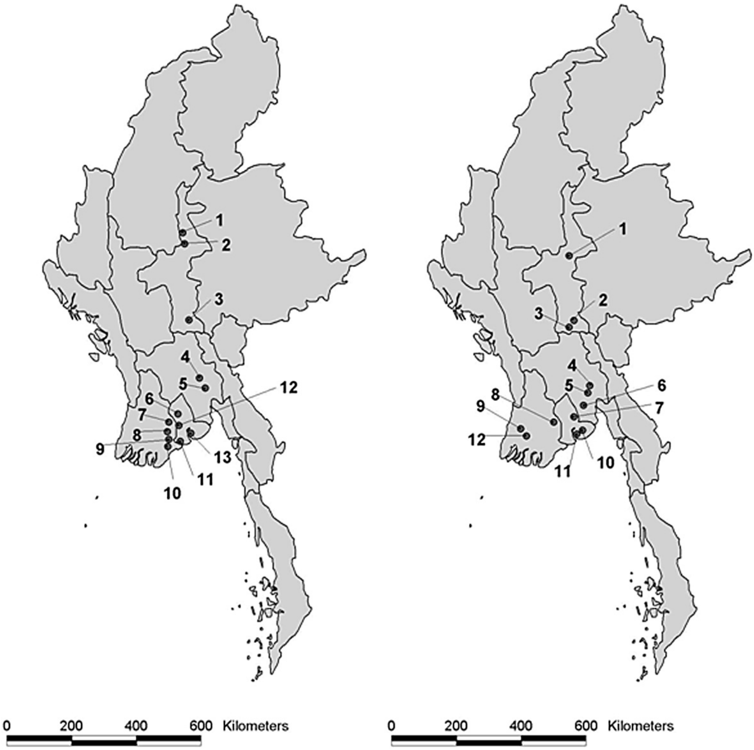
(e) Management practices in the seedbed and field: seed source, transplanting or direct seeding, weed management, pest and disease incidence and their management,

(f) Perceived yield limiting problems such as climate, soil, agronomic and/or socio-economic conditions.

3.1 Sampling pattern and methods of assessment

In addition to the interviews, one field per farm of the variety Manawthukha was surveyed to assess the disease and pest incidence or severity in both years. To this end, a "W" sampling pattern was used in each field following IRRI's integrated pest survey (Elazegui *et al.*, 1990). These assessments were conducted once for each field between heading and flowering of the rice plants. Assessments were spaced in 10 m intervals

Figure 1: Location of Survey Areas in Myanmar in 2001 and 2002.
Townships in 2001: 1: Mattaya; 2: Patheingyi; 3: Pyinmana; 4: Kyauktaga; 5: Nyaunglebin; 6: Htantabin; 7: Nyaungdon; 8: Maubin; 9: Kyaiklatt; 10: Phyapon; 11: Kungyangon; 12: Twantay; 13: Kyauktan.
In 2002: 1: Kyaukse; 2: Pyinmana; 3: Leway, 4: Nyaunglebin; 5: Daik-U; 6: Bago; 7: Hlegu; 8: Nyaungdon; 9: Pathein; 10: Thongwa; 11: Kyauktan; 12: Myaungmya.



starting at a hill at least 1 m away from the field border. A total of 12 hills were randomly chosen in each field.

For all diseases and parts observed, the total number of infected hills was recorded and expressed as the percentage of the total number of hills surveyed. Assessments were made in the following way:

(a) The severity of bacterial leaf blight (caused by *Xanthomonas oryzae* pv. *oryzae*) was determined as the percentage of leaf area affected on the uppermost three leaves of two randomly selected tillers per hill.

(b) The incidence of sheath rot (caused by *Sarocladium oryzae*) was determined by counting the number of infected tillers or panicles per hill and then expressed as the percentage of total tillers.

(c) Tiller height and uppermost lesion height were measured for rice sheath blight (caused by *Rhizoctonia solani*) and then expressed as a percentage ratio (i.e. relative lesion height) following IRRI 1988:
Relative lesion height (%) = (vertical height of the uppermost lesion on stem or leaf or sheath / plant height) × 100.

(d) The number of infected tillers with false smut (caused by *Ustilaginoidea virens*) was recorded and then expressed as the percentage of total tillers.

(e) The number of hills attacked by stem borers (*Sesamia inferens*, *Scripophaga incertulas* and *S. innotata*) and rice hispa (*Dicladispa armigera*) were counted and then expressed as percentages of total tillers.

(f) The severity of rice gall midge (*Orseolia oryzae*) was assessed by recording the number of infested hills and tillers and then expressing them as a percentage. Percentages of all infestation and infection were then calculated according to the Standard Evaluation System (SES) for rice (IRRI, 1988).

To measure yield, four 0.25 m^2 harvest-areas about 2 meters away from the surrounding borders were randomly marked as sampling areas. All above ground material was harvested and total fresh weight and grain yield were determined. A sub-sample of 100 g of fresh grain and straw were taken to determine dry weight. Grain yield at 14% moisture content was calculated according to the following formula:
Adjusted grain weight (at 14% moisture) = $A \times W$ where W = weight of the harvested grain and $A = (100 - M)/86$ where M is the moisture content (%) of grains.

To determine the straw dry weight, the straw was dried in the sun to weight constancy.

3.2 Data analysis and processing

Data were analyzed using GenStat 5th edition (2001). Averages were compared by t-tests. Multiple and linear regression analyses were also used as required. For the fertilizer input comparison, type dependent conversion factors for nutrient concentrations in mineral fertilizers were employed. This method proved more difficult for farmyard manure (FYM), which likely had a different composition at each site. As such, an estimation of the N-content in FYM followed Dobermann and Fairhurst's list of average N concentrations of fresh and composted cattle manure (DOBERMANN *et al.*, 2000).

4 Results

4.1 Water, climate, and the environment

The survey data revealed that of the 21 townships represented in the study, twelve were rainfed and seven used sporadic supplementary irrigation taken from catchments. In two townships of Upper Myanmar all rice was irrigated. Untimely flooding was seen as a severe constraint to rice production, especially in Lower Myanmar, which experienced generally more rainfall during 2001 and 2002 than Upper Myanmar. Although this rainfall was within the normal range, inadequate drainage facilities adversely affected yields. Overall, farmers from townships of Upper Myanmar (mean yield = 5.66 t ha^{-1})

achieved higher yields than farmers from townships of Lower Myanmar (mean yield = 4.01 t ha^{-1}), possibly as a result of irrigation and better water management.

4.2 Crop rotations

The size of individual fields in this survey was found to range from 0.2 to 0.5 ha, with animal and human labour comprising the main energy sources for land preparation, transplanting, weeding, fertilization, water management and harvesting. Many farmers were found to practice double or triple cropping as an expressed means of increasing their income. Overall however, the majority of the surveyed farmers cultivated two crops per year with rice-rice, rice-blackgram (*Vigna mungo* L.) or rice-greengram (*Vigna radiata* L.) being the dominant cropping systems (Table 1). Relay cropping was common in some areas such as in Patheingyi Township in Upper Myanmar, where farmers broadcasted chickpea, blackgram or greengram about two weeks before harvesting the monsoon rice to obtain enough moisture for the second crop. Thus, good yields were achieved for both rice and this second crop.

Only in areas of Upper Myanmar where supplementary irrigation is available were triple crop rotations encountered. Some farmers from townships located in Upper Myanmar produced three crops per year with a legume (e.g. *Lens esculenta* Moench or *Cicer arietinum* L.) or an oil crop such as *Sesamum indicum* L. in the rotation. In addition, the cultivation of legumes depended on market access and the shifting price of legumes at the market. Patheingyi Township is a noteworthy example, as respondents often mentioned their proximity to the urban markets of Mandalay as a reason for the inclusion of legumes in the rotation.

4.3 Seed quality

Most farmers in both Upper and Lower Myanmar sowed seed from their own harvest or from neighbouring farms, rather than purchasing seed as recommended from the Myanmar Agriculture Service (MAS) (Fig. 2). Respondents mentioned that due to poor transportation and communication infrastructures certified seeds of improved rice varieties were often unobtainable. As a result, a considerable amount of varietal degeneration was found in all areas of rice cultivation surveyed, likely the result of farmers using seeds from their own harvest for extended time periods. Although the removal of off-types or abnormal panicles before harvest was found to be a common practice, overall stand uniformity was poor.

4.4 Fertilizers and agrochemical inputs

The rate of N applications during the rainy season decreased from 95 kg N in 1998 to 35 kg N in 2002 with an increasing number of farmers having stopped the application of N-fertilizer altogether during this period. Overall, application rates were considerably higher in Upper than in Lower Myanmar (Fig. 3a, b). Trends in P and K application were the same in Upper Myanmar whereas in Lower Myanmar the rates were always low. No relationship between farm size and N input was found. The majority of farmers surveyed (50-85% depending on the year) did not use farmyard manure (FYM), and

Table 1: Townships where interviews were conducted, number of respondents per village, cropping patterns and water management of interviewed farmers in Myanmar in 2001 and 2002.

	Township	*Village*	*Farmers*	*Cropping pattern* ‡	*Land form* §
			2001		
Upper Myanmar					
	Mattaya	Panya	5	R-R	I
	Patheingyi	Thamataw	3	R-C-Se	I
		Thantsenkone	2	R-C-Se/Su	I
	Pyinmana	Thittat	5*	R-R, R-R-G	R+I
Lower Myanmar					
	Htantabin	Ahasugyi	2	R, R-R	R
	Kungyangon	Kamapa	1	R-R	R
	Kyaiklatt	Ngapichaung	5	R-R	R
	Kyauktaga	Khingyi	5	R-G	R+I
	Kyauktan	Nyaungwine	3	R-G, R-C	R
	Maubin	Nyaungwine	5	R-R, R-G	R
	Nyaungdon	Samalaut	5†	R-G	R+I
	Nyaunglebin	Ahaleywa	3	R, R-G	R
		Shanywa	2	R-G	R+I
	Phyapon	Chaungtwin	5	R-R	I
	Twantay	Yangonpauk	1	R	R
Total	13		52		
			2002		
Upper Myanmar					
	Kyaukse	Htanaungpinhla	5	R-C-Se, R-R	R+I
	Leway	Mwayyolay	5	R-G, R-G-Su	R+I
	Pyinmana	Thittat	5*	R-R, R-R-G	R+I
Lower Myanmar					
	Bago	Mayin	5	R-G	R
	Daik-U	Bote	3	R-G	R
		Layse	2	R-G	R
	Hlegu	Wanetkone	5	R-R, R-G	R+I
	Kyauktan	Padawa	2	R-G	R
	Myaungmya	Phayachaung	5	R-R	R+I
	Nyaungdon	Samalaut	5†	R-G	R+I
	Nyaunglaybin	Kaukayt	1	R-G	R
		Sankalay	1	R-G	R
		Thayetkone	1	R-G	R
	Pathein	Myochaung	4	R-R	R+I
		Pyinkatoekone	1	R-G	R
	Thonegwa	Ahnaut	5	R-G	R
Total	12		55		

* Four of five farmers in Pyinmana were interviewed in both years;
† All five farmers in Nyaungdon were interviewed in both years;
‡ R = rice, G = blackgram or greengram, C = chickpea, Se = sesame, Su = sunflower;
§ I = irrigated, R = rainfed

Figure 2: Sources of seed of a total of 98 interviewed Myanmar farmers during 2001 and 2002.

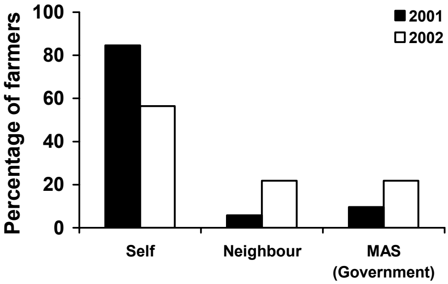
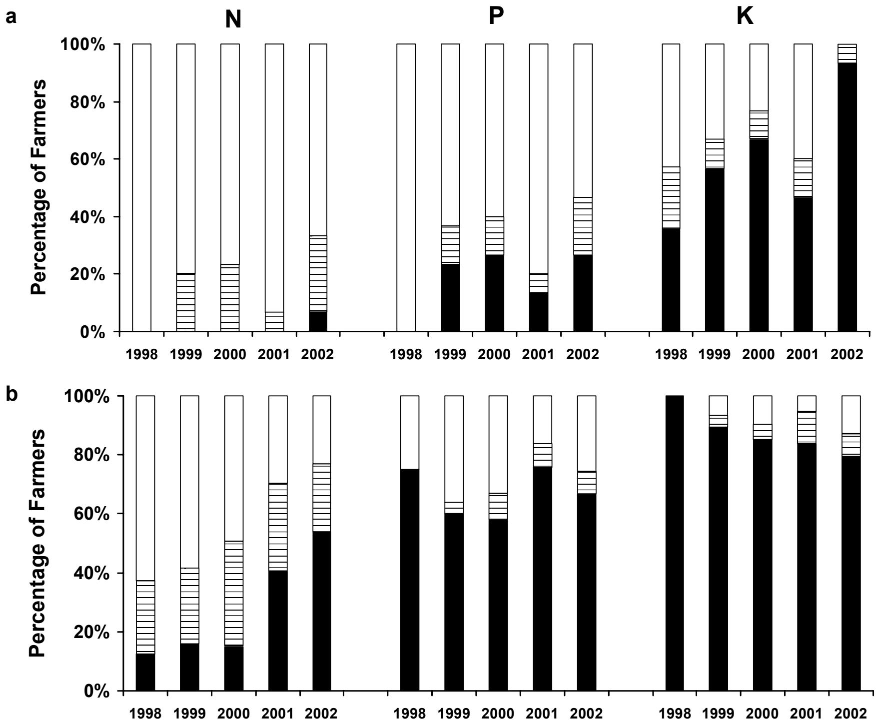


Figure 3: Percentage of farmers who applied the recommended rate (white sections), less than the recommended rate (striped sections) or none (black sections) in the wet season between 1998 and 2002 in (a) Upper and (b) Lower Myanmar. The recommended rates were 56 kg ha^{-1} N, 13 kg ha^{-1} P, and 20 kg ha^{-1} K. The number of respondents in Upper Myanmar was 14, 30, 30, 15, and 15 in 1998-2002 respectively, and 8, 75, 73, 37, and 39 in Lower Myanmar.



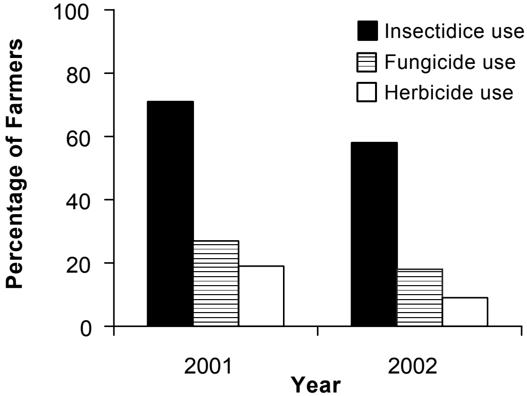
those who did only applied it at a rate of 2 –4 t ha^{-1} in addition to or as a substitute for chemical fertilizers.

The highest rates of fertilizer application were observed in the Mattaya and Patheingyi Townships in 2001 and in Kyaukse and Pyinmana in 2002, all townships in Upper Myanmar with irrigation facilities. Most farmers from the remaining townships utilized only limited amounts N fertilizers.

In both years, most farmers applied both chemical fertilizers and FYM to the seedbed at rates higher than those applied to transplanted fields. Farmers mentioned that they believed a heavy fertilization of the nursery would result in healthier seedlings, and this was often cited as being more effective than spreading small amounts of available manure over a larger area.

Overall, the percentage of farmers in both years who used some form of chemical insecticide was greater than for herbicides or fungicides (Fig. 4).

Figure 4: The percentage of farmers who used herbicides, fungicides and insecticides during 2001 (n=52) and 2002 (n=55)



4.5 Weed control

Only 52% of the interviewed respondents practised any form of weed control, although farmers faced difficulties with weed growth in both the rainy and dry seasons, often exaggerated by poor water management. The respondents of Upper Myanmar (73%) were more likely than those of Lower Myanmar (43%) to use weed control. Hand weeding was the most often employed method of control, as it allows for the selection of weeds useful for animal and human nutrition (Table 2). Although a variety of herbicides for rice production are available on the Myanmar market, they are little used and were often cited by respondents as being too expensive. Overall, farmers in all regions expressed only very basic knowledge about chemical weed control methods.

Table 2: Weed control practices of farmers surveyed in Myanmar in 2001 and 2002.

Township and Year	*Weed control (No. of farmers*)*		
	Hand weeding	*Herbicides*	*No weeding*
Upper Myanmar			
Kyaukse (02)	3	-	2
Leway (02)	3	-	2
Mattaya (01)	4	1	-
Patheingyi (01)	3	-	2
Pyinmana (01+ 02)	-	6	-
Lower Myanmar			
Kyaiklatt (01)	1	2	2
Maubin (01)	3	1	1
Myaungmya (02)	1	-	4
Nyaungdon (01 + 02)	5	-	-
Pathein (02)	1	-	4
Phyapon (01)	3	-	2
Bago (02)	-	-	5
Daik-U (02)	2	-	3
Kyauktaga (01)	5	-	-
Nyaunglebin (01)	-	-	5
Nyaunglebin (02)	2	-	1
Hlegu (02)	1	-	4
Htantabin (01)	-	-	2
Kyauktan (01)	2	1	-
Kyauktan (02)	-	-	2
Kungyangon (01)	-	-	1
Thongwa (02)	-	-	5
Twantay (01)	1	-	-
Total (98 farmers)	40	11	47
(%)	41	11	48

* Farmers interviewed in both 2001 and 2002 were counted only once.

4.6 Diseases

Generally, the damage level of diseases was quite low during the survey period. Rice sheath blight, bacterial leaf blight (BLB) and sheath rot were the most commonly found diseases in the surveyed areas, lesser so false smut and ufra disease. Less than 15% of the fields surveyed over the two years were found to be disease free (Fig. 5).

Most widespread (that is with the highest incidence) and severity was sheath blight, with around 60% of the fields being infected in both years. Within infected fields in 2001, incidences ranged from 8-100%. Sheath blight severity in 2001 was highest in Kyauktaga Township (43%) and in 2002 in Bago (58%).

Figure 5: Incidence of rice diseases in surveyed fields in 2001 and 2002.

Twenty and 15% of fields surveyed were infected with BLB in 2001 and 2002, respectively, with overall severities ranging between 1.4 and 55%. In both years, BLB was mostly observed in Lower Myanmar, for example, in Htandabin Township in 2001 (22% severity), and in 2002 in Bago (55%), Deik-U (34%) and Nyaungdon (42%) in Lower Myanmar, and only in Leway Township (41%) in Upper Myanmar. Although not a universal problem, if BLB occurred, it did so with a high incidence. Likewise sheath rot, with incidence ranging from 5 to 34%, was also more severe in Lower Myanmar in both years. Sheath rot occurred in approximately 50% of the fields in 2002 while in 2001 it was almost absent.

False smut and ufra disease were found only to be localized problems. False smut was observed in only 2 out of 52 fields in 2001 (in the Lower Myanmar Townships of Htantabin at 10% and in Nyaunglebin at 5% incidence). In 2002 however, incidence reached 12% in Kyaukse in Upper Myanmar and 25% in Kyauktan in Lower. Ufra was found only in Lower Myanmar during the 2002 rainy season, where its incidence, although not wide spread, reached high levels (for example, 68% in Myaungmya township). The negative effects of Ufra on rice yield could not be ascertained, as farmers harvested early to avoid future nematode problems.

No significant correlation between the amount of mineral N applied and incidence or severity of any disease was found (r 0.12 to 0.19).

Mean sheath blight severity in rice legume systems was found to be 19% (n=64), higher than in rice-rice systems (4.53%, n=37; $P < 0.001$; Fig.6).

4.7 Insect pests

Very few insect pests were observed in the fields surveyed. The most commonly found rice pests were stem borer (*Scirpophaga incertulas*), rice gall midge (*Orseolia oryzae*), Jassid (*Nephotettix apicalis*) and rice ear bug (*Leptocorisa* spp.) (Fig. 7).

The results of the survey also showed that although there were pests in some areas, the levels of their infestation was low, except for the gall midge. Although the incidence of

Figure 6: Incidences of bacterial leaf blight (BLB) and sheath blight in 2001 and 2002 in different cropping systems. Rice only is one single crop of rice per year while all other systems were some form of double cropping. Double counting was used 15 times for fields where both BLB and sheath blight were present.

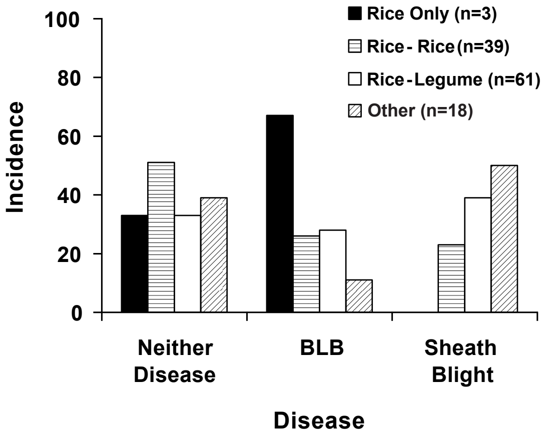
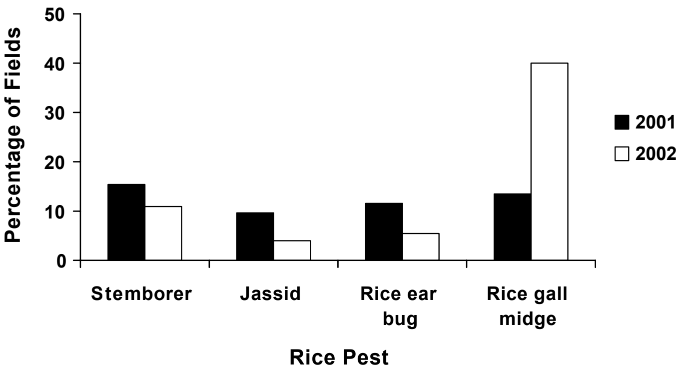


Figure 7: Percentage of fields infested with stemborer, jassid, rice ear bug and rice gall midge in 2001 and 2002.



this pest was low in 2001, a severe outbreak of rice gall midge occurred in 22 of the 55 surveyed fields, observed in Hlegu, Bago, Nyaunglebin and Daik-U townships where they clearly affected yields. Formerly, the rice gall midge was not a major rice pest in Myanmar. However, the abnormally heavy rains of the 2002 rainy season favoured the spread of the rice gall midge in those areas. The outbreak was found to have started in the seedbed before moving into the paddies.

4.8 Yields

Little difference was found between the yields reported by farmers and those measured during the survey. In most areas, average rice grain yields changed little over the period between 1998 and 2001/2, but showed considerable geographic variation. In 2002, for example, measured yields were generally higher in Upper Myanmar (3.7- 7.5 t ha^{-1}) than in Lower Myanmar (1.0-6.7 t ha^{-1}) during both rainy and dry seasons. Average total yields increased with the number of crops per year from 2.4 t ha^{-1} for single cropping (3 farmers) to 4.3 t ha^{-1} for double cropping (74 farmers) to 5.7 t ha^{-1} for triple cropping (15 farmers). The differences between triple and double cropped fields were highly significant ($P<0.001$, T-test). No comparison could were made for single crops because of the small sample size of respondents using such cropping systems.

The effects of crop rotation on rice yields were less clear and the number of crops from the same system was too low to conduct statistical comparisons for most pairs. When compared with T-tests, yields of double rice crops per year and rice-legume crop rotation were not significantly different (Table 3). Measured rice yields on irrigated land were 5.1 t ha^{-1} (25 farms), whereas on rainfed (54 farms) or rainfed and irrigated (13 farms) only 4.2 t ha^{-1}. Again, the large number of cropping systems involved did not justify a valid statistical comparison.

Measured yield levels of farmers using mineral fertilizer or manure were overall 36% ($P<0.001$) higher than of those who did not use fertilizers (Table 3). However, there was a huge variation in yields ranging from 1 to 5.3 t ha^{-1} for respondents who did not apply mineral N or FYM (33%) and from 1.8 to 6.7 t ha^{-1} for those who applied N either as urea, FYM, or both (67%). Multiple regression analysis suggested that at these yield levels the application of urea was only loosely correlated with rice yield. Application of K and rainfall appeared to affect the rice grain yield negatively, however:

$Y = 5.048 + 0.005\ \mathrm{N} - 0.22\ \mathrm{K} - 0.0004$ Rainfall, ($P< 0.001$, $r^2 + 0.21$)
Where Y = grain yield in kg ha^{-1}

The effects of weed control and insecticide application interacted with fertiliser application. While on farms that used fertilisers weed control increased yields by 29% ($P<0.001$) yields of unfertilised crops were somewhat reduced (10%) albeit not statistically significant. Similarly, when separating fertilizer users and non-users, insecticide applications enhanced the yields of those farmers who did use fertilizers by about 16%; this, however, was not statistically significant ($P=0.09$). In contrast, on farms where no fertilizers were applied, insecticide use appeared to be correlated with a yield reduction of 20% ($P=0.05$) (Table 3).

5 Discussion

Constraints to rice production in Myanmar seem to vary regionally but are tightly linked to the management practices and socioeconomic conditions of the farmers.

Throughout the various geographic regions surveyed, grain yield losses due to diseases and pests appeared for the most part to be insignificant. BLB should be an important disease of monsoon rice in the Bago and Ayeyarwady Divisions of Lower Myanmar

Table 3: Effects of management practices on rice yields measured in farmers' fields in Myanmar in 2001 and 2002.

Farmers Practice	*n*	*Mean yield (t ha^{-1})**	*P (t-Test)*
Cropping pattern			
Rice – rice	32	4.5 ± 1.76	0.35
Rice – legumes	41	4.2 ± 1.79	
Fertilizer			
User	62	4.9 ± 1.41	<0.001
Non-user	30	3.6 ± 1.13	
Weed Control			
Weeding	54	4.8 ± 1.95	<0.008
Non-weeding	36	4.0± 1.88	
Fertilizer users			
Weeding	41	5.3 ± 1.21	<0.001
Non-weeding	24	4.1 ± 1.46	
Fertilizer non-user			
Weeding	14	3.4 ± 0.88	0.38
Non-weeding	13	3.8 ± 1.31	
Insecticides			
User	57	4.6 ± 1.46	0.23
Non-user	35	4.2 ± 1.44	
Fertilizer users			
Insecticide user	42	5.1 ± 1.26	0.09
Non-user	20	4.4 ± 1.6	
Fertilizer non-user			
Insecticide user	15	3.2 ± 0.93	0.05
Non-user	15	4.0 ± 1.2	

* Data represent means followed by their standard deviation

with severity dependent on the variety of rice cultivated (Garcia *et al.*, 1998). Indeed, Manawthuka was previously found susceptible to BLB under favourable conditions (Hein *et al.*, 1993). However, during the seasons surveyed in this study, BLB was not severe in most of the regions.

The observed increased sheath blight incidence in rice-legume rotations agrees with the results of Kim *et al.* (1992), who reported that sheath blight was more severe in rotation systems (rice paddy and upland crops) than in continuous paddy fields. Kim *et al.* (1992) hypothesized that this was due to larger amounts of available N in the rotation plots. However, when grain legumes are harvested, N-balances are often negative leaving little to no additional N to the subsequent crop. Thus, it is unlikely that the increases in sheath blight infestation were due to N effects. More likely, the survival of the sclerotia of *R. solani* is reduced in the anaerobic paddy conditions given the absence of upland crops.

While agrochemical inputs were very low, their application was often done ineffectively. In particular, while weeds appeared the most severe problem in the field, farmers mostly used organophosphate insecticides.

Although dry season rice yields are higher than those in the rainy season, the rice double and triple cropping systems were limited to a few areas of Upper Myanmar with reliable irrigation. The popularity of rice-blackgram or rice-greengram cropping patterns can be partially explained by the minimal irrigation water or external input requirements of pulses. Also, in recent years, farmers preferred to grow legumes as a second crop instead of rice because of the high market value of the former. Farmers seemed to be aware of the role of legumes in enhancing soil fertility, but perhaps more importantly, pulses have become a genuine cash crop, with private sector exports climbing from 831,000 t in 2001/2 to 1,034,000 in 2001/2 (MOAI, 2003; Okamoto, 2004). It can therefore be hypothesized that such rice-legume cropping patterns will likely continue to shape the agroecosystems of Myanmar.

Reported and measured rice yields were generally higher in Upper Myanmar than in Lower Myanmar, likely the result of higher radiation and favourable socioeconomic conditions. The Mandalay Division of Upper Myanmar for example, enjoys a climate particularly suited to rice production, and access to year round irrigation water allows for the cultivation of three crops per year. In addition, spatial proximity to urban markets directly correlates with higher profits than what is obtainable to farmers in other regions. This additional income allows for the purchase and use of additional inputs to further enhance yields.

The most common problems of fertility are inadequate amounts and improperly applied mineral and organic fertilizers. Although respondents expressed the knowledge that fertilizer applications can positively affect their yield, the farmers of this survey, and in particular those of Lower Myanmar, generally used low rates of N, and almost no P or K during the rainy season. Likewise, the total amount of available FYM remains severely limited, as farmers possess few animals and little disposable income for off-farm purchasing.

In addition, a 1992 government reduction in the private importation of agricultural inputs has since resulted in a shortage of fertilizer supply and increased prices. Based on informal discussions with farmers, Naing (2004) estimated that expenses for fertilizer comprise over 25% of the total rice production cost. To exasperate the problem, this shortage of mineral fertilizer has occurred during the progressive adoption of HYVs of rice and the expansion of area under irrigated farming. Thus, and as oft mentioned by respondents, inadequate and costly inputs, weeding, high labour costs, poor drainage and untimely irrigation all together contribute to low crop yields, especially in Lower Myanmar.

The application of fertilizer to the seedbed at rates higher than for fields, most likely was of little use because such fertilization may lead only to enhanced shoot growth and thus results in earlier transplanting, but does not correlate with higher grain yields (Grist, 1975). While excessively high N-inputs may result in increased disease problems, moderate N inputs of up to 80 kg ha^{-1} split into four (that is basal, 2 weeks after transplanting, at panicle initiation and at flowering) increased yields substantially both in Lower and Upper Myanmar (Thein, 2004) without affecting disease levels (Naing, 2004).

While the mean yields were increased by 36% through fertilizer use, the huge variation in yields among farmers using fertilizers and the relatively weak correlation of N-inputs with yields clearly indicate that other factors other than N are important in limiting rice yields. The interactions of fertiliser use and weed control and insecticide applications with respect to yield (Table 3) are not straightforward to explain. Possibly, competition from weeds in stands that are not fertilised is lower due to overall plant density. However, no data are available to test this. As the overall incidence of insect pests was very low during this survey, it was surprising to see any affects of insecticide application on yield. As many insects are more attracted to better-fertilized crops, it appears logical that the effects of insecticide on yield should be more pronounced in fertilized crops. However, the fact that insecticides affected yields negatively when no fertilizers were applied cannot be explained.

In addition to a complete lack of weed control on almost 50% of the surveyed farms due to the cost of labour, weeding itself often could not be accomplished effectively due to direct seeding. This method impedes the later use of hoes and consequently, often only the aboveground parts of the weeds are removed, resulting in rapid re-infestation.

Even if fertilizer and weed management were optimized, another limiting factor is seed quality. Less than 20% of farmers use certified seed, and the low quality of seed used results in poor germination and infestations with seed borne diseases. The observed cases of false smut and ufra point to the need of improvements in the seed sector. Likewise, diseases such as bacterial leaf blight and sheath rot are also seed borne and can be a direct consequence of unclean seeds (Ou, 1985). Moreover, rice seed can be contaminated with weed seeds of similar maturity, further contributing to the observed weed problem.

6 Conclusions

This study shows that agronomic problems such as low rates of applied manure and chemical fertilizers, low seed quality and poor weed and water management appear to be the most serious limitations to rice production in Myanmar. In particular, the very low amounts of fertilizer that are currently applied to rice are probably the major reason for the low yields of rice in Myanmar. The use of fertilizers, particularly of N, is essential for increasing rice yield. In addition, sources of P and K are needed. While market opportunities determine which crops farmers grow, the cropping sequence per se had little to no effect on rice productivity. Based on our findings and recent research results the following recommendations can be made:

(a) While overall higher amounts of fertilizer are needed, the high fertilization of the seedbed uncovered in this study does not seem to be necessary.

(b) There is a need to improve weed management practices, especially to use hoes for more effective removal.

(c) Water management has to be improved to allow a more efficient management of the resource at the farm level.

(d) The seed production sector should be strengthened to supply quality seeds at affordable prices to farmers throughout the country. In addition, farmers should be trained to carefully select and manage their own seed production fields.

(e) In the current situation, it appears that most pesticide applications are unnecessary or counterproductive. Insecticides usually have a higher human toxicity than fungicides and herbicides, and when considering the rudimentary understanding of pesticides and pesticide safety expressed by respondents, the potential for health hazards are real. In view of their high cost and the associated health hazards especially when not applied with the proper precautions, any recommendation for their use appears unwise.

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Journal of Agriculture and Rural Development in the Tropics and Subtropics
Volume 109, No. 2, 2008, pages 169–180

Effect of Inoculation with Rhizobacteria and Arbuscular Mycorrhizal Fungi on Growth and Yield of *Capsicum chinense* Jacquin

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Abstract

We evaluated the effect of two rhizobacteria (*Azotobacter chroococcum* and *Azospirillum brasilense*) and a commercial product containing multiple strains of arbuscular mycorrhizal fungi (AMF) and an NPK fertiliser on the growth and yield of habanero chilli (*Capsicum chinense* Jacquin). All treatments were applied as single or combined inoculants, under nursery and field conditions, in a completely randomised design. The biofertilisers were applied to the roots by coating or dipping, with the inoculants in a solid or liquid support, respectively. At 30 days after inoculation, populations of 2.5×10^6 to 1.3×10^6 cfu g soil^{-1} of *A. brasilense* and 10.3×10^5 to 2.6×10^5 of *A. chroococcum* were detected in the rhizosphere of the crop. The prevalence of colonisation of plants inoculated with AMF ranged from 35 to 57%, with the greatest values recorded for the treatment involving single biofertilisation by root coating. In the nursery phase, single biofertilisation promoted a higher growth and nutrient content in the crop than combined biofertilisation. However, in the field phase the combined biofertilisation increased the nutrient content of the plant leaves, which was significantly greater than observed in the NPK treatment.

The highest yields were recorded for the treatments involving a single inoculation of *A. chroococcum* and for those with the multi-strain of AMF, with average values of 2.5 and 2.3 kg plant^{-1} respectively, compared with 1.0 kg plant^{-1} obtained with the treatment in which NPK fertiliser was applied.

Keywords: Biofertiliser, Azospirillum brasilense, Azotobacter chroococcum, PGPR, root coating

1 Introduction

Mexico has the greatest genetic diversity of chillies and peppers (*Capsicum* spp.), and occupies second place in terms of world production. However, yields are generally very low with a mean of 13.7 t ha^{-1}. In spite of this, *Capsicum* spp. represents one of the main horticultural exports of Mexico (FAOSTAT, 2005). In organic farming systems,

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the use of organic fertiliser and microbial inoculants or biofertiliser represents a sustainable alternative to high inputs of chemical fertilisers used in the conventional production systems (Kennedy *et al.*, 2004).

Among the microorganisms that have been used as biofertilisers there is a group of bacteria known as plant growth promoting rhizobacteria (PGPR) and arbuscular mycorrhizal fungi (AMF), that have been recognized for their potential use in agriculture and horticulture (Azcon, 2000; Lucy *et al.*, 2004). The mechanisms by which PGPR promote plant growth are diverse, and often the beneficial effect is due to a combination of mechanisms (Bashan *et al.*, 2004). Nitrogen fixation, the solubilisation of phosphorous in the rhizosphere and the production of phytohormones, enhance plant growth directly. In mycorrhizal associations, plants supply carbohydrates to fungi, while fungi improve plant nutrition by increasing the absorption and translocation of nutrients, principally P, as well as N, K, Cu, Zn and Mg (Linderman, 1992).

The techniques that exist for the application of biofertilisers include seed coating (Terry *et al.*, 2002), which reduces production costs by using lower volumes of inoculants (Taylor and Harman, 1990). In the case of crops that require transplantation, such as the habanero chilli, one inoculation technique consists in dipping the roots of seedlings in a mixture of solid biofertiliser and water immediately before transplantation (Bashan, 1998).

In the present study we examined the effect of different methods of inoculation on the development of populations of *Azospirillum brasilense* and *Azotobacter chroococcum*, as well as micorrhizal colonisation in *Capsicum chinense* Jacquin. Additionally, we studied the effects of these treatments on growth and yield of *C. chinense* under tropical conditions.

2 Materials and Methods

2.1 Microbiological and plant material

Pure strains of *A. chroococcum* and *A. brasilense* were used in the experiments. These were isolated by the Instituto de Investigaciones Fundamentales en Agricultura Tropical (INIFAT), La Habana, Cuba, and reproduced in laboratory cultures. The *MICORRIZA* (NOCON S.A. de C.V.) product was used for the mycorrhizal inoculants, which is a low cost and commercially available product in Tabasco State, Mexico. This contains multi-strain arbuscular mycorrhizal fungi at a concentration of 5×10^6 spores ml^{-1}. The habanero chilli seedlings (*Capsicum chinense* Jacquin) were obtained from seeds commercialized by SEMINIS S.A. de C.V., Mexico. Habanero chilli seedlings of 45 d old were used in the nursery and field experiments.

2.2 Characterization of the soil

The soil used in the experiments was a loamy eutric Fluvisol according to FAO / UNESCO's classification, with 26% clay, 36% silt and 38% sand, an apparent density of 1.3 g cm^{-3}, pH(H_2O) value of 6.7, organic matter content 1.6%, total N content of 0.1 g 100 g dry soil^{-1}, P(Olsen) content of 12.2 mg kg^{-1}, K content of 0.9 cmol kg^{-1},

Ca of 12.5 cmol kg^{-1}, Mg of 6.4 cmol kg^{-1} and a cation exchange capacity (CEC) of 24.3 cmol kg^{-1} (ammonium acetate 1N, pH 7). This type of soil is common in Tabasco State.

2.3 Preparation of biofertilisers

In the case of the liquid biofertilisers, *A. chroococcum* was cultured in liquid Ashby medium enriched with NH_4NO_3 (3 g l^{-1}) and yeast extract (0.1 g l^{-1}), whereas *A. brasilense* was grown in a nutrient broth (Bioxon). Both were incubated at 30°C with orbital agitation (150 rpm) for 60 hours in the case of *A. chroococcum* and 48 hours in the case of *A. brasilense*, to obtain a concentration of $1{\times}10^9$ colony forming units (cfu) ml^{-1}. The solid biofertilisers (*A. chroococcum*, *A. brasilense* and AMF) were prepared from the liquid biofertilisers using a substrate of dry sugarcane press mud with a particle diameter of 1 mm, sterilized at 1.2 atm for 1 hour. Every kilogram of substrate was inoculated with 500 ml of the liquid inoculants. The inoculated solid substrates were incubated at 30°C for 10 days. The concentration of *A. brasilense* and *A. chroococcum* in solid supports was $1{\times}10^{10}$ cfu g^{-1} which was verified by the dilution plate count method. Agar Ashby medium was used for *A. chroococcum* and agar Congo red medium was used for *A. brasilense*.

2.4 Experimental design in the nursery

The nursery experiment was carried out in October 2005 in Tabasco, Mexico. Temperature ranged from 25 to 30°C during the experimental period. In this experiment we evaluated the effect of the different application methods (dipping and root coating in single or combined form) on rhizobacteria populations and micorrhizal colonisation as well as plant growth and leaf nutrient content. A completely randomised experiment was designed with 12 treatments and 5 repetitions (Table 1). Chilli plants were planted in seedling trays (150 individual cells). When plants had grown to the desired size they were individually inoculated with the treatments described in Table 1. Immediately after inoculation seedlings were individually transplanted to pots filled with 500 g of a substrate (soil: manure 1:1, previously sieved at 2 mm and sterilized twice at 1.5 atm for 30 min). The seedlings were watered daily with water to maintain the moisture at approximately 60% water holding capacity of the soil and maintained under nursery conditions during 30 days.

The single coating treatments (Ab_S, Ac_S, AMF_S) involved a 1:10 mixture of 10 g of biofertiliser and 90 ml of adherent (2 % w/v starch), whereas in the combined treatments (Ab_S+AMF_S, Ac_S+AMF_S) the mixture contained 10 g per inoculant and 180 ml of adherent. The root balls of seedlings were coated with the mixtures of the different treatments and allowed to dry in the shade for 10 min. In the treatments where non-combined biofertilisers were applied by dipping (Ab_L, Ac_L, AMF_L), the roots were submerged in their corresponding bacterial or AMF inoculants for five minutes. A 1:1 (v/v) mixture of each of the inoculants was previously prepared for the combined treatments applied by dipping roots (Ab_L+AML, Ac_L+AMF_L). Afterwards, the complete root ball of the seedling was submerged for 5 minutes in the inoculant preparation and

Table 1: Experimental treatments

Treatments	*Description*	*Support*	*Application method*
Ab_S	*A. brasilense*	solid	root coating
Ab_L	*A. brasilense*	liquid	root dipping
Ac_S	*A. chroococcum*	solid	root coating
Ac_L	*A. chroococcum*	liquid	root dipping
AMF_S	Arbuscular mycorrhizal fungi	solid	root coating
AMF_L	Arbuscular mycorrhizal fungi	liquid	root dipping
Ab_S+AMF_S	*A. brasilense*+Arbuscular mycorrh. fungi	solid	root coating
Ab_L + AMF_L	*A. brasilense*+Arbuscular mycorrh. fungi	liquid	root dipping
Ac_S + AMF_S	*A. chroococcum*+Arbuscular mycorrh. fungi	solid	root coating
Ac_L + AMF_L	*A. chroococcum*+Arbuscular mycorrh. fungi	liquid	root dipping
Control	—	—	—
Chemical Fertiliser	N:P:K (25:10:30 g plant^{-1})	—	soil application

allowed to dry in the shade for 10 min. For the NPK treatment a dose of 25:10:30 g plant^{-1} was applied directly to the substrate, adding all the P and K but only half of the N. The other half of N was added at the moment of transplantation in the field. Samples of 10 g of rhizospheric soil per plant were collected 30 days after inoculation to determine the rhizobacterial population. Soil samples were suspended in 90 ml sterile distilled water and shaken for 30 min at 150 rpm. Immediately after shaking, each suspension was serially diluted by pipetting 1 ml aliquots into 9 ml sterile water, to obtain a final dilution of 10-5 fold. A 0.1 ml volume of each dilution of the series was plated on Petri dishes with agar Congo red medium for the *A. brasilense* treatment, whereas Burk's N-free medium was used for *A. chroococcum* treatments. Three replicate dishes were prepared for each dilution. Agar plates were incubated at 30°C for 48-96 hours. After incubation, the number of colony forming units (cfu) g^{-1} of soil was determined by the pour plate method. Rhizobacteria were identified considering cellular and colony morphology, and by Gram staining (Holt, 2000, Bergey's Manual). Mycorrhizal colonization of roots in terms of percent infection was measured according to the method of Phillips and Hayman (1970).

2.5 Experimental design in the field

A group of 60 chilli plants were prepared in the same way as described for the nursery experiment. Chilli plants were transplanted to a biointensive tropical organic garden (soil characteristics as described in the nursery experiments). The plants were planted at a distance of 0.8 m between each other in a completely randomised design with 12 treatments and 5 repetitions (n= 5 plants). Plant growth and nutrient content were evaluated in leaves collected at 80 days after planting i.e. 110 after inoculation. The plants were harvested at 8 months after sowing and the yield was determined according to the fresh weight of the chilli fruits.

2.6 Evaluation of the growth and nutrient content of chilli plants

In the nursery experiment, the plant height (cm), number of leaves, fresh biomass and nutrient content were evaluated 30 days after inoculation or fertilisation. For nutrient analyses, the N content was determined by semi-micro Kjeldahl procedure (BREMMER, 1965). Total P and K content were determined by $\mathrm{HNO_3 - HClO_4}$ treatment and were measured by vanadomolybdate spectrophotometry and flame atomic-absorption spectrometry, respectively. In the field phase, the height (cm), number of branches and stem diameter at the base of the plant (cm), were evaluated 110 days after sowing. The leaves samples were collected from each plant during flowering to determinate the total nutrient content (N, P and K) using methods mentioned above. The fruits were harvested after 200 days.

2.7 Statistical analysis

Results were then subjected to a one way ANOVA, and means were compared by Duncan's multiple range Test ($p<0.05$). In the case of non normaly distribution data, an angular transformation (for the mycorrhizal colonisation data) and a logarithmic transformation were applied (for the rhizobacterial population). All analyses were performed using STATISTICA version 6.0 Software.

3 Results and Discussion

3.1 Rhizobacteria and mycorrhizal colonisation

The populations of both rhizobacteria decreased after inoculation during the period of the experiments. According to BAREA and AZCÓN-AGUILAR (1982), the decrease in the population of bacteria after inoculation may be related to difficulties in adapting to their new environment. However, the root exudates play a significant role in the growth of microorganisms (NARULA *et al.*, 2005). This exudation is reduced after 60 d past planting and much of the plant's energy reserves are channeled towards fruit/seed formation, thus causing an exponential decline in the survival of introduced bacteria. The population of *A. brasiliense* found in the rhizosphere of habanero chilli ranged from 1.3×10^6 to 2.4×10^6 cfu g^{-1} soil and was significantly greater (p¡0.05) than that determined for *A. chroococcum* with values of 6.8×10^5 to 1.0×10^6 cfu g^{-1} soil (Table 2). Root coating and dipping, either single or combined inoculation did not significantly affect the population of either rhizobacteria species.

Soil microorganisms influence AM fungal development and the establishment of symbiosis but no clear pattern of response has been found. Negative impacts upon the AM fungi include a reduction in spore germination and hyphal length in the extrametrical stage, decreased root colonisation and a decline in the metabolic activity of the internal mycelium (WYSS *et al.*, 1992). According to our results, the highest incidence of mycorrhizal colonisation (57.3%) was observed in the treatment AMF_S involving single biofertilisation by root coating (Table 2). The combined inoculation of rhizobacteria and AMF resulted in a lower colonisation in comparison with the treatments with AMF as the single inoculants (Table 2). These results differ from those of FITTER and GARBAYE (1994) who reported that rhizobacteria increased the capacity of AMF to colonise the roots of plants. However, according to GIANINAZZI-PEARSON (1982), free-living bacteria such *Azotobacter* and *Azospirillum* spp. can increase microbial populations in the rhizosphere of mycorrhizal plants.

Table 2: Population of rhizobacteria and mycorrhizal colonisation in *Capsicum chinense* Jacquin 30 days after inoculation in the different treatments under nursery conditions.

Treatments	*Rhizobacterial population (cfu g soil^{-1})*	*Mycorrhizal colonisation (%)*
Ab_S	1.3×10^6 ^{a}	nd
Ab_L	2.5×10^6 ^{a}	nd
Ac_S	7.0×10^5 ^{bc}	nd
Ac_L	6.8×10^5 ^{bc}	nd
AMF_S	nd	57.3 ^{a}
AMF_L	nd	47.3 ^{b}
Ab_S + AMF_S	1.5×10^6 ^{a}	42.0 ^{bc}
Ab_L + AMF_L	1.5×10^6 ^{a}	41.0 ^{cd}
Ac_S + AMF_S	10.3×10^5 ^{b}	35.3 ^{de}
Ac_L + AMF_L	2.6×10^5 ^{c}	37.0 ^{cde}
Control	nd	nd
NPK	nd	nd

Means followed by different letters are significantly different based on Duncan's multiple range test ($p < 0.05$), $a > b > c$. nd= not determined. cfu= colony forming units. Treatment codes are given in Table 1.

3.2 Effect of the treatments on the growth and nutrition of chilli plants: nursery experiment

The treatment Ab_S resulted in a significantly positive effect on the height of the plants (Table 3), in comparison with Ac_S, Ab_L+AMF_L, Ac_S+AMF_S, Ac_L+AMF_L and the Control. No significant differences occurred among the other treatments. The highest fresh biomass and number of leaves were also observed in the Ab_S treatment, and this was significantly different from Ac_S, Ac_L, Ab_S+AMF_S, Ab_L+AMF_L, Ac_S+AMF_S, Ac_L+AMF_L and the Control ($p<0.05$). No synergistic effects that might favour the growth of the crop were observed in the treatments involving combinations of biofertilisers (Table 3). Several studies have reported increases in growth and development for crops such as tomato, coriander, pepper and lettuce after inoculation with *Azotobacter* and *Azospirillum* (TERRY *et al.*, 2002; BASHAN *et al.*, 2004). However, the roots of pepper normally form symbiotic associations with AMF (MENA-VIOLANTE *et al.*, 2006), and the potential for AMF to increase plant growth under conditions of low soil P content has been well documented (LINDERMAN, 1992). In contrast, some Glomus isolates have been shown to stimulate plant growth independent of plant P nutrition or when P is not limiting (DAVIES JR. *et al.*, 1993).

Table 3: Growth and nutrient content (Total N, P, K) in plant tissue of *Capsicum chinense* Jacquin at 30 days post-inoculation in the nursery experiment.

	Growth parameters			*Nutrient content (%)*		
Treatments	Number Leaves	Height (cm)	Fresh weight (g)	N_{Total}	P	K
Ab_S	28.0 ^{a}	27.72 ^{a}	12.55 ^{a}	4.32 ^{a}	0.53 ^{b}	1.43 ^{e}
Ab_L	19.2 ^{cde}	26.38 ^{ab}	10.81 ^{ab}	4.18 ^{ab}	0.58 ^{a}	1.44 ^{e}
Ac_S	26.2 ^{ab}	22.96 ^{bcd}	8.41 ^{bcd}	3.78 ^{ef}	0.44 ^{d}	1.56 ^{de}
Ac_L	18.8 ^{cde}	25.08 ^{abcd}	9.25 ^{bcd}	3.75 ^{ef}	0.41 ^{e}	1.85 ^{c}
AMF_S	19.2 ^{cde}	24.96 ^{abcd}	10.01 ^{abcd}	4.07 ^{bc}	0.56 ^{a}	1.61 ^{d}
AMF_L	20.8 ^{cd}	26.08 ^{abc}	10.57 ^{abc}	4.00 ^{cd}	0.50 ^{c}	1.61 ^{d}
Ab_S + AMF_S	26.0 ^{b}	24.26 ^{abcd}	8.83 ^{bcd}	3.68 ^{f}	0.41 ^{e}	1.80 ^{c}
Ab_L + AMF_L	19.8 ^{cde}	21.20 ^{d}	7.19 ^{d}	3.73 ^{ef}	0.38 ^{f}	2.16 ^{b}
Ac_S + AMF_S	27.0 ^{ab}	21.86 ^{cd}	9.09 ^{bcd}	3.88 ^{de}	0.37 ^{f}	2.15 ^{b}
Ac_L + AMF_L	20.8 ^{cd}	21.56 ^{d}	7.70 ^{cd}	3.78 ^{ef}	0.43 ^{cd}	1.92 ^{c}
Control	18.0 ^{e}	20.96 ^{d}	7.59 ^{cd}	3.61 ^{f}	0.37 ^{d}	1.45 ^{e}
NPK	18.8 ^{cde}	24.94 ^{abcd}	10.58 ^{abc}	4.13 ^{bc}	0.52 ^{bc}	2.44 ^{a}

Means followed by different letters are significantly different based on Duncan's multiple range test ($p < 0.05$), $a > b > c$. Treatment codes are given in Table 1.

Previous studies have reported that the combined application of PGPR and AMF increased growth and development in inoculated plants (Bashan *et al.*, 2004). In our study, the greatest response in *C. chinense* was obtained when the biofertilisers were applied as single inoculants. The incipient effect on the growth of the plants with the combination of rhizobacteria and mycorrhiza may be related to the competition of each symbionts for carbonated compounds, a situation in which the host plant must both satisfy its physiological requirements and provide energy to the symbiont microorganisms (Azcon, 2000).

Significantly higher N content in plant tissue of *C. chinense* was observed in the treatments Ab_S (4.3%) and Ab_L (4.2%). The P content of plant tissue was significantly higher in treatments Ab_L (0.58%) and AMF_S (0.56%), than the others. The NPK treatment resulted in the highest K content (2.44%), (Table 3). The increase in the nutrient content of plants inoculated with PGPR is mainly due to the changes produced in the morphology of the roots by the phyto-hormones that are synthesized by many rhizobacteria and that result in an increase in root surface area (Bashan *et al.*, 2004). However, PGPR may also enhance mineral uptake, not only as a consequence of the increase in root surface area but also by stimulating proton efflux activity (Bashan, 1990). (Murty and Ladha, 1988) showed that *Azospirillum* inoculation increased P and NH_4^+ uptake by rice plants, although, whether this was a result of increased nutrient mobilization, or a secondary effect of improved root growth, was not demonstrated. Additionally, the roots that are colonized by mycorrhizal fungi use the extraradical mycelium to explore a greater volume of soil, and translocate nutrients from the soil to the plant more efficiently, resulting in improved plant nutrition (Linderman, 1992).

3.3 Effect of the treatments on the growth and nutrition of chilli plant: field experiment

Under field conditions the plant response to biofertiliser inoculation may be influenced by factors such as soil parameters, climatic conditions and other microbial interactions (LUCY *et al.*, 2004). Moreover, in unsterilized field soil conditions competition may occur between introduced and native microbial populations. In this study, the maximum plant growth values in the field occurred when the biofertilisers were applied singly (Table 4). The treatments that significantly stimulated the height of the plants were AMF by root coating or dipping (AMF_S and AMF_L) and *A. chroococcum* by root coating (Ac_S). Additionally, treatments Ac_S and AMF_L resulted in stem diameter values that were significantly high than observed in other treatments ($p < 0.05$). The number of branches was significantly greater in the AMFs treatment than the Control ($p < 0.05$) but did not differ significantly with respect to the other treatments.

Table 4: Growth and nutrient content (Total N, P, K) in plant tissue of *Capsicum chinense* Jacquin at 30 days post-inoculation in the nursery experiment.

Treatments	*Growth parameters*			*Nutrient content (%)*		
	Height (cm)	*Stem diameter (cm)*	*Number of branches*	N_{Total}	P	K
Ab_S	29.40 ^{bcd}	0.47 ^{f}	6.4 ^{a}	3.50 ^{e}	0.50 ^{a}	2.42 ^{a}
Ab_L	33.60 ^{bc}	1.27 ^{bc}	6.6 ^{a}	3.65 ^{d}	0.32 ^{f}	1.77 ^{c}
Ac_S	42.20 ^{a}	1.50 ^{ab}	7.6 ^{a}	2.79 ^{h}	0.36 ^{e}	1.12 ^{f}
Ac_L	34.20 ^{b}	1.20 ^{bcd}	7.8 ^{a}	3.24 ^{f}	0.33 ^{f}	1.39 ^{de}
AM_S	45.80 ^{a}	1.27 ^{bc}	8.0 ^{a}	3.00 ^{g}	0.21 ^{h}	1.34 ^{ef}
AM_L	42.80 ^{a}	1.73 ^{a}	7.4 ^{a}	3.04 ^{g}	0.35 ^{ef}	1.84 ^{c}
$Ab_S + AM_S$	30.20 ^{bcd}	0.90 ^{de}	7.0 ^{a}	4.35 ^{a}	0.40 ^{d}	1.62 ^{cd}
$Ab_L + AM_L$	27.00 ^{cd}	0.70 ^{ef}	5.4 ^{ab}	4.02 ^{c}	0.49 ^{ab}	2.11 ^{b}
$Ac_S + AM_S$	26.80 ^{cd}	0.70 ^{ef}	5.2 ^{ab}	4.17 ^{b}	0.47 ^{b}	2.23 ^{ab}
$Ac_L + AM_L$	25.80 ^{d}	1.10 ^{cd}	7.8 ^{a}	4.38 ^{a}	0.43 ^{c}	1.73 ^{c}
Control	25.20 ^{d}	0.43 ^{f}	3.3 ^{b}	2.80 ^{h}	0.23 ^{gh}	1.26 ^{ef}
NPK	27.80 ^{bcd}	1.03 ^{cde}	6.8 ^{a}	2.94 ^{g}	0.25 ^{g}	1.43 ^{de}

Means followed by different letters are significantly different based on Duncan's multiple range test ($p < 0.05$), $a > b > c$. nd= not determined. cfu= colony forming units. Treatment codes are given in Table 1.

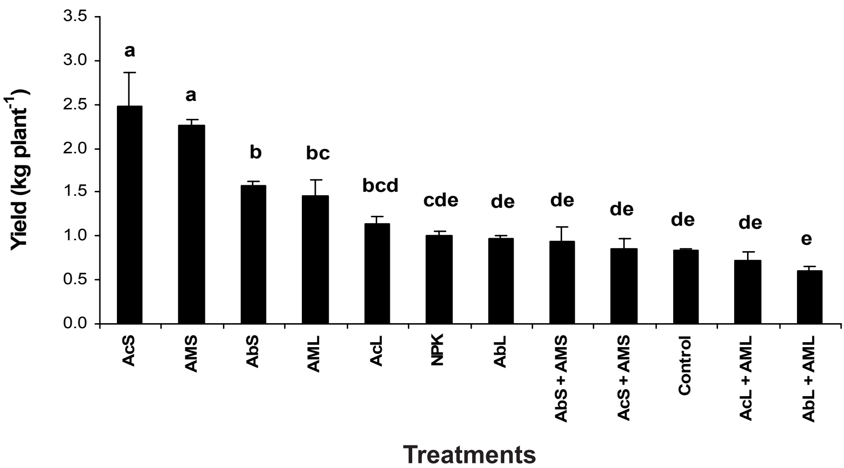
The combined inoculation with rhizobacteria and AMF seem to be the most effective treatment to improve N uptake. The leaf analysis of plants (Table 4) showed a greater N content with treatments Ac_L+AMF_L and Abs+AMFs with 4.3% for both treatments, and this was significantly greater than observed in the other treatments ($p < 0.05$). Generally, *Azotobacter* does not form intimate metabolic associations with the host plant and they therefore have a limited supply of carbon to provide energy for nitrogen fixation (HUBBELL and GASKINS, 1984). Spores of mycorrhizal fungi seem to provide *Azotobacter* with an operational base in the vicinity of roots and a supply of carbon that increases the efficiency of both mycorrhizae and *Azotobacter*. In the case of P and

K, the Ab_S treatment resulted in the highest content (0.5% and 2.4%, respectively) and this was significantly greater than observed in treatments Ab_L, Ac_S, Ac_L, AMF_S, AMF_L, Ab_S+AMF_S, Ac_L+AMF_L, Control and NPK ($p < 0.05$).

3.4 Effect of the treatments on the yield of chilli plants

The use of PGPR to increase crop yield has been limited due the variability and inconsistency of results between laboratory, greenhouse and field studies. The application of biofertilisers had a positive effect on the yield of chilli fruits. The maximum values were recorded for treatments Ac_S with 2.5 kg plant^{-1} (25 t ha^{-1}) and AMF_S with 2.3 kg plant^{-1} (23 t ha^{-1}), compared with 1.0 kg plant^{-1} (10 t ha^{-1}) that was obtained with the NPK treatment and 0.8 kg plant^{-1} (8 t ha^{-1}) obtained in the Control treatment (Figure 1). Treatments that used combinations of biofertilisers resulted in significantly lower yields than those that were applied as single inoculants. It is also important to point out that the yield obtained was significantly greater with the treatments applied in solid supports compared with those applied in liquid supports.

Figure 1: Effect of the different treatments on the yield of *Capsicum chinense* Jacquin. Means followed by different letters are significantly different based on Duncan's multirange Test ($p < 0.05$), a > b > c. Errors bars = standard error of mean (n= 5).



In this study, *Azotobacter* in solid support (Ac_S) resulted in increases in plant height, the stem diameter and the yield but not in the nutrition of habanero chilli. These results suggest that plant responses to these bacteria could be associated with plant growth hormones, rather than the results of nitrogen fixation and phosphate solubilisation. DOBBELAERE *et al.* (2002) also found that *A. brasilense* and *A. irakense* strains stimulated overall plant growth, including root development and increased yield of spring wheat and maize. However, neither rhizobacteria species affected the N content of plants or grains. The effect of AMF on *Capsicum annuum* L. plants has been studied, in some detail with records of positive effects on growth, development, yield and some parameters of fruit quality such as size, colour and pigment content (Aguilera-Gómez *et al.*, 1999; Mena-Violante *et al.*, 2006).

4 Conclusion

The application of biofertilisers to *C. chinense* plants had a positive effect on the growth and nutrition of the crop with respect to the control and the NPK fertiliser treatment. The application of a root coating technique did not modify the concentration of the population of rhizobacteria or mycorrhizal fungi in the rhizosphere of *C. chinense*, but, this technique resulted in greater yields than the application of biofertilisers by root immersion. Biofertilisation with *Azotobacter chroococcum* and arbuscular mycorrhizal fungi applied as single inoculants in solid supports and by root coating provided the highest crop yields that even exceeded that of the NPK treatment. It is possible therefore, to obtain good yields with the application of biofertilisers under tropical conditions similar to those established in this study.

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Journal of Agriculture and Rural Development in the Tropics and Subtropics
Volume 109, No. 2, 2008, pages 181–190

Species Richness in Relation to the Presence of Crop Plants in Families of Higher Plants

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Abstract

Crop species richness and percentages of cultivated plants in 75 families comprising more than 220000 species were analyzed. Three major groups have been made. The first group is including the "big five" families with 10000 and more species in each. The second group comprises 50 families with more than thousand and up to 10000 species and finally the third group contains families with relatively high numbers of crop species. The percentage of cultivated species is various, from 0.16 to 7.25 in group 1, 0 to 7.24 in group 2 and 2.30 to 32.5 in group 3. The results show that there is a positive correlation (r = + 0.56) between number of crop plants and species diversity of the families.

Keywords: agrobiodiversity, species richness, crop plants, plant families

1 Introduction

One important task of agrobiodiversity (Hammer and Khoshbakht, 2004) is to collect information concerning the plants and animals which are actively grown or kept by mankind (Hammer, 2004). The neolithic revolution created farmers from hunters and gatherers who were able to produce food and other necessary products from cultivated plants and domesticated animals. For plants Rudolf Mansfeld made one of compiling the first trials of all species grown by human (Mansfeld, 1959). This book with a concise treatment of the species, excluded ornamentals, evidently because of their great numbers (recently Khoshbakht and Hammer (2007, 2008) estimated their total number to be 28000 species), and forest trees (later treatment by Schultze-Motel (1966). For domesticated animals such a list has still to be compiled (Hammer *et al.*, 2003). Mansfeld's list is now in the third edition (Hanelt and IPK, 2001). On the basis of this treatment, Hammer (2004) estimated the number of crop plants in the sense of Mansfeld to be about 7000. Biodiversity research has done intensive work to establish the total number of higher plants. The general consensus is now 250000 species (Ungricht, 2004). Considering the Mansfeld approach we are now able to calculate

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that 2.8 % of the higher plants species are agricultural and horticultural plants. There is still no information for botanical families, apart from occasional estimations.

From these percentages and the absolute figures conclusions can be drawn about the usability of members from different families as crop plants. A general question is concerning high species numbers in families and their possible influence on the number of prospective crop plant species.

2 Material and Methods

As the basis for the calculation of the species numbers in crop plants the already mentioned Mansfeld Encyclopedia (Hanelt and IPK, 2001) has been used, which contains all available agricultural and horticultural crop plants, plants cultivated for food and feed, raw materials etc. (for the different groups of commodity see Schultze-Motel (1986, pp. 1891-1909)). For this first calculation the economic importance of crop plants has not been considered. The numbers of species have been taken from Heywood *et al.* (2007). In some cases the numbers for our calculations have been adjusted by using additional sources (e.g. Hunziker (2001) for the Solanaceae). Three major groups have been made. To the first group the "big five" families have been drawn (10000 and more species each). The second group comprises 50 families with thousand and more up to c. 6870 species (Lamiaceae). A third group contains families with relatively high numbers of crop species according to our experiences. This group comprises 20 families. They are the result of a somehow biased selection. Small families have been excluded because it is easily understandable that the relative numbers (percentages) in these families will go to 100, especially in the case of monotypic families – *Eucommia ulmoides* (family: Eucommiaceae) is a crop plant in East Asia.

3 Results and Discussion

Altogether we have analyzed 75 families (including the largest 56) comprising about 223757 species, i.e. the most part of the available species number in higher plants. The results are presented in table 1 (group 1) for the "big five" families. They include about 85000 species together, i.e. about one third of the total species number in higher plants. Their percentages reach from 0.16 % (Orchidaceae) to 7.25 % (Poaceae). The reasons are evident. There are only few Orchidaceae as crop plants, e.g. several *Vanilla* species being grown for condiment, *Bletilla striata* (Thunb.) Reichenb. cultivated as a medicinal plant in East Asia and *Cymbidium virescens* Lind. which is cultivated as a vegetable in China. The general structure of the Orchidaceae allows only a few modes of use (see examples above), their tiny seeds are not useful as food for man, the production of biomass is mostly low and they have limited biosubstances. The ecological (cultivation) requirements are high in comparison with other plant groups. On the other hand, the Orchidaceae is one of the most successful families for ornaments, especially due to biotechnology. The Poaceae with 7.25 % of crop species are very successful in this respect. They are important as food for mankind (especially fruits and seeds) and livestock (especially green parts), apart from many other uses (Hanelt and IPK, 2001). Their functional similarity makes the use of many grass-species possible and, accordingly, they are often cultivated. Their low level of poisonous substances makes them easily usable. Their importance comes from the high number of grain and fodder crops.

The largest family in flowering plants, the Compositae has 1.14 % of crop species and is thus below the average. But it does not belong to the "poor" families with respect to crop plants, as the Rubiaceae (0.56 %) from the "big five" families.

Together with the Leguminosae (3.38%), the other large above-level family, very important for human and animal nutrition, it will be used for a special comparison with respect to biodiversity (in preparation). Table 1 (group 2) contains the 50 families of the second category. The Eriocaulaceae have no crop plants. But this interesting family contains some ornamentals (e.g. *Syngonanthus elegans* (Bong.) Ruhl. or *Eriocaulon aquaticum* (Hill) Druce). All the other families have contributed at least some crop plants, as the Gesneriaceae (0.075 %, highly specialized, small seeds) and Begoniaceae (small seeds). Both have contributed a great number of ornamentals.

Preadaptation (according to Hammer (1998), e.g. adaptation to fruit dispersal by animals, has pushed the number of species useful for man, which have been later cultivated, especially in the Moraceae (6.95%), Clusiaceae (3.13 %), Rutaceae (5.06 %) and also the Solanaceae (3.71 %). More examples of this type appear in the third group. The outstanding family of fruit bearers with the highest score of 7.73 % are the Rosaceae with many fruit-beariung species in all suitable climatic zones, from northern latitudes (*Rubus arcticus* L.) to tropical areas (*Prunus africana* (Hook. f.) Kalkman), but especially common in the temperate area. Many species of other families with large scores can be uniformly used as vegetables, potherbs and greens, as the Chenopodiaceae (7.08 %), which are also excellent crops for saline agriculture (Lieth *et al.*, 1999). Interesting vegetables/fodder plants come also from the Polygonaceae (7.3 %), the already mentioned Solanaceae and the Malvaceae (3.45 %). A special case are the Cactaceae (4.05 %). Adapted to dry climates, they are often the only usable greens (mostly succulent stems) for man and animals. Many of them produce excellent fruits and are also planted for hedges. There are also combinations of these three and still more uses. Recent local studies about Cactaceae, especially in Mexico (Scheinvar, 2004, 2007; Reyes-Agüero, 2005) which are not yet included in the Mansfeld Encyclopedia, will even push the score of this family. The morphologically similar, convergent Euphorbiaceae (2.73%) have more phytoactive substances than the Cactaceae. They are, therefore, less usable for food and feed. But they are unique hedge plants and of new interest for the production of fuel (*Jatropha* spp., *Euphorbia tirucalli* L.) and other chemicals. Here is another future increase of species under cultivation possible. Special cases are also the Zingiberaceae (5.92 %) with their many species usable for spices and condiments. Their chemical constituents have been a permanent stimulus for the cultivation of different species. Similarly the Verbenaceae (3.94 %) can be used as spices and condiments. Better known in the temperate areas are the Apiaceae (3.0 %) with a great number of vegetables, spices and condiments. Brassicaceae (2.12 %) are an example of different organs used for vegetables and also important oil crops.

The third group (table 1, group 3) comprises families with less than 1000 species. As already stated, they have been selected somewhat arbitrarily. The main criterion for their selection was that they contain a good amount of crop plants. Among this group there are some larger families (700 and more species) containing relatively many crop plants, as the Sapotaceae (7 %) which are rich in fruit species, the same is true for Anacardiaceae (9.57 %) and Burseraceae (5,71 %). Cucurbitaceae (9.13 %) show a good mixture of fruits and fruit vegetable species. Dioscoreaceae (9.13 %) are important for their starchy bulbs. All these families show a high percentage of crop plants and, because of their great number of species, they are comparable to the best families in group 2. Some of the smaller selected families show extremely high percentages of crop plants, as the Agavaceae (15 %), the Juglandaceae (18.3 %), and particularly the Musaceae (32.5 %). Here, at least a part of the high percentages is the effect of the small species numbers within these families. Table 2 (after HAMMER (1999) summarizes the 39 most important crop plants of the world. Surprisingly, all plants from this table are present in our three groups proofing the value of our selection criteria. 19 crops belong to group 1 ("the big five"), 14 crops to group 2 and 6 crops to group 3. Most of the important crops come from the Poaceae (9), followed by Leguminosae (8), and Arecaceae (2). All from the "big five", except Orchidaceae, have important crop plants. The results show that there is a positive correlation (r = + 0.56) between number of crop plants and species diversity of the families. There are some families rich in species but only with a few crop plants, as Orchidaceae from the "big five", or Gesneriaceae, Begoniaceae or Eriocaulaceae, which contain only few or even no crop plant species. The reasons are similar to that of the Orchidaceae and have been already discussed. A more detailed analysis is however necessary for a deeper discussion of the advantages/disadvantages of the species in the different families with respect to the possibilities to become crop plants.

Table 1: Families of higher plants with their numbers of species and cultivated species and cultivated species.

Family	*Number of all species*	*Number of cultivated species*	*% of cultivated species*
Group 1 (Number of species > 10,000)			
Asteraceae (Compositae)	25000	284	1.14
Leguminosae	19000-19700	653	3.38
Orchidaceae	18000-20000	31	0.16
Rubiaceae	13150	74	0.56
Poaceae (Gramineae)	10000	725	7.25
Group 2 (1000 < Number of species < 10,000)			
Euphorbiaceae	6300	172	2.73
Lamiaceae (Labiatae)	6870	169	2.46
Scrophulariaceae	5800	27	0.47

(Table 1 continuation)

Family	*Number of all species*	*Number of cultivated species*	*% of cultivated species*
Myrtaceae	5800	95	1.64
Apocynaceae	5000-6000	91	1.65
Melastomataceae	4570	18	0.39
Cyperaceae	4500	46	1.02
Ericaceae	4050	28	0.70
Apiaceae (Umbelliferae)	3500- 3700	108	3.0
Solanaceae	1000-2000 or 3000-4000	130	3.71
Gesneriaceae	3500	2	0.075
Rosaceae	2000 + 1300–1500 apomicts	263	7.74
Brassicaceae (Cruciferae)	3350	71	2.12
Araceae	3200	66	2.10
Acanthaceae	3000	36	1.2
Piperaceae	3000	26	0.87
Boraginaceae	2700	39	1.44
Lauraceae	2500-2750	37	1.41
Bromeliaceae	2600	19	0.73
Annonaceae	2500	23	0.92
Ranunculaceae	2500	33	1.32
Campanulaceae	2250	9	0.40
Caryophyllaceae	2200	17	0.77
Cactaceae	2000	81	4.05
Malvaceae	2000	69	3.45
Phyllanthaceae	2000	9	0.45
Arecaceae (Palmae)	2000	46	2.30
Sapindaceae	1900	36	1.89
Convolvulaceae	1840	32	1.74
Iridaceae	1800	19	1.06
Urticaceae	1700	28	1.65
Rutaceae	1700	86	5.06
Proteaceae	1700	10	0.59
Mesembryanthemaceae (Aizoaceae)	1680	13	0.77
Gentianaceae	1650	8	0.48
Clusiaceae (Guttiferae)	1630	51	3.13
Araliaceae	1450	26	1.79

(Table 1 continuation)

Family	*Number of all species*	*Number of cultivated species*	*% of cultivated species*
Begoniaceae	1400	1	0.07
Myrsinaceae	1320	2	0.15
Malpighiaceae	1300	19	1.46
Zingiberaceae	1300	77	5.92
Celastraceae	1200	9	0.75
Chenopodiaceae	1200	85	7.08
Eriocaulaceae	1200	0	0
Crassulaceae	900-1500	22	1.83
Verbenaceae	1150	45	3.91
Polygonaceae	1100	80	7.27
Moraceae	1050	73	6.95
Amaranthaceae	1000	26	2.6
Polygalaceae	1000	7	0.70
Group 3 (selected for containing relatively many crop plants)			
Salicaceae	885	39	4.41
Sapotaceae	800	56	7
Alliaceae	600-750	27	4
Dioscoreaceae	800	73	9.13
Vitaceae	800	33	4.13
Cucurbitaceae	750-850	62	7.75
Burseraceae	700	40	5.71
Anacardiaceae	700	67	9.57
Passifloraceae	700	29	4.14
Fagaceae	620-750	26	3.80
Liliaceae	640	19	2.30
Meliaceae	550	21	3.82
Chrysobalanaceae	520	19	3.65
Sterculiaceae	415	37	8.92
Valerianaceae	350	21	6
Agavaceae	300	45	15
Grossulariaceae	200	25	12.5
Betulaceae	130	13	10
Juglandaceae	60	11	18.30
Musaceae	40	13	32.5

Table 2: The most important crop plants of the world (after Hammer 1999) with their families, numbers of accessions kept in the gene banks of the world (after FAO (1996)) and production in EEDM (estimated edible dry matter in Million ton, after HARLAN (1998))

Crop	*Family*	*Group*	*No. of accessions*	*EEDM (m/t)*
Triticum spp.	Poaceae	1	784 500	468
Hordeum vulgare	Poaceae	1	485 000	160
Oryza spp.	Poaceae	1	420 500	330
Zea mays	Poaceae	1	277 000	429
Phaseolus spp.	Leguminosae	1	268 500	14
Glycine max	Leguminosae	1	174 500	88
Sorghum spp.	Leguminosae	1	168 500	60
Brassica spp.	Leguminosae	2	109 000	22
Vigna spp.	Leguminosae	1	85 500	–
Arachis hypogaea	Leguminosae	1	81 000	13
Lycopersicon esculentum	Solanaceae	2	78 000	33
Cicer arietinum	Leguminosae	1	67 500	–
Gossypium sp.	Malvaceae	2	49 000	48
Ipomoea batatas	Convolvulaceae	2	32 000	35
Solanum tuberosum	Solanacea	2	31 000	54
Manihot spp.	Euphorbiaceae	2	28 000	41
Hevea brasiliensis	Euphorbiaceae	2	27 500	–
Lens culinaris	Leguminosae	1	26 000	–
Allium spp.	Alliaceae	3	25 500	26
Beta vulgaris var. *altissima*	Chenopodiac.	2	24 000	34
Elaeis guineensis	Arecaceae	2	21 000	–
Coffea spp.	Rubiaceae	1	21 000	–
Saccharum spp.	Poaceae	1	19 000	–
Dioscorea spp.	Dioscoreaceae	3	11 500	63
Musa spp.	Musaceae	3	10 500	11
Nicotiana tabacum	Solanaceae	2	9750	–
Theobroma spp.	Sterculariaceae	3	9500	–
Colocasia spp.	Araceae	2	6000	–
Cocos nucifera	Arecaceae	2	1000	53
Avena sp.	Poaceae	1	–	43
Secale cereale	Poaceae	1	–	29
Millets (dif. Gen.)	Poaceae	1	–	26
Pisum sativum	Leguminosae	1	–	12
Vitis sp.	Vitaceae	3	–	11
Helianthus annuus	Asteraceae	1	–	9.7
Malus domestica	Rosaceae	2	–	5.5
Citrus sp.	Rutaceae	2	–	4.4
Mangifera indica	Anacardiaceae	3	–	1.8

4 Conclusions

From our study the following conclusions can be drawn:

(1) There is a positive correlation between species richness and number of crop plants in the plant families.

(2) Highly specialized families and other plant groups are often less useful as crop plants.

(3) Families with a wide distribution often contain many crop species. A narrow distribution, often connected with a high specialization, evidently reduces the possibility of generating crop plants.

(4) There are many reasons for creating new crop plants from wild species (e.g. landscaping and wind protection, salt-plant agriculture, developing new pasture plants, energy and petrol plants) but there is also a number of crop plants which had been forgotten or are not yet detected or described by scientists. Perspective areas for the latter case are Latin America and South-East Asia. Intensifying the respective studies, the number of crop plants (7000) will still somewhat increase.

(5) On the other hand, there is a reduction of the crop plants used. The present trend to use less than 100 important crop plants (see table 2) or concentrate only on seven columns of world nutrition (Brücher, 1982) is dangerous in the light of biodiversity.

(6) There is a negative trend for species diversity in world agriculture, but the number of cultivated ornamentals is drastically increasing (Khoshbakht and Hammer, 2008). Lawn grasses are also included in this trend. At the time of Zohary (1973) there was still an increase of segetal species. Now we have a tremendous increase of ornamentals and lawn grasses.

(7) Preadaptation to use by man is often the precondition for the evolution of crop plants. Fruit shrubs and trees can serve as a good example.

(8) Morphologically closely related plants have been often taken into cultivation. But also similarity by convergence can have the same effect (e.g. Cactaceae and Euphorbiaceae).

(9) Principally all plants can become domesticated. There are many examples that plants loose their detrimental or poisonous characters under domestication. Some plants are cultivated exactly because of that characters (e.g. Cactaceae with sharp thorns as hedges, medicinal plants with poisonous substances). A greater obstacle against effective use as crop plants may be high specialization, as e.g. in Orchidaceae or Gesneriaceae (see point two).

Acknowledgment:
This research was supported by financial grant of Shahid Beheshti University. The principal author expresses his gratitude to vice-presidency for research and technology for this financial support.

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Journal of Agriculture and Rural Development in the Tropics and Subtropics
Volume 109, No. 2, 2008, pages 191–199

Traits for Screening and Selection of Cowpea Genotypes for Drought Tolerance at Early Stages of Breeding

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Abstract

The association of leaf water content with yield-attributes such as pod setting and number of pods/plant and seed yield in cowpea was examined using midday drop of leaf relative water content (RWC) determined from morning (800 h) and midday (1330 h) measurements of RWC. Midday drop of RWC was significantly correlated to pod setting ratio ($R^2 = 0.80$, $P < 0.01$), number of pods/plant ($R^2 = 0.87$, $P < 0.01$) and seed yield ($R^2 = 0.37$, $P < 0.05$). There was a significant genotypic variation for leaf water potential (LWP) at 800 and 1330 h and for RWC at 1330 h. Significant genotypic differences were also observed in pod setting ratio, number of pods/plant, number of seeds/pod, 1000-seed weight, biomass and seed yield. Pod setting ratio was significantly and positively correlated with number of pods/plant ($R^2 = 0.80$, $P < 0.01$) and seed yield ($R^2 = 0.38$, $P < 0.05$). These results showed that the genotypes with a smaller reduction in midday drop of RWC produced a larger number of pods/plant and consequently had higher seed yield as compared with a larger midday drop of RWC. The results also showed that there was a large genotypic variation in the midday drop of RWC, which was correlated with yield-attributes and seed yield. It may therefore be possible to use midday drop of RWC as a screening and selection trait for drought tolerance of cowpea genotypes.

Keywords: Cowpea, drought, pod setting, relative water content, screening trait, *Vigna unguiculata* L. Walp.

1 Introduction

Cowpea (*Vigna unguiculata* L. Walp.) is one of the most important arid legumes cultivated for pulse and forage production in arid and semi-arid regions of the country. The crop grown under rainfed conditions often encounters drought during the pod formation period either due to long dry spells or early withdrawal of monsoon rains. Breeding improved genotypes for the arid and semiarid tropics by selection solely for seed yield

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is difficult, because of the variability in amount and temporal distribution of available moisture from year to year. The genotypic variation in yield is low under these conditions. Researchers (OMAE *et al.*, 2007; SINGH *et al.*, 2004, 2007; SHARMA *et al.*, 2007) now believe better adapted and high yielding genotypes could be bred more efficiently and effectively if traits that confer yield under drought conditions could be identified and used as selection criteria at the early stages of breeding programmes. However, there are examples where morpho-physiological traits have been used to identify drought tolerant genotypes in *Brassica* species (KUMAR and SINGH, 1998; SHARMA *et al.*, 2007), cowpea (MATSUI and SINGH, 2003) and snap bean (OMAE *et al.*, 2005b). The usefulness of selection for a trait depends on its correlations with seed yield in drought conditions. Midday drop in leaf relative water content in beans showed that with a limited reduction the genotypes displayed higher pod setting, number of pods/plant and finally higher seed yield in drought conditions (OMAE *et al.*, 2005a, 2007). The objective of this study was to evaluate the germplasm lines tested in initial varietal trials (IVT-I) for physiological traits such as leaf water potential, relative water content and midday drop in leaf relative water content during pod formation stage and correlate these differences with pod setting, number of pods and seed yield. This will aim at understanding the morphological and physiological traits that influence the productivity of cowpea, which may be helpful in the selection at early stages of breeding and further utilized as a trait in screening for drought tolerance.

2 Materials and Methods

The experiment was conducted in drought plots at CCS Haryana Agricultural University, Hisar, India (20 10' N, 75 45' E). The drought plots (30m in length, 6m in width and 2m in depth) filled with dune sand of 22±2.26% water holding capacity were constructed especially to screen large populations for drought tolerance. Twenty genotypes of cowpea (IVT-I received from Project Coordinator, Arid Legumes, CAZRI, Jodhpur, India; Table 1) were grown under drought conditions in a randomized block design with three replications of a plot size of 2.80×1.80 m, utilizing standard farming practices. The soil contained 14 cm of available water in the 195 cm soil depth at the time of seeding. Seeding was done on 24 July. During the growing season 13.51 cm rainfall was received. No post sowing irrigation was applied to the crop. Also no rainfall was received after 45 DAS. Soil moisture content (by Neutron Moisture Meter, Troxler, USA) was recorded at 60 DAS, i.e., on the day of measurement of the leaf water status. On the average, the values were 5.38+ 0.78% (w/w, mean ±SD) at the 0-15 cm, 6.49±0.43% at the 15-45 cm, 7.89±0.46 at the 45-75 cm, 9.35±0.26 at the 75-105 cm, 12.59±0.58 at the 105-135 cm, 13.21±0.24 at the 135-165 cm and 16.45±0.68% at the 165-195 cm soil depth.

Measurements of leaf water potential, LWP (by Pressure Chamber Apparatus as described by SCHOLANDER *et al.* (1965) and leaf relative water content (RWC) were made 60 DAS (pod formation stage) at two times, i.e., between 730-800 h (referred as "800 h") and 1300-1330 h (referred as "1330 h"). A fully expanded youngest leaf from the top of the plant on the main shoot was used for the measurements.

Table 1: Leaf water potential (LWP), relative water content (RWC) and midday drop of RWC (ratio of RWC at 800 h to 1330 h) measured 60 DAS (pod formation period) in cowpea genotypes.

Genotypes	*LWP (MPa)*		*RWC (%)*		*Midday drop*
	800 h	*1330 h*	*800 h*	*1330 h*	*of RWC (%)*
CP 1	-0.57	-0.85	89.41	83.75	6.34
CP 2	-0.50	-0.73	95.72	86.74	9.38
CP 3	-0.57	-0.90	92.69	83.95	9.43
CP 4	-0.72	-0.75	93.40	85.96	7.96
CP 5	-0.63	-0.85	95.03	91.33	3.89
CP 6	-0.63	-1.12	95.11	94.16	1.00
CP 7	-0.68	-0.90	94.88	89.29	5.89
CP 8	-0.68	-0.90	93.39	87.78	6.01
CP 9	-0.73	-0.98	94.73	88.06	7.04
CP 10	-0.77	-0.83	94.44	91.32	3.31
CP 11	-0.68	-0.90	91.86	84.89	7.59
CP 12	-0.67	-0.90	89.18	78.80	11.63
CP 13	-0.67	-0.80	91.80	79.86	13.01
CP 14	-0.52	-0.88	91.47	79.70	12.86
CP 15	-0.72	-1.00	96.53	83.84	13.14
CP 16	-0.87	-0.78	90.59	79.75	11.97
CP 17	-0.72	-0.85	92.70	81.38	12.21
CP 18	-0.77	-0.82	90.77	80.73	11.06
CP 19	-0.75	-1.12	92.15	85.59	7.12
CP 20	-0.87	-1.12	99.22	86.41	12.91
LSD ($P < 0.05$)	0.08	0.12	NS	6.48	
CV	7.81	8.05	5.29	4.59	

RWC was estimated by using the following equation (Kumar and Elston, 1992):

$$RWC = (f.wt – d.wt)/(m.wt – d.wt)\,,$$

where $f.wt$, $d.wt$ and $m.wt$ are the fresh, oven-dry and fully-hydrated (maximum) weights of the leaf tissue. Midday drop of RWC was determined as the ratio of RWC at midday (1330 h) to that in the morning (800 h).

For the determination of pod setting ratio, 25 flowers per replication were tagged on the same day, i.e., on the day of measurement of plant water status. Only recently opened flowers were used for the study. Pod setting ratio was calculated as the ratio of the number of flowers tagged to the number of pods formed on the tagged flowers and expressed as per cent. All mature pods in each plot were harvested, and the number of pods/plant, biomass and seed yield/plot was recorded. Biomass and seed yield were converted to values per unit area. The number of seeds/pod (from 20 pods in each plot) and 1000-seed weight were measured.

3 Results and Discussion

Although severe drought seldom occurs during the monsoon season, a long dry spell during the reproductive period (15 September-15 October) of cowpea may cause plant water deficit severe enough to cause reduction in seed yield. The yield reduction is mainly caused by decrease in plant water status due to drought and or excessive transpiration in arid legumes including cowpea (Garg *et al.*, 2005). In this experiment, the water deficit seemed to have developed slowly as evident by narrow differences in LWP and RWC at 800 h (Table 1). However, the differences among the genotypes in LWP and RWC at 1330 h were substantially large and significant. At 1330 h, genotypes CP 6, CP 4 and CP 5 maintained highest (>90%) while genotypes CP 12, CP 14, CP 16 and CP 13 had the lowest RWC (<80%). The genotypic differences in midday drop of RWC were very large ranged from 1-13.14%. The midday drop of RWC was smallest in genotype CP 6 (1%) followed by genotypes CP 10 (3%), CP 5 (3.89%), CP 7 (5.89%) and the remaining genotypes in which the drop ranged from 6.01 to 13.14%. Higher RWC may be maintained either by developing a LWP gradient from soil to plant as displayed by genotypes CP 6, CP 7, CP 8, CP 9, CP 11 and CP 19 or by reduced water loss from the plant organs as displayed by genotypes CP 5, CP 10 and CP 4. The former genotypes had higher ability to extract moisture at low soil water content due to reduced LWP which contributed to the maintenance of higher RWC (Omae *et al.*, 2005a). In cowpea, osmotic adjustment had also been found to be responsible in preventing the detrimental effects of drought in leaves (Sumithra *et al.*, 2007). On the other side, the latter genotypes maintained higher LWP as well as RWC perhaps due to reduced transpiration. The two types of mechanism suggests that the former genotypes may be better for soils where water is available in deeper layers due to their increased water extracting capacity whereas the latter genotypes maintained higher plant water status due to reduced water loss and therefore may perform better under conserved soil moisture conditions.

The per cent pod set, number of pods/plant, seeds/pod, 1000-seed weight, biomass and seed yield showed significant genotypic differences (Table 2). The pod setting was observed more than 50% in genotypes CP 5, CP 6, CP 1, CP 10, CP 4, CP 7, CP 9, CP 2, CP 19, CP 8 and CP 12 while it ranged between 36.7 to 46.7% in the remaining genotypes. Genotypes CP 6, CP 5, CP 10, CP 1, CP 8 and CP 9 produced >20 pods/plant. Most of the genotypes had >10 seeds/pod except genotypes CP 14, CP 11, CP 16 and CP 18 in which the number of seeds/pod was <10. Genotypes CP 14, CP 12, CP 3 and CP 9 displayed the boldest seeds (>150 g 1000-seed weight) while genotypes CP 5 and CP 20 the smallest seeds (<100 g 1000-seed weight). The biomass/m^2 was highest but statistically similar in genotypes CP 15, CP 9 and CP 1 which was significantly higher than the remaining genotypes. Genotypes CP 7, CP 5, CP 8, CP 1 and CP 20 produced seed yield >100 g/m^2, whereas genotypes CP 14, CP 13 and CP 17 <50 g/m^2 seed yield.

LWP or RWC either 800 h or 1330 h did not significantly correlate with either the pod setting ratio, number of pods/plant or the seed yield. However, the midday drop of RWC strongly and negatively correlated with pod setting ratio and number of pods/plant

Table 2: Pod setting ratio, yield-attributes and yield of cowpea genotypes.

Genotypes	*Pod setting ratio (%)*	*Pods/plant*	*Seeds/pod*	*1000 seed weight (g)*	*Biomass/ m^2 (g)*	*Seed yield/ m^2 (g)*
CP 1	66.67	22.78	15.89	109.83	619.05	114.44
CP 2	56.67	15.00	11.17	125.30	311.94	54.09
CP 3	43.33	11.89	10.33	155.85	519.60	60.49
CP 4	60.00	17.11	13.11	124.02	415.51	87.44
CP 5	80.00	27.00	11.89	74.46	371.87	134.32
CP 6	73.33	34.22	11.78	110.15	375.61	93.73
CP 7	60.00	17.89	11.44	138.37	628.70	153.39
CP 8	53.33	22.11	11.89	126.52	502.60	133.38
CP 9	60.00	20.78	11.56	152.94	470.99	128.72
CP 10	66.67	23.22	11.22	103.89	310.81	99.61
CP 11	56.67	16.00	8.89	132.22	307.91	76.13
CP 12	50.00	14.22	10.00	161.16	254.79	72.82
CP 13	40.00	8.11	10.44	147.14	182.13	43.26
CP 14	43.33	10.67	7.56	170.53	221.65	41.80
CP 15	36.67	11.44	11.44	148.02	679.68	90.41
CP 16	40.00	11.44	9.11	116.33	231.95	60.57
CP 17	43.33	11.00	10.22	126.65	305.40	47.10
CP 18	36.67	12.78	9.78	140.26	238.32	51.56
CP 19	56.67	17.11	11.11	107.12	276.91	63.65
CP 20	46.67	13.33	11.56	95.94	446.72	106.05
LSD ($P < 0.05$)	13.93	11.62	3.01	12.40	116.93	38.88
CV	15.69	42.04	16.75	5.82	18.37	27.36

(Fig. 1a,b) and poorly but significantly with seed yield (Fig. 1c). The relationships showed that the genotypes with a smaller midday drop of RWC set higher pods and produced larger number of pods/plant and consequently had higher seed yield as compared with the plants with a larger midday drop of RWC. There are reports that even short diurnal fluctuations in plant water status at the time of fertilization could adversely affect the development and function of reproductive organs (TSUKAGUCHI *et al.*, 2003). The results also showed that pod setting ratio was correlated with the number of pods/plant and seed yield (Fig. 2a,b).

The final test of utilization for a genotype with drought tolerance would be the enhancement of yield performance. Pod setting ratio showed large significant genotypic differences displaying that similar differences may exist in transfer of assimilates to flowers necessary for the development and function of reproductive organs (OMAE *et al.*, 2005a). It is interesting to note that midday drop of RWC showed a strong significant association with pod setting ratio. Genotypes with a smaller reduction in midday RWC set more pods and vice versa.

Figure 1: Relationship between midday drop of leaf relative water content (RWC) and (a) pod setting ratio, (b) number of pods plant^{-1} and (c) seed yield in cowpea. * and ** indicate significance at 1 and 5% level, respectively.

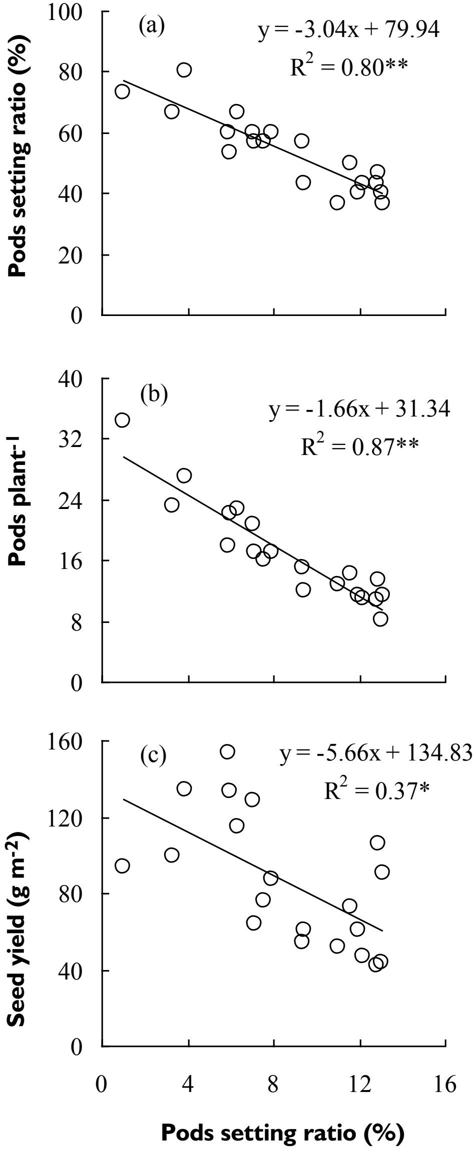
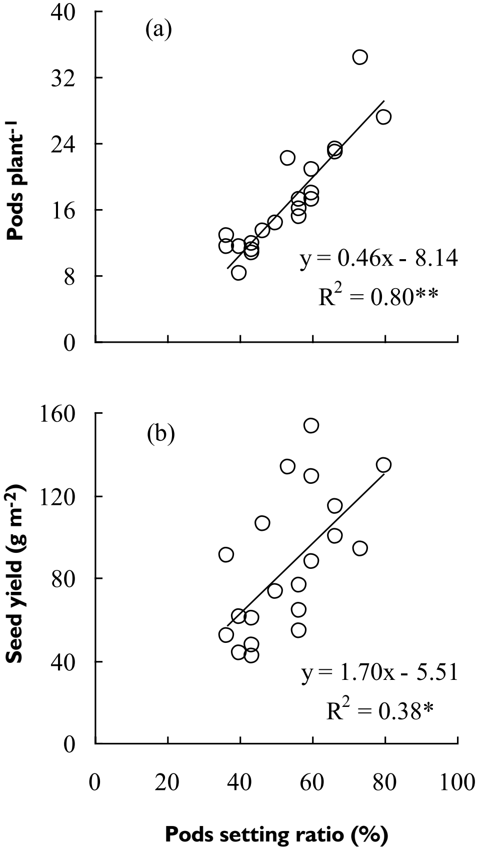


Figure 2: Relationship between pod setting ratio and (a) number of pods plant^{-1} and (b) seed yield in cowpea. * and ** indicate significance at 1 and 5% level, respectively.



Osmotic adjustment and cell wall elasticity enable the plants to maintain higher RWC, turgor and turgor related processes during water deficit (Morgan *et al.*, 1986; Kumar and Singh, 1998; Sumithra *et al.*, 2007). This allowed more pod setting and their survival longer in drought tolerant than susceptible genotypes. In this study, significant genotypic differences were observed in LWP, RWC and midday drop of RWC. But the plants made similar recovery in RWC overnight (as shown by non significant differences in RWC at 800 h), however, the water loss during the day time showed very large differences (1-13%). Therefore, selection for smaller midday drop of RWC in cowpea may be desirable under drought conditions occurring especially during pod formation. The use of midday drop of RWC as a physiological trait to screen cowpea germplasm needs further research particularly on inheritance.

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Ausschreibung des Hans H. Ruthenberg-Graduierten-Förderpreises der Eiselen-Stiftung Ulm

Die Eiselen-Stiftung Ulm schreibt hiermit zum 11. Mal ihren **Hans Hartwig Ruthenberg-Graduierten-Förderpreis** aus, der mit **7.500 €** dotiert ist und höchstens auf drei Preisträger aufgeteilt werden kann.

Einsendeschluß für die Bewerbungen ist der 30. April 2009.

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Journal of Agriculture and Rural Development in the Tropics and Subtropics
Volume 109, No. 2, 2008, pages 201–206

Buchbesprechungen

Sabine Landsrath und Karl Hammer; 2007

Pflanzliche Agrarbiodiversität – eine essayisistische Überarbeitung Friedrich Alefelds "Landwirthschaftlicher Flora" von 1866

Schriften des Vereins zur Erhaltung der Nutzpflanzenvielfalt Band 6. Cremlingen – Schandelah. 164 S., broschürt, A4

In den Jahren von 1850 bis 1870 erlebte die industrielle Entwicklung in Deutschland ihren Durchbruch. Die Folgen der industriellen Revolution für Wirtschaft und Politik sind bekannt, ihre Wirkung auf die gesamte Gesellschaft, auf Natur und Umwelt hält unvermittelt an. Heute, über 140 Jahre nach Erscheinen von Friedrich Alefelds Flora wissen wir, was jener bereits spürte, daß die landwirtschaftliche Biodiversität in dem Maße abnimmt, wie die Industrialisierung voranschreitet.

Es gab damals und gibt auch heute nur wenige professionelle Botaniker, denen die Kulturpflanzen so am Herzen liegen wie jenem hessischen Landarzt. Seinem Wirken als Hobby-Botaniker und Kulturpflanzenforscher verdanken wir exakte Beschreibungen vieler Sorten und Varietäten. Er begründete Unterarten, führte die Kategorie der Varietätengruppe (heute Konvarietät, convar.) in die formale Taxonomie ein und erfaßte die landwirtschaftliche Vielfalt just zu dem Zeitpunkt, als sie in Deutschland ihren Zenit überschritt. Für uns ist es ein Segen, daß er wenig Literatur zu seinem Thema fand, daß er kaum irgendwo abschreiben konnte. Friedrich Alefeld ging den langwierigen und umständlichen aber sauberen Weg: Er knüpfte Kontakte, sammelte Pflanzen, führte eigene Anbauversuche mit ihnen durch, zeichnete seine Beobachtungen auf und publizierte sie. Früh erkannte er, daß verbale Beschreibungen und Zeichnungen auch zur Charakterisierung von Kulturpflanzensorten nicht ausreichen. Daher forderte er eine Typisierung der Varietäten ein, genau wie sie bei den Wildpflanzen seit langem vorgeschrieben ist und allgemein akzeptiert wird.

Die essayistische Auseinandersetzung der Autoren gründet sich auf der Behandlung der jeweiligen Arten durch Alefeld, stellt also keine neuerliche Erfassung und Inventarisierung der Kulturpflanzenvielfalt in Hessen, in Deutschland oder darüber hinaus dar. Sie versteht sich vielmehr als Ausgangsbasis für ein derartiges, durchaus wünschenswertes Unterfangen. Eben dafür ist die Gegenüberstellung der von Alefeld verwendeten und der heute gültigen wissenschaftlichen wie auch der Volksnamen von großem Wert. Die Veränderungen der zurückliegenden über 100 Jahre werden wie in einem Zeitraffer zusammengefaßt, neuere Literatur und Bestimmungshilfen zitiert, vor allem aber Quellen für lebendes Saat- und Pflanzgut der heute selten gewordenen Arten und Sorten genannt. Neben den Genbanken sind dies vor allem die nichtstaatlichen Organisationen, Stiftungen, Vereine und rührige Einzelpersonen, die sich für den Erhalt und für die Nutzung des lebenden kulturellen Erbes engagieren. Allen voran sei der Verein zur Erhaltung der Nutzpflanzenvielfalt (VEN e.V.) genannt, der auch die einzige deutsche Kulturpflanzenzeitschrift mit wissenschaftlichem Anspruch herausgibt, das Samensurium und eben jene Schriftenreihe, in der als Heft 6 die „Pflanzliche Agrarbiodiversität“ erschien (vgl. http://www.nutzpflanzenvielfalt.de).

Möge dieser Band den Anstoß zur Erarbeitung einer „Neuen Landwirtschaftlichen Flora Deutschlands“ geben, in der auch all jene Arten und Sorten verzeichnet und beschrieben sind, die allen amtlichen Sortimentsbereinigungen und Vereinheitlichungsbestrebungen zum Trotz ihren Platz in Landwirtschaft und Gartenbau behaupten, sich neue Wege bahnen oder eben auch immer wieder Liebhaber finden, die sich ihrer annehmen, sie erhalten, vermarkten und nutzen. Wer in Stadt und Land über Hecken und Zäune hinweg mit Gärtnern ins Gespräch kommt wird überrascht sein, neben traditionellen Gewächsen noch oder wieder so viele, zudem oft namenlose Kulturpflanzenarten und -sorten aus benachbarten Ländern, aus dem Mittelmeerraum und selbst aus den Tropen bei uns anzutreffen. Friedrich Alefeld hätte seine helle Freude daran.

Thomas Gladis, Eichstetten a.K.

Reinhard Bindseil; 2008

Ruanda im Leben des Afrikaforschers, Literaten und Kaiserlichen Residenten Richard Kandt (1867 1918). – Historische Darstellung der deutschen kolonialen Präsens im Land der tausend Hügel (1894-1916) in einem biographischen Rahmen.
399 Seiten (davon 132 Seiten deutschsprachiger Text), 14 historische Photos, zahlreiche Kartenskizzen, dreisprachige Ausgabe: Deutsch - Französisch - Englisch, Hrg. vom Ruanda Komitee Trier e.V. in Zusammenarbeit mit der Geographischen Gesellschaft der Universität Trier, GGT - Trier, 2008. ISBN 3-921-599-57-1. Preis: 19,90 €

Le Rwanda vu à travers le portrait biographique de l'explorateur de l'Afrique, homme de lettres et résident impérial Richard Kandt (1867 1918). – Histoire de la présence coloniale allemande au pays de mille collines (1884-1916) dans un cadre biographique.
399 pages (103 pages de texte en Français), 14 photos historiques, de nombreuses cartes, édition en trois langues: allemand - français - anglais, édite par Ruanda Komitee Trier, en collaboration avec la société géographique de 1'Université de Trèves, 2008. ISBN 3-921-599-57-1. Prix: 19,90 €

Rwanda as Depicted in the Biography of Richard Kandt, Explorer of Africa, Man of Letters, and Imperial Resident (1867 1918). – A Historic Portrayal in the Land of a Thousand Hills (1884-1916) in a Biographical Setting.

399 pages (99 pages English text), 14 historical Photos, numerous maps, edition in three languages: German -French - English, published by Ruanda Komitee Trier. in Cooperation with the Geographical Association of the University of Trier, 2008. ISBN 3-921-599-57-1. Price: 19,90 €

Der Autor, selbst einige Jahre als Botschafter der Bundesrepublik Deutschland in Ruanda tätig, stellt hier eine Persönlichkeit vor, die, obwohl heute vergleichsweise wenig bekannt, zu ihrer Zeit Erstaunliches zur Erforschung dieses damals noch relativ unerschlossenen Teils der Kolonie Deutsch-Ostafrika beigetragen hat. Richard Kandt lebte zwischen 1897 und 1914, zunächst als Privatforscher und ab 1907 als „Resident", d.h. offizieller Vertreter des Gouverneurs in Ruanda. Als hervorragender Landeskenner verfasste er das Buch „Caput Nili", das zwischen 1905 und 1921 in sechs Auflagen erschienen ist. Er kann als der eigentliche Entdecker der Nilquelle gelten, denn, während Speke 1858 lediglich konstatierte, dass der Kagera als einziger Zufluss zum Viktoriasee der Ursprung des Nil sein müsse, hat Kandt die Lage der Quelle bestimmt und das Gebiet erforscht und beschrieben. Aufgrund seiner intensiven Studien von Sprache und Kultur erkannte er bereits die tieferen Ursachen des Konflikts zwischen der Tutsi-Minderheit und der unterdrückten Hutu-Mehrheit, der 50 bis 80 Jahre später zu verheerendem Völkermord führen sollte. Allerdings hat er als „Resident" die Herrschaft der Tutsi festgeschrieben, als er in Ruanda als einzigem Gebiet in der Kolonie, die Verwaltung durch „Indirect Rule" einführte. Dies war, wie er ausführte, möglich, da in Ruanda aufgrund der späten Erschließung durch die Kolonialmacht, und im Unterschied zu dem Rest der Kolonie, die traditionellen Strukturen noch nicht zerstört waren. In seiner Zeit als „Resident" hat Kandt nicht nur die Kolonialverwaltung organisiert und die wirtschaftliche Erschließung des Landes vorangetrieben, sondern er konnte auch dem König gegenüber erhebliche zivilisatorische Neuerungen durchsetzen, wie die Abschaffung der Folter und der Todesstrafe. Aus der Beschreibung der Tätigkeiten und der Lebensweise Kandts erfährt der Leser viel über Geschichte, Natur und Kultur des Landes. Der Autor ergänzt dies durch eine chronologische Übersicht deutsch-ruandischer Daten von 1884-2008, sowie eine Beschreibung der Reisen der bekannten deutschen Forscher Franz Stuhlmann, Oscar Baumann, Graf G.A. von Götzen, A.E. Herzog zu Mecklenburg und Hans Meyer.

Reinhard Bindseil, ambassadeur de la République fédérale allemande au Rwanda pendant plusieurs années, présente Richard Kandt une personnalité relativement inconnue aujourd'hui, mais qui, à cette époque, avait beaucoup contribué à la connaissance de cette partie de la colonie allemande de l'Afrique de l'Est. Kandt séjourna au Rwanda entre 1897 et 1914, tout d'abord à titre privé comme chercheur puis après 1907 comme ≪Résident≫ c'est à dire comme délégué officiel du Gouverneur. Il acquit une grande connaissance du pays et rédigea plusieurs écrits dont le plus célèbre ≪Caput Nili≫ réédité six fois entre 1905 et 1921. Il détermina la position géographique de la source du fleuve Kagera comme étant la source du Nil. A partir de ses études fondamentales de la langue et de la culture, il comprit déjà les causes internes du conflit entre la minorité Tutsi et la majorité Hutu opprimée, qui allait aboutir au terrible génocide 50 à 80 années plus tard. Pourtant, comme ≪Résident≫, Kandt permit le renforcement du pouvoir des Tutsis quand il introduisit le système de l'≪Indirect Rule≫ au Rwanda. C'était possible, constate-t-il, parce qu'au Rwanda les structures politiques traditionnelles n'étaient pas encore détruites par le pouvoir colonial appliqué plus tardivement en comparaison des autres régions de la colonie. Pendant sa période comme ≪Résident≫, Kandt organisa l'administration coloniale et renforça la mise en valeur économique du pays. Il fit faire par le roi quelques innovations civiles, par exemple l'abolition de la torture et de la peine capitale. En lisant cette œuvre sur la vie et les activités de Richard Kandt, le lecteur apprendra beaucoup sur l'histoire, la nature et la culture du Rwanda. Le récit est complété par un aperçu de la chronologie germano-rwandaise de 1884 à 2008, ainsi que par une liste des explorateurs allemands au Rwanda de 1890 à 1914, du nom de Franz Stuhlmann, Oscar Baumann, comte G.A. Götzen, A.E. Duc de Mecklenburg et Hans Meyer.

The author, a former Ambassador of the Federal Republic of Germany to Rwanda, introduces a personality who, although rather unknown today, at his time contributed remarkably to the knowledge on Rwanda, a then relatively unexplored part of German East Africa. Richard Kandt lived in Rwanda between 1897 and 1914, as private researcher at first, and from 1907 onwards as "Resident", i.e. official representative of the Governor of the Colony. Having been an excellent connoisseur of Rwanda, he was author of the book: "Caput Nili", which appeared in six editions between 1905 and 1921. He merits to be called true explorer of the source of the Nile, since Speke in 1858 had merely stated that the Kagera River, being the only confluent to Lake Victoria, must be head water of the Nile, whereas Kandt visited the respective location and determined the exact position of the source. Based on his in-depth studies of language and culture he foresaw the underlying causes of conflicts between the Tutsi minority and the oppressed Hutu majority which, 50 to 80 years later, resulted in disastrous genocide. Nevertheless, during his term of administration he confirmed the power of the Tutsi by establishing the system of "Indirect Rule". He was convinced that Rwanda was the only part of the colony where this was possible, since colonial power had been introduced rather late and, in contrast to other parts of the colony, traditional political structures hadn't been destroyed yet. During his term as "Resident" Kandt organized colonial administration, fostered economic progress, and even managed to achieve some civil innovations on the Part of the Tutsi king, like abolishing torture and death penalty. The Story of work and life of Richard Kandt acquaints the reader with numerous facts on Rwandan history, natural environment and culture. The story is complemented by a chronological overview of German-Rwandan relations from 1884 to 2008, and an account of journeys undertaken to Rwanda by famous German explorers, namely, Franz Stuhlmann, Oscar Baumann, Graf G.A. von Götzen, A.E. Duke of Mecklenburg und Hans Meyer.

Eckhard Baum, Witzenhausen

Schmelzer, G.H. & Gurib-Fakim, A. (Editors); 2008

Plant Resources of Tropical Africa 11 (1). Medicinal plants 1.
PROTA Foundation, Wageningen , Netherlands/Backhuys Publishers, Leiden, Netherlands/CTA, Wageningen, Netherlands. 791 pp. ISBN 978-90-5782-204-9/978-3-8236-1532-3 (book + CD-Rom)

Von dem Grossprojekt PROTA(Plant Resources of Tropical Africa), das seit 2004 relativ schnell voranschreitet, sind bisher schon fünf Bände erschienen (von geplanten 16). Jetzt gibt es einen weiteren umfangreichen Teilband, die unter PROTA 11 laufenden Arzneipflanzen (Medicinal plants 1). Der gesamte Komplex Arzneipflanzen ist auf 4 Teile konzipiert.
Afrika ist für die Arzneipflanzen besonders wichtig. Es gibt regelrecht einen Reichtum an Arten, von denen im Teilband 134 wichtige und 272 Arten von gegenwärtig geringerer Bedeutung behandelt werden. Die Beschreibungen zu den Arten entsprechen dem schon bewährten PROTA-Schema. Sie reichen je nach Bedeutung der Art, von einer halben bis zu mehreren Seiten und umfassen den Protolog, die Familie, die Chromosomenzahl, Volksnamen, Herkunft und geographische Verbreitung, Nutzen, Produktion und internationaler Handel, Eigenschaften, Verfälschungen und Ersatz, Beschreibung, andere botanische Information, Wachstum und Entwicklung, Ökologie, Vermehrung, Management, Schädlinge und Krankheiten, Ertrag, Behandlung nach der Ernte, genetische Ressourcen, Ausblick, wichtige Referenzen, andere Referenzen, Quellen für die Abbildungen und Autoren (soweit Informationen zu den einzelnen Punkten vorhanden waren, bei den meisten Arten auch Verbreitungskarten in Afrika). Ein ganzes Heer von Autoren (S. 6 - 12) wird unterstützt durch einen umfangreichen PROTA-Apparat (S. 13 - 14), zu dem einige der aktivsten Autoren gehören. Neben vielen wildwachsenden gibt es auch zahlreiche Kultursippen, wobei diese, wie für die Arzneipflanzen charakteristisch, durch die Kultur meist wenig genetisch verändert sind.
Einen gewissen Eindruck von der behandelten Diversität gewinnt man durch einen Vergleich der hier gebotenene Materialfülle mit der umfangreichsten Welt-Kulturpflanzenflora (Mansfeld's Encyclopedia of Agricultural and Horticultural Crops, P. Hanelt and IPK (eds.), 6 vols., 2001).
Hier erfolgt die Aufzählung der Sippen, die im "Mansfeld" noch nicht erfasst sind, besonders auch, um die Vielfalt zu demonstrieren: *Adenia cissampeloides* (Plach. et Hook.) Harms (Passifloraceae), *Alchornea floribunda* Müll. Arg. (Euphorbiaceae), *Aloe rabaiensis* Rendle, *A. secundiflora* Engl., *A. turkanensis* Christian, *A. volkensii* Engl. (alle Asphodelaceae), *Anthocleista nobilis* G. Don, *A. schweinfurthii* Gilg (beide Loganiaceae), *Bersama abyssinica* Fresen.(Melianthaceae), *Brindelia atroviridis* Müll. Arg. (Euphorbiaceae), *Caesalpinia benthamiana* (Baill.) Herend. et Zarucchi, *C. volkensii* Harms, *Cassia abbreviata* Oliv., *C. angolensis* Welw. ex Hiern. (alle Caesalpiniaceae), *Cavacoa aurea* (Cavaco) J. Léonard (Euphorbiaceae), *Chamaecrista biensis* (Steyaert) Lock (Caesalpiniaceae), *Cissampelos mucronata* A. Rich.(Menispermaceae), *Croton haumanianus* J. Léonard, *C. jatrophoides* Pax, *C. lobatus* L., *C. mubango* Müll. Arg., *C. sylvati-*

cus Hochst. ex C. Krauss (alle Euphorbiaceae), *Detarium microcarpum* Guill. et Perr., *Erythropheum africanum* (Welw. ex Benth.) Harms (beide Caesalpiniaceae), *Euphorbia paganorum* A. Chev., *E. peplus* L., *E. pereskiifolia* Hollet ex Bail. (alle Euphorbiaceae), *Harrisonia abyssicnica* Oliv. (Simaroubaceae), *Holarrhena floribunda* (G. Don) T. Durand. et Schinz, *H. pubescens* Wall. ex G. Don (beide Apocynaceae), *Hymenocardia acida* Tul.(Euphorbiaceae), *Jateorhiza macrantha* (Hook. f.) Exell et Mendoca (Menispermaceae), *Lycium shawii* Roem. et Schult.(Solanaceae), *Mallotus oppositifolius* (Geisler) Müll. Arg. , *Maprounea africana* Müll. Arg. (beide Euphorbiaceae), *Microdesmis keyayana* J. Léonard (Pandaceae), *Ochrosia borbonica* J.F. Gmel. (Apocynaceae), *Penianthus longifolius* Miers, *P. patulinervis* Hutch. et Dalziel (beide Menispermaceae), *Phyllanthus maderaspatensis* L., *Ph. reticulatus* Poir.(beide Euphorbiaceae), *Physalis lagascae* Roem. et Schult. (Solanaceae), *Plumbago auriculata* Lam. (Plumbaginaceae), *Rauvolfia caffra* Sond. (Apocynaceae), *Senna podocarpa* (Guill. et Perr.) Lock (Caesalpiniaceae), *Shirakiopsis elliptica* (Hochst.) Esser (Euphorbiaceae), *Solanum erythracanthum* Dunal (Solanaceae), *Strychnos aculeata* Soler., *St. icaja* Baill. (beide Loganiaceae), *Uapaca guineensis* Müll. Arg. (Euphorbiaceae) und *Voacanga africana* Stapf (Apocynaceae).
Weitere 79 Arten sind im "Mansfeld" vorhanden und werden hier mit meist vielen zusätzlichen Informationen präsentiert. Wenn man die Kultursippen im Sinne "Mansfelds", zuzüglich einiger forstlich und als Zierpflanzen kultivierter Arten, von der Gesamtanzahl der hier behandelten Arten subtrahiert kommt man auf rund 250 Wildarten von Arzneipflanzen, die damit den grössten Teil des vorliegenden Werkes ausmachen.
Hinweise gibt es im vorliegenden Werk nicht nur zur Nutzung als Arzneipflanzen, sondern beispielsweise auch als Gemüse, Heckenpflanze, Fetischpflanze, zur Landschaftsgestaltung und Holzgewinnung.
Der Teilband setzt den hohen Standard des bisherigen Werkes fort. Eine Welt der Vielfalt hinsichtlich der medizinischen Nutzung von Pflanzen wird eröffnet, unterstützt von einem umfangreichen Literaturanhang (S. 635 - 768!). Register der wissenschaftlichen (S. 769 - 781) und der Volknamen (S. 782 - 788, recht bescheiden) schließen das Werk ab.
Gleichzeitig ist eine französischsprachige Version erschienen, die den Gebrauchswert des Buches in und für Afrika noch erhöht. Dem ambitionierten PROTA-Unternehmen ist ein schneller Fortgang zu wünschen.

Karl Hammer, Witzenhausen

Notes to authors

The Journal of Agriculture in the Tropics and Subtropics publishes papers and short communications dealing with original research in the fields of rural economy and farm management, plant production, soil science, animal nutrition and animal husbandry, veterinary hygiene and protection against epidemics, forestry and forest economy.
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Findings should be presented as brief as possible. Publication of a paper in consecutive parts will be considered in exceptional cases.
The following set-up is recommended:
The introduction should be as brief as possible and should concentrate on the main topics of the paper. Reference should be made to recent and important literature on the subject, only.
Materials used and methods applied should be explained briefly. Well-known or established methods and procedures should not be described. New or important methods should be explained. With all its brevity, this part should enable the reader to assess the findings adequately.
Tables and Figures should be used to effectively present the results. Explanations and other remarks on the results can be included in the text.
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The summary should concentrate on the main results and conclusions to highlight the author's contribution. It should be suitable for information storage and retrieval.

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April 2007