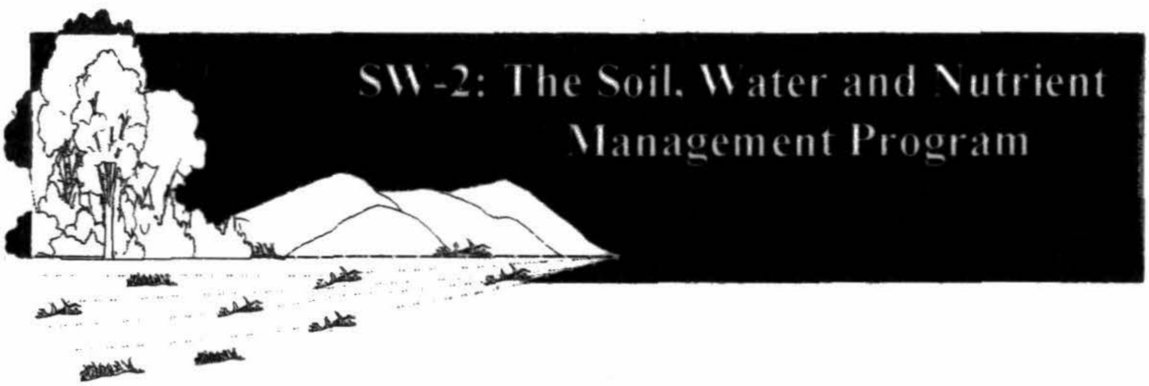

Annual Report
1999

CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

Project SW-2: **Soil, Water, and Nutrient Management (SWNM)**
A systemwide program of the CGIAR

Project overview

Objective: To contribute to long-term increases in agricultural productivity, poverty reduction, and the conservation and enhancement of land and water resources.

Outputs: Economically viable SWNM technologies that are socially acceptable and ecologically sound. Improved methods and diagnostic tools for participatory research. Indicators to monitor the environmental and economic impact of land use systems. Decision support systems, such as models and geographic information systems, for generating and extrapolating options. Stronger institutional capacity to implement SWNM programs and policies. A framework for partnerships between stakeholder groups. Information on appropriate policies to promote sustainable practices.

Gains: Linkages of research on SWNM at key sites within the CGIAR ecoregional programs. Improved research efficiency through collaboration among NARS, IARCs, and SROs (specialized research organizations rather than ARO's) through capacity building. Avoidance of duplication of efforts in SWNM and increased rate of technology development. A core group of resource management scientists. Accelerated scientific progress through sharing of experience, common methods, databases, and models across regions. Strengthened research projects already in place through an integrated approach. Complementation of ongoing research where knowledge gaps exist and provision of new knowledge required to improve natural resource management worldwide.

Milestones:

1998 Four research consortia active in Latin America (1), Africa (2), and Asia (1). Three training courses held on aspects of soil degradation in Asia, Africa, and Latin America. Publication on methods for watershed selection and on economic assessments of soil erosion.

1999 Database on use of organic resources for small-scale farmers. Guidelines for integrated nutrient management published. DSSAT models improved for use in tropical soils. Indicators of soil quality identified and compared with local knowledge. Research data from the MAS project in Brazil published as a book.

2000 Guidelines available for optimizing soil water use. Water and nutrient fluxes determined in watersheds under different land use management practices. Recommendations available for management of natural resources in areas of high risk from land degradation. Validation of soil quality indicators.

2001 Cadre of local scientists, farmer groups, extension workers trained in development of local solutions to SWNM constraints in the four consortia.

Independent community-based investigations established by four consortia in benchmark areas.

Users: Farmers and other land users, NARS, extension workers, NGOs, and community-based groups.

Collaborators: IARCS, TSBF, IBSRAM, IFDC, ICRISAT, ICARDA, IITA, ICRAF, ORSTOM, NARS, universities and advanced research organizations of the four SWNM consortia.

CG System linkages: Saving Biodiversity (5%), Increasing Productivity (35%), Protecting the Environment (35%), Strengthening NARS (15%), Improving Policies (10%).

CIAT project linkages: Confronting soil degradation (PE-2); Watershed resource management (PE-3); Land use studies (PE-4); Smallholder systems (PE-5); Participatory methods (SN-3).

Purpose:
The program's primary objective is to develop effective, ecologically sound technologies and systems for land management and conservation. Related objectives are to:

- Develop, test and promote new, community-based institutional mechanisms that encourage the use of sustainable technologies
- Through research partnerships, enhance the capacity of stakeholders to plan and implement programs on sustainable land management
- Develop and promote policies that address equity issues such as gender, access to resources and, land tenure.

Rationale:
As global food production has expanded to meet growing demands, the soils of both marginal and fertile lands have suffered. The effects of degradation, which also bring problems of water quantity and quality, cannot always be compensated, even partially, by applying fertilizers. Instead, natural soil fertility must be maintained, conserved and enhanced, requiring increased research emphasis on soil, water and nutrient management. The SWNM program addresses this challenge by bringing together four complementary research consortia.

The SWNM program was approved by the TAC of the CGIAR in 1996. The four consortia of the program with their target areas and regions are presented in Table 1.

Table 1. The consortia of the SWNM program

Consortium	Target area	Conveners
Combating Nutrient Depletion (CNDC)	East and West Africa	TSBF, IFDC, KARI and ARI
Managing Acid Soils (MAS)	Latin America	CIAT and EMBRAPA
Managing Soil Erosion (MSEC)	S-East Asia	IBSRAM and CSAR
Optimizing soil water use (OSWU)	West/North and Sub-Saharan Africa	ICRISAT, ICARDA and IER

The GCIAR has no formal reporting requirements for Systemwide Programs (SWP's) other than an annual financial report. However the SWNM program does present a progress report to the CGIAR and its donors at the Mid-Term meeting held annually during May. In addition from 1998 CIAT has included the SWNM program in its set of project profiles and is reported as project SW-2. Information about the SWNM program has been placed on the CIAT home page on the internet.

Following the guidelines of the CGIAR on systemwide programs, CIAT has three roles in the SWNM program.

- As a host institute, i.e., houses the secretariat and provides financial accounting.
- As a co-convener of the program CIAT has responsibility for facilitation, coordination and representation. It plays a major role in establishing the program and its development.
- As a lead institute CIAT leads a specific technical and management component. This is the MAS consortium.

The SWNM program's logframe is presented below and is still under development pending contributions from the four research consortia.

Summary	Indicators	Means of verification	Important assumptions
Goal: To contribute to the long-term increases in agricultural productivity, poverty reduction and the conservation and enhancement of land and water resources	Agricultural production increased in benchmark sites. Farmer's income increased. Land degradation halted or decreased.	Agricultural census data Human welfare statistics	
Purpose: Effective,	20% of farmers in	Surveys of land use	Policy environment

ecologically sound technologies and systems for sustainable land management and conservation developed, disseminated and implemented by land users.	target areas adopt at least one new SWNM technologies per consortium through individual and community-based actions . Information on SWNM technologies published.	practices. Lists of publications, web pages. Bulletins and brochures.	is favorable for the adoption of improved SWNM technologies. Farmers are reached through NARES and IARC's. NARES have the means to disseminate technologies and information
Outputs: Technologies and tools for improved Soil, Water and Nutrient Management developed. Community-based institutional mechanisms that encourage use of sustainable land management practices developed, tested and promoted. Capacity of stakeholders to plan and implement research programs on sustainable land management enhanced. Policies that address equity issues, access to resources, and land tenure developed.	At least two new or improved SWNM technologies developed by each of the 4 research consortia. Each consortium has established at least one community-based organization in each target area or study site . X number of farmers, NARES personnel, policy makers trained. At least four training manuals and guidelines for SWNM produced Guidelines and decision support systems developed	Publications in international journals. Manuals and decision support tools. Annual reports. Annual reports, newsletters and bulletins Numbers of training courses, field visits held. Numbers of personnel trained. Institutional reports. Policy guideline documents. Publications in international journals	External funding levels are maintained. Benchmark sites established and maintained with partners. Community-based groups continue with their own resources. Institutions within each consortium maintain their matching support for the SWNM program. NARES have means to execute programs Policy makers are open to dialogue with SWNM program

Activities: Output 1: 1.1 On-farm and on-station experiments on SWNM. 1.2 Develop and test decision support tools for improved water and nutrient use efficiency. 1.3 Develop and test sets of land quality indicators.	Number of experiments and trials established At least one decision support tools developed by each consortium At least two sets of land quality indicators available for two different agroecosystems	Annual reports Publications Decision support tools available via guidelines, computer programs. Annual reports, bulletins Land quality monitoring systems in use by land users.	Appropriate mix of inter-disciplinary scientists maintained within each consortium. Continued accessibility to benchmark sites. Farmers maintain their interest in experiments on their farms.
Output 2: 2.1 Test and refine methods for participatory research in SWNM.	Number of participatory groups conducting SWNM research	Annual reports, bulletins Publications in international journals	
Output 3: 3.1 Training courses on SWNM technologies. Student theses projects.	Number of training courses held, number of students enrolled for higher degrees	Lists of training courses and trainees. Theses available in libraries.	Trained staff remain in NARES
Output 4: 4.1 Models and decision support tools developed for improved SWNM policies.	Number of decision support tools and models. Number of meetings held with policy makers	Computer models and decision support tools available. Publications in international journals	

Highlights of the overall SWNM program

(To be completed on receipt of reports from other consortia

Highlights of the MAS project

Progress towards achieving milestones of the SWNM

SWNM:

The TAC have stated that the primary test of a systemwide program must be that it enhances cooperation, thereby improving the work of the CGIAR system.

The SWNM program now involves over 60 different organizations, made up of NARS, NGO's, SRO's and IARC's, who operate within the four SWNM consortia. In addition to this we have estimated that for every $ that enters the SWNM from the donors another $4-5 is leveraged either in the form of matching funds, usually staff time and facilities, or as additional special projects submitted to non-traditional sources (at least with respect to the CGIAR donors). An example is a project from the German Science Foundation that supports students from Bayreuth University participating in the MAS project in Brazil. Another is a successful project bid by the MSEC to the Asian Development Bank. For these aspects alone the SWNM can be considered to be successful.

The MSEC has published a sloping land management handbook and an on-farm resource assessment methods handbook. These are essentially tools for conducting participatory SWNM research. MSEC has also published a document on the analysis of the impact of soil erosion (Enters, 1998). IFDC, as part of the CNDC, has developed refined maps for nutrient depletion in Africa. TSBF has produced an Organic Resources Database and a Decision Support Tool for the use of organic materials.The MAS consortium has published two books one on agropastoral systems and another on land management in the savannas of Latin America.

Progress towards achieving milestones of the MAS consortium :

The MAS consortium initiated its first project in 1996 in the Brazilian and Colombian savanna ecosystem. The work breakdown structure of this multi-institutional and inter-disciplinary project is presented in Figure 1. There is deliberate overlap with the outputs and activities of project PE-2 in order to place CIAT's efforts on Soil, Water and Nutrient Management into a broader context both within Latin America and also in other regions of the world via across-consortia activity under the overall SWNM systemwide program. It also represents the "main streaming" of systemwide activities into CIAT's project portfolio as originally envisaged by TAC.

In 1999 the first MAS project was completed and in August 1999 a new effort was initiated in Central America. Institutional representatives from Nicaragua and Honduras met separately to define the needs and priorities for SWNM activities. Representatives were drawn from NARES, NGO's and universities. A consortium meeting was then held in Honduras August 11-12, 1999 to bring together the two sets of prioritized topics with the priorities of the overall SWNM program. A new steering committee was elected with two members each from Honduras and Nicaragua. The group is now developing its strategic plan and project workplan. The group also re-named the MAS consortium as the MIS consortium (maneji Integrado de Suelos).

Figure 1. Work breakdown structure of the MAS project linking activities to outputs.

PROGRAM GOAL
To maintain or improve the natural resource base and preserve the biodiversity of natural ecosystems while increasing agricultural productivity of tropical acid soils

?

PROJECT PURPOSE
To achieve environmental protection during intensification of agriculture on acid-soil savannas of Latin America via the development of technologies that conserve the soil resource base and limit adverse environmental effects

?

Output 1: Identification of the driving forces behind land use changes	Output 2: Improved soil quality and more efficient agropastoral/ rotation systems	Output 3: Assessment of the impact of improved systems on environmental quality	Output 4: Sustainable prototype systems designed and validated through farmer participation	Output 5: Greater institutional capacity through information exchange and training
Activities: 1.1 Characterize land use change and identify driving forces using farm surveys and GIS analysis 1.2 Evaluate economic viability of current land use systems 1.3 Determine farmer perception of on- and off-site environmental impacts 1.4 Document and analyze adoption of existing technologies and farmer demand for new technologies 1.5 Use participatory field diagnosis and GIS analysis to target and increase adoption of sustainable technologies 1.6 Ex-ante analysis of potential technological and policy interventions using multiple objective models to quantify trade offs between farmer and ecological objectives.	Activities: 2.1 Identify and quantify controls on organic matter, nutrient and water dynamics in traditional and improved production systems 2.2 Assess and quantify principal soil degradative processes (erosion, compaction, nutrient imbalances) 2.3 Estimate contribution of soil biota to nutrient cycling and soil physical conditions 2.4 Estimate effects of management and inputs on sub-soil chemistry and root development	Activities: 3.1 Quantify impact of improved systems on: - Greenhouse gas emissions (CO_2, CH_4, NO_x) - C storage/loss from soils - Fate of agrochemicals - Water quality 3.2 Assess on-farm environmental impact using land quality indicators. 3.3 Economic evaluation of selected off-site environmental impacts	Activities: 4.1 Select components and systems through farmer participation; validate prototype systems on-farm 4.2 Assess nutrient balances on- and off-farm and on a regional basis 4.3 Calibrate, validate and refine crop and pasture models on nutrient dynamics and productivity over the long term 4.4 Identify and test methods of soil restoration to improve soil quality	Activities: 5.1 Prepare and publish a start-of-the-art document on management of acid soils 5.2 Organize workshops: - Of collaborators for project development, monitoring and information exchange - To transfer knowledge gained to stakeholders (in conjunction with national partners) 5.3 Publish bulletin/newsletter on acid soil research 5.4 Cadre of personnel trained in management of acid soils

Output 1: Identification of driving forces behind land use change

Activity for this output was essentially finished in 1998 and has been reported on previously in 1997/98. See publication list for details.

Output 2: Improved soil quality and more efficient agropastoral/rotational systems

Outputs 2.1 and 2.4 are reported here together

2.1 Identify and quantify controls on organic matter, nutrient and water dynamics in traditional and improved production systems

2.4 Estimate effects of management and inputs on sub-soil chemistry and root development

Four topics from activities in the Brazilian cerrados are reported here namely;

i) Partitioning of Phosphorous, Sulphur, and Molybdenum in Differently Used Brazilian Savannah Oxisols,

ii) Nutrient Storage in Above-Ground Biomass of the Cerrado Vegetation.

iii) Annual Course of Matric Potential in Differently Used Savanna Oxisols, Brazil.

iv) Soil Acidification in *Pinus caribaea* forests on Brazilian Savanna Oxisols.

Partitioning of Phosphorous, Sulphur, and Molybdenum in Differently Used Brazilian Savannah Oxisols.

Summary

The plant nutrients P, S, and Mo mainly occur as oxyanions in soils which may be strongly sorbed in Oxisols due to the high positive surface charge. The objective of this work was to compare P, S, and Mo concentrations and partitioning in differently used Oxisols with similar properties in an on-farm experiment. Soil samples (0-0.15 m) were taken from three replicate plots of each of conventional tillage (CT) and no-till (NT) maize/soybean and conventional tillage sugarcane (SC) cropping systems, degraded (DP) and productive (PP) pastures, *Eucalyptus* (EU) and *Pinus* (PI) reforestations, and native savannah (CE). The samples were sequentially extracted with (1) 0.5 M $NaHCO_3$, (2) 0.1 M NaOH, (3) 1 M HCl, (4) hot concentrated HCl, and (5) concentrated $HClO_4/HNO_3$. In the extracts inorganic (P_i) and total P, S, and Mo were determined. Organic P (P_o) was calculated as total P-P_i. Total concentrations were 333-567 mg P kg^{-1}, 231-284 mg S kg^{-1}, and 3.2-3.9 mg Mo kg^{-1}. The most important fractions in all studied systems were the NaOH-fraction for P (38-49 % of total P), the $HClO_4/HNO_3$-fraction for S (27-35 % of total S) and the concentrated HCl-fraction for Mo (86-90 % of total Mo). The proportion of the plant-available $NaHCO_3$+NaOH fractions decreased along the line S > P > Mo. Fertilisation increased plant-available P and S fractions in CT and NT whereas recalcitrant ones (concentrated HCl and $HClO_4/HNO_3$) remained unchanged. P_i/P_o ratios in NT and CT were higher than in CE because fertilizer P mainly accumulated in inorganic P fractions. The pasture had lower P concentrations indicating export by grazing. Thus, 12-20 years of land use had marked effects on P, smaller ones on S, and almost none on Mo concentrations and partitioning.

Introduction

Large parts of the Brazilian savannah region (the *Cerrados*) are covered by nutrient-poor Oxisols with low P, S, and Mo concentrations. As a consequence of the positive charge of Fe oxides which occur in high concentrations in Oxisols, P is strongly sorbed resulting in low plant-available P concentrations. In soils, S and Mo also mainly exist as oxyanions. Therefore, it is likely that these plant nutrients also are strongly retained in Oxisols. In strongly weathered Oxisols, only organic and in Fe oxides occluded P forms are found in more than trace amounts. In Colombian soils under natural savannah about half of total P was found in recalcitrant fractions extractable with strong acids. Only 11 % could be considered as plant-available (Friesen et al., 1997).

Land-use impacts on P concentrations and partitioning in both, temperate and tropical soils, have been studied by various authors. Generally, in unfertilised cropping systems total P concentrations decrease and organic P fractions are the major source for plant-available. In fertilised systems, labile inorganic P fractions ($NaHCO_3$-P_i and NaOH-P_i) increase and fertiliser P is slowly transformed into more strongly bound P forms whereas organic P concentrations remain unchanged.

Information on S and Mo partitioning in tropical soils and on land-use effects on S and Mo concentrations and partitioning is scarce. Few studies deal with the impact of S fertilizing on S forms in soils. In an Cerrado Oxisol, detectable KCl-extractable sulphate was only found after liming or addition of organic materials (Mottavalli et al., 1993). Most information about the land-use impact on P and S were obtained in controlled studies on research stations ("on-station"). The results may not necessarily be transferable to "on-farm" conditions.

The objectives of this work were (1) to determine the P, S, and Mo concentrations and partitioning in differently used savannah Oxisols and (2) to asses the land-use influence on P, S, and Mo pools in an on-farm experiment. We used a sequential extraction procedure developed to partition P in soils also to extract S and Mo because of the chemical similarity of the elements.

Materials and Methods

Study sites

The study area is located southeast of Uberlândia (Minas Gerais, about 400 km S of Brasilia. Within an area of about 100 km², three spatially disconnected plots of each of eight systems representing the most important land-use systems of the study region were selected: (1) conventional tillage maize/soybean rotation (CT, annual ploughing with plug and disk harrow, one harvest per year: maize (*Zea mays* L.)-soybean (*Glycine max* L. Merr.) rotation, (2) no-till maize-soybean rotation (NT, two harvests per year, first soybean, second maize, (the two maize-soybean systems are annually fertilised with about 100 kg P ha^{-1}, 30 kg S ha^{-1}, 0.1 kg Mo ha^{-1}, the second crop in NT received additional 50 kg P ha^{-1}, 15 kg S ha^{-1}, 0.05 kg Mo ha^{-1}), (3) conventionally-tilled sugarcane (SC, *Saccharum officinalis* (L.), initial fertilisation of 100 kg P ha^{-1}), (4) degraded pasture (DP, *Brachiaria decumbens* Stapf, partly open soil, some invasive Cerrado plants, initial fertilisation with 60 kg P ha^{-1}.), (5) productive pasture (PP, *Brachiaria decumbens* Stapf, pure grass, initially fertilised with 60 kg P ha^{-1}, further with 25 kg P ha^{-1} every four years), (6) *Pinus caribaea* Morelet plantation (PI), (7) *Eucalyptus grandis* W. Hill ex Maiden plantation (both forest plantations were initially fertilised with 80 g Superphosphate per plant corresponding to 25 kg P ha^{-1}). Native savannah soils (*Cerrado*, CE) were used as references (8). All study sites are continuously used for the same purposes for 20 (PI, EU), 12 (DP, PP, CT), or 1-6 years (SC) and passed directly from natural vegetation to the current land-use system except for the NT soils which were used as conventionally tilled cropping systems for 9-11 years and the SC soils which were used as pastures 6-11 years prior to the present land use. We only chose plots at comparable topographic positions with macroscopically similar soils. A prerequisite for statistical evaluation is the independence of the replicates. Although a completely randomised distribution of the study plots could not be realised, because we had to use the existing systems, we consider the statistical prerequisites for variance analysis to be met as the minimum distance between two replicates of the same system is 300 m.

Composite samples (0-15 cm) consisting of 5 subsamples were taken from 10x10 m^2 plots of each of the three replicates per system at the end of the rainy season in April 1997. All samples were air-dried (40° C) and sieved to < 2 mm.

Chemical and physical characterisation
Particle-size distribution was determined after removal of Fe oxides with Na-dithionite and organic matter with H_2O_2 at 90 °C and following dispersion with hexametaphosphate. Coarse and fine sand were sieved to 250-2000 and 50-250 µm, respectively. Silt and clay concentrations were determined with the pipette method.

The following soil properties were determined: pH with a glass electrode in H_2O and 1 M KCl, soil:solution ratio 1:2.5, total concentrations of C, N, and S by dry combustion and gas chromatographic separation with a CNS analyser (Elementar Vario EL), effective cation exchange capacity (ECEC) by extracion with 1 M NH_4-acetate, Al in poorly ordered Fe oxides with the oxalate-buffer method (Al_o,), crystalline Fe oxides with the cold dithionite-citrate-buffer (DCB) method (Fe_d,). Metal concentrations in the extracts were determined with flame atomic absorption spectrometry (Varian SpectrAA 400).

Phosphorous, sulphur, and molybdenum fractionation
The fractionation scheme of Hedley et al. (1982) in a modified version was used to sequentially partition soil P, S, and Mo into 5 fractions. The fractionation scheme and an approximate characterisation of the obtained fractions are given in Fig. 2.

Total P and S concentrations in the extracts were determined with inductively coupled plasma-atomic emission spectroscopy (ICP-AES, GBC Integra XMP). Total Mo was measured with inductively coupled plasma-mass spectroscopy (VG Plasmaquad PQ2 -Turbo+MS, VG Elemental).

Calculations and statistical analyses

The sum of the P, S, and Mo concentrations in the sequential extracts was taken as total concentration. Total S concentrations were determined independently as given above.

Main and interactive affect means were tested by using Tukey's honestly significant difference (HSD) mean separation test. Statistical analysis was conducted with STATISTICA for Windows 5. The significance level was set at $p < 0.05$.

Extraction solution	**Pool**
1 g soil	
$0{,}5$ M $NaHCO_3$	Plant available Pi, Po, S, Mo
Residue	
$0{,}1$ M NaOH	Medium-term plant-available Al assoiciated P_i, P_o, S, Mp
Residue	
1 M HCl	Ca associated P, S, Mo
Residue	
Hot conc. HCl	In Fe oxides occluded P, S, Mo
Residue	
$HclO_4$-HNO_3- Digestion	Residual fraction

Figure 2: Fractionation scheme (Thiessen and Moir, 1993, modified).

Results and Discussion

Comparability of the soils

Differences in concentrations and partitioning of P, S, and Mo between land-use systems can only be interpreted as caused by land-use practices if the soils were comparable prior to the beginning of land use. To test this prerequisite we compared soil characteristics which are not or only little influenced by land use like soil type, particle-size distribution, and Al_o and Fe_d concentrations.

All soils are anionic Acrustoxes with about 70-80 % of clay. Concentrations of clay, Fe_d, and Al_o do not differ significantly between the land-use systems (Tab. 2). Additionally, the standard deviations of Fe_d and Al_o concentrations, between the replicate plots of one system (Fe_d: 9.1, Al_o: 0.27, n=3) are similar to those between all plots (Fe_d: 9.2, Al_o: 0.33, n=24). We, therefore, assume that the soils had comparable properties prior to land use and differences can be interpreted as result of land-use practices.

Table 2 : Average properties of the study soils (0-15 cm).

	C	N	PH	pH	ECEC[a]	Fe_d[b]	Al_o[c]	Clay
	---[g kg^{-1}]---		($H_2$0)	(KCl)	[mmol$_c$ kg^{-1}]	[g kg^{-1}]		[mg kg^{-1}]
Cerrado (CE)	24.8	1.42	4.71	3.99	4.8	42.23	3.45	680
Degraded Pasture (DP)	20.1	1.11	4.74	4.53	3.6	40.60	4.68	820
Productive Pasture (PP)	23.0	1.35	4.89	4.10	8.0	39.37	3.62	780
Eucalyptus (EU)	24.6	1.43	5.38	4.40	14.7	34.17	3.50	690
Pinus (PI)	21.8	1.38	5.91	5.02	35.1	40.50	3.20	730
Conventional Tillage Sugarcane (SC)	21.1	1.33	6.16	5.41	39.6	45.63	3.12	810
No-till Maize-Soybean (NT)	23.8	1.39	5.12	4.22	11.5	41.63	3.47	720
Conv. Tillage Maize-Soybean (CT)	23.3	1.40	5.69	4.57	18.2	40.58	3.50	690

[a] Effective cation exchange capacity
[b] Dithionite-citrate extractable Fe
[c] Oxalate-extractable Al

Concentrations and partitioning of P, S, and Mo

Total concentrations of P, S, and Mo range between 333 and 567 mg kg^{-1}, 231 and 284 mg kg^{-1}, and 3.2 and 3.9 mg kg^{-1}, respectively (Tab. 3). Compared with concentrations found in agriculturally used surface soils of the temperate regions (P: 500-3000 mg kg^{-1}, S: 400-500 mg kg^{-1},), P and S concentrations are low, but P concentrations are about two times higher than those Friesen et al. (1997) reported for Colombian Oxisols.

Total S concentrations are not significantly different between the sum of the sequential extraction and the dry combustion and gaschromatographic detection with the CNS analyser indicating a quantitative and reproducible S extraction with the sequential extraction (Tab. 3).

The distribution of P, S, and Mo among the fractions of the Hedley sequence is element-specific (Fig. 3). The partitioning is similar in all studied land-use systems. The largest P fraction is extracted with NaOH, followed by similar proportions extracted with concentrated HCl and $HNO_3/HClO_4$. No P was detected in the dilute HCl fraction because Ca-phosphate is absent in many strongly weathered soils. The $NaHCO_3$-extractable proportion of total P concentrations in the study soils (4-5%) is small compared with those in soils of the temperate region but also compared with those in other Oxisols as reported by Friesen et al. (1997) who detected about 8-20 % of total P in the $NaHCO_3$-fraction.

The largest S fraction is the $HNO_3/HClO_4$ fraction. The proportions of extracted S decrease along the line NaOH > concentrated HCl > $NaHCO_3$ > dilute HCl. Sulphur is the only of the studied elements which was found in the dilute HCl fraction.

Most of the Mo is extracted with the concentrated HCl fraction, followed by decreasing proportions in the NaOH and $HNO_3/HClO_4$ fraction. However, we did not detect any Mo in the plant-available $NaHCO_3$- and dilute HCl-fractions.

Table 3: Average P, S, and Mo concentrations in the fractions of the sequential extraction. Values followed by different letters are significantly different between the land-use systems at $P < 0.05$ (Tukeys HSD test).

a) Phosphorous

	$NaHCO_3$-P_i	$NaHCO_3$-P_o	NaOH-P_I	NaOH-P_o	1 M HCl-P	HCl_{conc}-P	HNO_3/HNO_4-P	P_{tot}[a]
	[mg kg^{-1}]							
Cerrado (CE)	6.7a	10.9a	41.5a	101.2a	nd	120ab	108a	388a
Degraded Pasture (DP)	5.8a	11.1a	40.0a	88.9a	nd	114ab	83b	341a
Productive Pasture (PP)	6.2a	14.7a	40.5a	96.6a	nd	97b	78b	333a
Eucalyptus (EU)	9.6ab	10.7a	70.0a	110.9a	nd	115ab	87b	403a
Pinus (PI)	9.6ab	7.3a	47.9a	118.7a	nd	95b	82b	361a
Conventional Tillage (SC)	6.5a	7.6a	51.4a	103.4a	nd	114ab	87b	370a
No-till Maize-Soybean (NT)	19.1b	9.0a	159.5b	120.4a	nd	172a	87b	567b
Conv.Tillage Maize-Soybean (CT)	14.1ab	6.0a	119.9ab	117.9a	nd	158ab	84b	500ab

b) Sulphur

	$NaHCO_3$-S	NaOH-S	1 M HCl-S	HCl_{conc}-S	HNO_3/$HClO_4$-S	S_{tot}[a]	CNS-S[b]
	[mg kg^{-1}]						
Cerrado (CE)	30.8ab	57.3a	20.4a	47.6a	83.2a	239a	247a
Degraded Pasture (DP)	36.8ab	57.2a	21.5a	50.6a	64.9a	231a	242a
Productive Pasture (PP)	36.6ab	64.6ab	21.6a	49.7a	68.9a	241a	263a
Eucalyptus (EU)	34.6ab	60.5a	20.6a	41.2a	80.4a	237a	249a
Pinus (PI)	42.9ab	55.9a	20.6a	35.9a	80.4a	236a	236a
Conventional Tillage (SC)	27.8b	62.9ab	21.0a	44.5a	84.4a	240a	242a
No-till Maize-Soybean (NT)	59.3a	74.5b	23.7a	51.8a	75.2a	284a	277a
Conv. Tillage Maize-Soybean (CT)	29.5ab	64.4ab	25.2a	51.3a	69.1a	239a	247a

c) Molybdenum

	$NaHCO_3$-Mo	NaOH-Mo	1 M HCl-Mo	HCl_{conc}-Mo	HNO_3/$HClO_4$-Mo	Mo_{tot}[a]
	[mg kg^{-1}]					
Cerrado (CE)	nd	0.29a	Nd	3.01a	0.17a	3.46a
Degraded Pasture (DP)	nd	0.24a	Nd	3.16a	0.12ab	3.53a
Productive Pasture (PP)	nd	0.28a	Nd	2.83a	0.10b	3.21a
Eucalyptus (EU)	nd	0.32a	Nd	3.07a	0.12ab	3.50a
Pinus (PI)	nd	0.40a	Nd	2.92a	0.09b	3.41a
Conventional Tillage (SC)	nd	0.26a	Nd	2.98a	0.11b	3.35a
No-till Maize-Soybean (NT)	nd	0.41a	Nd	3.24a	0.12ab	3.77a
Conv. Tillage Maize-Soybean (CT)	nd	0.44a	Nd	3.37a	0.10b	3.92a

[a]P_{tot}, S_{tot}, Mo_{tot} = sum of the fractions of the extraction sequence,
[b]CNS-S = total S concentrations determined with a CNS-analyzer.

The proportions of the directly plant-available fraction $NaHCO_3$ decrease on average along the line S > P > Mo, those of the medium-term plant-available NaOH fraction are similar for S and P and smaller for Mo. For all studied elements and in all studied soils, high proportions (50-90 %) of total concentrations are detected in the strongly bound fractions extracted with concentrated HCl and HNO_3/$HClO_4$, consisting of P, S, and Mo occluded in Fe oxides. Friesen et al. (1997) only extracted 40-50 % of total P with these recalcitrant fractions, probably due to smaller concentrations of Fe oxides in the studied coarser-textured soils.

Land-use influence on P, S, and Mo concentrations and partitioning

The land-use influence is most apparent for P, it is smaller for S and Mo. Total P in NT and CT soils is 64 and 28 % higher, respectively, than in CE due to the regular fertilisation. However, there are no differences in total P concentrations between SC and CE, because of the low fertilisation rate in SC and the short time the soils are used for surgarcane production. Pasture soils (DP and PP), in contrast, have about 12-15 % smaller concentrations of total P than soils in CE. This may be attributable to the removal by grazing if the assumption of similar geogenic P concentrations is true.

The land-use influence is stronger on the plant-available P fractions extracted with $NaHCO_3$ and NaOH than on the more strongly bound fractions. In NT, CT, and EU, 104 %, 68 %, and 29 % more P is extracted from soil with these fractions, respectively, than in CE. Phosphorous concentrations in the concentrated HCl-fraction of the NT and CT -soils are higher than in CE soils. Although the differences are not significant, this may indicate the transformation of fertiliser P into less plant-available P fractions.

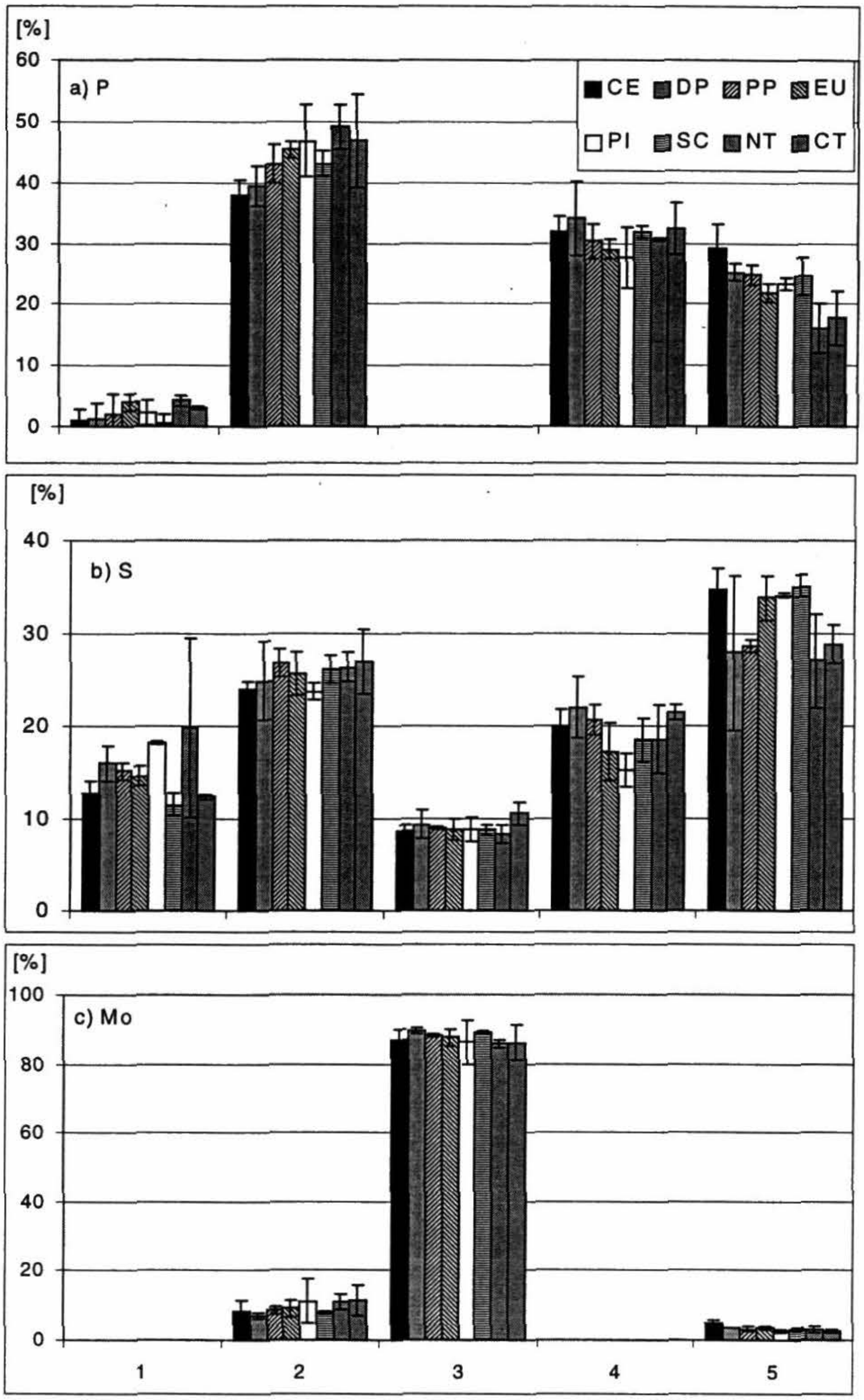

Figure 3: Average partitioning of P, S, and Mo among the fractions of the sequential extraction and standard deviations (n = 3) in soils of conventional tillage (CT) and no-till (NT) maize/soybean rotations, conventional tillage sugarcane (SC), *Eucalyptus* (EU) and *Pinus* (PI) plantations, degraded (DP) and productive pastures (PP), and natural savannah (CE).

Phosphorous concentrations in the recalcitrant $HNO_3/HClO_4$-fraction are not significantly different between the land-use systems. However, the soils in CE contain significantly higher P concentrations in this fraction than those in the other systems. As it seems unlikely that strongly bound P has been removed from the systems, the higher P concentrations in CE may only be explained by geogenically higher P concentrations. For all other soils similar P concentrations in the $HNO_3/HClO_4$-fraction indicate similar geogenic P concentrations underlining the above assumption that differences in total P concentrations between the pasture soils and the other systems are attributable to removal by grazing.

The two plant-available fractions are the only ones containing organic P. The plant-available P_i fractions are higher in NT and CT than in CE. The differences are significant between CE and NT only. Organically bound P fractions, in contrast, do not differ significantly between the cropping systems and CE. This resulted in a change of the P_i/P_o ratios. Whereas in CE about 70 % of P in $NaHCO_3$+NaOH-fractions is organic, the proportion in NT and CT is < 50 %.

Higher S concentrations are found in the $NaHCO_3$- and NaOH-fractions of NT than CE soils. The differences are significant for the NaOH-fraction only. Sulphur in the dilute HCl fraction and total S also tend to be higher in the cropping systems but differences are smaller than for P and not significant. This probably is attributable to smaller amounts of S fertilisers applied to the systems and to stronger leaching of the applied S. There are no significant differences in total S concentrations and any S fraction between CT and CE. This may be related with the lower fertilisation rate in CT where no second crop is grown. Another reason may be stronger sulphate leaching in CT than in NT because CT is unvegetated for a longer period than NT, particularly at the end of the rainy season.

There are no significant differences in total Mo concentrations between the systems. Like P, Mo concentrations in the $HNO_3/HClO_4$-fraction are significantly higher than in most of the other systems probably also due to higher geogenic concentrations. In NT NaOH-Mo concentrations in soil are slightly higher than in CE soils, however, the differences are not significant.

It was not possible to distinguish between inorganic and organic S and Mo forms because of the low concentrations of the respective oxyanions in the extracts.

Conclusions

Total P and S concentrations in the studied Oxisols are low, compared with concentrations found in many surface soils of the temperate regions but comparable with concentrations reported for other Oxisols. The concentrations of Mo are comparable with those reported for temperate soils. No data is available to compare our results with Mo concentrations from other Oxisols. The partitioning of P, S, and Mo in the studied Oxisols is element-specific and similar in all studied systems. The proportions of the plant-available fractions decrease along the line S > P > Mo.

Land-use impacts on element partitioning decrease along the line P > S > Mo. Land-use influences on P and S concentrations in plant-available fractions ($NaHCO_3$ and NaOH) are most apparent. The impacts decrease as plant availability decreases. The land-use influence on concentrations and partitioning of P of our on-farm experiment is similar to that reported from on-station experiments but differences are smaller. The 12-20 year-long use of the studied Oxisols for cropping resulted in increased P and S concentrations whereas those of Mo are almost unaffected.

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Nutrient Storage in Above-Ground Biomass of the Cerrado Vegetation.

Summary

About 20 % of Brazil are covered by savannas. In the last 30 years, the clearing of the so-called Cerrados for agriculture and cattle raising increased. During this process the trees were completely removed, including parts of their roots, and the plant nutrients contained in the trees got lost from the system.

The objective of this master thesis was a) to describe the Cerrado vegetation, and b) to determine the above-ground biomass and nutrient stocks therein. The examined Cerrado stand was situated at the southern edge of the Planalto Central, in the so-called Triângulo Mineiro, south of the city of Uberlândia, Minas Gerais. It has a subtropical Aw climate according to Köppen with and annual precipitation of 1548 mm and an average annual temperature of 22.7 °C. The soil was classified as an Anionic Acrustox according to the US Soil Taxonomy.

The minimum area of the vegetation was determined and the dominant species of all life-forms were collected on five plots (15x15 m). A list of the most important species was made.

To determine the above-ground biomass and the nutrient concentrations of the Cerrado plants were analyzed. The four tree species *Pouteria torta* (Mart.) Radlk., *Kielmeyera coriacea* (Spreng.) Mart., *Caryocar brasiliense* Cambess., and *Ouratea hexasperma* (St.-Hil.) Baill. and the four shrub species *Miconia albicans* (Sw.) Triana, *Parinari obtusifolia* Hook. f., *Campomanesia velutina* O.C. Berg, and *Myrcia rostrata* DC. were harvested in the second half of the rainy season 1997/98 and separated into different plant compartments (stems, branches, bark, leaves). Mixed samples of the above-ground parts of the grass-herb layer were taken on five 1-m² plots. The fresh and dry biomass was determined gravimetrically. In the plant samples the total concentrations of Al, C, Ca, Fe, K, Mg, Mn, N, Na, P, S, and Zn were determined.

On a plot size of 15x15 m, an average of 99 spermatophytic species was found. The minimum area of 30x30 m contained 146 species. Tree height ranged from 3.7 to 6.0 m and tree cover ranged from 15 to 50 % (mean 25 %). A comparison with literature data showed that the studied Cerrado can be classified as a Cerrado in the strict sense.

The fresh weight of the entire Cerrado plant biomass was 30.3 Mg ha^{-1}, and the dry weight was 15.8 Mg ha^{-1}. Fifty-five percent of the above-ground biomass of the Cerrado vegetation was stored in the branches of the tree layer. The major part of the remaining biomass (38 %) was found in the ground vegetation layer. The proportions of the dry weight of Cerrado biomass in individual species decreased in the order *Pouteria* (39.5 %) > *Caryocar* (6.7 %) > *Miconia* (6.4 %) > *Kielmeyera* (5.3 %) > *Ouratea* (2.8 %) > *Campomanesia* (0.3 %) = *Parinari* (0.3 %) > *Myrcia* (0.2 %).

The concentrations of C, Na, and S hardly differed between the different plant parts. Phloem-mobile elements, like K, Mg, N, and P, accumulated mainly in leaves and growing tissue. Elements which are less mobile in plants, like Al, Ca, Fe, Mn, and Zn, accumulated in the dead plant biomass.

A comparison with literature data of element concentrations in plants showed that the concentrations of K, Na, and P in the Cerrado plants were lower than the lowest literature values, those of Mg, N, and Zn corresponded to the lower literature values. The concentrations of Ca, Fe, and S were within the range of reference values, and the concentrations of Mn and particularly of Al were higher. In general, the nutrient concentrations between the species did not differ substantially. Exceptions were the shrub *Miconia* with its high Al concentration in all plant compartments, and the trees *Caryocar* and *Ouratea* and particularly the shrub *Myrcia* with their high Mn concentrations. The tree *Pouteria* contained low Ca concentrations in most compartments.

The proportions of the analyzed elements in the above-ground biomass decreased along the line C (96.4 % of dry weight) > N (1.59 %) > Ca (0.50 %) = K (0.50 %) > Al (0.26 %) > S (0.21 %) > Mg (0.18 %) > P (0.17 %) > Fe (0.10 %) > Mn (0.04 %) > Na (0.005

%) > Zn (0.003 %). The largest part of nutrients was found in the woody plant compartments (branches and stems) of the trees and bigger shrubs.

The results demonstrate that particularly the removal of the woody parts of the vegetation results in the most pronounced nutrient losses from the system.

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Annual Course of Matric Potential in Differently Used Savanna Oxisols, Brazil.

Summary

Sustainable land use in periodically dry Brazilian savannas requires a water-conserving strategy. We hypothesized that the annual course of matric potentials (Ψ_M) in very-fine, isohyperthermic Anionic Acrustoxes of *Pinus* plantations (PI), degraded (DP) and productive pastures (PP), no-till (NT) and conventional tillage (CT) cropping, and natural savanna (Cerrado, CE) differed significantly. On three plots in each of these land-use systems water input and Ψ_M with tensiometers at 0.15, 0.30, 0.80, 1.2, and 2.0 m depth was measured weekly between March 27, 1997 and April 28, 1998. Precipitation between April 29, 1997 and April 28, 1998 was 1562 mm, with only 210 mm in May to September, when Ψ_M at 0.15 and 0.30 m depth decreased to < -80 kPa in all systems; lowest Ψ_M at 2 m depth was -57 kPa. During the monitored period, the PI soils had lower average Ψ_M at 0.8-2 m depth (-60 kPa) than those in CE (-46) indicating higher rainfall interception losses and higher transpiration. In CT , average Ψ_M at 0.8-2 m depth (-29) were higher than in NT (-51) because of different crops and different soil management. Between June and November Ψ_M at 2 m depth in CE decreased to a lower value (-42), than in vegetation-free CT (-22) and NT (-27). In DP and PP soils Ψ_M were similar to those in CE soils at all depths. The estimated average water storage in the upper 2 m during the monitored period was 565 mm (CT) > 553 (PP) > 541 (DP) > 537 (CE) > 526 (NT) > 479 (PI). Our results show that mainly the vegetation type and tillage practices control the annual course of matric potential in differently used savanna Oxisols.

Introduction

In the last 30 years, an intensive agriculture developed on the nutrient-poor soils of the Brazilian savanna region (the Cerrados). Large parts of natural Cerrado were cleared and afforested or transformed to pasture and cropping. Agriculture in this region is water-limited. In soils under native vegetation, matric potentials at 0.5 m soil depth decrease below the permanent wilting point, i.e. the matric potential at which plants wilt, only one month after the end of the rainy. If dry periods occur during critical stages of crop growth, like flowering, water stress may result in severe yield losses. Land-use practices which result in changed water budgets may therefore affect crop yields and, in the long term, may also have impacts on the groundwater level and storage.

The soil water content is influenced by the water consumption of plants and by soil management. Because forests generally consume more water and have a greater interception capacity resulting in a higher evaporation losses, lower soil water contents are often found in soils under forest than under cropping systems or pastures. In conventionally tilled soils, pore continuity is reduced compared with no-till soils resulting in reduced evaporation.

The objective of this work was to compare the annual course of matric potentials in differently used Brazilian savanna Oxisols and to evaluate the systems with regard to the water availability for plants and water storage in the rooting zone.

Materials and Methods

Study sites

The study area is located southeast of Uberlândia (State of Minas Gerais) about 400 km S of Brasilia. Within an area of about 100 km², three plots of each of the following six land-use and natural systems were selected: (1) *Pinus* plantations (PI), (2) degraded (DP) and (3) productive pastures (PP), (4) no-till (NT) and (5) conventional tillage (CT) cropping, and (6) natural savanna (Cerrado, CE). We considered these land-use systems the most important ones in the study region. To allow for statistical evaluation with variance analysis we aimed at selecting independent replicates of each system. As our objective was to conduct an on-farm experiment we had to select the experimental plots in existing land-use systems. Thus, an entirely randomized plot selection was not possible. However, we only chose replicate plots of each land-use and natural system which were separated from each other by a distance of at least 300 m and, except for PI, by an area which was differently used between the replicate plots. The PI forest covered a large area without intermixed plots with different land-use. We assume that the prerequisites for variance analysis have been met by this experimental design.

The PI system consisted of *Pinus caribaea* Morelet planted in 1977 which received an initial fertilization of 25 kg P ha^{-1} (80 g Superphosphate per plant). In both, DP and PP *Brachiaria decumbens* Stapf, an imported grass species from Africa, was planted as a monoculture in 1985. The DP had vegetation-free spots and some invaded Cerrado plants while PP was a pure grass pasture with a closed vegetation cover. Both pastures were fertilized with 130 kg P ha^{-1} when established; PP was further fertilized with 40 kg N ha^{-1}, 60 kg P ha^{-1}, and 40 kg K ha^{-1} every four years. The CT soils have been plowed or loosened with a disk harrow 2-3 times per year for 12 years and used for corn (*Zea mays* L.)-soybean (*Glycine max* (L.) Merr.) rotation. In 1996, soybean was harvested at the end of March, then corn was planted on November 11, 1997 and harvested on April 1, 1998. The NT systems have been established only between 1 and 3 years prior to the beginning of our experiment in 1997 after the plots had been used as CT in the way described above for 9-11 years. In the rainy season 1996/1997, after the harvest of soybean in the end of March, corn was planted on February 10, 1997 and harvested on June 15, 1997, then soybean was planted on November 28, 1997 and harvested on April 16, 1998. In 1998 the soil moisture did not support a second crop because of an unusual dryness due to the "El Niño" effect. Both cropping systems (CT, NT) were fertilized with an annual average of about 70 kg N ha^{-1}, 100 kg P ha^{-1}, 160 kg K ha^{-1}. The Cerrado vegetation was characterized by an open grassland with a 15-40 % cover of 3-5 m high trees and may be considered as typical. The dominant tree species are *Pouteria torta* (Mart.) Radlk., *Kielmeyera coriacea* (Spreng.) Mart., *Caryocar brasiliense* Camb., *Ouratea hexasperma* (St. Hil.) Benth., and *Miconia albicans* (Sw.) Triana.

All study sites had slopes below 1°; they have been continuously used for the same purposes for 12 (DP, PP, NT, CT) or 20 (PI) years and passed directly from natural vegetation to the current land-use system except for the NT soils. All study soils developed from fine limnic sediments of the lower Tertiary. The soils were homogeneously weathered to a depth of several meters.

Equipment and measurements

On each of the 18 plots a 10 x 10 m area was fenced and equipped with five replicate tensiometers at each of 0.15, 0.3, 0.8, 1.2, and 2 m depths. All plots were equipped with 5 rain collectors consisting of a sampling bottle and a funnel with a diameter of 115 mm to measure soil water input at 0.3 m height above the soil surface. Each sampling bottle was protected against larger particles and small animals with a polyethylene net (0.5 mm mesh width). A table-tennis ball was used to reduce evaporation. Tensiometers and rain collectors were placed within and between the crop rows in the cropping systems, and near and between the trees in CE and PI. During the rainy season (March-April 1997 and October 1997-April 1998) and during the dry season (May-October 1997), • . were read and precipitation measured weekly and biweekly, respectively. The soils in CT were hoed manually instead of plowing on October 9 and November 21, 1997, within the fenced plots as tensiometers could not be removed. Weed in NT was controlled by the application of 1.2 kg ha^{-1} glyphosate (Roundup, Monsanto, St. Louis, Missouri) on November 27, 1997.

Meteorological data

Precipitation data, and daily maximum and minimum temperatures were provided by the Fazenda Pinusplan, a commercial farm producing mainly corn, soybean, and *Pinus*. The meteorological station of the farm is located near Plot CE2 and CT2 (Fig. 1) in the study area.

Soil physical characterization

Particle-size distribution was determined in 0-0.15 m, 0.15-0.3 m, 0.3-0.8 m, 0.8-1.2 m, 1.2-2 m layers after removal of the oxides with Na-dithionite and of organic matter with H_2O_2 at 90°C, following dispersion with hexametaphosphate. Coarse and fine sand were sieved to 250-2000 and 50-250 μm, respectively. Silt and clay concentrations were determined with the pipet method. Soil density was determined gravimetrically by taking 5 undisturbed 100-mL soil cores.

To determine soil water characteristic curves, five undisturbed soil samples were taken from each of the layers 0-0.15 m, 0.15-0.3 m, 0.3-0.8 m, 0.8-1.2 m, 1.2-2 m with 100-mL steel rings from one selected soil in each of CE and NT (CE1 and CT2 in Fig. 1). The five replicate cores per layer were taken from various depths to account for the heterogeneity within one layer. The gravimetrical soil water content was determined at • . of -0.316, -1.0, -3.16, -10.0, and -31.6 kPa after equilibrating on ceramic plates. Water content at -1584,8 kPa was determined in a pressure pot using disturbed samples.

Soil chemical characterization

Soil organic carbon (SOC) was determined with a CHNS-analyzer (Vario EL, Elementar Analysensysteme GmbH, Hanau, Germany). Aluminum in poorly ordered Fe oxides was extracted with the oxalate-buffer method (Al_o,), crystalline Fe oxides with the cold dithionite-citrate-buffer (DCB) method (Fe_d,). Aluminum and Fe were measured with flame atomic absorption spectrophotometry (Varian AA 400, Varian, Mulgrave, Australia).

Calculations and statistical evaluation

To fit soil water characteristic curves to the measured values the Soil Hydraulic Properties Fitting (SHYPFIT) program was used. The soil water characteristic curves obtained for a specific layer of one soil in each of CE and NT were averaged to estimate water storage in the soil layers. Estimates were calculated for the dry season (May-October 1997) and the rainy season (November 1997-April 1998) separately (Equation 1).

$$WS_{sl} = \rho_{sl} \cdot l_{sl} \cdot \theta_{sl} \qquad [1]$$

where WS_{sl} is the water storage in the soil layer (sl) [mm], • $_{sl}$ the soil bulk density [Mg m^{-3}], l_{sl} the depth of the soil layer [m], and θ_{sl} average water content in the soil layer [g kg^{-1}].

Water storages of the soil layers were summed to get the water storage of the uppermost two meters (Equation 2).

$$WS = WS_{0\text{-}0.15} + WS_{0.15\text{-}0.3} + WS_{0.3\text{-}0.8} + WS_{0.8\text{-}1.2} + WS_{1.2\text{-}2.0} \qquad [2]$$

Main and interactive means of the soil water characteristic curves, Fe_d and Al_o concentrations, texture, and the calculated water contents were tested with Tukey's honestly significant difference (HSD) mean separation test (Hartung and Elpelt, 1989). Mean Ψ_M were tested with the Wilcoxon matched pairs test. Significance was set at $P < 0.05$. Statistical analyses were performed with STATISTICA for Windows 5.1.

Results and Discussion

Comparability of the soils

All studied soils were very-fine isohyperthermic Anionic with high clay concentrations (615-885 g kg^{-1}). There was no significant change in clay content with increasing soil depth in any individual soil (data not shown). Clay, silt, coarse, and fine sand concentrations were not significantly different between the land-use systems within any individual soil layer (Table 4). The Al_o and Fe_d concentrations of the same depth layer were not significantly different between any of the studied soils of all land-use systems. Additionally, the average standard deviations of the Al_o and Fe_d concentrations, between the replicate plots of one system (Fe_d: 9.1 g kg^{-1}, Al_o: 0.27 g kg^{-1}) were comparable to those between all soils (Fe_d: 9.2, Al_o: 0.33). Thus, we assume that the soils had comparable properties prior to land use and differences in • $_M$ and water storage can be interpreted as the result of land-use practices which also are the reason for small but significant differences in SOC concentrations.

Climate and soil water input

Between April 29, 1997 and April 28, 1998 the average maximum temperature was 29°C, the average minimum temperature 16°C, with only small variations during the year. Total precipitation during that time was 1562 mm, 1342 mm fell between October 1997 and April 1998 and only 220 mm during the dry season between the end of April and September 1997 (Fig. 4). The cumulative precipitation between April 29, 1997 and April 28, 1998 is comparable with the mean annual precipitation between 1981 and 1990 of 1550 mm (Rosa et al., 1991). However, due to the "El Niño" effect, precipitation during the dry season 1997 was higher (220 mm) compared with the average of 130 mm between 1981 and 1990.

The land-use systems with a noncontinuous canopy (CE, DP) received higher soil water inputs than the other land-use systems because of the smaller loss due to the evaporation of intercepted water (Table 5). Reduced soil water input on the PI plots are related with evaporation of water intercepted by the needles. Smallest inputs were measured for CT where corn was planted in the rainy season of 1997/98.

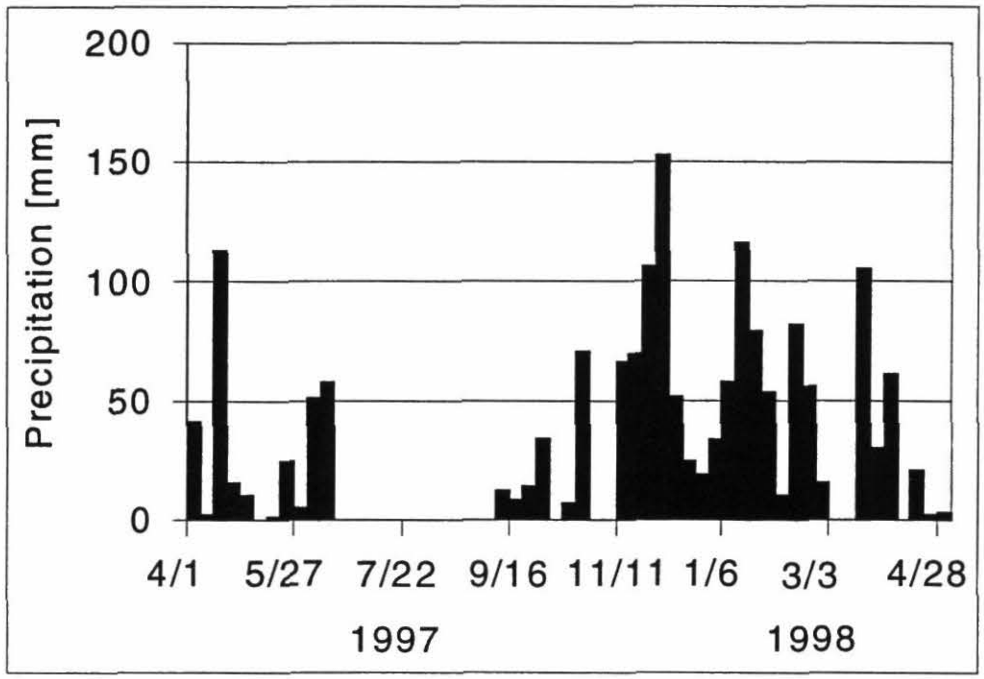

Figure 4: Precipitation between April 1, 1997 and April 28, 1998 recorded at the Fazenda Pinusplan, a commercial farm.

Table 4: Mean soil organic C (SOC), citrate-dithionite *extractable* Fe (Fe_d), oxalate-extractable Al (Al_o), and particle-size distribution of native Cerrado (CE), Pinus (PI), no-till cropping (NT), conventional tillage (CT), degraded pasture (DP), and productive pasture (PP).

Soil depth	Plot	SOC	Fed	Al_o	Particle-size distribution				Bulk density
					Coarse sand	Fine sand	Silt	Clay	
M		------------------			g kg^{-1}			------------------	Mg m^{-3}
0-0.15	CE	22.0ab†	32.1	2.8	139	68	88	705	0.88ab
	PI	21.9b	30.7	3.4	106	65	96	733	0.82b
	NT	21.7b	32.2	3.0	104	62	116	718	0.99a
	CT	20.8b	38.4	3.0	127a	67	115	692	1.03a
	DP	22.4b	31.2	2.9	97	59	50	793	1.00a
	PP	26.7a	24.2	3.0	100	61	78	762	0.96ab
0.15-0.3	CE	17.7	33.3	2.9	138	70	83	708	0.99
	PI	15.8	31.1	3.1	104	65	76	755	0.95
	NT	19.0	32.4	3.1	104	62	133	702	0.92
	CT	17.4	39.9	3.2	121	64	110	705	1.10
	DP	18.4	32.1	2.9	97	51	55	797	0.94
	PP	18.5	25.9	2.9	102	61	47	790	0.94
0.3-0.8	CE	11.3	32.0	2.7	127	62	130	680	0.94
	PI	11.4	30.6	3.2	90	57	88	765	0.89
	NT	11.7	32.6	3.1	89	53	125	733	0.88
	CT	10.9	40.2	3.1	103	60	107	730	0.85
	DP	12.0	31.9	2.9	90	49	63	798	0.86
	PP	12.4	26.0	2.8	94	51	78	778	0.90
0.8-1.2	CE	8.4	31.8	2.6	121	62	129	688	0.84
	PI	8.3	30.5	2.6	90	59	105	746	0.84
	NT	8.9	32.3	3.1	88	53	130	729	0.85
	CT	7.4	40.0	3.1	101	58	141	700	0.86
	DP	8.2	31.5	2.6	84	49	45	821	0.85
	PP	8.5	25.4	2.8	87	48	102	763	0.86
1.2-2	CE	6.4	31.5	2.5	117	65	134	684	0.82
	PI	6.9	29.4	2.5	93	58	101	748	0.79
	NT	6.8	31.5	3.0	85	55	139	721	0.83
	CT	6.3	38.8	3.0	100	59	102	738	0.82
	DP	6.7	31.2	2.5	87	55	74	785	0.81
	PP	6.7	24.8	2.9	84	50	96	770	0.82

† Means followed by different letters are significantly different between the land-use systems at $P <$ 0.05 (Tukeys HSD test). Missing letters indicate that there were no significant differences between the land-use systems.

Table 5: Mean soil water input (measured at 0.3 m above surface) into different land-use systems from March 27, 1997 to April 28, 1998.

Land-use system	Soil water input
	-------mm-------
Native Cerrado (CE)	1560a†
Pinus (PI)	1335ab
Degraded pasture (DP)	1503a
Productive pasture (PP)	1425a
No-till cropping (NT)	1366ab
Conventional tillage cropping (CT)	1103b

† Means followed by different letters are significantly different between the land-use systems at $P < 0.05$ (Tukeys HSD test).

Matric potentials

Matric potentials at 0.15 and 0.3 m depth reflected the precipitation in all land-use systems (Figures 5 a and b). Missing values during the dry season indicate that Ψ_M decreased to < -80 kPa, and thus could no more be measured with the used tensiometers. At 0.8-2 m depth, it took more time until Ψ_M increased during a wet period (Figures 5c-e). At 2 m depth, maximum Ψ_M was only reached about two months after the first rain. This was a result of the low unsaturated hydraulic conductivity of Oxisols due to the pseudosand and pseudosilt structure, i.e., the formation of sand- and silt-sized aggregates stabilized by Fe. After the soil had been rewetted at 2 m depth, Ψ_M remained almost constant around -5 kPa during the whole rainy season (December 1997-April 1998, Fig. 5e). During the whole dry season (June-November 1997), there was plant-available water at soil depths of 0.8-2 m in all land-use systems (Fig. 5c-5e).

The course of Ψ_M in PI soils paralleled that in CE soils, but the average Ψ_M of the whole monitored period at $\geq$ 0.3 m soil depth under PI was significantly lower (Fig. 5b-5e). Differences in Ψ_M between PI and CE increased with soil depth. During periods of little rain, differences between PI and CE became greater as a result of the higher evapotranspiration rates of PI. The greatest differences were recorded at the end of August ($\Psi_{M, CE}$ - $\Psi_{M, PI}$ Ψ30 kPa). During the rainy season, the differences were smaller. In December or later, during wet periods, Ψ_M in both systems were nearly identical. During short dry periods from December to April, differences in Ψ_M between CE and PI soils increased but were generally < 10 kPa.

Average Ψ_M of the whole monitored period at 0.15 m depth were not significantly different between CT, NT, and CE (Fig. 5a). Average Ψ_M in CT were significantly higher than in CE at 0.3, 1.2, and 2 m depth (Fig. 5b, 5d, and 5e) and in NT at 0.3-2 m depth (Fig. 5b-5e). Average Ψ_M in NT at 0.8 and 1.2 m depth were significantly lower than in CE (Fig. 5c and 5d). However, differences in soil Ψ_M between the cropping systems and CE varied in the course of the year.

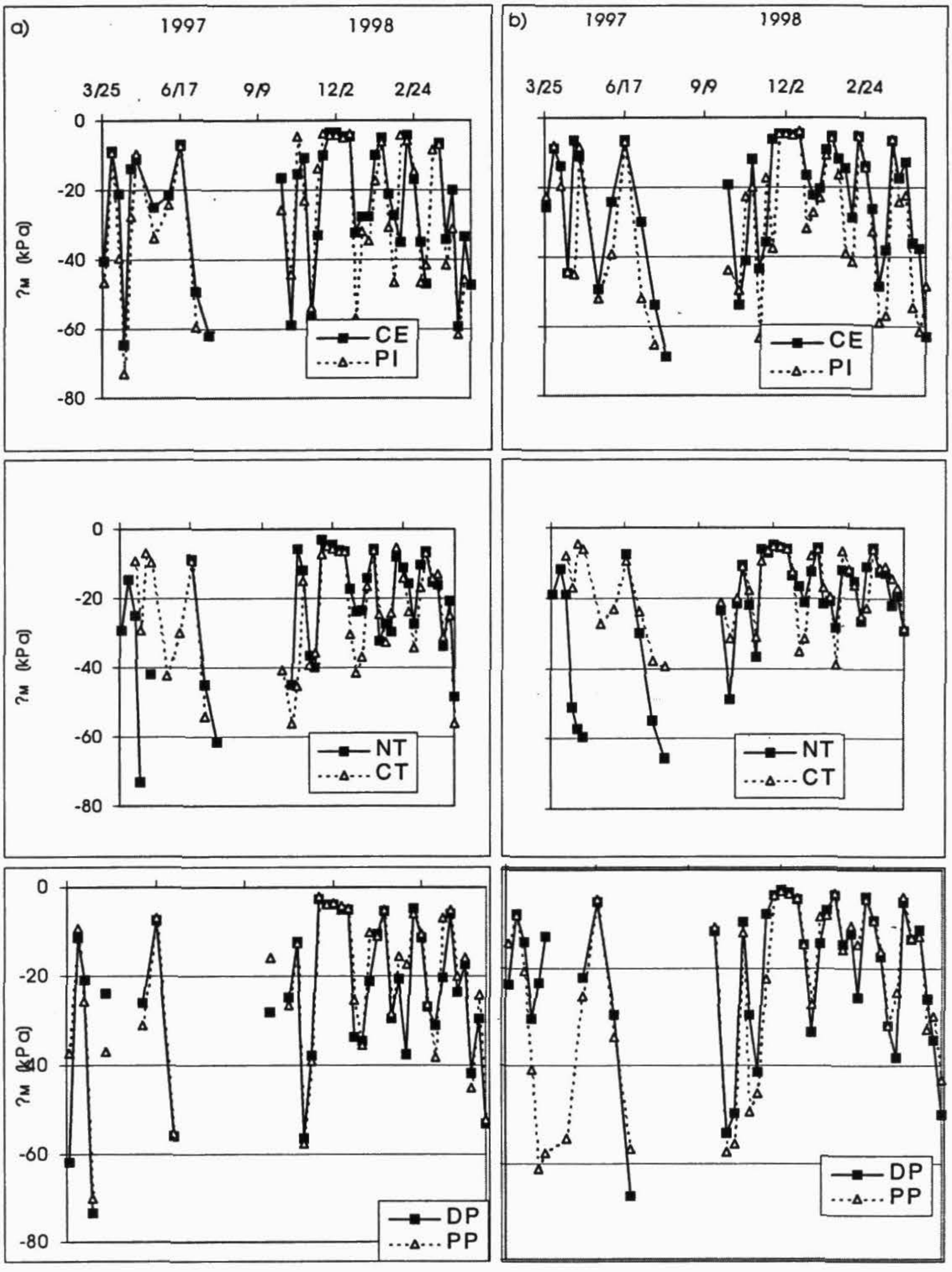

Figure 5(a-b): Course of matric potentials (Ψ_M) at (a) 0.15 m and (b) 0.30 m depth in soils of native Cerrado (CE), Pinus (PI), no-till cropping (NT), conventional tillage cropping (CT), degraded pasture (DP), productive pasture (PP) between March 27, 1997 and April 28, 1998. Shown values are averages of three replicates per treatment.

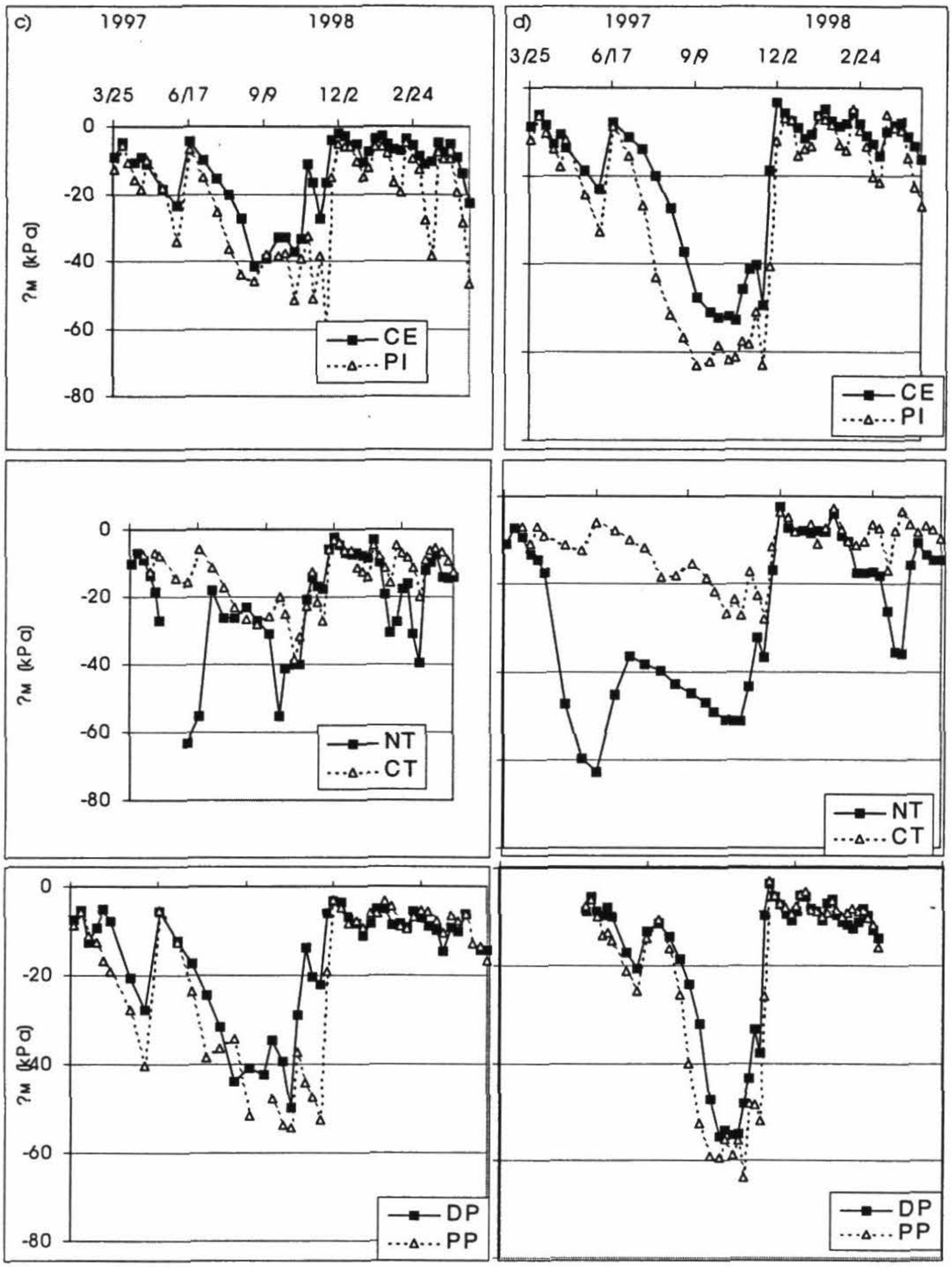

Figure 5(c-d): Course of matric potentials (Ψ_M) at (c) 0.80 m and (d) 1.20 m depth in soils of native Cerrado (CE), Pinus (PI), no-till cropping (NT), conventional tillage cropping (CT), degraded pasture (DP), productive pasture (PP) between March 27, 1997 and April 28, 1998. Shown values are averages of three replicates per treatment.

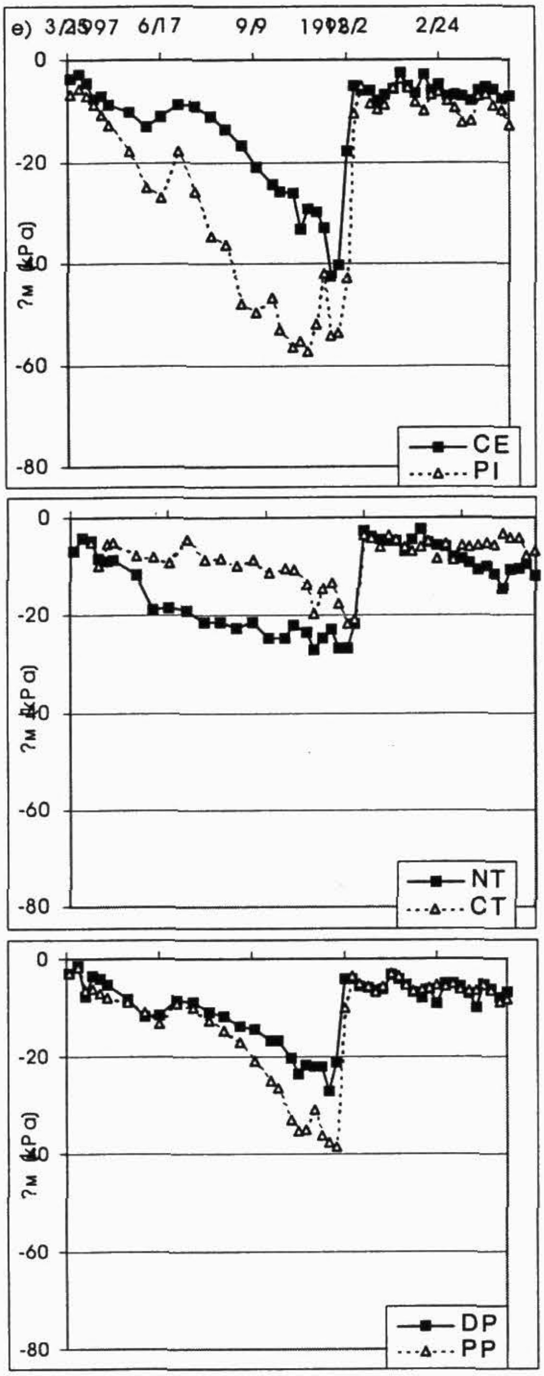

Figure 5(e): Course of matric potentials (Ψ_M) at (e) 2.00 m depth in soils of native Cerrado (CE), *Pinus* (PI), no-till cropping (NT), conventional tillage cropping (CT), degraded pasture (DP), productive pasture (PP) between March 27, 1997 and April 28, 1998. Shown values are averages of three replicates per treatment.

The reasons for differences in Ψ_M between CE, CT, and NT are related with different plant cover and with different soil management. Between the end of March and June 15, 1997, the NT soils were cropped with corn while the CT soils were without crops. The water consumption of the corn probably lowered Ψ_M. This may, in part, also be the reason for the lower Ψ_M in NT than in CT at 0.3 to 2 m depth during the dry season (June-November 1997, Fig. 5b-5e). However, evaporation from NT soils may also have been higher than from CT soils, because plowing destroys the pore continuity and thus reduces evaporation. After the harvest in CT and in NT, the water consumption of the partly evergreen vegetation in CE was higher and Ψ_M consequently decreased to a lower value than in the cropping systems.

Lower Ψ_M at 0.8-2 m depth in NT than in CT during the period of high biomass production (February-April 1998, Fig. 5c, 5d, and 5e) can be explained by higher transpiration coefficients of soybean than of corn and similar average biomass production (soybean: 11.3 Mg dry mass ha^{-1}, corn: 12.8 Mg ha^{-1}) on our plots during the vegetation period 1997/1998. Lower Ψ_M in NT than in CT soils could also be attributable to a lower infiltration rate and a lower saturated hydraulic water conductivity in NT than in CT and therefore slower soil water refill, particularly at greater depth. However, infiltration in all study soils was rapid and we never observed any surface water even during strong rainfall events. Evaporation losses from surface water may thus be excluded. Furthermore, NT soils should display a higher water conductivity than CT soils because of the higher pore continuity and we measured a higher soil water input into NT soils than into CT soils (Table 5). An additional reason for lower Ψ_M in NT than in CT between February and April 1998 may be the lower water storage in NT soils resulting from the water consumption at the end of the preceding cropping period.

Differences in Ψ_M between the pasture systems and CE were smaller than between the other systems and CE. There were no significant differences in average Ψ_M of the monitored period at 0.15 and 0.3 m depth between CE, PP, and DP (Fig. 5a and 5b). Between 0.8 and 1.2 m depth, small but significant differences between the three land-use systems were recorded (Fig. 5c and 5d). Between December 1997 and April 1998, the average Ψ_M in DP at 0.8 and 2 m depth were significantly lower than in PP and CE (Fig. 5c and 5e); at 1.2 m depth the average Ψ_M in DP was significantly lower than in PP (Fig. 5d). Between May and November 1997, average Ψ_M at 0.8-2 m depth in PP were significantly lower than in DP (Fig. 5c-5e) and at 0.8-1.2 m depth also significantly lower than in CE (Fig. 5c and 5d). Lower Ψ_M in DP than in PP at greater depth during the rainy season may be related with the water uptake of the invaded natural Cerrado brushes and trees which possibly have a greater rooting depth than the grass in PP. Differences in Ψ_M between the pasture systems during the dry season, in contrast, indicate a higher water consumption of the PP vegetation which is denser and shows a more intensive grass rooting.

Water storage

The soil water content can be estimated from Ψ_M with the help of the soil water characteristic curve. The shape of the soil water characteristic curve is influenced by soil texture and bulk density. We found that there were only small differences in texture between the studied soils and between the soil depths within one soil (Table 4). At 0-0.15 m soil depth, the average soil density in PI was significantly smaller than in NT, CT, and DP. There was no other significant difference in soil density between the various layers of the soils of the same land-use system and between the same layers among the different land-use systems. As a result of the great similarity in soil texture and bulk densities among the studied soils we did not expect significant differences in the soil water characteristic curve. Therefore, we chose only one soil in each of the CE and CT treatments to determine the soil water characteristic curves for five soil layers of each of the selected two soils (Figure 6).

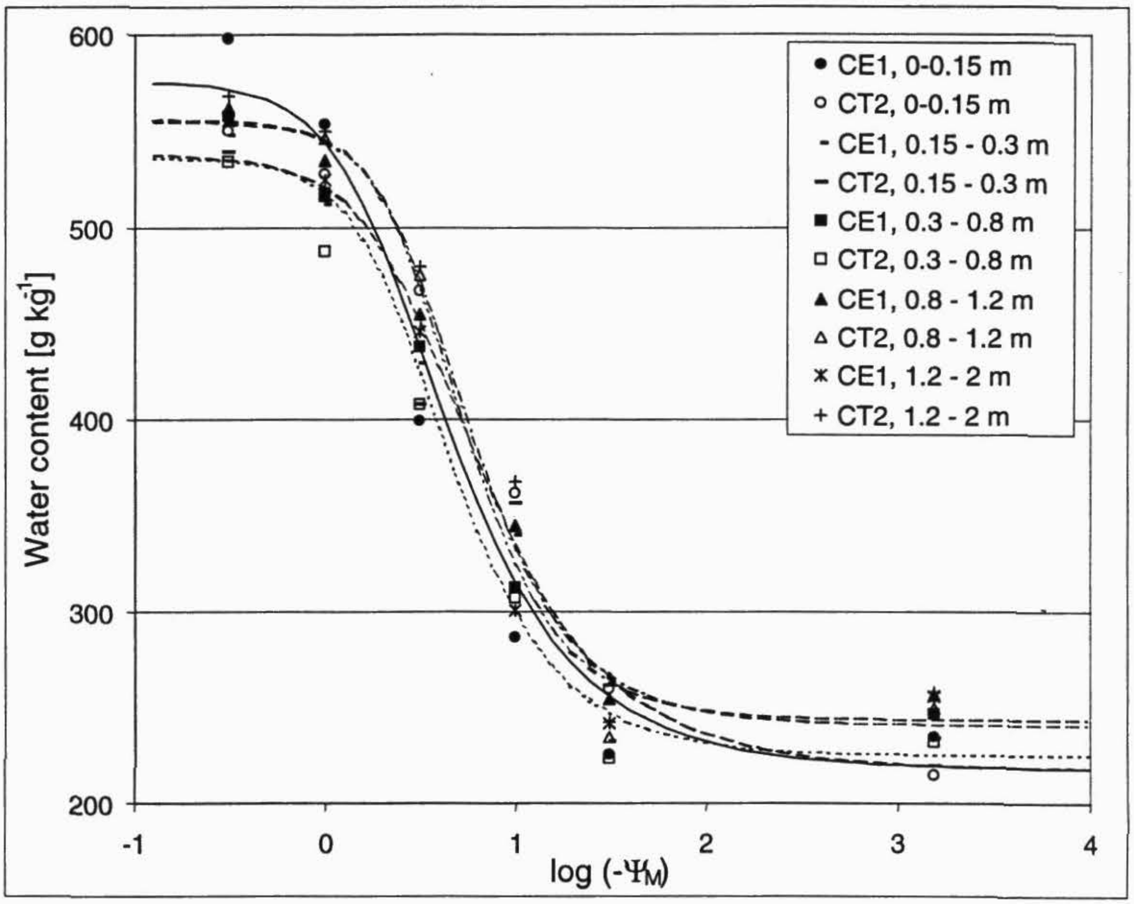

Figure 6: Measured (data points) and fitted (lines) soil water characteristic curves in two selected soils in each of Cerrado (CE) and conventional tillage (CT) treatments (CE1 and CT2 in Fig. 1) at 0-0.15, 0.15-0.30, 0.30-0.80, 0.80-1.20, 1.20-2.00 m depths.

The shape of the soil water characteristic curves was typical for Oxisols with kaolinitic and oxidic mineralogy. At high Ψ_M, the soils retain water like coarse-textured temperate soils, but at low Ψ_M they retain water like clayey-textured ones. This is attributable to the strong pseudosand aggregation of Oxisols consisting of positively charged oxyhydroxides and negatively charged kaolinite and organic matter.

The water content at the monitored Ψ_M range was not significantly different between the selected CE and CT soils at 0.8-1.2 and 1.2-2.0 m depth. For the layers above 0.8 m depth, small but significant differences in water content at a given Ψ_M between the selected CT and CE soils and between different layers within the same soil occurred at Ψ_M above -3.16 and below -1584.9 kPa but not between -10.0 and -3.16 kPa which covered the most frequently measured range of Ψ_M in the field. We concluded that for this range of Ψ_M, the water content at a given Ψ_M was comparable between the two soils and differences in Ψ_M measured with the tensiometers can directly be interpreted as differences in soil water contents. The lack of significant differences between the water characteristic curves of the selected CE and CT soils led us to the assumption that, at the range of Ψ_M observed in the field, an appropriate estimate of the water content of the soils in all studied land-use systems is possible by using only one water characteristic curve (averaged from the two determined curves) for each individual soil layer. As the tensiometers only work down to -80 kPa we could not estimate plant-available water contents in soils at $\Psi_M < -80$ kPa. However, the difference in water contents between -31.6 and -1584.9 kPa was only 20-46 g kg^{-1} for all studied soil samples being in the same range as reported for Oxisols of northeastern Brazil (20-40 g kg^{-1}). Therefore, the difference in water contents between -80 kPa and the permanent wilting point at -1584.9 kPa which has to be added to the estimated water content in our study soils is small.

With the help of the averaged water characteristic curves and the soil densities of the five soil layers (0-0.15, 0.15-0.3, 0.3-0.8, 0.8-1.2, and 1.2-2 m) the average water storage of each system in the uppermost two meters was estimated using Equations 1 and 2. During the rainy season, the average water storages were not significantly different among all studied land-use systems, except for PI where the average water storage in the uppermost 2 m was significantly smaller than in all other land-use systems (Table 6). During the dry season differences were more pronounced; the water storage decreased along the line CT > DP = PP > CE > NT > PI.

Conclusions

Our results indicate that mainly the type of vegetation controls the annual course of Ψ_M in differently used savanna Oxisols because it influences evapotranspiration, interception, and stemflow. In CT, plowing probably additionally results in reduced evaporation and thus increased Ψ_M because the pore continuity is destroyed. Both pasture systems show similar annual courses of Ψ_M in soil as CE, indicating that the soil water budget under pasture is close to that of the natural system. In PI and NT soils, Ψ_M are decreased and the average annual water storage is reduced compared with CE.

Table 6: Mean water storage in the uppermost two meters of native Cerrado (CE), Pinus (PI), no-till cropping (NT), conventional tillage (CT), degraded pasture (DP), and productive pasture (PP).

	Land-use system					
	CE	PI	NT	CT	DP	PP
	---------------------------mm---------------------------					
Dry season: May-Oct. 1997	476 b†	429 c	460 bc	523 a	480 b	479 b
Rainy season: Nov. 1997-Apr. 1998	587 a	516 b	578 a	620 a	586 a	608 a
Whole period: May 1997-Apr. 1998	537a	479b	526ab	565a	541a	553a

† Means followed by different letters are significantly different between the land-use systems at $P < 0.05$ (Tukeys HSD test).

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Soil Acidification in *Pinus caribaea* forests on Brazilian Savanna Oxisols.

Summary

The transformation of large areas in the Brazilian savanna into *Pinus* plantations may have resulted in soil acidification. The objective of this study was to determine if afforestation with *Pinus caribaea* Morelet (PI) influenced soil acidification by comparing the metal status of the soil solid phase and the course of metal concentrations in soil solution during one rainy season with those under natural savanna vegetation (*Cerrado*, CE). Surface soil samples (0-0.15 m) from three spatially disconnected plots in CE and PI were sequentially extracted. At each plot, soil solution at 0.15, 0.3, 0.8, 1.2, and 2 m depth and in PI additionally litter leachate were collected between Oct. 1997 and Apr. 1998. Extracts and soil solution were analyzed for Al, Ca, Cu, Fe, K, Mg, Mn, Na, Si, and Zn concentrations, soil solution also for pH and electrical conductivity (EC). Total concentrations in soil solid phase ranged between 94,000-155,000 mg kg^{-1} (Al), 29-39 (Ca), 21-31 (Cu), 44,000-61,000 (Fe), 91-141 (K), 21-29 (Mg), 28-57 (Mn), 73-94 (Na), and 13-21 (Zn). Whereas 27-83 % of total K, Ca, Mg, and Na concentrations were exchangeable, > 83 % of total Cu, Fe, Mn, Zn, and Al were bound in hardly plant-available forms. There were no significant differences in concentrations and partitioning between CE and PI. At the beginning of the rainy season (Oct. to Dec.), metal

concentrations in soil solution were 2-5 times larger and more variable than between Dec. and Apr. because of the mineralization of organic matter which accumulated during the dry season. Metal concentrations in CE soil solution between Dec. and Apr. were extremely small at all depths (Al: not detected (n.d.)-3.26 µmol l^{-1}, Ca: 2.8-11.7 , K: 0.9-6.7, Mg: 0.7-8.3, Mn: n.d.-0.14, Na: 5.5-40.1, Zn: 0.13-1.02). Up to 1.2 m soil depth, soil solution pH was significantly lower in PI than in CE. Concentrations of Ca, K, Mg, and Na were up to two times larger than in CE, those of Mn and Al 9 and 60 times, respectively. Whereas the soil solid phase did not show significant differences in metal concentrations and partitioning, the soil solution composition clearly indicated enhanced acidification in PI. This resulted in increased leaching of plant nutrients from the topsoil.

Introduction

Thirty years ago, more than 200.000 ha of the Brazilian savanna (the "Cerrados") were transformed into *Pinus* plantations. From the temperate zone, it is known that *Pinus* plantations may change soil properties considerably. The afforestation of formerly unforested land leads to the accumulation of litter layers which are deeper and more acid in coniferous than in deciduous forests. The release of organic acids from the litter layer causes enhanced cation leaching from the underlying mineral soil if the soil has a high H^+ buffer rate. In soils with a low H^+ buffer rate decreased soil pH has been observed. Soil solutions under *Pinus* frequently are more acid and have larger Al concentrations than under deciduous forests on originally comparable soils. Parfitt et al. (1998) reported between 2 and 6 times larger Ca, Mg, K, and Na concentrations under *Pinus radiata* in New Zealand than under pasture. However, up to now, no data are available on the impacts of *Pinus* plantations on chemical properties of highly weathered tropical soils.

The most frequent soil types of the Brazilian Cerrados are Oxisols. Their surface soil pH generally ranges between 4.3 and 5.4 and is mainly controlled by the buffering of Al oxides. There is a considerable risk of Al toxicity to plants which may be enhanced under *Pinus* plantations because of soil acidification. The exchange sites are mainly covered with the highly competitive Al^{3+} ion, whereas percentages of exchangeable Ca, K, and Mg are low. Micronutrients such as Fe, Cu, Mn, and Zn are strongly retained in the soil, mainly by sorption to Fe and Al oxides. Soil acidification would result in additional leaching of Ca, Mg, and K but would also render micronutrients more plant-available.

To detect a possible acidification in young *Pinus* plantation the analysis of the soil solution composition may be more suitable than that of the soil solid phase. The objective of this study then was to determine if afforestation with *Pinus caribaea* influenced soil acidification by comparing the metal status of the soil solid phase and the course of metal concentrations in soil solution in *Cerrado* and *Pinus* during the rainy season. Particularly, we aimed at examining whether there are indications for the impoverishment of soil fertility.

Materials and Methods

Study Sites

The study area is located southeast of Uberlândia (Minas Gerais, about 400 km S of Brasilia. Within the study area, three spatially disconnected plots (minimum distance > 300 m) of native savanna vegetation (*Cerrado*, CE) and *Pinus caribaea* Morelet plantation (PI) were selected. All study sites have inclinations < 1°. The average maximum temperature between April 29, 1997 and April 28, 1998 was 29 °C, the average minimum temperature 16 °C. The *Cerrado* vegetation is characterized by an open grassland with a 15-40 % cover of 3-5 m high trees. We most frequently found *Andropogon Minarum* Kunth, *Axonopus barbigerus* (Kunth) Hitchc., *Tristachya chrysothrix* Nees, and *Echinolaena inflexa* (Poir.) Chase of the family *Poaceae* which comprises the highest number of species; among the herbaceous species, members of the families *Asteraceae*, *Rubiaceae*, *Fabaceae*, and *Mimosaceae* are most abundant. The dominant tree species are *Pouteria torta* (Mart.) Radlk., *Kielmeyera coriacea* (Spreng.) Mart., *Caryocar brasiliense* Camb., *Ouratea hexasperma* (St. Hil.) Benth., and *Miconia albicans* (Sw.) Triana. According to Sarmiento (1984) the studied *Cerrado* may be considered as "typical". *Pinus* was planted 20 years ago and fertilized with 80 g Superphosphate per plant on the plantation date. Originally, 1670 trees ha^{-1} were planted which resulted in a fertilizer application of approximately 13 kg P ha^{-1}. Today, there are about 950 trees ha^{-1}, with an average height of 21 m and an average breast height diameter of 0.25 m. Beneath the *Pinus* vegetation a 0.1 m deep litter layer accumulated whereas the litter layer in *Cerrado* is shallow and does not completely cover the soil.

Equipment and sampling

On each of the 6 plots a 10 x 10 m area was fenced and equipped with 5 replicate suction cups and manual reading tensiometers at each of 0.15, 0.3, 0.8, 1.2, and 2 m depths in March 1997. Suction cups and tensiometers were placed representatively near and between the trees. The major constituents of the porous cups are Al_2O_3 (70 %) and SiO_2 (29 %) with an average pore diameter of 1 µm. The suction cups were allowed to equilibrate with the soil solution for the last 1.5 months of the preceding rainy season and the 4.5 months lasting dry season (Apr.-Sep. 1997). Through each of the cups, more than 1.5 l soil solution were pumped and the solution discarded prior to sampling. The soil solution was collected with permanent under-pressure produced by vacuum pumps. The pressure was weekly adjusted according to the current soil suctions measured with the tensiometers. The soil solutions collected with five suction cups per depth and plot were combined. In the *Pinus* plantations zero-tension lysimeters were additionally installed beneath the organic layer to collect the litter leachate. They consisted of 0.16 x 0.16 m plastic boxes which were covered with a polyethylene net. Solution samples were collected weekly during the rainy season 1997/98 (Oct. 15, 1997-Apr. 28, 1998). During this period, total precipitation was 1343 mm, average throughfall in CE 1336 mm and in PI 1157 mm.

From each of the 6 plots, we took one surface soil sample (0-0.15 m), consisting of 5 subsamples which were combined and one sample from each of 0.15-0.3, 0.3-0.8, 0.8-1.2, 1.2-2 m layers taken from the walls of a soil pit. Additionally, we sampled the organic horizons. All samples were dried at 40° C, the mineral soil samples were sieved to < 2 mm, the organic samples were ground for analysis.

Chemical and physical characterization

Electrical conductivity (EC) and pH of the soil solutions were measured in a subsample immediately after sampling with a conductivity electrode (WTW LF 318) and a standard pH electrode (Orion U 402-S7), respectively. Electrical conductivity was measured prior to the pH and the subsample was discarded after pH measurement because of contamination with K released by the pH electrode. The remaining solutions were frozen for storage. Litter leachate was filtered (Schleicher & Schuell 311844) prior to the analyses.

The following properties were determined in all soil samples: pH with a standard pH electrode in H_2O and 1 M KCl, soil:solution ratio 1:2.5, effective cation exchange capacity (ECEC) by extraction with 1 M NH_4-acetate, crystalline Fe oxides with the cold dithionite-citrate-buffer (DCB) method (Fe_d,).

Surface soil samples (0-15 cm) were sequentially extracted to determine the partitioning of Al, Cu, Fe, Mn, and Zn (Table 7). Calcium, K, Mg, and Na were only determined in the first fraction of the sequential extraction procedure; total Ca, K, Mg, and Na concentrations were determined in separate digestions with strong acids (Step 7 of the sequential extraction) which were also used to determine the total concentrations of all metals in the subsoil samples (> 0.15 m depth).

In soil solutions and extracts, we determined the concentrations of Ca, Fe, K, Mg, Na, and Si with flame atomic absorption spectrometry (Varian SpectrAA 400), Cu with graphite tube atomic absorption spectrometry (Varian AA 400 Z), and Al, Mn, and Zn using inductively coupled plasma-mass spectroscopy (VG PlasmaQuad PQ2 Turbo Plus, VG Elemental),

Particle-size distribution was determined after removal of the Fe oxides with Na-dithionite and the organic matter with H_2O_2 at 90 °C and following dispersion with hexametaphosphate. Sand was sieved to 50-2000 μm. Silt and clay concentrations were determined with the pipette method.

Calculations and statistical evaluation

Total metal concentrations in soil samples were calculated as the sum of the seven fractions of the sequential extraction procedure except where determined by acid digestion.

Mean values of the soil parameters were tested for differences between CE and PI by using Tukey's honestly significant difference (HSD) mean separation test. To compare average metal concentrations in the soil solution between the systems and between the various depths of one system, the Wilcoxon matched-pairs test for connected data rows was used. Significance was set at $p < 0.05$. Statistical analyses were performed with STATISTICA for windows 5.1 (StatSoft, 1995, Loll and Nielsen, Hamburg, Germany).

Table 7: Steps of the sequential extraction procedure of Zeien and Brümmer (1989)

Step	Extractant	Equilibration time	pH	Approximate nature of metal
1	1 M NH_4NO_3	24 h	natural	readily soluble and exchangeable
2	1 M NH_4-acetate	24 h	6.0	carbonate-bound, specifically adsorbed and weak organic and inorganic complexes
3	0.1 M $NH_2OH \cdot HCl$ + 0.2 1 M NH_4-acetate	30 min	6.0	Bound to Mn oxides
4	0.025 M NH_4EDTA	90 min.	4.6	bound to organic substance (stable complexes)
5	0.2 M NH_4-oxalate,	4 h	3.25	Bound to amorphous and poorly ordered Fe oxides (=Fe_o)
6	0.1 M ascorbic acid in 0.2 M NH_4-oxalate	30 min in boiling water	3.25	bound to crystalline Fe oxides (= Fe_a)
7	3 parts concentrated HNO_3 and 1 part concentrated $HClO_4$	until dryness (sandbath)		residual (mainly bound within silicates)

Results and Discussion

Soil properties

Differences in chemical properties between CE and PI soils may be the result of *Pinus* plantation if soil properties were comparable prior to the plantation of the trees. To test this prerequisite we compared soil characteristics which are not or only little influenced by land use like soil type, particle-size distribution, and concentrations of dithionite-extractable Fe.

All studied soils are very-fine, isohyperthermic Anionic Acrustoxes with 68-76 % clay (Table 8). There is no significant change in clay content with increasing soil depth in any individual soil (not shown). There is no significant difference in concentrations of clay, silt, sand, and organic C, in effective cation exchange capacity (ECEC) and in pH between CE and PI, although pH and ECEC tend to be lower in PI.

Total concentrations in soil solid phase

Total metal concentrations do not significantly differ between CE and PI at any depth (Table 9). Total Ca, Cu, Mg, Mn, Na, and Zn concentrations are smaller than in many temperate soils, those of Al and Fe are larger because of desilication. Concentrations of Al, Ca, Fe, K, Mg, and Na are comparable with those of other tropical Oxisols. When compared with concentrations in Costa Rican Oxisols (Wilcke et al., 1998), Cu, Mn, and

Zn concentrations are small, indicating an advanced state of weathering of the studied Oxisols.

Table 8: Average pH (H_2O), pH (KCl), organic C (OC), effective cation-exchange capacity (ECEC), dithionite-extractable Fe (Fe_d), texture, and bulk density in the *Cerrado* and *Pinus* soils (standard deviations in brackets).

a) *Cerrado*

Site	PH (H_2O)	pH (KCl)	OC	ECEC	Fe_d	Texture Clay	Texture Silt	Texture Sand	Bulk density
			g kg^{-1}	mmol$_c$ kg^{-1}			g kg^{-1}		Mg m^{-3}
0-0.15 m	4.8	4.2	22.0	6.81	32	705	88	207	0.88
			(1.3)	(1.6)	(8.7)	(78)	(69)	(22)	(0.07)
0-0.3 m	5.2	4.4	17.7	6.68	33	708	83	208	0.99
			(1.2)	(1.2)	(8.7)	(65)	(51)	(19)	(0.02)
0.3-0.8 m	5.2	4.8	11.3	6.50	32	680	130	190	0.94
			(1.3)	(1.5)	(9.0)	(83)	(80)	(12)	(0.14)
0.8-1.2 m	5.3	5.4	8.4	7.13	32	688	129	183	0.84
			(0.8)	(1.2)	(8.7)	(92)	(93)	(3)	(0.02)
1.2-2 m	5.4	5.8	6.4	6.59	31	684	134	182	0.82
			(0.2)	(2.1)	(8.5)	(62)	(64)	(3)	(0.02)

b) *Pinus*

Site	PH (H_2O)	pH (KCl)	OC	ECEC	Fe_d	Texture Clay	Texture Silt	Texture Sand	Bulk density
			g kg^{-1}	mmol$_c$ kg^{-1}			g kg^{-1}		Mg m^{-3}
0-0.15 m	4.6	4.0	21.9	5.95	31	733	96	171	0.82
			(1.4)	(0.4)	(4.2)	(78)	(64)	(14)	(0.02)
0-0.3 m	4.8	4.3	15.8	7.42	31	755	76	169	0.95
			(1.6)	(1.9)	(3.9)	(61)	(50)	(14)	(0.01)
0.3-0.8 m	4.7	4.6	11.4	5.53	31	765	88	147	0.89
			(0.6)	(0.5)	(3.9)	(56)	(43)	(14)	(0.07)
0.8-1.2 m	4.7	5.1	8.3	4.73	30	746	105	149	0.84
			(0.4)	(0.6)	(4.6)	(93)	(78)	(15)	(0.04)
1.2-2 m	4.8	5.6	6.9	4.96	29	748	101	151	0.79
			(0.2)	(1.4)	(3.9)	(85)	(67)	(19)	(0.03)

Tab. 9: Average total metal concentrations and standard deviations (in brackets) in the organic horizons and mineral soil layers in *Cerrado* (CE) and *Pinus* (PI) (n=3).

Soil layer	Al ($g\ kg^{-1}$)		Ca ($mg\ kg^{-1}$)		Cu ($mg\ kg^{-1}$)		Fe ($g\ kg^{-1}$)		K ($mg\ kg^{-1}$)		Mg ($mg\ kg^{-1}$)		Mn ($mg\ kg^{-1}$)		Na ($mg\ kg^{-1}$)		Zn ($mg\ kg^{-1}$)	
	CE	PI	CE	PI	CE	PI	CE	PI	CE	PI	CE	PI	CE	PI	CE	PI	CE	PI
Oi	3(0,8)	2(0,3)	2390(830)	981(14)	9(0.2)	4(5)	1.7(0.3)	1(0.2)	340(40)	626(77)	400(140)	251(20)	139(32)	121(19)	180(18)	162(5)	12(6)	4(1)
Of[a]		7(2)		1093(302)		7(7)		4(1)		259(15)		145(42)		116(28)		103(7)		5(1)
Oa[a]		29(3)		226(98)		10(9)		15(3)		223(17)		35(7)		30(4)		100(9)		7(6)
0-0.15 m	149(10)	130(32)	33(4)	35(5)	27(4)	25(10)	54(9)	53(2)	134(14)	115(21)	25(4)	28(2)	42(13)	42(12)	81(11)	77(2)	17(4)	16(2)
0.15-0.3 m	159(12)	131(34)	29(3)	31(2)	29(5)	25(9)	59(11)	54(0.6)	127(20)	106(20)	28(4)	26(4)	46(14)	43(11)	74(5)	81(12)	18(6)	16(4)
0.3-0.8 m	171(26)	140(34)	26(1)	31(4)	31(2)	29(0,4)	60(11)	57(1)	124(14)	117(30)	28(2)	28(5)	49(19)	41(9)	70(6)	78(5)	21(1)	18(6)
0.8-1.2 m	175(13)	143(36)	29(1)	33(5)	36(2)	26(1)	61(12)	56(3)	125(17)	114(32)	29(3)	26(6)	50(17)	38(9)	68(3)	76(3)	20(4)	18(9)
1.2-2.0 m	177(14)	151(30)	29(1)	32(2)	33(2)	28(1)	60(10)	57(1)	137(12)	119(13)	29(4)	27(4)	45(12)	40(6)	80(5)	71(3)	20(5)	17(6)

[a]Exist only in PI.

The concentrations of Al, Cu, Fe, and Zn tend to increase with increasing soil depth. However, differences between the various sampled layers are not significant. The differences in concentrations of the other metals between the sampled layers are small and do not show any consistent trend. The increase of lithogenic metal concentrations in younger soils from temperate regions is often more pronounced than that in the studied CE and PI soils. This indicates that the study soils are strongly and homogeneously weathered throughout the uppermost 2 m of the soil profile.

Metal partitioning in surface soil
The proportions of alkali and earth alkali metals in Fraction 1 decrease along the line Ca (74-83 % of total Ca) > Na (43-59 %) > K (34-48 %) > Mg (27-48 %) tending to be smaller in PI than in CE. However, the differences between PI and CE are not significant. The proportions of readily soluble and exchangeable Ca, K, and Mg in the studied Oxisols where much larger than in many temperate soils where frequently < 5 % of the total concentrations is found in this fraction.

There are no signifcant differences in Al, Cu, Fe, Mn, and Zn partitioning between PI and CE (Fig. 7). In the soils of both systems more than 83 % of total Cu, Fe, Mn, Zn, and Al concentrations are extracted with the sum of the Fractions 5 to 7 which characterize hardly plant-available soil pools. The largest fraction for all studied metals is Fraction 7 which comprises 61-91 % of the total concentrations. Consequently the plant-available proportions are small. Less than 6 % of total Cu, Fe, and Zn and about 12 % of total Mn are found in Fractions 1+2 which mainly represent exchangeable metals considered as directly available to plants.

Metal partitioning in the studied Oxisols is substantially different from that reported for many temperate soils. In the latter, most Mn is often found in the easily reducible phase extracted with Fraction 3 and most Cu in organically bound forms extracted with Fraction 4. Similar results have been reported by Wilcke et al. (1998) for Costa Rican Oxisols.

Chemical composition of the soil solution in CE
The solution pH in CE ranges between 4.4 and 6.9 (Table 10). It increases slightly with soil depth (Fig. 8). The course of the solution pH during the rainy season shows short-time variations (Fig. 8). This may be the result of the decoupling of mineralization and ion uptake connected with H^+ production or consumption. The electrical conductivity (EC) as a measure for total dissolved salt concentrations in CE soil solution is extremely low when compared with less weathered soils.

The most abundant metals in soil solution are Na, Ca, K, and Mg. Concentrations of Cu, Fe, and Si are below the detection limit in all solutions (< 0.016 μmol Cu l^{-1};< 1.8 μmol Fe l^{-1}; < 36 μmol Si l^{-1}). Metal concentrations in soil solutions under natural forest in temperate regions are 10-100 times larger than those measured in CE soil solution.

During the high rainy season, when temporal variations are small, there are no significant differences in metal concentrations between 0.15 and 0.3 m depth (Fig. 8). Between 0.3 and 2 m depth average concentrations of all metals except for Al and Zn increase significantly with increasing soil depth. Aluminum and Zn concentrations do not show a distinct trend with soil depth.

In the studied CE Oxisols, the weathering intensity is similar in the upper 2 m. Smaller metal concentrations in topsoil solution, therefore, may be explained by the more pronounced metal uptake by plant roots. Furthermore, the subsoil contains net positive charge which is indicated by a higher soil pH in KCl than in H_2O. The consequence may be reduced metal sorption because cations are repulsed from the soil surfaces and therefore sorbed to a lesser extent.

The temporal course of metal concentrations in soil solution during the rainy season can be divided into two phases (Table 10, Fig. 9). During the first weeks of the sampling period, the soil was rewetted after 5 months with only little rain. Between Oct. 21 and Dec. 16, 1997 concentrations in soil solution are larger and more variable than between Dec. 23, 1997 and Apr. 28, 1998.

Chemical composition of the soil solution in PI

Similar to that in CE, the chemical composition of the soil solution in PI was highly variable between Oct. and Nov. 1997 and no consistent differences could be observed between CE and PI. However, there are significant differences in chemical solution properties during the high rainy season (Dec. 23-Apr. 28).

Between 0.15 and 1.2 m depth the soil solution pH in PI is 0.2 to 0.6 pH units lower than in CE, the EC is about five times higher (Fig. 8) whereas at 2 m depth pH and EC do not differ significantly between CE and PI. This indicates that the acidification front of the 20-years-old PI forest has reached a soil depth between 1.2 and 2 m depth.

The depth distribution of Ca, K, Mg, and Na concentrations in soil solution is similar in CE and PI. However, concentrations of Ca, K, Mg, and Na are up to two times larger in PI than in CE. Mn and Al concentrations increase between the litter leachate ("0 m") and solution at 1.2 m soil depth where concentrations are up to 9 (Mn) and 60 (Al) times larger than in CE. Between 1.2 m and 2 m soil depth, concentrations of Al and Mn sharply decrease. At 2 m depth concentrations of Al are similar in CE and PI. The larger concentrations of Mn and Al at 0.15-1.2 m soil depth are related to the lower solution pH in PI than in CE. There are no consistent differences in Zn concentrations between CE and PI.

There are no significant differences in the temporal course of metal concentrations between CE and PI (Fig. 9, 10). The course of the pH, EC, and metal concentrations in litter leachate parallels that of the soil solution at 0.15 m depth.

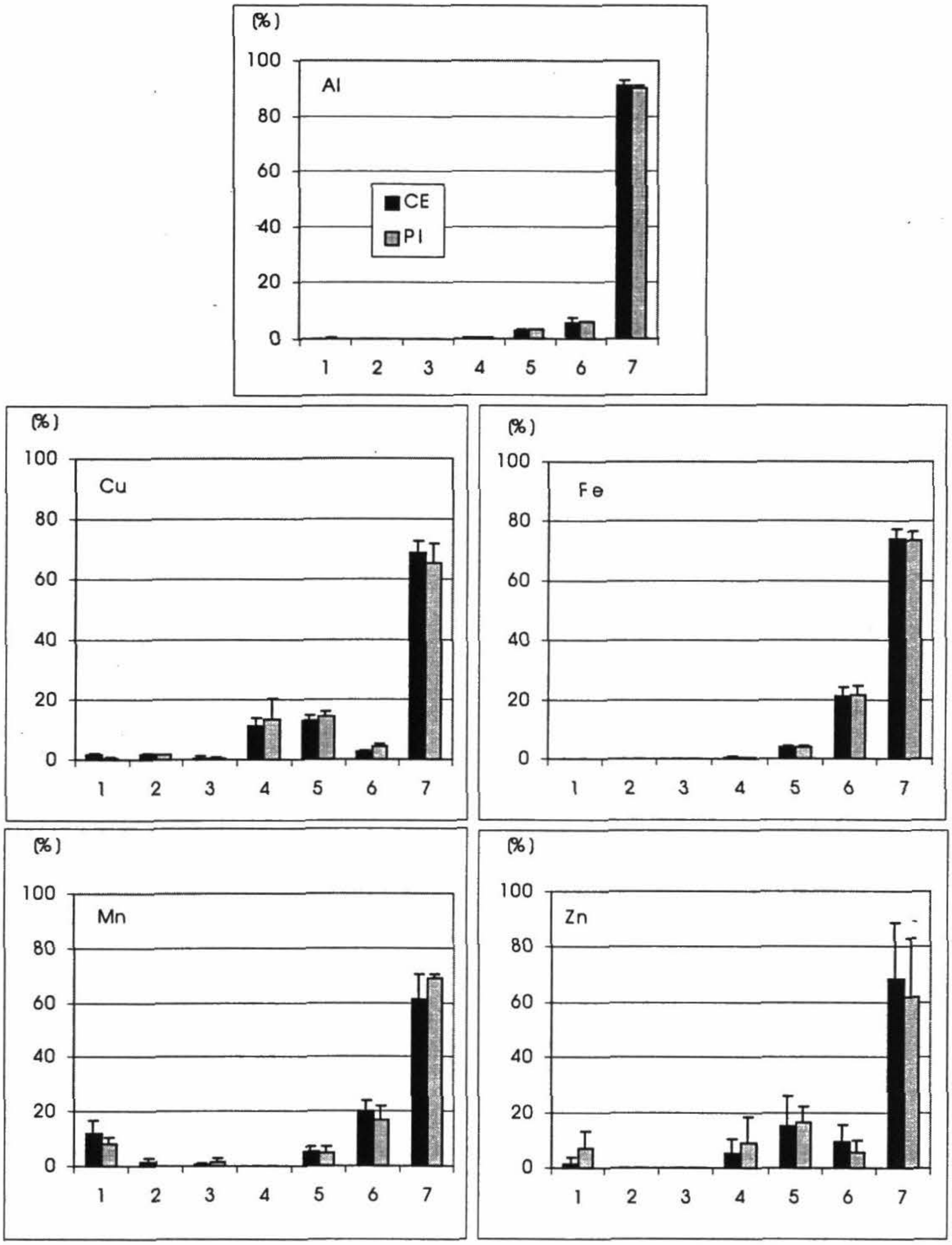

Figure 7: Partitioning of Al, Cu, Fe, Mn, and Zn in *Cerrado* (CE) and *Pinus* (PI) topsoils (0-0.15 m). Fractions 1 to 7 refer to the steps of the sequential extraction procedure of Zeien and Brümmer (1989) listed in Table 6.

Tab. 10: Ranges of pH, electrical conductivity (EC), and K, Ca, Mg, Na, Zn, Mn, and Al concentrations in soil solution. a) at the beginning of the rainy season (Oct. 21, 1997 – Dec. 16, 1997)

		Cerrado 0.15 m	0.3 m	0.8 m	1.2 m	2.0 m	*Pinus* *litter leachate*	*0.15 m*	0.3 m	0.8 m	1.2 m	2.0 m	Tropical Soils[1,2,3]
PH		4.6-6.2	4.4-6.5	4.5-5.8	5.5-6.9	5.4-6.0	3.9-5.1	4. 6-5.1	4.5-5.1	4.6-5.6	4.7-5.3	5.0-6.4	4.2-4.9
EC	[μS cm^{-1}]	13-131	17-188	16-114	29-65	15-31	14-135	14-65	22-66	20-60	28-58	17-67	
Al	[μmol l^{-1}]	1.0-5.7	0.9-6.4	0.4-21.9	0.9-11.0	0.2-3.4	9.0-25.6	8.6-21.6	12.0-19.3	0.4-15.5	5.5-23.1	0.2-12.4	6.7-61
Ca	[μmol l^{-1}]	4.05-30.4	4.39-16.1	8.15-66.18	19.33-97.14	17.7-70.3	6.8-25.9	5.98-39.24	8.76-132.37	8.94-36.31	17.57-39.37	21.80-60.22	8.5-62
K	[μmol l^{-1}]	2.1-30.7	2.1-7.4	3.7-12.3	8.1-14.4	6.4-10.0	25.7-109.7	7.7-67.3	9.3-83.8	8.6-17.4	8.9-12.7	9.3-14.8	9-35
Mg	[μmol l^{-1}]	1.8-27.7	1.8-8.6	4.2-17.8	10.1-36.4	9.0-20.6	4.2-10.6	3.9-21.2	6.8-38.9	7.8-27.9	18.5-24.0	10.4-30.1	3-23
Mn	[μmol l^{-1}]	0.04-0.8	n.d.-0.3	0.03-0.24	0.13-0.41	0.17-0.52	0.02-0.52	0.43-0.98	0.47-1.80	0.45-0.98	0.81-1.13	0.37-0.46	0.2-1.4
Na	[μmol l^{-1}]	8.4-80.3	8.4-47.2	12.9-196.8	19.3-201.2	30.3-166.2	55.8-137.4	14.0-170.6	15.1-367.1	16.8-165.2	22.2-97.5	33.1-188.8	24-109
Zn	[μmol l^{-1}]	0.2-0.6	0.3-1.1	0.5-8.8	1.0-13.0	1.4-4.2	1.2-4.5	0.5-1.4	0.4-5.0	0.3-0.9	0.8-1.3	0.9-1.8	

b) during the high rainy season (Dec. 23, 1997 – Apr. 28, 1998)

		Cerrado 0.15 m	0.3 m	0.8 m	1.2 m	2.0 m	*Pinus* litter leachate	0.15 m	0.3 m	0.8 m	1.2 m	2.0 m	Temperate Soils[4,5]
PH		4.9-6.7	4.7-5.6	4.9-5.9	5.0-5.8	5.1-6.0	4.5-5.3	4.5-5.2	4.5-4.8	4.4-4.9	4.5-4.8	5.2-6.1	4.6-6.5
EC	[μS cm^{-1}]	1-7	2-8	1-8	2-8	4-8	8.7-38.3	10-21	16-28	3-28	21-28	3-9	42-100
Al	[μmol l^{-1}]	n.d.-2.1	n.d.-2.3	n.d.-1.5	n.d.-3.3	n.d.-1.2	6.1-30.2	5.9-23.1	10.4-37.4	11.7-25.5	18.5-37.8	n.d.-4.6	
Ca	[μmol l^{-1}]	2.84-5.56	2.80-11.67	3.32-8.67	3.32-14.26	4.30-11.33	4.4-14.8	4.36-8.87	4.55-20.05	4.59-11.26	6.21-11.47	5.44-12.16	140-250
K	[μmol l^{-1}]	0.9-2.1	1.2-2.5	1.8-4.3	2.5-6.7	3.4-6.3	12.3-71.0	2.2-9.4	3.0-10.9	5.3-11.1	5.0-6.9	3.4-12.0	10-61
Mg	[μmol l^{-1}]	0.70-2.04	0.78-2.36	1.62-4.69	2.45-8.27	2.80-6.50	2.2-7.9	2.54-12.62	3.90-11.32	3.47-15.87	4.51-13.05	6.36-13.81	29-330
Mn	[μmol l^{-1}]	n.d.-0.06	n.d.-0.05	n.d.-0.10	0.05-0.13	0.04-0.14	0.01-0.23	0.21-0.49	0.30-0.97	0.44-0.87	0.55-0.98	0.20-0.31	
Na	[μmol l^{-1}]	5.5-10.9	5.7-20.8	6.1-21.8	8.8-23.1	14.5-40.1	22.1-187.8	8.3-21.9	5.8-26.8	8.2-20.6	9.3-21.7	10.1-33.2	39-61
Zn	[μmol l^{-1}]	0.1-0.7	0.1-1.1	0.2-1.1	0.3-0.9	0.3-1.0	0.7-3.6	0.3-1.5	0.3-4.7	0.2-0.6	0.4-0.9	0.4-0.9	

[1]Steinhardt (1979), [2]Hölscher (1995), [3]Jordan (1982), [4]Bäumler and Zech (1998), [5]Tokuchi et al. (1993).

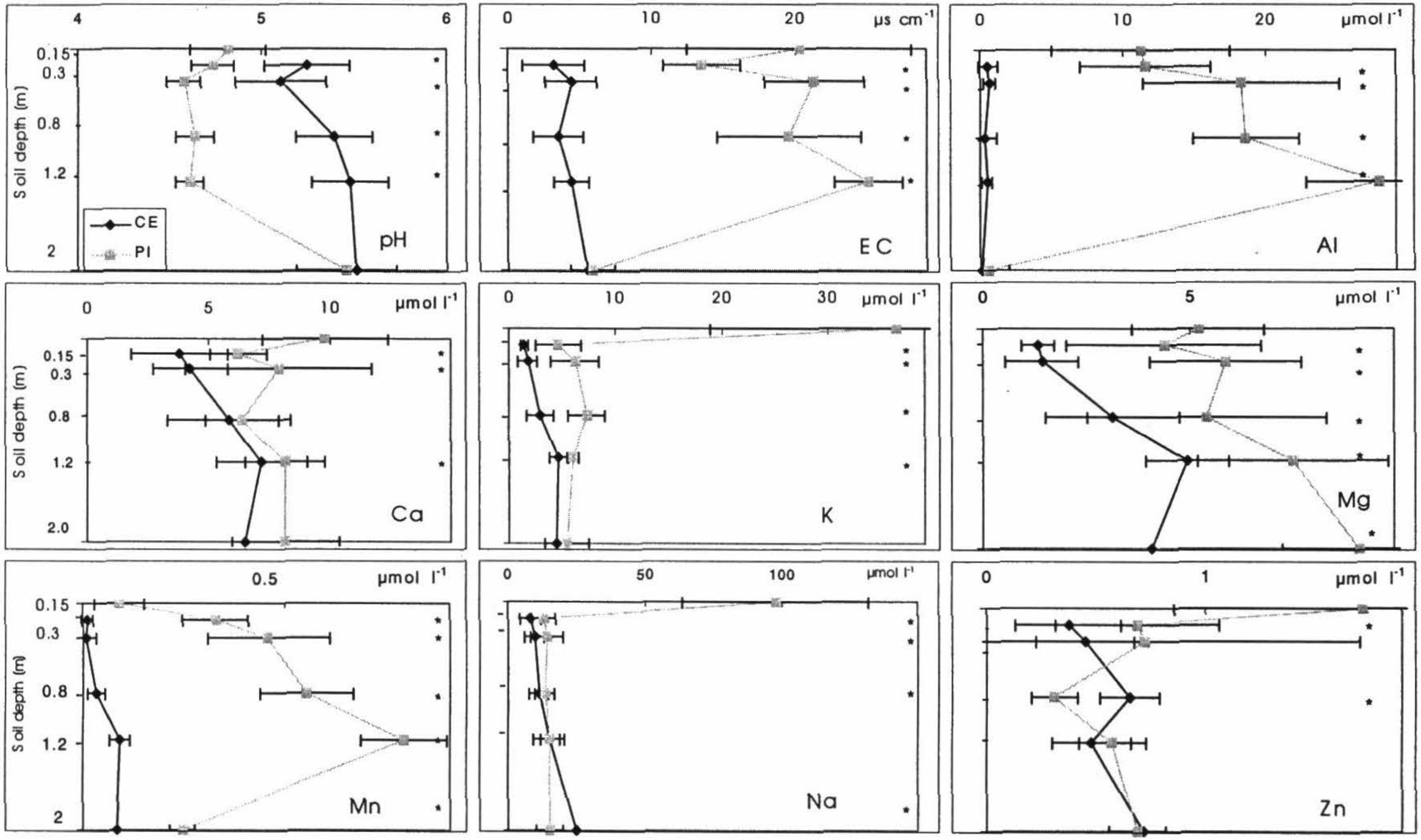

Figure 8: Average pH, electrical conductivity (EC), and concentrations of Al, Ca, K, Mg, Mn, Na, and Zn in soil solution at 0.15, 0.3, 0.8, 1.2, and 2 m depth of *Cerrado* and *Pinus* between Dec 23, 1997 and Apr. 28, 1998 (n = 3). Values followed by an * are significantly

Conclusions

Nutrient concentrations in soil solution under natural Cerrado vegetation are small because of the advanced weathering state of the studied Oxisols. Additionally, micronutrients are strongly sorbed to Fe oxides.

Whereas concentrations and partitioning of metals in the soil solid phase do not show significant differences between CE and PI, pH in soil solution is significantly lower and metal concentrations in soil solution are significantly larger in PI than in CE, particularly those of Mn and Al. The larger Ca, K, Mg, and Na concentrations at greater soil depth in PI than in CE indicate enhanced leaching to below the uppermost 2 m. The increased Mn concentrations in PI soil solution at 0-1.2 m depth compared with CE indicate Mn leaching from surface soil, but as concentrations decrease at 2 m soil depth, Mn probably is not lost from the uppermost 2 m.

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2.2 Assess and quantify principal soil degradative processes (erosion, compaction, nutrient imbalances)

No activity reported but see report of PE-2

2.3 Estimate the contribution of soil biota and nutrient cycling and soil physical conditions

This activity continued in 1999 and is pending recipt of a report from L. Mariani currently at the University of Paris, France.

Three publications on the role of earthworms in soil fertility have been published (see publication list) and two Doctorate Theses are now available. The first is entitled "Estructura de las comunidades y dinámica de las poplaciones de lombrices de tierra en las sabanas naturales y pertubadas de Carimagua (Colombia)" by J.J. Jimenez Universidad Complutense de Madrid. The second is entitled "Role fonctionnel et

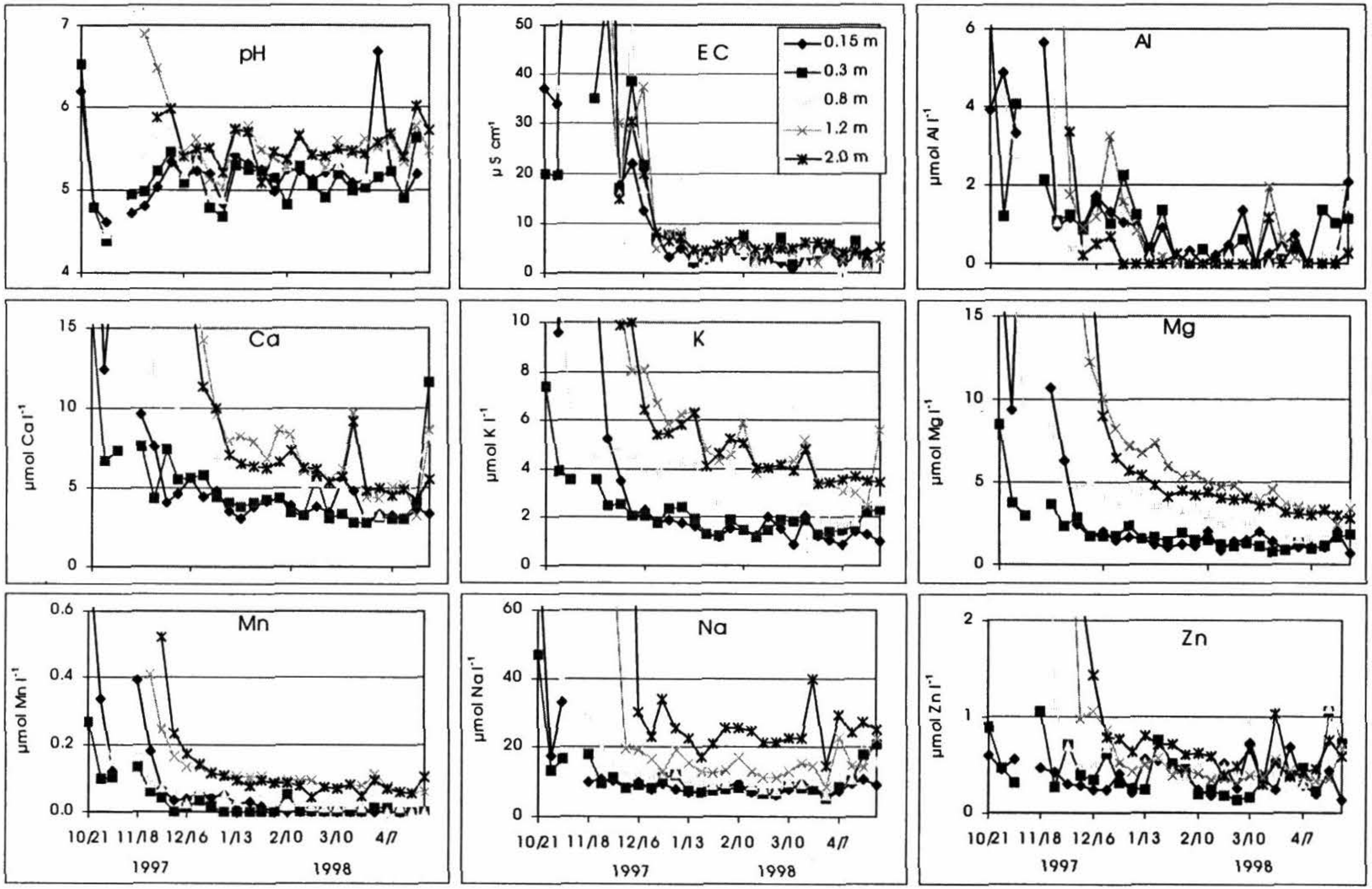

Figure 9: Temporal course of pH, electrical conductivity (EC) and concentrations of Al, Ca, K, Mg, Mn, Na, and Zn in soil solution at 0.15, 0.3, 0.8, 1.2, and 2 m depth of *Cerrado* during the rainy season. Large concentrations at the beginning of the rainy season were cut.

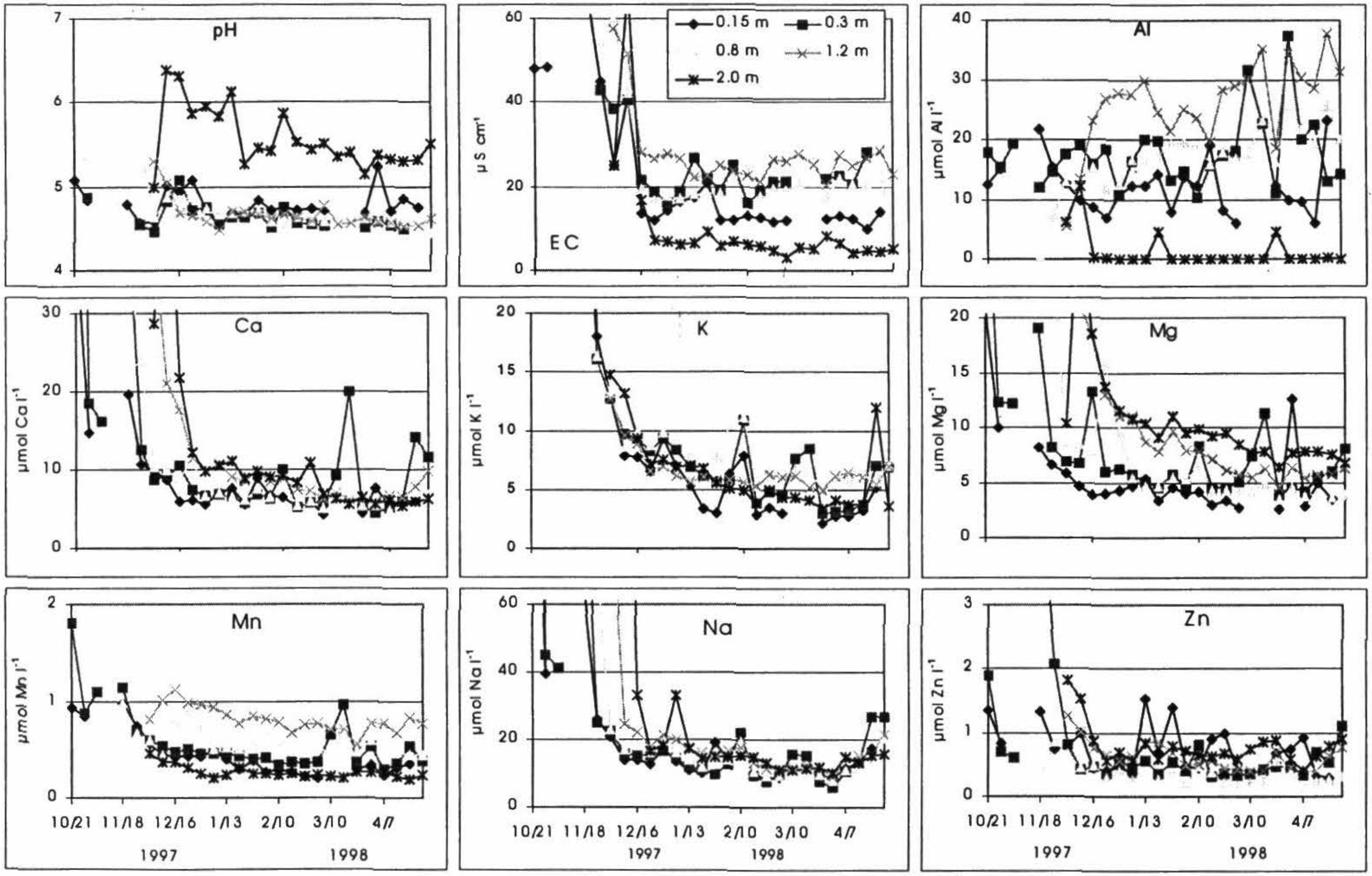

Figure 10: Temporal course of pH, electrical conductivity (EC) and concentrations of Al, Ca, K, Mg, Mn, Na, and Zn in soil solution at 0.15, 0.3, 0.8, 1.2, and 2 m depth of *Pinus* during the rainy season. Large concentrations at the beginning of the rainy season were cut.

réponses aux pratiques agricoles des vers de terre et autres ingénieurs écologiques dans les savanes Colombiennes" by T. Decaëns, Université Pierre et Marie Curie - Paris VI.

Of particular interest is the finding of large increases in total carbon contents of the earthworm casts compared with the bulk soil (between 1.4 and 1.6 times greater in casts). Possible explanations of this observation include;

i) fixation of atmospheric CO_2 by autotrophic microorganisms in casts,
ii) Attraction of roots and retention of dead roots in ageing casts,
iii) Accumulation of organic material in casts by other cast-dwelling invertebrates including enriched faecal pellets.

Details are published by Decaéns et al. Biol. Fert. Soils 28, 1999.

Contributors:
P. Lavelle, T. Decaëns, L. Mariani (University of Paris/ORSTOM), J.J. Jimenez, A.G. Moreno (University Complutense, Madrid), A. F. Rangel, N. Asakawa, R. Thomas, M. Fisher (CIAT).

Output 3: Assessment of the impact of improved systems on environmental quality

3.1 Quantify the impact of improved systems on; greenhouse gas emissions, C storage/loss from soils, fate of agrochemicals and water quality

Here we report on the activity to determine the effect of different land use systems on soil solutions in the Brazilian cerrados. Studies on greenhouse gas emissions will form the thesis of a pre-doctoral student, Marco Rondon, who is currently at Cornell University preparing his thesis.

Nutrient Concentrations in Soil Solution of Brazilian Oxisols under Conventional and No-Tillage During the Beginning Rainy Season.

Summary

At the beginning rainy season mineralization releases plant nutrients into soil solution. We hypothesized that the chemical composition of the soil solution at that time differed between conventional (CT) and no-tillage (NT) soybean (*Glycine max* (L.) Merr.) fields. We collected the soil solution at 0.15, 0.3, 0.8, 1.2, and 2 m depth and precipitation in 1- to 3-day intervals in October 28 through December 23, 1998 on three plots of each of CT and NT, and determined pH, electrical conductivity (EC), Ca, K, Mg, NO_3^-, NH_4^+, Cl^-, and total organic carbon (TOC) concentrations. Soil solution pH in NT was 0.3-0.8 units lower than in CT and inversely related with TOC concentrations (average in NT: 1.02, CT: 0.70 mmol L^{-1}). Average Cl^-, Ca, and Mg concentrations at 0.15-0.3 m depth were significantly higher in CT (1.09, 1.1, and 0.25 mmol L^{-1}, respectively) than in NT (0.50, 0.83, and 0.17). No differences existed in average Na (0.09 mmol L^{-1}) and NO_3^- concentrations (2.2) between CT and NT. At 0.8-2 m, average NO_3^- (0.30 mmol L^{-1}), Cl^-

(0.18), Ca (0.19), Mg (0.05), and Na (0.04) concentrations in CT were significantly lower than in NT (NO_3^-: 0.38, Cl^-: 0.40, Ca: 0.23, Mg: 0.09, Na: 0.06). In the monitored period, the Cl^- which had accumulated during the dry season and which was applied by fertilizing on October 29 reached a depth of 0.3 m in CT and of 1.2 m in NT. The results indicated higher mineralization rates and faster leaching in NT than in CT.

Introduction

The management system, i.e. different tillage techniques and no-till, effect chemical and physical soil properties. Various authors reported higher concentrations of soil organic matter in no-till (NT) than in conventional tillage (CT) surface soils and, as a consequence of higher nitrification rates, enhanced soil acidification. Microbial activity is higher in NT than in CT resulting in higher concentrations of microbial biomass. Arshad et al. (1990) observed higher carbohydrate, amino acid, and aliphate but lower aromate concentrations in British Columbian soils under NT than under CT indicating a more pronounced accumulation of easily mineralizable organic matter in NT than in CT.

The reports on the influence of tillage techniques on physical properties in literature are ambiguous. Whereas Hill (1990) observed reduced macropore volume under NT than under CT, other authors found increased macropore volume and continuity as a consequence of reduced tillage practices (Chan and Mead, 1989; Wu et al., 1995). In Oxisols of Paraná, Brazil, Roth et al. (1988) detected increased bulk density and reduced macropore volume at 0-0.2 m depth under NT than under CT whereas at 0.2-0.3 m depth bulk density was lower and macropore volume higher in NT than in CT. At 0.7-0.8 m depth, no tillage influence was observed. Increased infiltration rates and higher saturated hydraulic conductivity in NT than in CT may lead to faster solute transport (Wu et al., 1995). Additionally, reduced evaporation by mulching effects of the plant residues result in higher water. The effects of reduced tillage practices on nutrient leaching are also discussed contrarily in literature. Whereas Tyler and Thomas (1977) in a lysimeter study in Kentucky found higher NO_3^- and Cl^- leaching rates in NT than in CT, Drury et al. (1993) detected higher NO_3^- concentrations in the drainage water from Canadian Mollisols under CT than under NT. Up to now, most studies on the effects of different tillage practices were conducted on temperate soils. The knowledge on tropical soils is scarce. In periodically dry regions, the rewetting of the soil at the beginning of the rainy season induces mineralization flushes . Easily mineralizable organic matter like dead microbes, roots, and small soil fauna accumulates during dry periods. Drury et al. (1993) consequently measured considerable higher NO_3^- concentrations in the soil solution during the rewetting of a Canadian soil after a drought.

The objective of this study was to compare the effect of CT and NT on chemical soil solid phase and soil solution properties of Brazilian savanna Oxisols during the beginning rainy season. We particularly tested the hypotheses that the differences in mineralization and leaching rates between CT and NT result in different soil solution compositions.

Material and Methods

Study Sites

We selected three spatially disconnected plots in each of conventional (CT) and no tillage (NT) cropping systems southeast of Uberlândia (State of Minas Gerais, about 400 km S of Brasília. To allow for statistical evaluation with variance analysis we aimed at selecting independent replicates of each system. As our objective was to conduct an on-farm experiment we had to use experimental plots in the existing land-use systems. Thus, an entirely randomized plot selection was not possible. However, we only chose replicate plots of each land-use system which were separated from each other by a distance of at least 1.3 km. All study sites have inclinations < 1° and all study soils developed from fine limnic sediments of the lower Tertiary. The soils were homogeneously weathered to a depth of several meters.

The CT soils have been plowed or loosened with a disk harrow 2-3 times per year for 12 years and used for corn (*Zea mays* L.)-soybean (*Glycine max* (L.) Merr.) rotation. In 1997 corn was planted on November 11, and harvested on April 1, 1998. The NT systems have been established only between 1 and 3 years prior to the beginning of our experiment in 1997 after the plots had been used as CT in the way described above for 9-11 years. In 1997, soybean was planted on November 28, and harvested on April 16, 1998. Both, CT and NT were fertilized with an annual average of about 70 kg N ha^{-1}, 100 kg P ha^{-1}, 160 kg K ha^{-1}. In the rainy season 1998/99, CT and NT received the same amount of fertilizer on October 29 (42 kg P ha^{-1} and 63 kg K ha^{-1} applied as $Ca(H_2PO_4)_2$ and KCl) and soybean was planted on November 9 and 10. Prior to plantation, CT was manually hoed two times to simulate disk harrowing on October 23 and November 5 and on NT 1.4 kg ha^{-1} glyphosate (Roundup, Monsanto, St. Louis, MO) was applied to control weed growth.

Equipment and sampling

On each of the six plots a 10 x 10 m area was fenced and equipped with five replicate tensiometers and suction cups at each of 0.15, 0.3, 0.8, 1.2, and 2 m depth in March 1997. The major constituents of the porous cups were Al_2O_3 (70 %) and SiO_2 (29 %) with an average pore diameter of 1 µm. The soil solution was collected with permanent under-pressure produced by vacuum pumps. The pressure was weekly adjusted according to the current matric potential measured with the tensiometers. The soil solutions collected with five suction cups per depth and plot were combined. All plots were equipped with five rain collectors consisting of a sampling bottle and a funnel with a diameter of 115 mm to measure soil water input at 0.3 m height above the soil surface. Each sampling bottle was protected against larger particles and small animals with a polyethylene net (0.5 mm mesh width). A table-tennis ball was used to reduce evaporation. Tensiometers and rain collectors were placed within and between the crop rows.

Matric potential was measured and precipitation, and soil solution samples were collected in 1- to 3-day intervals on 30 sampling dates between October 28 and December 23, 1998 during the beginning rainy season. Additionally, we sampled the soil solution on 4 sampling dates during the last month of the rainy season 1997/1998 (April 7 to April 28, 1998).

At all six plots one composite soil sample from each of the 0-0.15, 0.15-0.3, 0.3-0.8, 0.8-1.2, 1.2-2 m layers was taken in January 1998. While at each plot the samples of the 0-0.15 m layer were taken from five locations and combined those of the deeper layers were taken from a soil pit. All samples were dried at 40° C and sieved to < 2 mm.

Chemical and physical characterization

The following soil chemical parameters were determined: soil organic carbon (SOC) with a CHNS-analyzer (Vario EL, Elementar Analysensysteme GmbH, Hanau, Germany), effective cation-exchange capacity (ECEC) by extraction with 1 *M* NH_4-acetate, base saturation was calculated as the proportion of the charge equivalent of extractable Ca+K+Mg+Na of the ECEC (BS), soil pH in water and 1 *M* KCl (soil:solution ratio 1:2.5) was measured with a standard pH electrode (Orion U402-S7, Boston, MA), Al in poorly-ordered Fe oxides was extracted with the oxalate-buffer method (Al_o,), crystalline Fe oxides with the cold dithionite-citrate-buffer (DCB) method (Fe_d,).

Precipitation samples were filtered through ashless white ribbon filters (Nr. 300111, Schleicher and Schuell, Dassel, Germany) and solution samples were frozen for storage. In precipitation and soil solution the following parameters were determined: solution pH with a standard pH electrode as described above (the measurement was conducted in a subsample which was afterwards discarded because of the contamination with K released by the pH electrode), electrical conductivity with a conductivity electrode (LF 318, WTW, Weinheim, Germany), total organic carbon (TOC) with an automatic total organic C analyzer (TOC-5050, Shimadzu Corporation, Tokyo, Japan), Cl^- with a Cl^--sensitive electrode (Orion, Boston, MA), NH_4^+ and NO_3^- with a rapid flow analyzer (RFA-300, Alpkem Corporation, Clackamas, OR), and Ca, K, Mg, and Na concentrations with flame atomic absorption spectrometry (Varian AA 400, Varian, Mulgrave, Australia) which was also used to determine the metal concentrations in the solid phase extracts.

Particle-size distribution was determined after removal of the Fe oxides with Na-dithionite and of organic matter with H_2O_2 at 90°C, following dispersion with hexametaphosphate. Coarse and fine sand were sieved to 250-2000 and 50-250 µm, respectively. Silt and clay concentrations were determined with the pipet method.
The soil water content was estimated from the measured matric potentials with the help of the soil water characteristic curve as described by Lilienfein et al. (1999).

Calculations and statistical evaluation

Average soil solid phase properties and nutrient input by precipitation were tested for differences between CT and NT by using Tukey's Honestly Significant Difference (HSD) mean separation test which was also used to compare average nutrient concentrations in soil solution in April 1998. To test the differences in average nutrient concentrations in the soil solution in October 28 through December 23 between CT and NT and between different depths of the same cropping system, the Wilcoxon matched pairs test for dependent data rows was used. Correlation analyses between the soil water content and nutrient concentrations in the soil solution were performed using the least square method. Significance was set at $P < 0.05$. Statistical analyses were performed with STATISTICA for Windows 5.1 (StatSoft, 1995, Hamburg, Germany).

Results and Discussion

Comparability of the soil

To assign observed differences in soil chemical composition between the two cropping systems to tillage practices we have to be sure that the following prerequisites are met: Prior to the beginning of land use the soils should have been comparable. The soils should have undergone a comparable land-use history and there may not be significant differences in nutrient input by precipitation and fertilizing.

We assume that the soils had comparable properties prior to the beginning of land-use because all studied soils are very-fine, isohyperthermic Anionic Acrustoxes which do not show any significant difference in SOC, Fe_d, and Al_o concentrations and in the ECEC, BS, pH and particle-size distribution between the two cropping systems at any depth (Table 11).

All soils were cultivated for about 12 years mainly to produce corn and soybean and received an annual average fertilizer application of about 70 kg N ha^{-1}, 100 kg P ha^{-1}, 160 kg K ha^{-1}. In the preceding rainy season, corn was cultivated in CT and soybean in NT which were fertilized at different rates (CT: 120 kg N, 100 kg P, and 140 kg K ha^{-1}; NT: 60 kg P and 170 kg K ha^{-1}). Nevertheless, average pH, TOC, and NO_3^- concentrations in April 1998, the last month of the preceding cropping season were not significantly different between the two cropping systems at any depth (Table 12). However, average pH was clearly lower in NT than in CT and lacking significance of the difference was related with the small data set (n = 3) and the large variances of the H^+ concentrations. There were few differences in nutrient concentrations in the soil solution between the cropping systems. At 0-0.3 m depth Cl^- concentrations were significantly higher, those of K significantly lower in CT than in NT. Average Ca, Mg, and Na concentrations were significantly higher in NT than in CT at 2 m depth which was reflected by significantly higher EC at this depth, those of Na were additionally significantly higher in NT than in CT at 0.8 m depth.

There were no significant differences in average soil water, H^+, TOC, and nutrient inputs between the two cropping systems during the monitored period (Table 13) and both cropping systems received the same amount of fertilizer on October 29.

Table 11: Average soil organic C (SOC), effective cation-exchange capacity (ECEC), base saturation (BS), pH, citrate-dithionite extractable Fe (Fe_d), oxalate-extractable Al (Al_o), and particle-size distribution of conventional and no-tillage Oxisols.

	SOC	ECEC	BS	pH (H_2O)	pH (KCl)	Fe_d	Al_o	Particle-size distribution Coarse Sand	Fine Sand	Silt	Clay
	g kg^{-1}	mmol$_c$ kg^{-1}	[%]			g kg^{-1}					
				Conventional tillage							
0-0.15 m	20.8	36.7	97	5.6	5.1	38	3.0	127	67	115	692
	(0.7) †	(4.1)	(1)			(9.4)	(0.21)	(22)	(3)	(39)	(50)
0.15-0.3 m	17.4	21.3	89	5.0	4.6	40	3.2	121	64	110	705
	(1.7)	(5.2)	(5)			(10.1)	(0.28)	(21)	(2)	(48)	(64)
0.3-0.8 m	10.9	14.6	73	5.0	4.9	40	3.1	103	60	107	730
	(1.3)	(2.6)	(6)			(10.0)	(0.25)	(20)	(2)	(23)	(31)
0.8-1.2 m	7.4	11.2	62	4.9	5.5	40	3.1	101	58	141	700
	(1.4)	(0.4)	(7)			(9.1)	(0.26)	(21)	(4)	(73)	(63)
1.2-2 m	6.3	11.3	58	5.0	5.8	39	3.0	100	59	102	738
	(0.4)	(0.8)	(3)			(9.3)	(0.18)	(22)	(3)	(34)	(38)
				No-tillage							
0-0.15 m	21.7	35.1	96	5.5	4.9	32	3.0	104	62	116	718
	(0.7)	(8.3)	(1)			(11.1)	(0.18)	(18)	(4)	(49)	(64)
0.15-0.3 m	19.0	28.2	95	5.5	4.7	32	3.1	104	62	133	702
	(0.5)	(9.2)	(2)			(11.0)	(0.22)	(22)	(8)	(34)	(49)
0.3-0.8 m	11.7	14.9	78	5.4	5.0	33	3.1	89	53	125	733
	(0.5)	(0.5)	(10)			(12.8)	(0.19)	(17)	(2)	(15)	(31)
0.8-1.2 m	8.9	11.8	68	5.0	4.8	32	3.1	88	53	130	729
	(0.5)	(2.2)	(4)			(12.7)	(0.09)	(21)	(9)	(2)	(17)
1.2-2 m	6.8	11.3	69	4.9	6.0	32	3.0	85	55	139	721
	(0.5)	(1.2)	(9)			(12.5)	(0.09)	(17)	(6)	(17)	(23)

† In brackets: standard deviation.

From these results we conclude that the major part of differences in soil solution chemical composition between CT and NT at the beginning of the rainy season 1998/99 may be assigned to the actual tillage practices.

Soil water content and Cl^- concentrations in soil solution

The soil water content varied over a wide range in the soil during the monitored period (Fig. 11). Consequently, changes in soil solution nutrient concentrations during the monitored period may partly have been caused by the varying soil water content. To eliminate dilution/concentration effects on nutrient concentrations in the soil solution, nutrient concentrations may be normalized to those of a conservative tracer because changes in the soil water content result in changed nutrient concentrations but not in changed nutrient to tracer ratios. In continuously humid soils which are close to steady-state water flow conditions, Cl^- has been considered as conservative tracer.

Table 12: Average pH, total organic carbon concentration (TOC), electrical conductivity (EC), and NO_3^-, Cl^-, Ca, K, Mg, and Na concentrations in soil solution of conventional and no-tillage Oxisols in April 1998.

	pH	TOC	EC	NO_3^-	Cl^-	Ca	K	Mg	Na
		Mmol L^{-1}	mS cm^{-1}	------------------------------mmol L^{-1}------------------------------					
				Conventional Tillage					
0.15 m	6.7	0.64	0.14a	0.62	0.23a	0.36a	0.19b	0.13a	0.02a
0.3 m	6.3	0.37	0.13a	0.43	0.17a	0.31a	0.11b	0.10a	0.02a
0.8 m	6.5	0.31	0.09a	0.38	0.12a	0.25a	0.04a	0.09a	0.02b
1.2 m	6.0	0.29	0.01a	0.47	0.25a	0.24a	0.06a	0.09a	0.03a
2 m	6.2	0.36	0.02b	0.12	0.06a	0.03b	0.03a	0.02b	0.02b
				No-tillage					
0.15 m	6.4	0.63	0.16a	0.89	0.03b	0.36a	0.49a	0.10a	0.03a
0.3 m	6.0	0.44	0.13a	0.66	0.03b	0.27a	0.38a	0.07a	0.03a
0.8 m	6.1	0.43	0.09a	0.19	0.26a	0.16a	0.12a	0.09a	0.04a
1.2 m	5.0	0.55	0.20a	0.64	0.79a	0.45a	0.09a	0.23a	0.05a
2 m	5.4	0.37	0.07a	0.34	0.15a	0.14a	0.03a	0.07a	0.04a

† Values followed by different letters are significantly different between conventional (CT) and no-tillage (NT) at $P < 0.05$ (Tukeys HSD test). Missing letters indicate that there were no significant differences between CT and NT.

Table 13: Average daily input rates of precipitation, H^+, total organic carbon (TOC), NO_3^-, NH_4^+, Cl^-, Ca, K, Mg, and Na between October 22 and December 23, 1998 into conventional (CT) and no-tillage (NT) Oxisols.

	Precipitation	H^+	TOC	NO_3^-	NH_4^+	Cl^-	Ca	K	Mg	Na
	Mm d^{-1}	- - - - - - - - - - - - - - - - - - - -μmol m^{-2} d^{-1}- -								
CT	8.3	33	2304	125	148	151	90	95	56	141
	(1.3)†	(33	(273)	(40)	(34)	(46)	(32)	(26)	(9)	(38)
NT	7.9	15	2305	160	174	139	105	101	71	119
	(0.9)	(6)	(300)	(47)	(70)	(45)	(31)	(25)	(36)	(9)

† In brackets: standard deviation.

For our systems, however, the plot of the water content against Cl^- concentrations illustrates that there was no relationship between the two parameters. This is shown for 0.15 m depth in Fig. 12 but also holds for all other depths (not shown). The reason probably was that at the beginning rainy season there was no steady-state water flow. During the dry season, Cl^- was deposited but not leached and thus accumulated at the soil surface. Furthermore, the fertilization on October 29 resulted in an additional Cl^- input. Thus, we may not eliminate the influence of varying water contents on nutrient concentrations by normalizing them to Cl^-. We instead ran correlation analyses between water contents and nutrient concentrations to estimate the importance of the variations in water contents for nutrient concentrations. There was no significant correlation between the soil water content and the concentrations of any nutrient at 0-0.8 m depth. This indicated that the influence of varying water contents on nutrient concentrations was negligible. At 1.2-2 m depth few significant correlations indicated a larger influence of water contents on nutrient concentrations in soil solution. However, the coefficients of determination were smaller than 0.55 indicating that at most 55 % of the variability in nutrient concentrations can be explained by changes in the soil water contents. In most cases, less than 30 % of the variability was attributable to varying water contents.

As the Cl^- input occurred in one single pulse at the beginning of the monitored period, Cl^- can be considered as a tracer of the water-flow regime. At 0.15 and 0.3 m depth, Cl^- concentrations in soil solution increased at the beginning of the monitored period (Fig. 13). Highest Cl^- concentrations at 0.15 m depth were recorded on November 13 and 16 in CT and NT, respectively and at 0.3 m depth on December 3 and 5 in CT and NT, respectively. At greater depths, Cl^- concentrations in NT decreased at the beginning of the monitored period probably because remaining Cl^- of the preceding rainy season was leached. Highest Cl^- concentrations at 0.3-1.2 m depth in NT occurred nearly simultaneously between December 2 and 5. During the monitored period, the Cl^- pulse did not reach depths of 0.8-2 m in CT and of 2 m in NT.

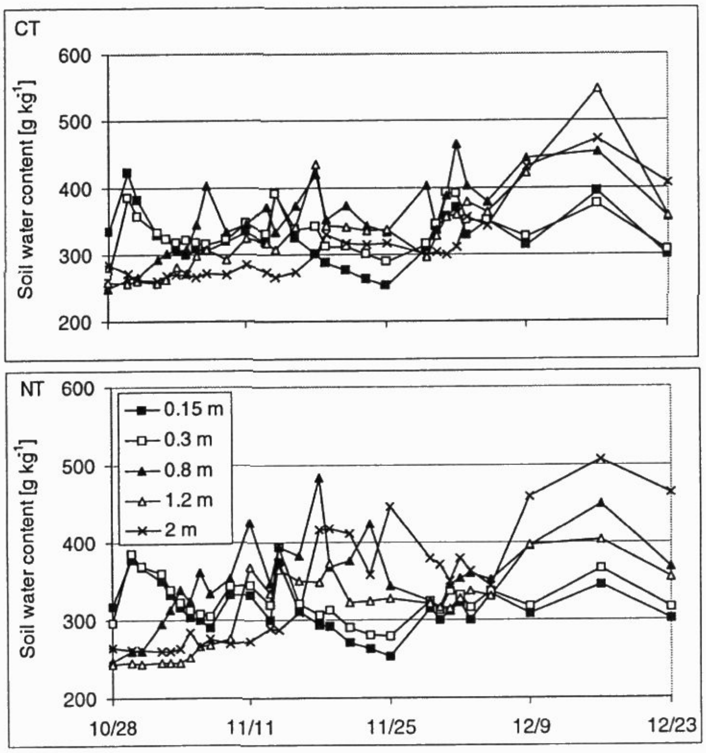

Figure 11: Course of soil water content in conventional (CT) and no-tillage (NT) Oxisols at the beginning rainy season (October 28 - December 23, 1998).

The results indicated that in NT Cl^- was rapidly transported down to 1.2 m depth, probably due to preferential flow along macropores, which was not observed in CT. The reason for the differences may be higher pore continuity and therefore probably higher hydraulic conductivity in NT than in CT. In CT, pores are destroyed by plowing (Chan and Mead, 1989; Wu et al., 1995). These differences in leaching rates may also explain the higher average Cl^- concentrations in soil solution at 0-0.3 m depth and lower ones at 0.8-2 m depth in CT than in NT between October 28 and December 23 (Table 14).

Table 14: Average pH, total organic carbon concentration (TOC), electrical conductivity (EC), and NO_3^-, Cl^-, Ca, K, Mg, and Na concentrations in soil solution of conventional and no-tillage Oxisols at the beginning rainy season (October 28 – December 23, 1998).

	pH	TOC	EC	NO_3^-	Cl^-	Ca	K	Mg	Na
		mmol L^{-1}	mS cm^{-1}	- - - - - -	- - - - - -	- - - mmol L^{-1} - - -	- - - - - -	- - - - - -	
				Conventional tillage					
0.15 m	5.8a	0.49a	0.43a	2.29a	1.47a	1.21a	0.37b	0.27a	0.086a
0.3 m	5.3a	0.37b	0.35a	2.04a	0.71a	1.00a	0.19b	0.23a	0.084a
0.8 m	5.8a	0.74b	0.11b	0.45a	0.16b	0.28a	0.04b	0.08a	0.052b
1.2 m	4.9a	0.79b	0.10b	0.38b	0.32b	0.26b	0.06b	0.07b	0.045b
2 m	5.5a	1.10a	0.02b	0.06b	0.05b	0.04b	0.04a	0.02b	0.034b
				No-tillage					
0.15 m	5.3b	0.56a	0.38b	2.31a	0.55b	0.88b	0.67a	0.17b	0.090a
0.3 m	5.0b	0.69a	0.34a	2.18a	0.45b	0.78b	0.59a	0.16b	0.085a
0.8 m	5.2b	0.85a	0.12a	0.37b	0.36a	0.23a	0.17a	0.08a	0.065a
1.2 m	4.6b	1.67a	0.15a	0.47a	0.70a	0.32a	0.10a	0.14a	0.061a
2 m	4.7b	1.30a	0.08a	0.31a	0.15a	0.15a	0.04a	0.05a	0.056a

†Values followed by different letters are significantly different between conventional (CT) and no-tillage (NT) at $P < 0.05$ (Wilcoxon matched-pairs test). Missing letters indicate that there were no significant differences between CT and NT.

Soil solution chemical composition

Nutrient concentrations in the solution of our study soils are comparable with those in other Brazilian Oxisols used for cropping (Table 14). Bassoi and Carvalho (1992) detected between 2.3-3.3 mmol NO_3^- L^{-1}, 0.5-0.94 mmol K L^{-1}, 0.5-1.27 mmol Ca L^{-1}, and 0.2-0.5 mmol Mg L^{-1} at 0.3-0.9 m depth during the first 3 months after plantation of corn and fertilization near São Paulo

In both, CT and NT, average pH, EC, Cl^-, Ca, K, Mg, and Na concentrations between October 28 and December 23 decreased with increasing soil depth, while the TOC concentrations increased. Higher average pH, EC, and nutrient concentrations in the surface soil solution were attributable to the nutrient accumulation during the dry season and to fertilizer and lime application. Increasing TOC concentrations with depth indicated that water-soluble organic matter concentrations increased relative to the water content. This may be explained by lower water contents at 1.2-2 m depth during the beginning of the rainy season (Fig. 11) when TOC concentrations are particularly high (Fig. 15) and would be in line with the finding that there was some influence of the water content on solute concentrations at 1.2-2 m depth. The concentrations of TOC correlated significantly with the water content at 1.2 m depth in NT (r = -0.57*) and at 2 m depth in CT (r = -0.72*) and NT (r = -0.68*). Additionally, the larger proportion of hydophilic substances of the soluble organic matter pool in the subsoil may also contribute to increased TOC concentrations.

At the beginning rainy season 1998/99 EC, TOC and nutrient concentrations in CT and NT were almost at all depths higher than at the end of the rainy season 1997/98 and the depth gradients were steeper mainly because of the greater temporal proximity to fertilizing. In contrast, pH was lower which probably reflected the higher mineralization rates at the beginning rainy season.

Higher TOC concentrations in NT than in CT may reflect a higher release of soluble organic matter by mineralization or the dissolution of a larger pool of easily water-soluble organic matter. As the mineralization of soil organic matter results in H^+ release a higher mineralization rate would also explain the lower solution pH in NT than in CT. The generally higher nutrient concentrations in CT than in NT at 0.15-0.3 m depth and lower ones at 0.8-2 m depth support the assumption of faster solute transport in NT than in CT.

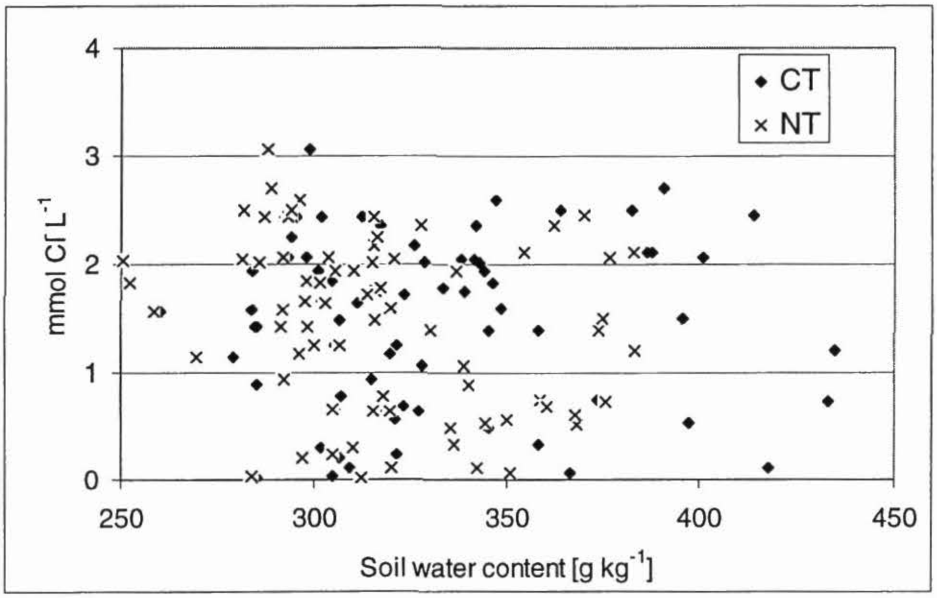

Figure 12: Relationship between soil water content and soil solution Cl^- concentrations at 0.15 m depth in conventional (CT) and no-tillage (NT) Oxisols at the beginning rainy season (October 28 - December 23, 1998).

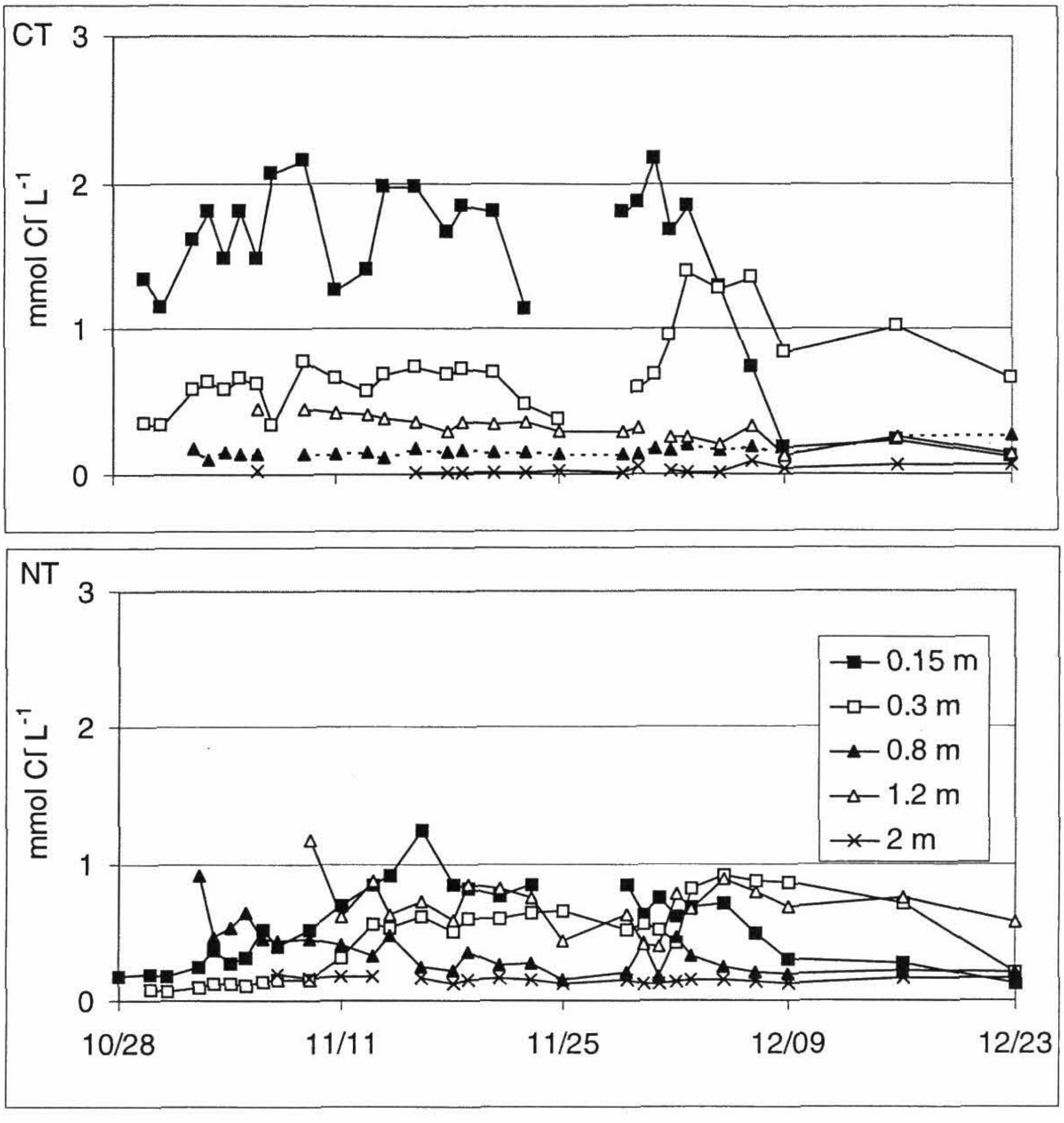

Figure 13: Course of soil solution Cl^- concentrations in conventional (CT) and no-tillage (NT) Oxisols at the beginning rainy season (October 28- December 23, 1998).

The temporal course of the soil solution concentrations was influenced by the quantity and distribution of the soil water input. Total soil water input during the monitored period was 526 mm in CT and 495 mm in NT. The cumulative soil water input is presented in Fig. 14. At the beginning rainy season, precipitation was highly variable, therefore the weekly soil water input varied between 0 to 134 and 0 to 106 mm in CT and NT, respectively.

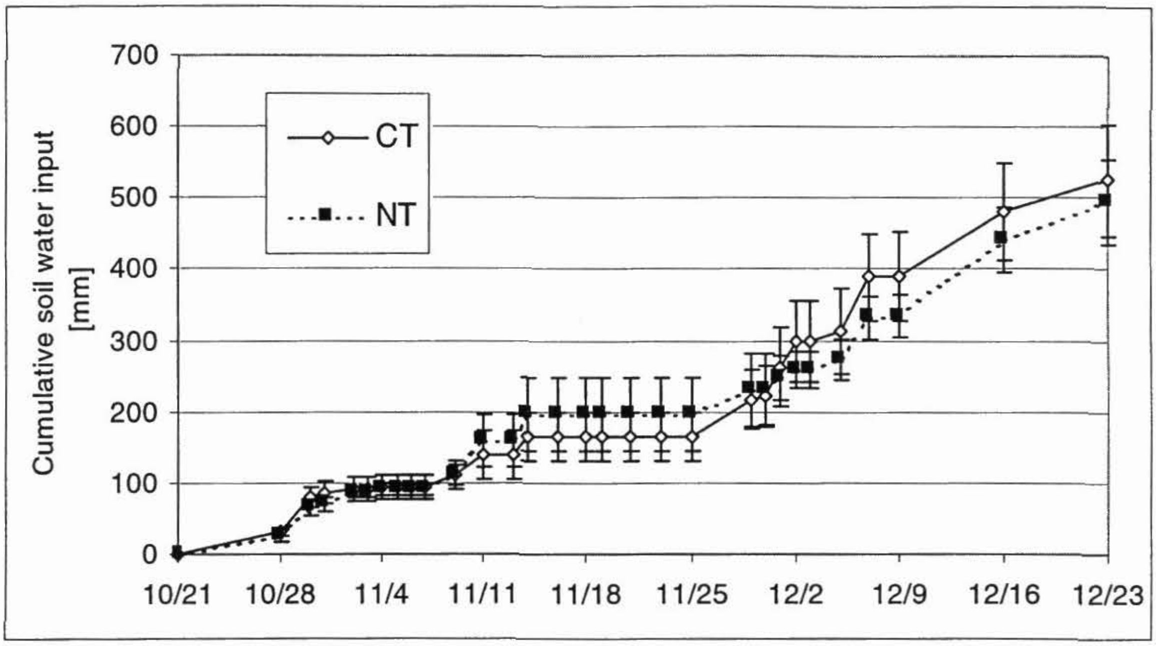

Figure 14: Cumulative soil water input into conventional (CT) and no-tillage (NT) Oxisols at the beginning rainy season (October 22 - December 23, 1998).

Total organic C concentrations were highest after the first rains and decreased until end of December to a level which is comparable to that in April 1998 (Fig. 15, Tab. 12). Total organic C concentrations in soil solution reflected the mineralization flushes when the soil was rewetted. The course of the TOC concentrations was inversely related with that of soil solution pH. During periods with high TOC concentrations, solution pH was lower than during periods of low TOC concentrations probably because of H^+ release during mineralization. Generally, nutrient concentrations at the beginning of the monitored period are higher than at the end (December 9-23) because of fertilization, the release of nutrients into the soil solution by mineralization, and the accumulation of nutrients at the soil surface mainly by dry deposition during the dry season. The highest variations in soil solution chemical composition were observed at 0.15 and 0.3 m depth. At the beginning of the rainy season, nutrient concentrations at 0-0.3 m depth were substantially higher than at 0.8-2 m depth. In the course of the monitored period, nutrients were leached to greater depths and concentrations at 0-0.3 m depth decreased and became comparable to those at 0.8-2 m depth. In NT, NO_3^-, Ca, and K concentrations at 0-0.3 m depth decreased simultaneously, whereas in CT, concentrations at 0.15 m depth decreased earlier than at 0.3 m depth again reflecting the faster leaching in NT than in CT.

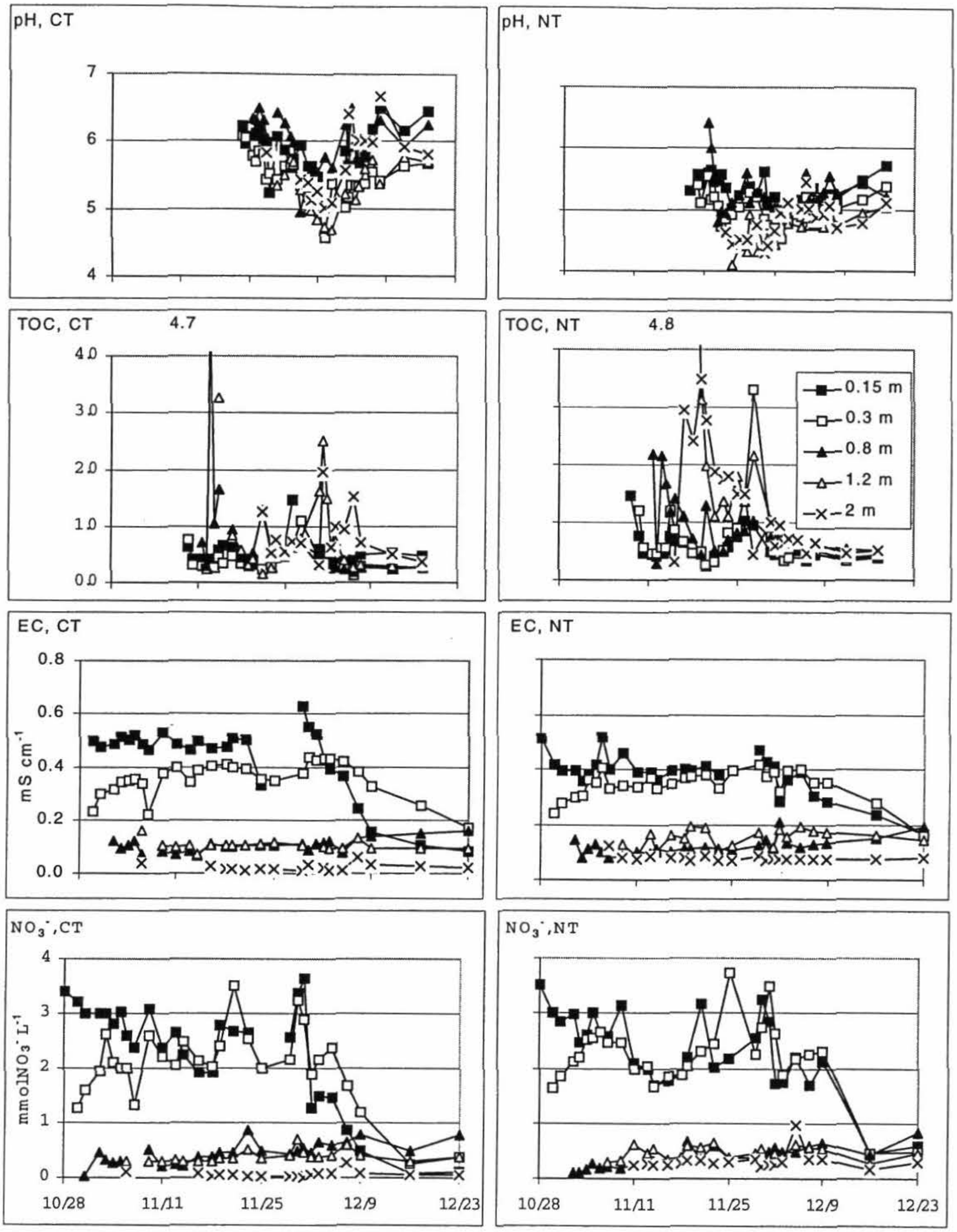

Figure 15(1): Course of solution pH, electrical conductivity (EC) and concentrations of total organic carbon (TOC), NO_3^-, Ca, K, Mg, and Na in conventional (CT) and no-tillage (NT) Oxisols at the beginning rainy season (October 28 - December 23, 1998).

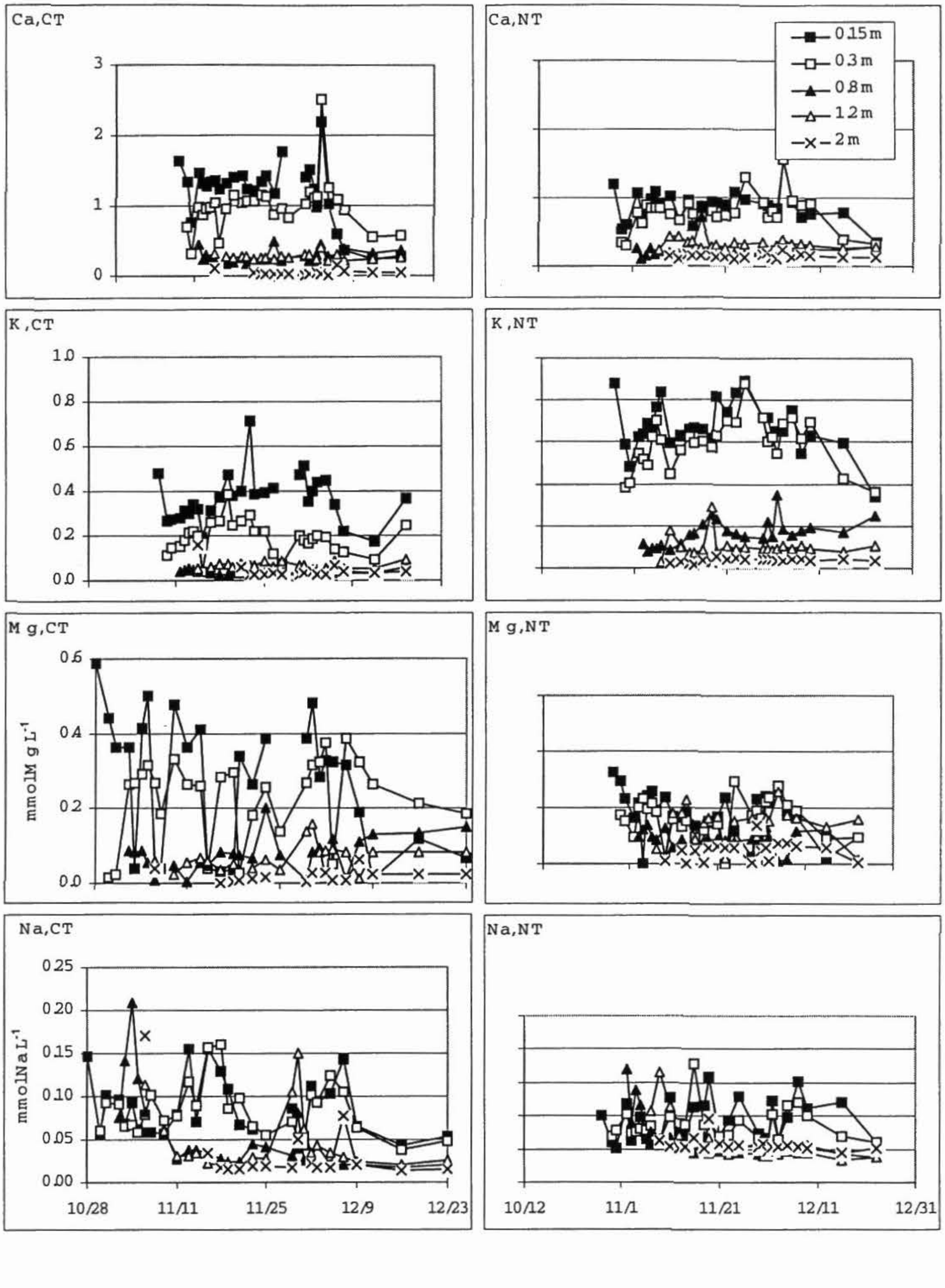

Figure 15(2): Course of solution pH, electrical conductivity (EC) and concentrations of total organic carbon (TOC), NO_3^-, Ca, K, Mg, and Na in conventional (CT) and no-tillage (NT) Oxisols at the beginning rainy season (October 28 - December 23, 1998).

Conclusions

Two to four years of NT did no result in changed soil solid phase properties. In contrast, chemical composition of the soil solution was substantially affected by the different tillage practices. Lower soil solution pH in NT than in CT indicated enhanced soil acidification in NT, probably because of higher mineralization rates. Higher mineralization rates and a larger pool of readily water-soluble organic matter were also a likely explanation for higher TOC concentrations in NT than in CT.

Faster appearance of an initial Cl^- pulse to the soil surface at greater soil depth in NT than in CT indicated a faster solute transport along preferential pathways due to the higher pore continuity in NT than in CT. This was confirmed by the lower average nutrient concentrations in the surface soil solution and higher one in the subsoil solution under NT than under CT. The consequence may be higher nutrient losses from the rooting zone by leaching in NT than in CT.

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Future activities

In the beginning of May 1999, the experimental work in Brazil will be completed. The scientific equipment will be removed from all plots except for those under Cerrado and Pinus. The latter will in future be run by the Federal University of Uberlândia. The samples will be transported to Bayreuth where the laboratory analyses will be performed. Further publications will include the following aspects:

- Nutrient storage in above- and belowground biomass and in soil.
- Water and nutrient inputs into soils by precipitation and fertilization.
- Water and nutrient inputs into soils by stemflow.
- Differences in chemical composition of soil solution between the land-use systems.
- Modelling of water and nutrient fluxes in soil.
- Water and nutrient budget of differently used savanna ecosystems.
- Evaluation of the sustainability of different land-use systems.

3.2 Assessing on-farm environmental impact using land quality indicators

No activity to report .

3.3 Economic evaluation of selected off-site environmental impacts

No activity to report. Lack of qualified staff has curtailed this activity.

Output 4: Sustainable prototype systems designed and validated through farmer participation

4.1 Select components and systems throgh farmer participation, validate systems on-farm.

An advisory booklet on the use of the forage legume *Stylosanthes guianensis* has been published (Ayarza et al. 1998).

4.2 Assess nutrient balances on- and off-farm and on a regional basis

See work reported under Output 3.1

4.3 Calibrate, validate and refine crop and pasture models on nutrient dynamics and productivity over the long term

Collaboration on the development of an improved sub-model of DSSAT for soil phosphorus has continued. This will be presented at an international workshop to be held in Nairobi, October 1999 by Dr. S. Daroub from Michigan Sate University, USA. The workshop is organized by TSBF, Nairobi and MAS funds will be used to support participation of consortia members.

4.4 Identify and test methods of soil restoration to improve soil quality

Aspects of this activty are presented in the book entitled "Sustainable land management for the Oxisols of the Latin American Savannas" (1999).

Output 5: Greater institutional capacity for Soil, Water and Nutrient Management through information exchange and training

5.1 Prepare and publish a state-of-the-art document on the management of acids soils.

An article entitled "Management and conservation of acid soils in the savannas of Latin America: Lessons learned from the agricultural development of the Brazilian Cerrados" was published in 1999 by the IAEA, Vienna (see publication list).

5.2 Organize workshops of collaborators for project development, monitoring and information exchange and to transfer knowledge gained to stakeholders.

Three planning workshops have been held in Central America. At the first two held in Nicaragua and Honduras respectively, participants from national programs, universities etc., met to prioritize the needs for SWNM work in the regions. In August a MAS consortium meeting was held in Honduras to develop a new MAS project for Central America.

5.3 Publish bulletins/newsletter on acid soil research

A bulletin and minutes of the SWNM meeting held at the Mid-Term meeting has been circulated to consortia members.

5.4 Cadre of personnel trained in management of acid soils

See list of trainees below.

Table 15. Training supported by MAS

Name	Nationality	Education	Institution	Research theme
J.G. Cobo	Colombia	M.Sc.	CATIE	Green manure/residue decomposition
M.A. Rondon	Colombia	Ph.D.	Cornell Univ.	Greenhouse gas fluxes
W. Trujillo	Colombia	Ph.D.	*Ohio State Univ.*	Carbon sequestration
S. Buhler	Switzerland	Ph.D.	ETH, Zurich	Phosphorus acquisition/cycling
A. Oberson	Switzerland	Post-doc	ETH, Zurich	Phosphorus acquisition/cycling
W. Wilcke	Germany	Post-doc	Bayreuth Univ.	Nutrient/water fluxes
J. Lilienfein	Germany	Post-doc	Bayreuth Univ.	Nutrient/water fluxes
S. Phirri	Zambia	Ph.D.	Norway Agric. Univ.	Phosphorus acquisition/cycling
L. Mariani	France	Ph.D.	Univ of Paris/ORSTOM	Modelling soil fauna populations
S.H. Daroub	Lebanon	Post-doc	Michigan State Univ.	Crop modelling
R. Delve	U.K.	Post-doc	TSBF/CIAT	Organic matter database
J.J. Jimenez	Spain	Ph.D.	Univ Complutense, Madrid	Earthworm dynamics
R. Westerhof	Netherlands	Ph.D.	Bayreuth Univ.	Soil quality indicators
H. Neufeldt	Germany	Ph.D.	Bayreuth Univ.	Soil quality indicators
T. Renz	Germany	M.Sc.	Bayreuth Univ.	Soil quality indicators
S. Fuhrmann	Germany	M.Sc.	Bayreuth Univ.	Soil quality indicators
A. Freibauer	Germany	M.Sc.	Bayreuth Univ.	Soil quality indicators
V. Laabs	Germany	M.Sc.	Bayreuth Univ.	Fate of agrochemicals
R. Gross	Germany	M.Sc.	Bayreuth Univ.	Fate of agrochemicals
T. Thiele	Germany	M.Sc.	Bayreuth Univ.	Podzolisation
Y. Zinn	Brazil	M.Sc.	EMBRAPA-CPAC	Soil organic matter
U. Schwantag	Germany	M.Sc.	Bayreuth Univ.	Water/nutrient fluxes
A. Schill	Germany	M.Sc.	Bayreuth Univ.	Water/nutrient fluxes
H. Ruiz	Colombia	M.Sc.	Nacional, Palmira	Improvement of degraded *soils*
E. Madero	Colombia	Ph. D.	Nacional, Palmira	Soil structure
D.M.Arias	Colombia	Ing. Agrn.	Nacional, Palmira	Drop impact on soil structure
H. Rivera	Colombia	Ph. D.	Nacional, Palmira	Erodibility of hillsides soils
I. Balcazar	Colombia	Ing. Ag.	Nacional, Palmira	Water movement
L. Cobo	Colombia	Ing. Agr.	Nacional, Palmira	Rainfall simulator
G.P. Botero	Colombia	Ing. Agr.	Nacional, Palmira	Water movement
G. Borrero	Colombia	M.Sc.	Nacional, Palmira	Phosphorus cycling
A.M. Patiño	Colombia	M.Sc.	Nacional, Palmira	Bio-structure of soils

List of publications supported by MAS in 1998/99

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List of donors

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Progress towards achieving milestones of the Combating Nutrient depletion Consortium (CNDC):

Activities of the consortium include IFDC in West Africa Savannas, TSBF in East African Highlands and IBSRAM on the economic assesment of soil nutrient depletion. The three reports are reproduced here as submitted by the co-convening IARC. These reports are in slightly different formats owing to time restrictions that prevented a rearrangement into a common format.

Combatting Nutrient Depletion Consortium: West African Savannas

Table of Contents

Acronyms

BNMS	Balanced Nutrient Management System
EPHTA	Ecoregional Program for the Humid & Subhumid Tropics of Sub-Saharan Africa
IAR	Institute of Agricultural Research, Zaria, Nigeria
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer
ICASA	International Consortium for Agricultural Systems Applications
IFA	International Fertilizer Industry Association
IFAD	International Fund for Agricultural Development
IFDC	International Fertilizer Development Center
IFDC-Africa	International Fertilizer Development Center-Africa
IITA	International Institute for Tropical Agriculture
INRAB	Institut National de Recherches Agricoles du Bénin

SUMMARY: Combating Nutrient Depletion Consortium, West African Savannas

The CNDC in the West African Savannas has been in operation since October 1997. The CNDC partners—Institute of Agricultural Research (IAR), Ahmadu Bello University, Zaria, Nigeria, Institut National des Recherches Agricoles du Bénin (INRAB), and IFDC—are using systems-based methodologies for soil fertility improvement research. CNDC effort in the region on the application of systems-based methodologies is also being promoted through EPHTA. The focus of CNDC activities in West Africa is not so much to initiate new research as to achieve greater impact from present knowledge. The primary focus is therefore to develop and use tools such as simulation models and decision support systems that synthesize available information on soil, water, and nutrient management and make it accessible to a range of clients. The research considers agroecological and socioeconomic factors and is conducted in benchmark sites of EPHTA. While there are six benchmark areas in the EPHTA region, CNDC activities currently focus on two benchmark areas: the Northern Guinea Savanna represented by IAR and the Derived/Costal Savanna represented by INRAB. The work breakdown structure of the consortium in West Africa (EPHTA region) is presented in Figure 1.

Project Title: Combat nutrient depletion through holistic systems-based approach

Output:

- Appropriate decision support systems identified for CNDC application.
- Ex-ante evaluation of nutrient balances and yield in key annual cereal food crop, annual cash crop and perennial food crop.
- Validation and quantification of nutrient dynamics in the above crops at two key benchmark areas of the Eco-regional Program for the Humid and Sub-Humid Tropics of Sub-Saharan Africa (EPHTA): Northern Guinea Savanna and Coastal / Derived Savanna.
- Trained personnel in advanced application of information technology and systems methodologies for technology transfer.

Figure 1. Work breakdown structure of the CNDC project linking activities to outputs.

PROGRAM GOAL
To maintain or improve the natural resource base and preserve the biodiversity of natural ecosystems while increasing agricultural productivity of tropical acid soils

PROJECT PURPOSE
To combat nutrient depletion based on the principle that the restoration and maintenance of the soils of sub-Sahara (SSA) is fundamental to sustainable development in the region.

Output: Decision support systems for EPHTA	Output: Validated and improved decision support systems	Output: Quantification and improved understanding of nutrient dynamics	Output: Identification of yield gaps in current cropping systems	Output: Greater institutional capacity for CND through training of scientists in the use of decision support systems and information exchange
Activities: 1.1 Identify decision support systems for integrated nutrient management 1.2 Establish natural resources database 1.3 Methodologies harmonization workshop	Activities: 2.1 Introduciton and adaption of decision tools for low soil fertility conditions 2.2 Using existing field trial results for validation and improvement of systems tools for tropical conditions 2.3 Incorporating and improving organic residue recycling in simulation models	Activities: 3.1 Quantify impact of : - climatic differences - cropping systems - INM - Phosphate rock on nutrient dynamics and soil fertility improvement	Activities: 4.1 Water-limited yield potential evaluated for selected sites 4.2 Estimating nutrient balances on- and off-farm and on a regional basis 4.3 Estimating yield-gaps under nutrient limited cropping systems	Activities: 5.1 Field training of systems based research and minimum data set collection 5.2 Training on use and understanding of decision support systems 5.3 Training on use and interpretation of simulated results 5.4 Information exchange through workshops and published bulletin/newsletter on CND

Project scientists:	IFDC:	Dr. U. Singh, Mr. P. Dejean, and Dr. H. Breman
	ABU:	Dr. V. O. Chude and Dr. I. Y. Amapu
	INRAB:	Dr. M. Adomou and Dr. A. Kouessi
	IITA:	Dr. Jan Diels

Background and Rationale

The consortium to Combat Nutrient Depletion in Africa (CNDC) was formed to work with African farmers to combat nutrient depletion based on the principle that the restoration and maintenance of the soils of sub-Saharan Africa (SSA) is fundamental to sustainable development in the region. The plan of action was derived from three working hypothesis:

More rapid, more economic and more sustainable increases in productivity can be achieved by investment in nutrient recapitalization than by recurrent fertilization.

1. Management of soil by integrated use of organic and inorganic sources of nutrients will lead to greater productivity, increased efficiency of nutrient use and cycling and reduction of negative on- and off-site impacts on the environment and natural resource base.
2. Effective implementation of measures to improve soil fertility is dependent on appropriate institutional frameworks and policies compatible with community and household goals and objectives.

The international conveners for CNDC are the International Fertilizer Development Center (IFDC), Lomé, Togo and the Tropical Soil Biology and Fertility Program (TSBF), Nairobi, Kenya with the Institute for Agricultural Research (IAR), Zaria, Nigeria, and the Kenya Agricultural Research Institute (KARI) as co-conveners representing the African NARS. The comparative advantage of the consortium is its ability to bring together a critical mass of expertise that can develop strategies that rebuild and maintain soil fertility on depleted lands including improved nutrient acquisition and management strategies as well as innovative policy initiatives. Active farmer-participation in design, execution, monitoring and evaluation of potential technologies is a central principle in the activity of the consortium. This is achieved in West African savannas through EPHTA/IITA collaboration and by on-farm trials of the Integrated Intensification and Input Accessibility Programs of IFDC-Africa.

The key issues facing the Combating Nutrient Depletion Consortium (CNDC) are plant nutrient mining, associated soil degradation, and low farmer-adoption of nutrient management strategies. The success of CNDC is dependent on achieving an agro-ecological sustainability in nutrient balance. The maintenance and improvement of nutrient balance would involve amendments for improvement of soil organic matter status, P availability and soil pH as well as use of inorganic and organic fertilizers. We propose that combating nutrient depletion strategies be:

- Dynamic and consider farmers' circumstances, and the variability associated with unique soil-climate-crop system
- Integrated with inorganic and organic sources of nutrients
- Attentive to P availability and its influence on input efficiency

In essence, the nutrient management technologies developed must consider agroecological and socioeconomic sustainability for successful farmer-adoption. The traditional way of technology evaluation by field trials over many seasons and sites are not only costly and time-consuming but it samples only a fraction of management options available to the farmer. We will use systems simulation and modeling to contribute to the above goals. Existing (and also constructed) natural resources database for soils, crops and climate, and decision support systems will be used to predict nutrient dynamics and crop yields. Validation of systems tools is not necessary for every site, season, and crop. It is however, crucial to show the reliability of the methodology; build confidence in the tools by training the scientists in the use of decision support systems and in conducting process-oriented field trials; and collect adequate data (soil, weather, crop) to simulate and hence manage the output.

While simulation models greatly improve our understanding of the processes and predict outcomes, our objective will be using these tools to maximize outcomes. The socioeconomic aspects of sustainability will be indirectly considered by the choice of the cropping systems and the intensity of input use.

OUTPUT 1: Decision Support Systems for EPHTA

Output 1.1 Identify decision support systems for integrated nutrient management

The following criteria were used in choosing the systems simulation packages for CND research:

- Widely tested in the tropical environment
- Data requirement is not overwhelming or hard to get
- Reliable prediction
- Transportable and user-friendly
- Ability to simulate water, N and P responses as a minimum
- The model could be modified (users have access to source code)
- Capabilities to handle inorganic and organic sources
- Predict changes in organic matter
- Ability to predict runoff and erosion would be desirable

Very few simulation models have been tested under tropical conditions and of these only the IBSNAT (CERES and GRO), Wageningen (SUCROS and MACROS), and APSIM models have reasonable data requirements for validation of the models under tropical conditions, particularly, sub-Saharan Africa (SSA). Restricted access to source codes have limited the use of APSIM models. Since one single decision tool does not apply to all situations, a tool-box approach is used where suite of models with similar data requirement are used to tackle issues related to soil fertility improvement and technology transfer. Much of the results presented are based on the Decision Support System for Agrotechnology Transfer (DSSAT) software (Tsuji et al., 1994). The DSSAT offers advantage over other software as it is actively supported by the International Consortium for Agricultural Systems Application – a consortium supported by Wageningen, IBSNAT and APSIM modelers (Jones and Tsuji, 1996). However, it does not handle mix cropping and P simulation is available for only a few crops.

To further promote the use and adoption of systems tools in West Africa, IFDC in collaboration with CNDC partners, Istitut Togolais de Recherche Agronomique, Cocoa Research Institute of Ghana, University of Science and Technology, Ghana, African Studies Program, University of Wisconsin-Madison, and the Wageningen Agricultural University, the Netherlands, has acquired funding support from the Netherlands Government through the Ecoregional Program for a project entitled "A Client-Oriented Systems Tool Box for Technology Transfer Related to Soil Fertility Improvement and Sustainable Agriculture in West Africa (COSTBox)." The project is financed for a period of 3 years.

The project seeks to achieve its goals through:

1. The development of methodologies that integrate the use of systems and participatory approaches, resulting in a client-oriented systems toolbox for technology transfer.
2. The creation of confidence in the research and extension agencies and NGO's in the use of systems tools and their results through on-station and on-farm validation.
3. The development of short-term training and hands-on application of DSS.

This additional project funding highlights one of the achievements of the CNDC in West Africa.

Output 1.2 Establish Natural Resources Database

As a pre-requisite to the field research, and application of simulation for analyzing management strategies, a collation of existing soil, climate, and crop data has been sought for the Northern Guinea Savanna (Zaria, Nigeria) and Coastal/Derived Savanna (Benin) and selected sites from Togo. The type of data needed for agroecological and socioeconomic characterization is given in Table 1.

Table 1. Minimum data set for running crop simulation models.

	Type of Data	Importance	Substitute (estimate)
Daily Weather	Solar radiation	Essential	Sunshine hr, cloud cover
	Maximum temperature	Essential	
	Minimum temperature	Essential	
	Rainfall	Essential	As close to experiment as possible
	Wind	Optional	Useful for ET modeling
	Relative humidity	Optional	For ET and disease model
	ET*	Optional	
Site Date	Latitude	Essential	For daylength determination, GIS*
	Slope	Essential	Runoff determination

Soil Data By Layer	Bulk density at 1/3 bar	Essential	
	Soil color	Essential	For estimating albedo
	Sand, silt, clay	Essential	For drained upper limit and lower limit
	Stones	Essential	Ditto,SHF*
	Root presence	Optional	For SHF
	Organic carbon/matter	Essential	For extractable soil water, SHF, N, P
	Al saturation	Optional	For SHF especially in acid soils
	PH	Essential	For SHF, N and P model
	Total N	Optional	Subst./est. OC
	KCl extr. NH4-N	Essential	Immed. before start of exp.
	KCl extr. NO3-N	Essential	Immed. before start of exp.
	Soil P	Essential	Bray, Olsen etc if P is a treatment
	CaCO3	Essential	For P modeling -- alkaline soil
	Oxalate extr. Fe and Al	Essential	For P modeling -- acid soil
	CEC	Essential	For P and N model
	Drained upper limit	Essential	Subst./est. sand, silt, clay etc
	Lower limit of plant extr.	Essential	Subst./est. sand, silt, clay etc
	Saturated water cont.	Essential	Subst./est. sand, silt, clay etc
	Drainage code	Essential	For determining infiltration coefficient
	Permeability code	Essential	For determining infiltration coefficient
Plant Management	Planting date	Essential	
	Planting density	Essential	
	Row spacing	Essential	
	Sowing depth	Essential	Affects emergence
	Tillage used	Optional	
	Cultivar used	Essential	
	Flowering/silking, etc. date	Optional	Helps in genetic coeff. est.
	Harvest (multiple) date(s)	Optional	Helps in genetic coeff. est.
Irrigation/Water	Amount	Essential	If irrigation trt.
	Type	Essential	If irrigation trt.
	Date(s)	Essential	If irrigation trt.
	Watertable depth	Essential	If at < 2m
	Type of Data	**Importance**	**Substitute (estimate)**
	Date of measurement	Essential	If watertable at < 2m
Fertilizer	Type	Essential	
	Amount	Essential	
	Date(s)	Essential	
	Method applied	Essential	
	Depth of application	Essential	
Previous Crop Residue	Above ground – amount	Essential	
	Type	Essential	
	% N (C:N)	Essential	
	% P	Essential	
	Incorporation date	Essential	
	Incorporation depth	Essential	
	Below ground root amount	Optional	Previous crop yield or biomass
	Nodule amount	Optional	

Residue Applied	Amount	Essential	If applied/trt
	Type	Essential	Used to est. %N , %P, quality
	% N content	Essential	
	% P	Essential	
	Date applied	Essential	
	Depth incorporated	Essential	
	Lignin:N	Optional	Can be derived from type/source
Price of Harvest Product	Maize grain	Essential	
	Cotton	Essential	
	Cowpea seed	Essential	
	Cassava tuber	Essential	
Price of Harvest by Product	Maize stover	Essential	
	Cowpea	Essential	
	Cotton seed	Essential	
	Cotton stover	Essential	
	Mucuna	Essential	
	Cassava leaf	Essential	
	Cassava stem	Essential	
Price of Fertilizers	Price of N fertilizer	Essential	
(including transport cost)	Price of P fertilizer	Essential	
	Price of K fertilizer	Essential	
	Cost of blanket fertilizer (lime, etc….)		
Cost of Fertilizer Application	Cost per N application	Essential	
(including transport cost)	Cost per P application	Essential	
	Cost of K application	Essential	
	Cost for blanket application		
	Type of Data	**Importance**	**Substitute (estimate)**
Cost of Organic Amendments	Cost of organic residue /manure		
	Labor cost for applying		
	Transportation		
Cost of Land Preparation	Labor	Essential	
	Tractor		
Seed Cost for Planting Material	Maize hybrid		
	Maize composite	Essential	
	Cotton	Essential	
	Cowpea	Essential	
	Mucuna		
	Cassava	Essential	
Planting Cost (labor)	Maize	Essential	
	Cotton	Essential	
	Cowpea	Essential	
	Cassava	Essential	

	Mucuna	Essential	
	planting implement		
Weeding Cost	Herbicide		
	Labor	Essential	
Pest and Disease	Cost of chemical (include transport)	Essential	
	Application	Essential	
Cost of Harvest and Post-Harvest	Labor		
	Drying and storage		
	Storage loss		
	Transport		
Land Cost/Rental			
Credit and Loans			
Land Tenure		Inference on attitude of the farmer	
Farm Size	Family income		
	Family size		
	Land area		
	Type of Data	**Importance**	**Substitute (estimate)**
Gender/Generation	Farm labor		
	Employed outside		
	Education level		
	Age		
	Traditional customs		
	Ethnic group		
Accessibility of Farm	Extension		
(agricultural policy)	Communication		
	Road		
	Market		
	House to field		
	Medical facilities		
	Schools		
	Post-harvest constraints		
	Political stability		
Farmer/Pasturalist			
Conflict			

*ET: evapotranspiration; SHF: soil hospitable factor; OC: organic carbon; GIS: geographic information system.

Without adequate data, even the simplest to the most complex decision support tools will be of little value. Therefore, our first priority was to collate soil and climate data from the region and encourage complete characterization of field sites in future research. Soil and climate data collation activity was begun in November 1997 in Togo, Benin, and Nigeria. The status of the data base is presented in Table 2.

Table 2. Soil-climate data base for CNDC-EPHTA sites.

Country	Soil profile characterization	Climate	Remarks
Nigeria	Zaria (2 sites)	1971-96	Complete
	IITA (Ibadan)	1978-97	Complete
	IITA (Kano)	1990-96	Complete
Togo	Davié station	1975-97	Estimated solar radiation
	Kokoumbo station	1975-97	Estimated solar radiation
	12 research farms	Incomplete	In progress
Benin	Sekou	1960-1996	Estimated solar radiation
	Niouli	Completed	
	Cotonou	1960-1995	Est. solar radiation (some years)

The development of natural resource inventories will remain an important activity of the CNDC. Information from other West African countries will also be incorporated in the data base through IFAD and IFA Projects at IFDC and BNMS and EPHTA sites of IITA. The installation of four new automated weather stations (through IFAD, IFA and Peanut CRSP Projects) in 1998 has also improved the quality of weather data from Togo (2 sites) and Benin (2 sites). As the soil and climate data from other areas in the EPHTA region becomes available ex-ante analyses would be extended to those sites as well.

Output 1.3 Methodologies Harmonization Workshop

On the invitation of EPHTA, IITA and IFDC co-organized a methodologies harmonization workshop, February 17-18, 1999, at IITA, Ibadan, Nigeria. Harmonization of methodologies is essential in ecoregional projects to reach common goals, and to obtain the synergism of ecoregional cooperation. The following methodologies were considered:

- Benchmark site selection criteria.
- Participatory technology development.
- Rural appraisal, monitoring and evaluation.
- Systems analysis and simulation.

Such harmonization will enhance effective introduction of CNDC products and approaches in the region. A paper on the "Role of Systems Analysis in EPHTA" was presented. The inclusion of the systems approach as one of the methodologies of the workshop also highlighted the renewed interest at IITA on systems approach and the impact of CNDC's systems approach on agricultural research in West Africa.

OUTPUT 2: Validated and Improved Decision Support Systems

Output 2.1 Introduction and Adaption of Decision Tools for Low Soil Fertility Conditions

Existing crop growth simulation models have reliably predicted effects of temperature and photoperiod on crop duration. However, these models generally do not consider the effects of extremely high or low temperatures, drought stress, and nutrient deficiencies on crop duration. Drought stress and deficiencies of N and P during the vegetative phase have resulted in delayed tassel initiation and silking. Similarly, stresses during the ripening phase have resulted in early senescence and maturity. Thus, harvesting, yield forecasting, and planting of the following crop in a sequence, livestock rearing or fisheries would be influenced. As part of the CNDC project, CERES-Maize model was modified to simulate the effect of N deficiency on phyllochron and phenological stages (Singh et al., 1998).

The delay in phasic development prior to silking was modeled with severe N stress resulting in decreased rate of thermal time accumulation. For the same degree of N stress, the delay was more pronounced during the reproductive phase (tassel initiation to silking) with N deficiency factor (NFAC) below 0.5 resulting in reduced rate of thermal time accumulation (Figure 2). The effect was manifested during the vegetative phase (emergence to tassel initiation) only under extremely severe conditions when NFAC fell below 0.38. The relationship presented in Figure 2 was based on results from field trials as well as greenhouse studies. The greater sensitivity of growth processes, for example, photosynthesis to nitrogen deficiency is also evident from the relationships presented in Figure 2. On any given day, NFAC of 0.6 would not influence phenology, however, the biomass accumulation would occur at 85% rate. The average N stress effect over the reproductive period (tassel initiation to silking) was used by the model to modify the anthesis to silking interval (ASI). The ASI factor in turn determines the grain numbers per ear.

The phyllochron, or the leaf appearance rate, is least affected by N stress. Over the range of NFAC given in Figure 2, the phyllochron varied from 45°C with no N stress (NFAC = 1) to 47°C with extreme N stress (NFAC = 0). In general, the final leaf number would change a little. For the sensitivity analysis presented in Figure 3, the final leaf number changed from 26 without any N stress during the reproductive stage (mean N stress = 1) to 23 leaves under extreme N deficiency. P deficiency, in contrast resulted in up to 32% increase in phyllochron (Rodriguez et al., 1998) and under increasing P stress conditions the final leaf numbers were reduced as well.

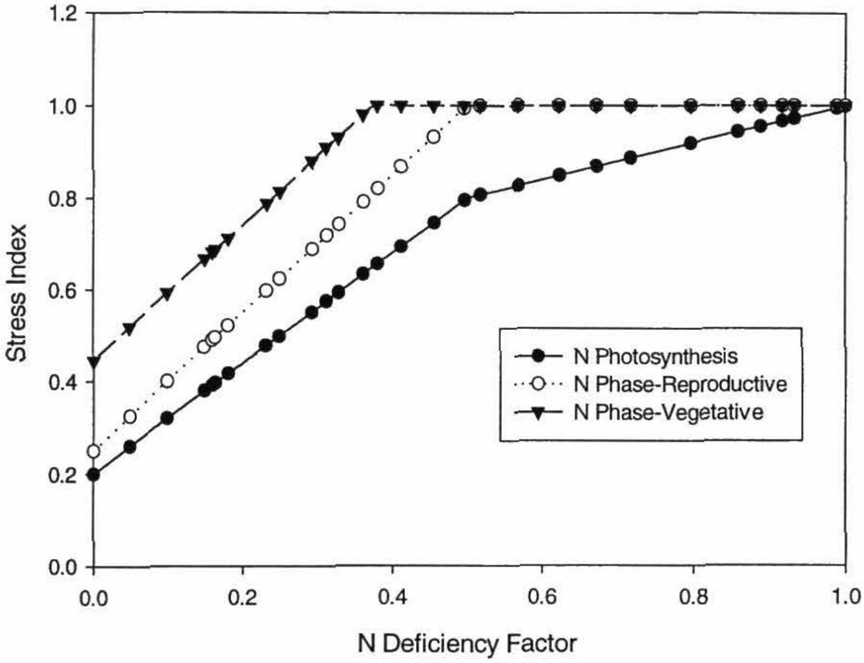


Figure 2 Relatioship between plant N deficiency factor and stress indices for growth (N photosynthesis), vegetative stage (N Phase-V) and reproductive stage (N Phase-R)

N stress during the grain-filling phase has the opposite effect compared with the pre-silking stress, that of reducing the grain-filling duration (Table 3). The combined effect of N stress on sowing to maturity duration may, however, be small. Under N limiting conditions, both the effect on growth and the shortened duration of the grain-filling stage contributes to lower grain yield.

Table 3. Effect of N application on phenological stages of two maize cultivars grown at three N rates.

Cultivar	N rate (kg N ha^{-1})	Days to silking	Grain filling duration (d)	Days to maturity
Pioneer X304C	0	83	53	136
	50	78	59	137
	200	78	59	137
H610	0	80	51	131
	50	76	57	133
	200	75	58	133

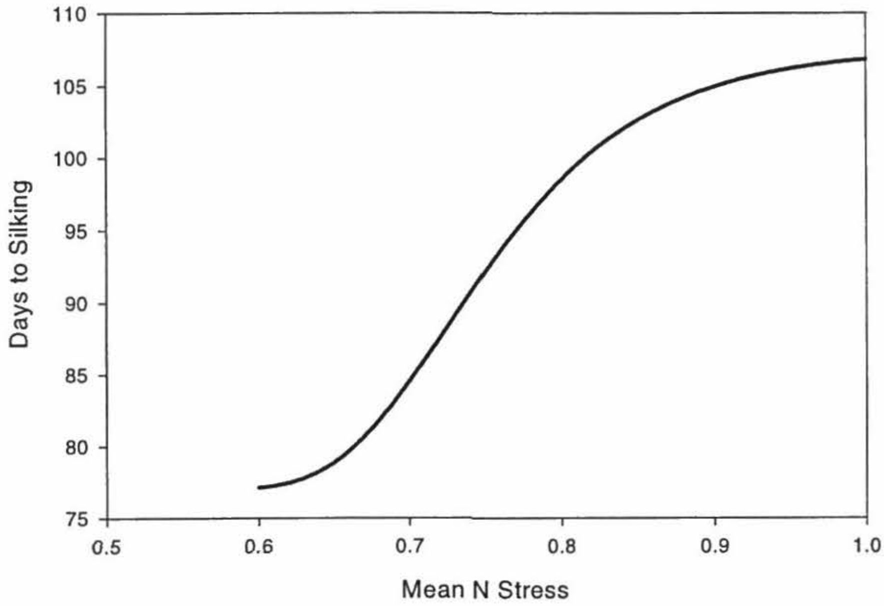


Figure 3 Sensitivity of CERES-Maize to the effect of mean N stress during reproductive phase on silking date (days after sowing)

Output 2.2 Using Existing Field Trial Results

Existing and historical experimental data from the EPHTA region is being collated, and depending on the completeness of the information, it has been used for validating the simulation models. The following existing experiments have been identified for maize model validation:

- Rock phosphate solubilization (Sekou 2, Benin)
- Organic and inorganic interactions (Sekou 1, Benin)
- NPK calibration (Zaria)
- Dynamics of soil nitrogen in cereal-based cropping systems in Nigeria Savanna (Oikeh et al., 1996)

Fortunately, the maize experiment by Oikeh, Chude and coworkers (1996), is well-documented with a complete minimum data set. This experiment is comprised of five genotypes and five rates of nitrogen application – 0, 30, 60, 90, and 120 kg N ha^{-1}. During 1993 the 120 kg N ha^{-1} was applied as a single and also as a split application. Soil-climate data from Zaria and the varietal information from the single application of 120 kg N ha^{-1} treatment were used to generate the genetic coefficients. The CERES-Maize model was then validated using the remaining treatments from the 1993-94 experiments. The climatic and soil characteristics for the experiment are given in Table 4.

The performance of the model with regards to grain yield response to N application with five maize cultivars is presented in Figure 4. At higher N rates, perhaps due to limitations of other nutrients, the differences in observed and simulated yields were greater. The low grain yields at 90 kg N ha^{-1} during the 1993 season was either associated with experimental error, limitations of nutrients other than N, or pests and diseases. The model correctly simulated lower yield in 1994 than 1993.

Output 2.3 Incorporating Organic Residue Recycling

The Organic Resource Database as developed by TSBF for over 600 locally available organic materials is being combined with dynamic soil-crop simulation model to evaluate and quantify alternative integrated nutrient management strategies for soil fertility improvement. The CERES models simulate organic residue recycling on a dynamic basis, considering C:N ratio. However, it does not incorporate the effect of lignin and phenolic content on residue decomposition rate and quality.

Output 3: Quantification and Improved Understanding of Nutrient Dynamics

Introduction

The on-station research ensures predictions are reliable (validation), calibration and improvement is possible if all the assumptions of the model are not fulfilled, and it provided NARS scientists practical experience with conducting systems-based inter- and cross disciplinary research. The trials will also evaluate improvement in soil organic matter status, nutrient availability, and nutrient balance and fertilizer use efficiency by:

- Increasing the use and efficiency of inorganic fertilizers and rock phosphate to improve quantity and quality of crop residue for recycling back to the soil with a key cereal food crop and a cash crop.
- Integrating organic and inorganic fertilizers with the key cereal- and cash- crop.
- Including a perennial food crop with extended growth duration.

Table 4. Climatic characteristics and soil types at the trial sites.

	Sekou Benin	Zaria Nigeria	Davié Togo	Koukombo Togo
Latitude (°)	6.7	11.1	7.4	10.3
Longitude (°)	2.2	7.4	1.2	0.42
Elevation (m)	105	686	76	110
Length of growing period (days)	240	190	240	190
Rainfall distribution	Bimodal	Mono-modal	Bi-modal	Mono-modal
Mean growing period temperature (°C)	26.9	25.0	27.2	27.6
Mean annual precipitation (mm)	1137	956	907	1125
Mean number of dry months (less than 3 wet days/month)	3	5.2	3.0	5.0
Mean annual temperature (°C)	27.0	24.5	27.5	27.9
Mean minimum temperature of coolest month (°C)	21.6	12.8	22.9	19.2
Soil type	Oxisol	Ultisol	Ultisol	Alfisol
Plant extractable soil water (mm)	10	16	22	14
Available mineral N (kg ha^{-1})	40	56	53	75

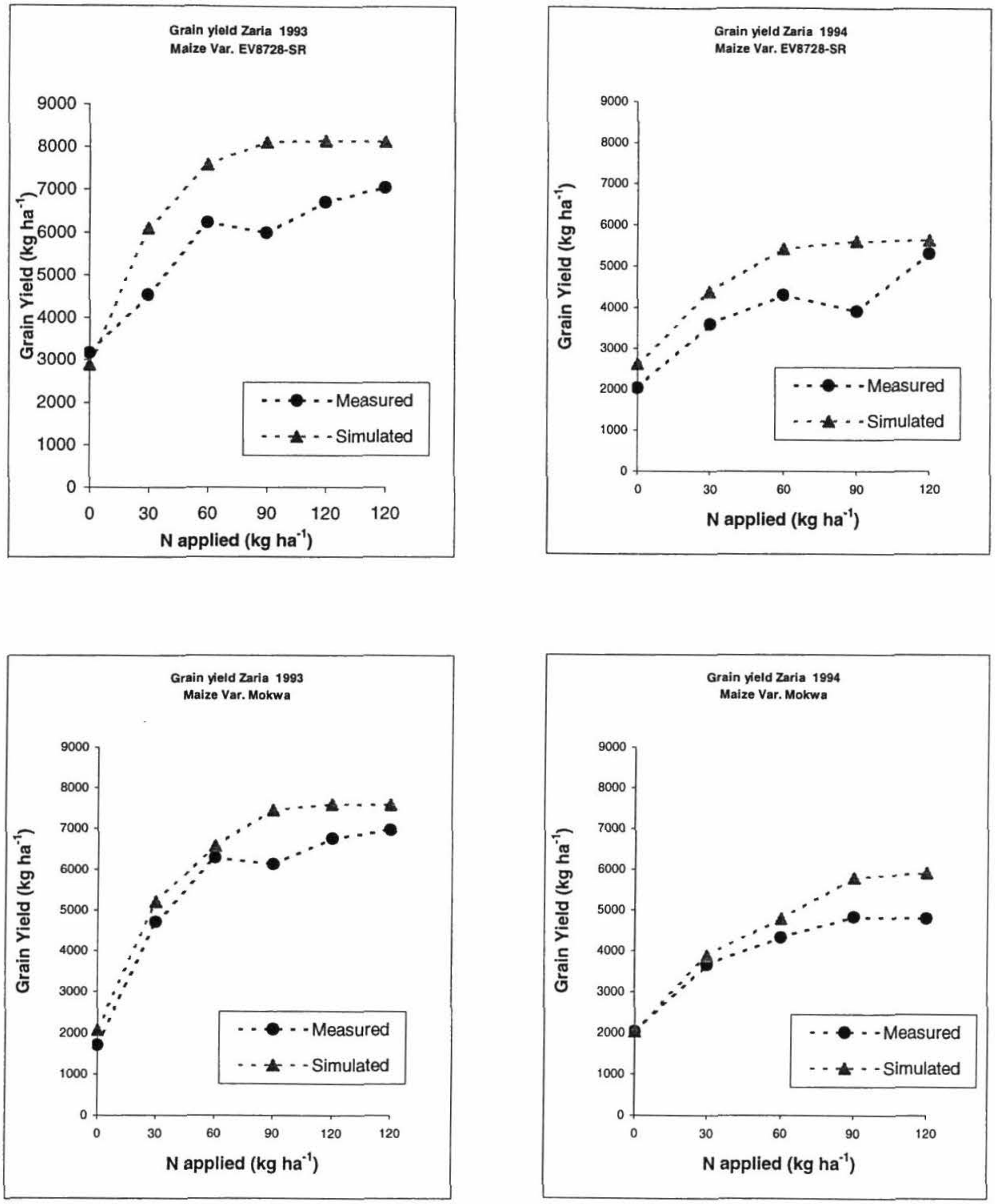


Figure 4. Comparison of observed and predicted grain yield response to nitrogen application for five genotypes over two seasons.

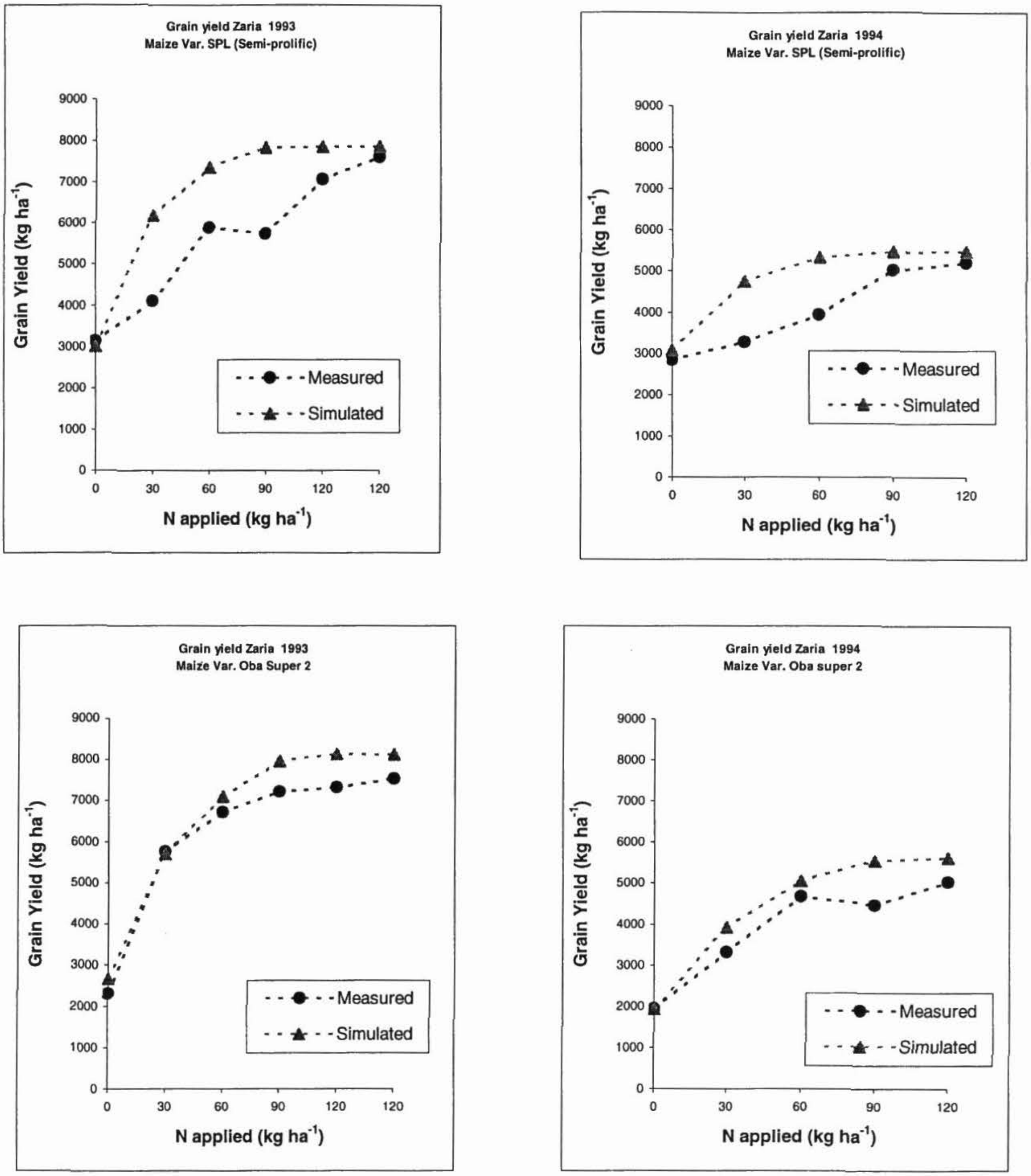
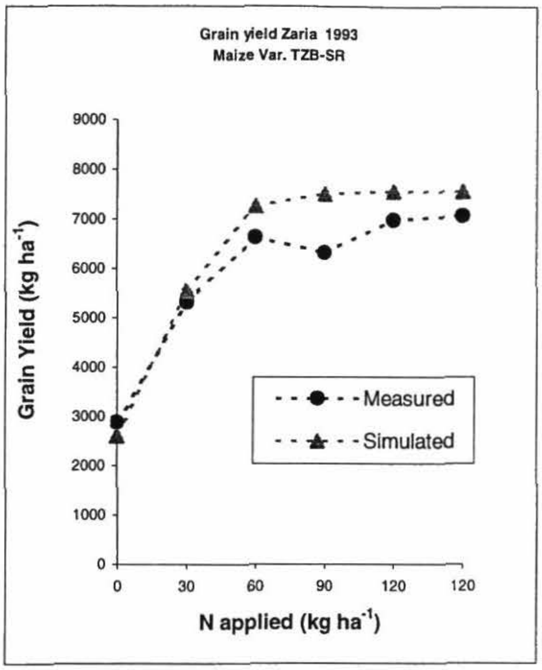


Figure 4 (cont). Comparison of observed and predicted grain yield response to nitrogen application for five genotypes over two seasons.



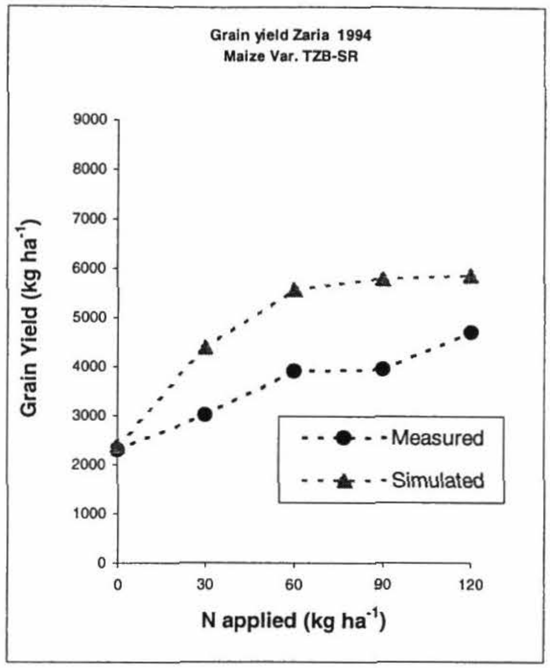
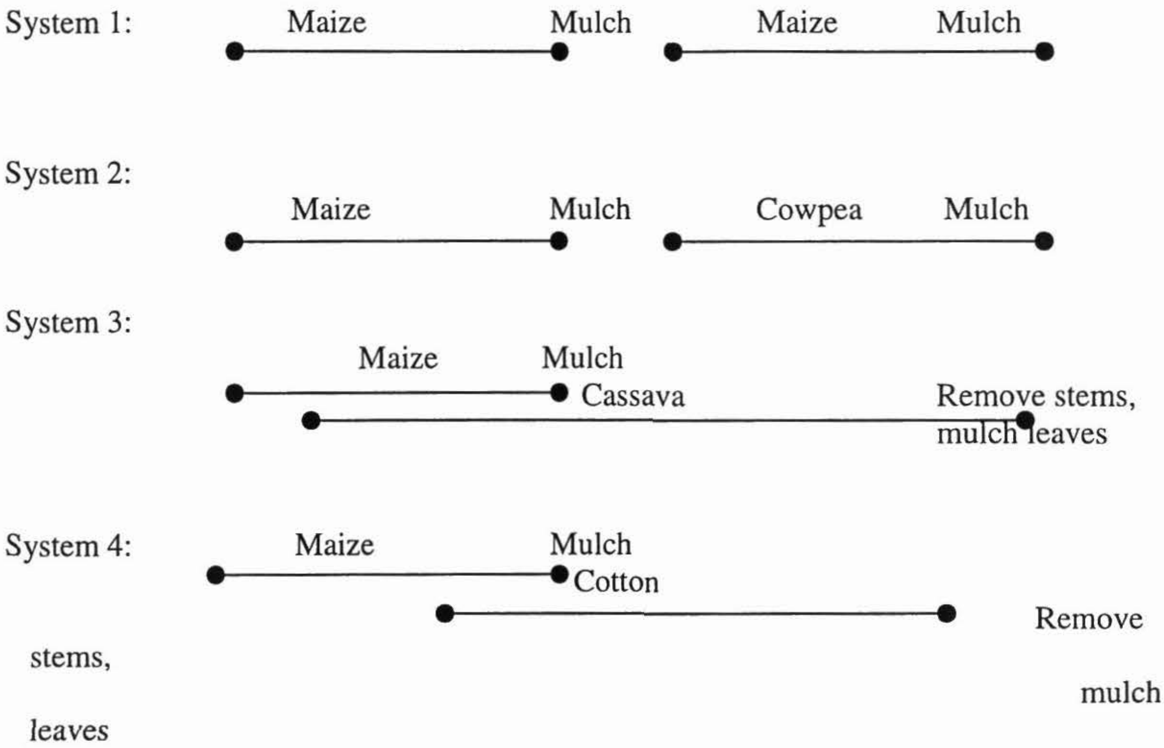


Figure 4 (cont.). Comparison of observed and predicted grain yield response to nitrogen application for five genotypes over two seasons.

Materials and Methods

Field experiments

Field experiments have been conducted under the auspices of the CNDC and the International Fund for Agricultural Development (IFAD) Projects in Benin, Nigeria and Togo. The climatic and soil characteristics for the experiments are presented in Table 4. Sekou, Benin, and Davié, Togo, has bi-modal rainfall distribution. The CNDC experiments have been designed to evaluate nutrient cycling in maize-maize, maize-cassava, maize-cowpea, and maize-cotton cropping systems. The experimental treatments have N and P rates ranging from 0 to180 kg ha^{-1}. Four cropping systems for Sekou site in Benin, with two crop seasons per year are schematically presented as follows:



The experiment was laid out in a randomized complete block design with incomplete factorial in four replications. The treatment combinations are shown in Table 5. Three rates of N and two P rates and P sources are common to the four cropping systems. An additional high N rate, N_3, was applied to the mono-cropped maize (System 1) and to maize in maize-cotton (System 4). Cotton also received an additional high N rate, N_{3C} (System 4). The N_0, N_1, N_2 and N_3 rates are 0, 60, 120 and 180 kg N ha^{-1}applied to maize, respectively. P_0 is without P fertilizer application and P_{TSP} and P_{PN} with 46 kg P_2O_5 ha^{-1} applied as TSP and 120 kg P_2O_5 ha^{-1} applied as rock phosphate (P_{PN}, phosphate natural) to maize. The corresponding fertilizer rates for cotton are NPK (14-23-14-5S-1B) at 200 kg ha^{-1} plus 50,100 or 150 kg urea ha^{-1}.

The IFAD trials, on the other hand, had a single-season maize crop with N rates of up to 400 kg N ha^{-1}. Only maize data is presented for reporting. However, for the long-term sequence analyses the information from maize-maize, maize-fallow, maize-mucuna was utilized. A more detailed analysis of other cropping systems will be possible once the data from the second season are available.

Table 5. Treatment combinations

Maize-Maize	Maize-Cowpea	Maize-Cassava	Maize-Cotton
1. N_0P_0 - N_0P_0	9. N_0P_0	15. N_0P_0	21. N_0P_0 - N_0P_0
2. N_0P_{TSP} - N_0P_{TSP}	10. N_0P_{TSP}	16. N_0P_{TSP}	22. N_0P_{TSP} - NPK+50 U
3. N_1P_{TSP} - N_1P_{TSP}	11. N_1P_{TSP}	17. N_1P_{TSP}	23. N_1P_{TSP} - NPK+50 U
4. $N1P_{PN}$ - N_1P_0	12. N_1P_{PN}	18. N_1P_{PN}	24. $N1P_{PN}$ - NPK+50 U
5. N_2P_{TSP} – N_2P_{TSP}	13. N_2P_{TSP}	19. N_2P_{TSP}	25. N_2P_{TSP} - NPK+100 U
6. N_2P_{PN} - N_2P_0	14. N_2P_{PN}	20. N_2P_{PN}	26. N_2P_{PN} - NPK+100 U
7. N_3P_{TSP} – N_3P_{TSP}			27. $N_{3c}P_{TSP}$ - NPK+150 U
8. N_3P_{PN} - N_3P_0			28. $N_{3c}P_{PN}$ - NPK+150 U

Note: 1. P_{PN} treatments did not receive any P application during the second season.
2. U = urea in kg ha^{-1}

Soil samples

Soil profile data as per "minimum data set" sheet (Table 1) was collected. Initial soil analysis for nitrate, ammonium, soil-P, pH and soil organic carbon and total N (at start of trial before land preparation) was conducted on soil samples from 4 depths to 70 cm (e.g., 0-15, 15-30, 30-50, and 50-70). Mineral N (KCl extractable $NH4^+$-N and $NO3^-N$) was analyzed by replicate. The following season, before land preparation, three treatments per crop system (- N_0P_0, $N_2P_{SSP(TSP)}$, and $N_2P_{SPR(PN)}$) at two depths (0-15 cm depth and 15-30 cm) were analyzed for: NH_4^+-N, NO_3^-N, soil-P, pH, and organic C.

Weather data

Daily weather data for rainfall, maximum and minimum temperature and solar radiation were collected at Sekou in Benin, Zaria in Nigeria, and Davié and Koukombo in Togo. During 1997 and 1998 daily solar radiation data at Davié and Koukombo were estimated from hours of bright sunshine.

Model evaluation

The genetic coefficients for the varieties sown were estimated from observed silking and maturity dates and observed grain yield and kernels per ear data from past field trials conducted in the region with high N and P application rates. The coefficients were adjusted until there was a match between observed and simulated dates of silking and maturity. Similarly, the coefficient for kernels per ear was derived.

Results and Discussion

The response to both P and N application on maize grain yield was highly significant at Zaria (Fig. 5). Grain yield increased from less than 500 kg ha^{-1} to over 1 t ha^{-1} on SSP application at 60 kg P_2O_5 ha^{-1}. The response on grain yield was similar with superphosphate (SSP) applied at 60 kg P_2O_5 ha^{-1} and Sokoto phosphate rock (SPR) applied at 120 kg P_2O_5 ha^{-1}. The harvest index (HI) increased from 0.10 without N and P application to 0.17 with P application and to 0.42 with 180 kg N and 60 kg P_2O_5 ha^{-1} applied as SSP.

There was a significant response (P=0.05) to P application on maize grain yield at Sekou, Benin (Fig. 6). However, on N application there was no significant response; the overall trend was lower grain yield with N application. The HI decreased from 0.23 without N to 0.18 with 180 kg N and 46 kg P_2O_5 ha^{-1} applied as TSP. Sources of P fertilizer (TSP and phosphate rock) had no effect.

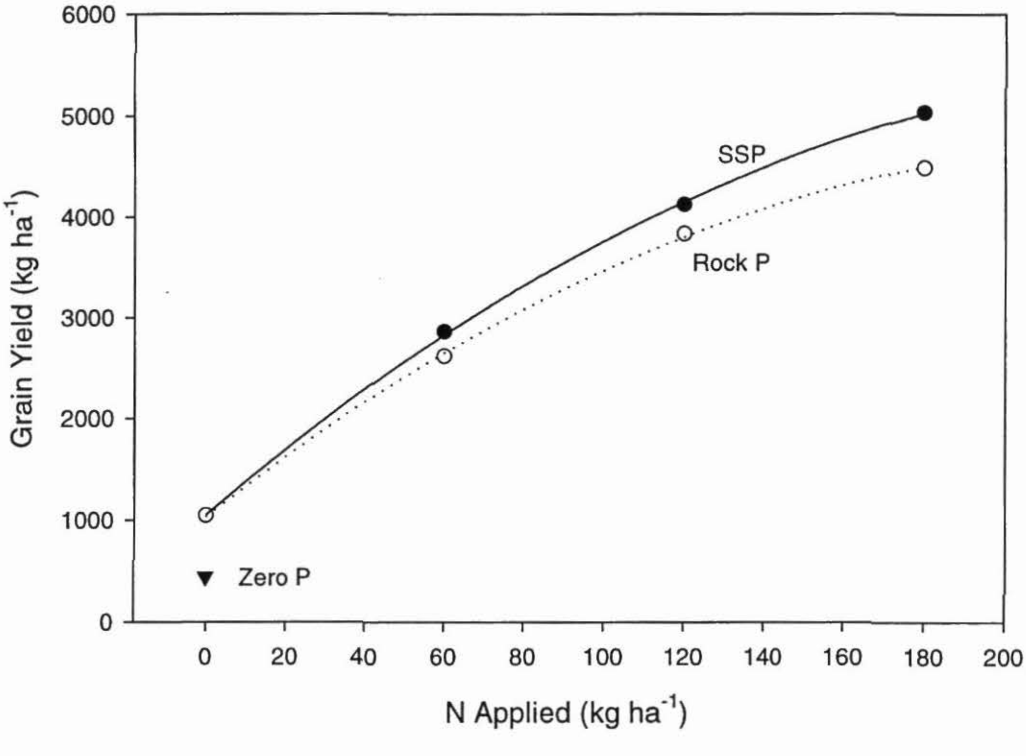


Figure 5. Maize grain yield response to N application with Sokoto phosphate rock and SSP at Zaria, Nigeria.

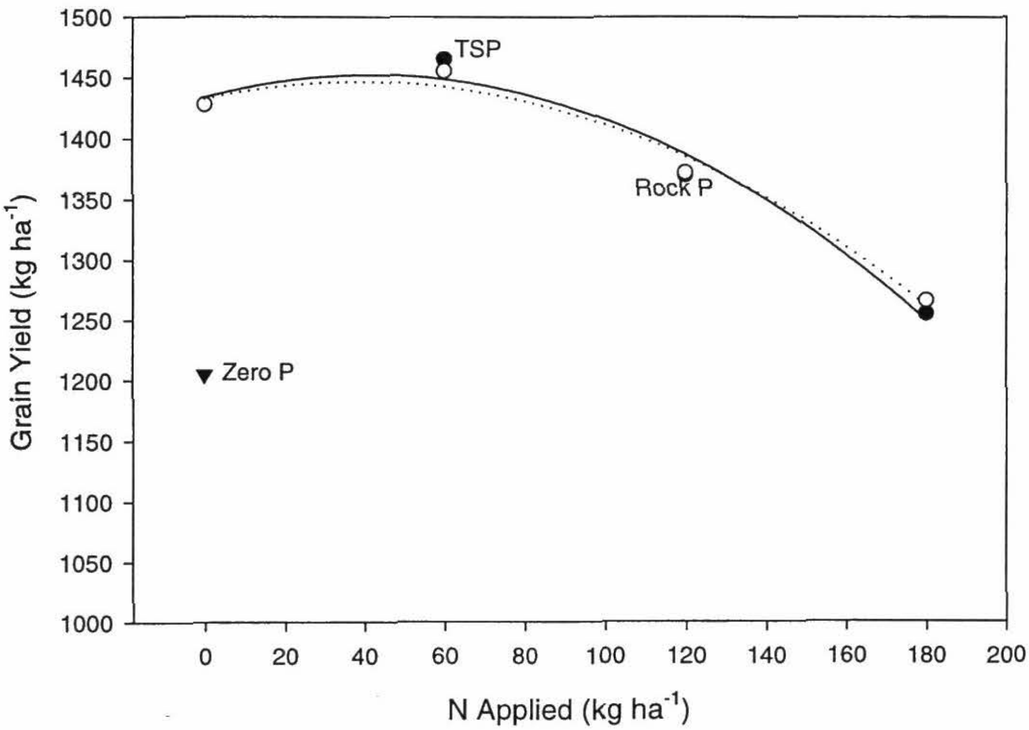


Figure 6 Maize grain yield response to N application with phosphate rock and TSP at Sekou, Benin.

The poor response to N application was attributed to a severe drought spell from anthesis stage to maturity during 1998 season. Dry matter samples collected at anthesis and harvest, and the rainfall data confirmed incidence of severe drought.

The CERES-Maize Model also predicted severe drought stress with the soil water content reaching wilting point by silking stage at Sekou and no grain yield response on N application. The data from other cropping systems at Zaria and the second season at Sekou is being analyzed. Simulation models will be validated for the prevailing conditions with range of N and P levels.

A comparison of observed and simulated maize grain yields for the experiments conducted in Benin, Nigeria and Togo is shown in Figure 7. Only those treatments with high P rates were used because the P submodel has yet to be tested in the region. Both the observed and simulated grain yields given throughout the paper are reported on a dry-weight basis. If the model were a perfect predictor and if there were no experimental error, all data points would lie on the 1:1 line. The overestimation (above the 1:1 line) arose due to the presence of uncontrollable factors in some plots such as weeds and termites, which resulted in lower observed yields. The model is also not sensitive to nutrients other than N and P.

Testing the performance of maize model was also done with N response experiments conducted on long-term control and fertilized plots from IFAD trials at Davié and Kokoumbo in Togo. The input data in these experiments were not as complete (estimated solar radiation and genetic coefficients).The model's performance at different N rates and varieties at Koukombo and Davié is shown in Fig. 7b, c. The model captured the nonsignificant response to N application due to drought stress at Davié during the 1998 season. The overestimation of yields by the model is to be expected because control of experimental factors (K, micronutrients, Al toxicity, pests and diseases) to which the model is insensitive could never be complete.

During 1997 season at Davié the harvest index was lower due to Zn deficiency. The model's prediction of biomass was reasonable (Figure 8), however, the yields were overpredicted due to the Zn deficiency .

OUTPUT 4: Yield-Gaps in Current Cropping Systems

Output 4.1 Water-Limited Yield Potential

Rainfed potential yields—conditions when water-limitations could restrict yield—for the key sites in Benin, Nigeria and Togo were determined.

Materials and Methods

The following simulation studies using long-term historical data for the last 12 years were undertaken for two sites, Koukombo and Davié, having mono-modal and bi-modal rainfall distribution, respectively. Monthly plantings were scheduled in the model for the first of the month; however, under water-limited simulation sowing within the next 30 days was possible only when a soil moisture condition of 40%-100% of field capacity for the top 30 cm was reached. Commonly grown maize genotypes, Podzarica (EV-8443) for Koukombo and Ikene (EV-8449) for Davié, were used.

Results and Discussion

Mean potential (non-limiting) production yields of 8 t ha^{-1} ($\pm$ standard deviation of 1.2 t ha^{-1}) with maize genotype Podzarica were attained at Koukombo during April-September plantings. Comparatively, at Davié, the maize genotype Ikene attained mean yields of 6 t ha^{-1} ($\pm$ standard deviation of 0.9 t ha^{-1}). The highest yields at Davié were obtained during the dry season.

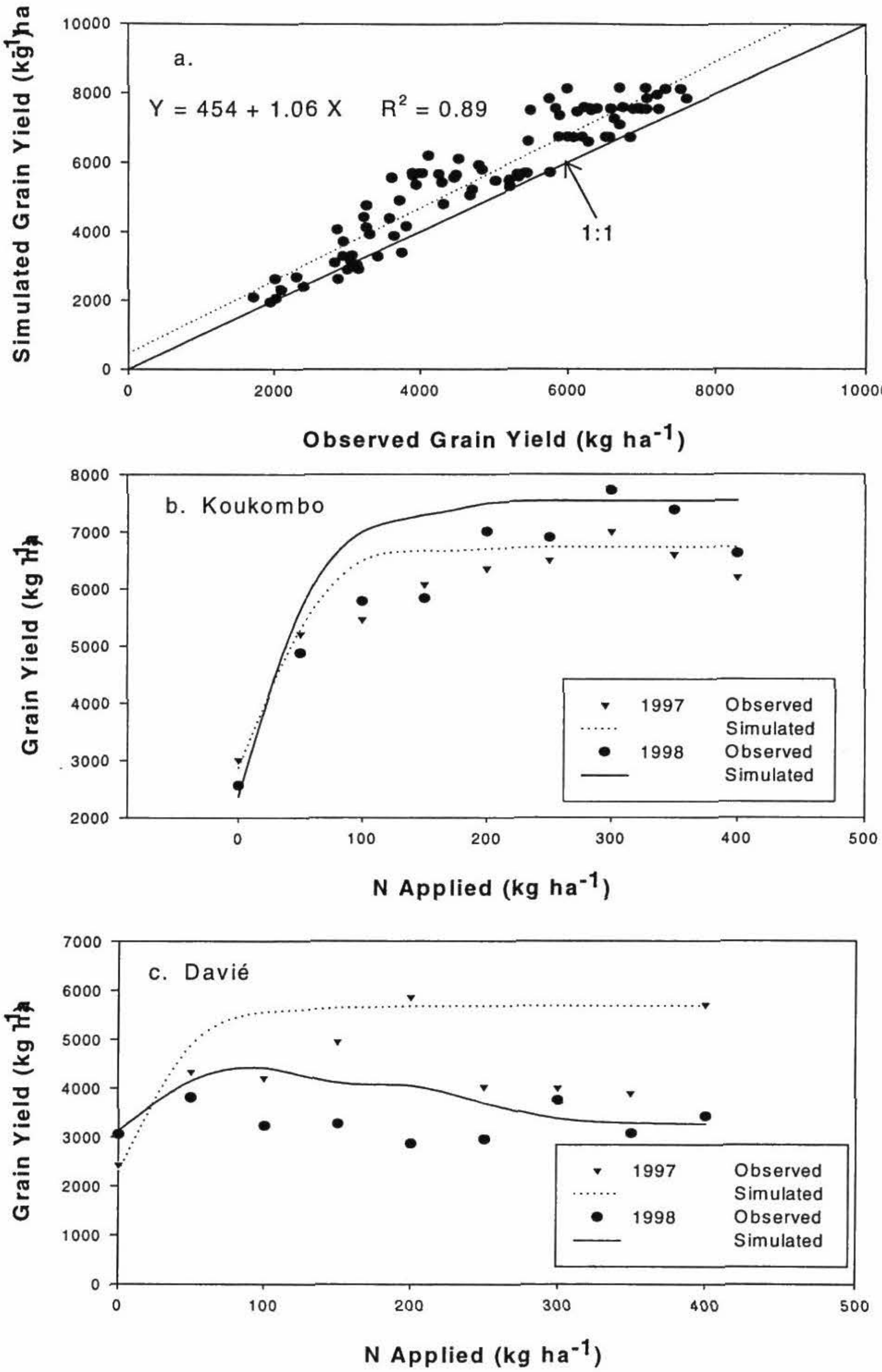
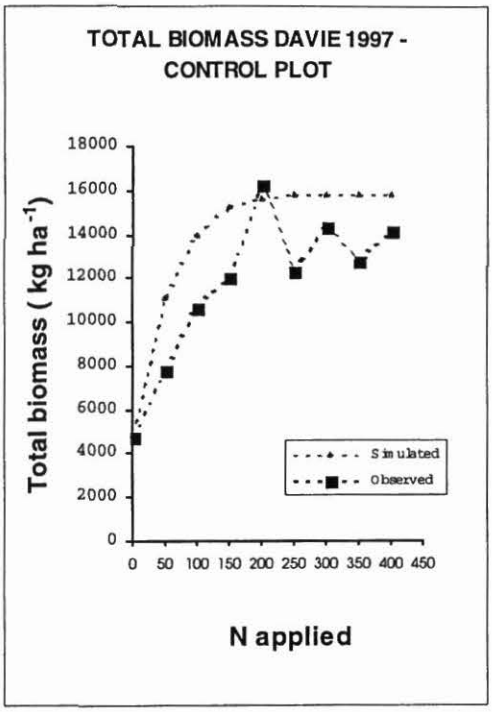


Figure 7. Comparison of observed and simulated maize grain yield based on 1:1 line (a) and observed and simulated response to applied N at Koukombo (b) and Davié (c).



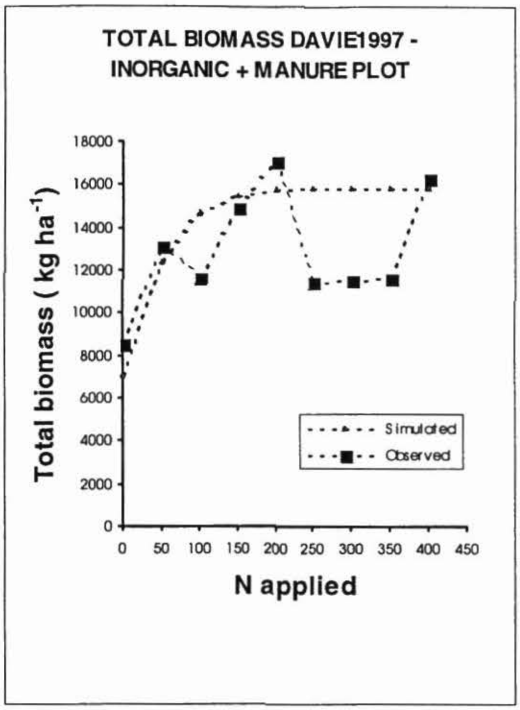


Figure 8: Comparison of simulated and observed total above-ground biomass response to N application at Davié

As evident from the mean-variance plot the ideal planting timeframe for rainfed-maize at Koukombo is the period, May-August (Fig. 9a). During this period more than 85% of the potential yield is reached under rainfed conditions (Fig. 9b). A sharp drop in yield is associated with late planting. Maize planting before May would result in increased risk associated with lower mean yields and increased variance. The planting window at Davié is wider -- from March to September (Fig. 9c). During this period, on an average, 70%-100% of the potential yield is reached under rainfed conditions (Fig. 9d). However, planting in the first season (May-June) is associated with much lower variance. The results as expected show a well-defined planting window for mono-modal environment and a less definite, broader planting window for bi-model rainfall environment. Few farmers who plant maize early in Davié and southern Togo, in general attained higher grain yields.

Output 4.2 Estimating Nutrient Depletion Rates

In the above simulations we had assumed that nutrient availability was nonlimiting, and the maize yields at both the sites were limited by genotype and environment including rainfall. However, most soils in SSA are generally deficient in nutrients. The rate of nutrient depletion is (1) supply-driven, for example, inherent soil fertility status, soil supplying capacity, and external inputs and (2) demand-driven—the frequency and amount nutrients removed. Nutrient replenishment/depletion therefore is highly site-

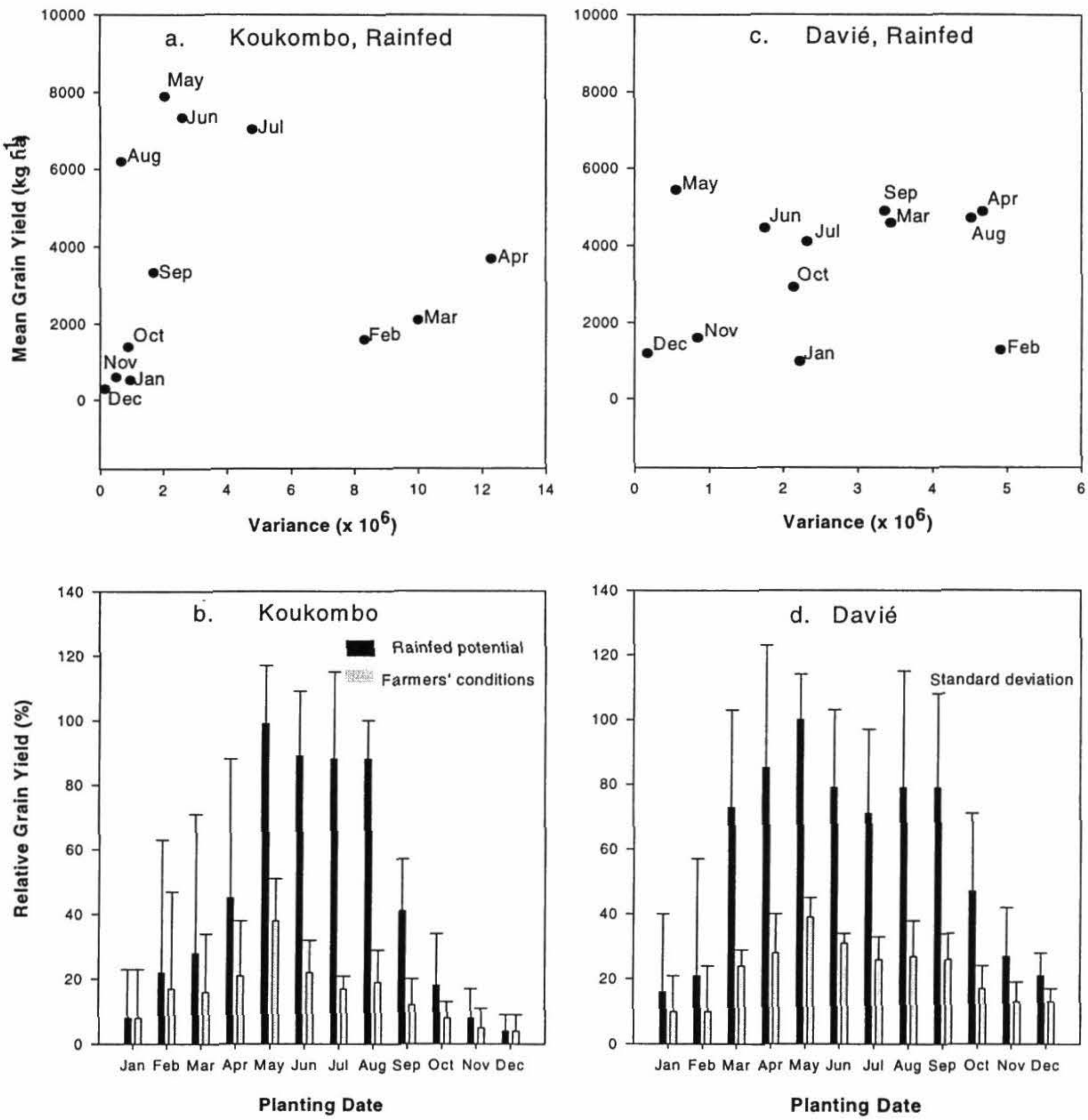


Figure 9 . Mean-variance for monthly planting dates at Koukombo (a) and Davié (c) and relative grain yield under rainfed yield potential conditions and nutrient-limited conditions (farmers' conditions) at Koukombo (b) and Davié (d).

specific depending on soil, climatic and cropping factors and by socioeconomic conditions and population density. The estimates of nutrients required to balance inflows and outflows of nutrients and thus prevent nutrient depletion are useful indicators for design of nutrient management strategies that can be adopted to prevent land degradation and increase production.

As evident from nutrient balance and depletion estimates the continued lack of application of nutrients is causing soil nutrient depletion and reduction in agricultural productivity in most agricultural areas in sub-Saharan Africa (Fig. 10).

In many instances, even drastic measures, such as doubling the application of fertilizer or manure or halving erosion losses, would not be enough to offset the calculated nutrient deficit (Henao and Baanante, 1999). The economic impact of such nutrient depletion is gleaned from Figure 11. The adoption of soil fertility improvement management package, however, is dependent on soil and climatic conditions, socio-cultural factors, and costs of inputs and grain prices. Within the CNDC framework efforts are being made to improve the estimates of nutrient depletion, predict the short- and the long-term impact of integrated nutrient management practices on nutrient depletion/replenishment rates and agricultural production in the region.

Output 4.3 Yield-Gaps Under Nutrient-Limited Cropping Systems

Based on potential yield under rainfed condition and actual yields obtained, existing yield-gaps were identified. We have atttempted to estimate requirements for key nutrients and recommend N and P rates based on potential yield versus cost:benefit ratio. Non-nutrient related constraints such as planting windows, options for crop rotation or second crop, genotypes, pests and diseases that may have contributed to the existing yield-gap were also considered. Based on long-term (>10 years) simulation with integrated use of inorganic and organic sources, changes in crop productivity and soil fertility were quantified over time to (a) examine the sustainability of current and proposed management strategies and cropping systems and (b) develop "baskets" of management for farmers, NGOs, extensionists and researchers to choose from.

Materials and Methods

A more typical farmer condition was simulated for nutrient-limited production, using soils from Koukombo and Davié (Table 4) with the following N, P and K input: 20 kg N ha^{-1}, 15 kg P_2O_5 ha^{-1}, and 15 kg K_2O ha^{-1}. We also assumed micronutrients, weeds, termites and other pest and diseases were fully controlled as not to influence the yield. Long-term historical weather data from the two sites were used.

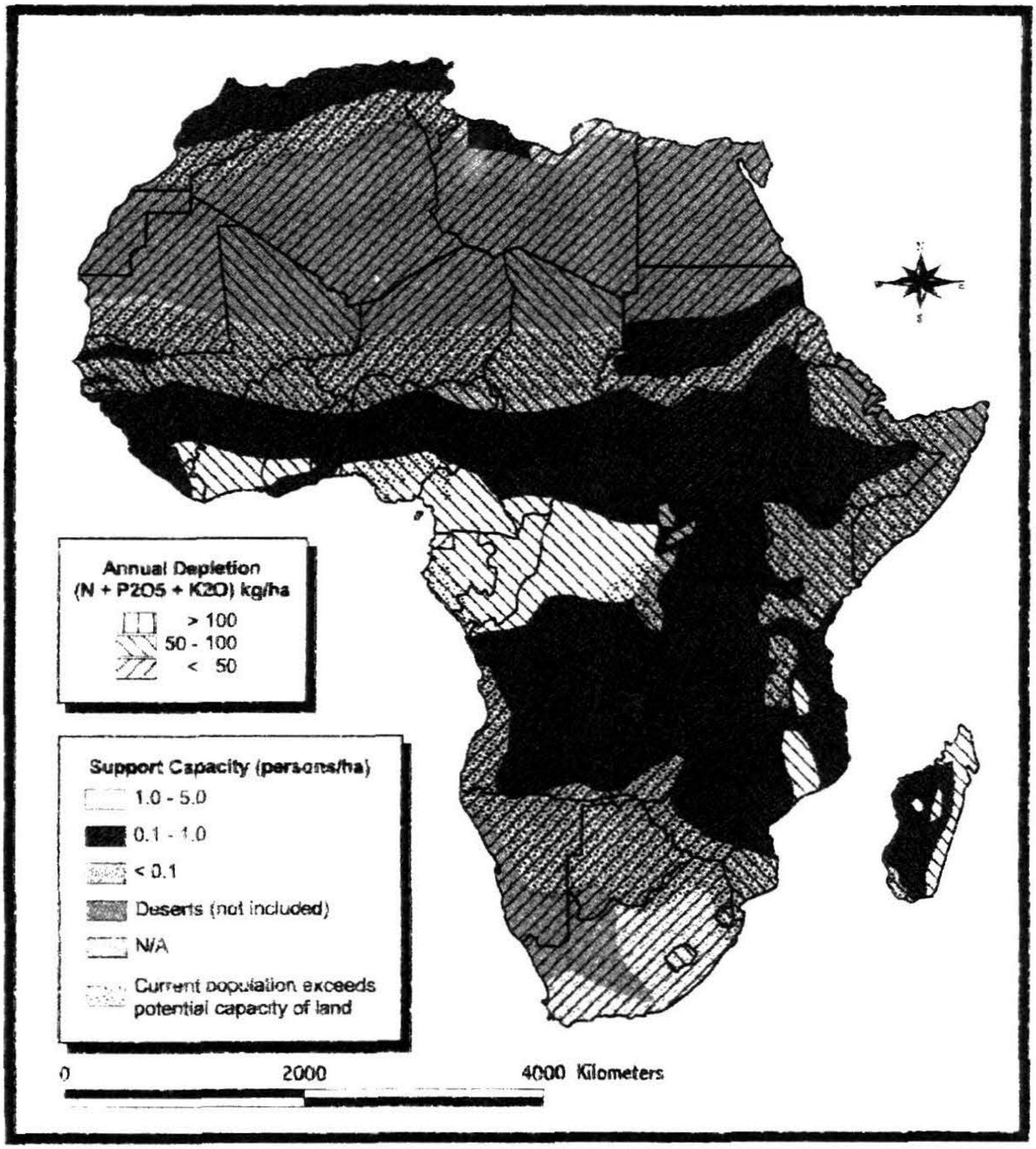


Figure 10. Average Nutrient Depletion (NPK) and Potential Population-Supporting Capacity. (Source : Henao and Baanante, 1999)

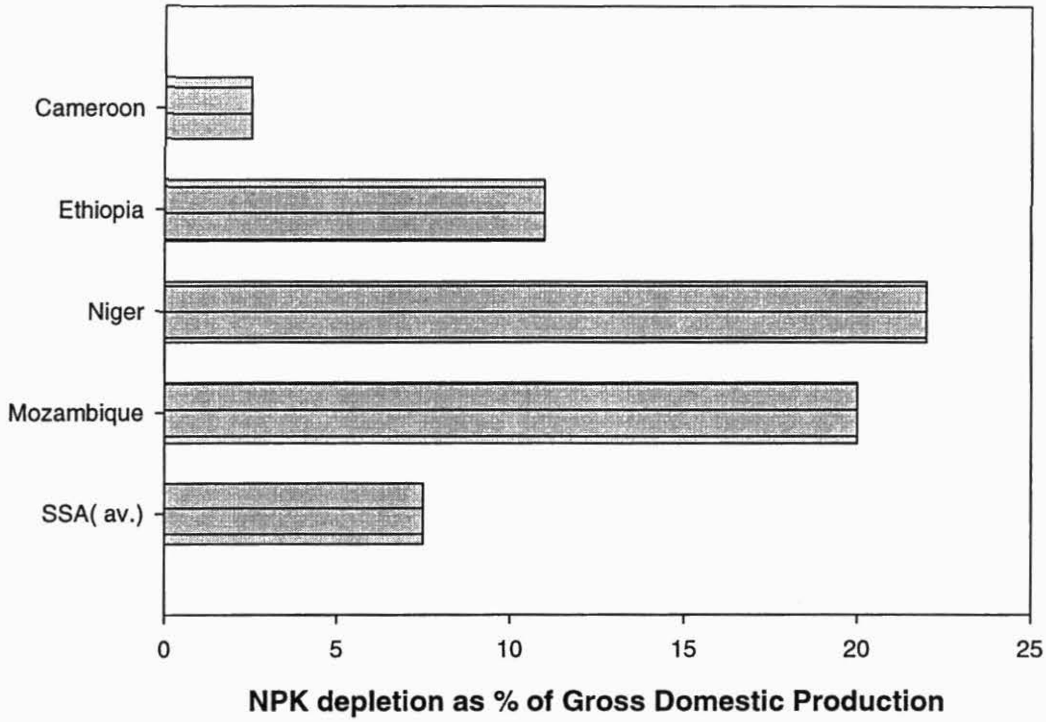


Figure 11 Economic impact of nutrient depletion in some Afican countries.

Results and Discussion

Simulated mean yields under May-August plantings ranged from 1.5 to 3.2 t ha^{-1}. In general these amounted to less than 30% of the potential grain yield for each of the planting dates (Fig. 9b, 9d). The simulated results show that in contrast to what is often stated, nutrient may be more limiting than water in sub-Saharan Africa. With external nutrient input and appropriate planting date and genotype, maize grain yields could be increased by 2-4 times the current farmers' yields.

The question, "How much external nutrient input is needed to reach the 80%-90% of the rainfed potential yield?" was explored. Since fertilizer response is dependent on seasonal weather variation, we used the past 12 years of weather data to capture the mean N response and the standard deviation at Koukombo and Davié (Fig. 12). Even in the P-deficient soils of SSA, adequate N application is necessary to achieve the full benefits of P application. The P rate was set at 45 kg P_2O_5 ha^{-1} and other nutrients were assumed nonlimiting. As expected the responses and nutrient use efficiency varied with different planting dates. The results for the optimum planting month, May, are presented.

The simulated mean grain yield response at Koukombo ranged from 3.0 to 8.0 t ha^{-1} across 0-250 kg N ha^{-1} rates, respectively (Fig. 12a). The corresponding apparent fertilizer recovery as simulated by the CERES-Maize was 40%-60%. The optimum yield, defined as 90% of the rainfed potential yield, at Koukombo would be reached at 175-200 kg N ha^{-1}. Based on the current prices and costs in Togo (Table 6) and mean-variance (EV) analysis, the EV efficiency improved with increased N rate up to 175 kg N ha^{-1} (Fig. 12b). Beyond 175 kg N ha^{-1} rates the mean monetary returns declined while the variance associated with them increased. The mean-Gini stochastic dominance approach, as given in the DSSAT program (Thornton and Hoogenboom,1994) and based on prices and costs in Table 6, resulted in the mean-Gini efficient N rate of 110 kg N ha^{-1} with the monetary returns of $642 ha^{-1}. The reported apparent N recoveries are generally lower, about 30%-35% (unpublished results , IFDC-Africa Division). The lower recoveries could be attributed to reduced crop growth and grain yield associated with soil acidity, pest and diseases, and other limiting nutrients to which the model is not sensitive.

Table 6. Costs and prices (mean $\pm$ standard deviation) used for economic analysis or maize and mucuna production.

Price of maize grain		\$180 $\pm$ 40 t^{-1}
Price of maize stover		\$ 5 t^{-1}
Maize seed cost		\$0.60 kg^{-1}
Mucuna seed cost		\$0.35 kg^{-1}
Mucuna-N supply price (assumed same as N fertilizer cost)		\$1.72 $\pm$ 0.10 kg^{-}
^{1}N		
Tillage cost	- maize	\$ 56 ha^{-1}
	- mucuna	\$ 20 ha^{-1}
Sowing cost	- maize	\$ 14 ha^{-1}
	- mucuna	\$ 10 ha^{-1}
Weeding cost for maize		\$ 64 ha^{-1}
Cost per N fertilizer application		\$4.50 ha^{-1}
Cost for applying mucuna residue		\$ 12 ha^{-1}
Harvesting cost of maize		\$ 30 ha^{-1}
Transportation cost for maize		\$ 20 ha^{-1}
Post-harvest costs for maize		\$ 40 ha^{-1}
N fertilizer cost		\$1.72 $\pm$ 0.10 kg^{-1}
P fertilizer cost as P_2O_5		\$1.72 $\pm$ 0.10 kg^{-1}
K fertilizer cost as K_2O		\$1.72 $\pm$ 0.10 kg^{-1}
Fertilizer application cost (other than N)		\$3.00 ha^{-1}

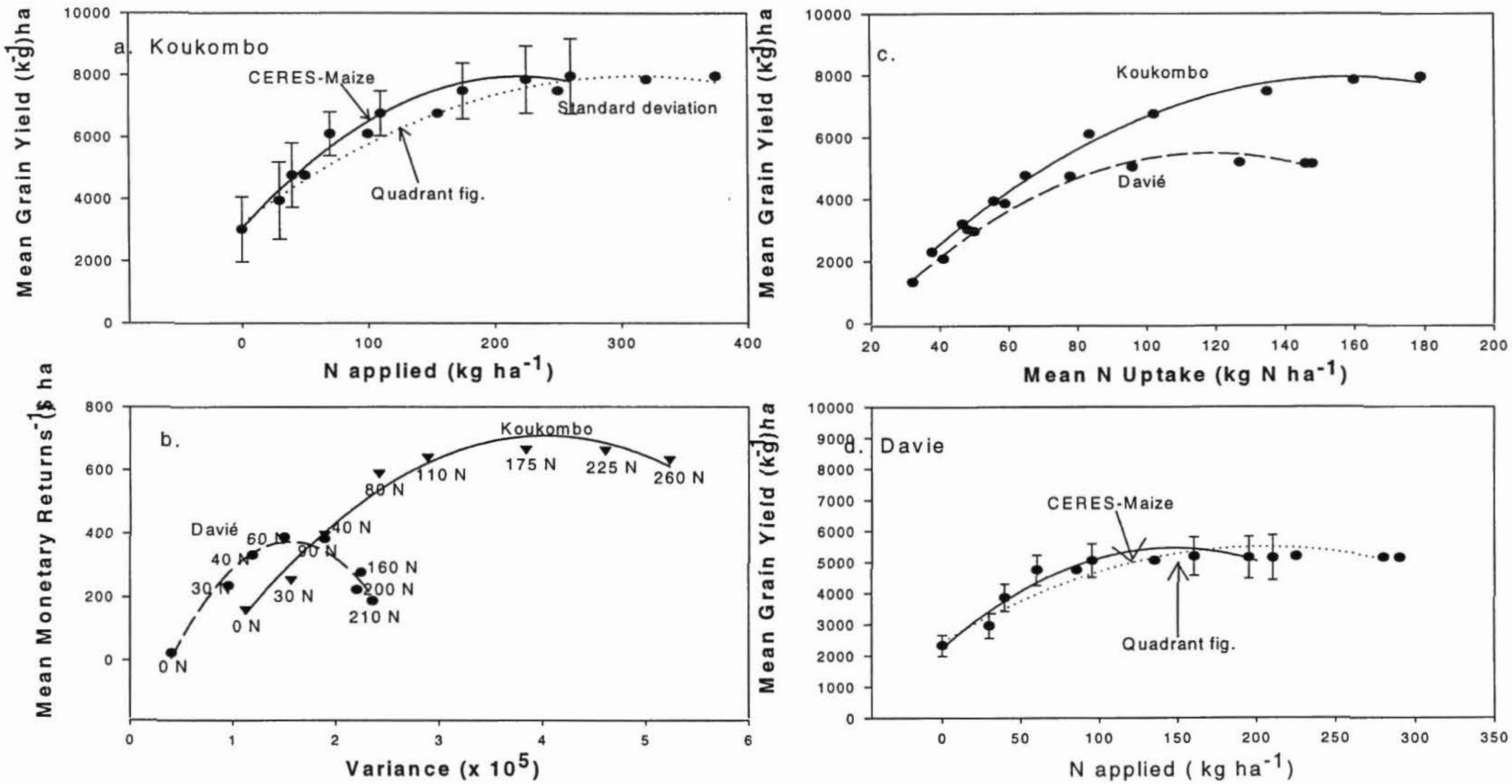
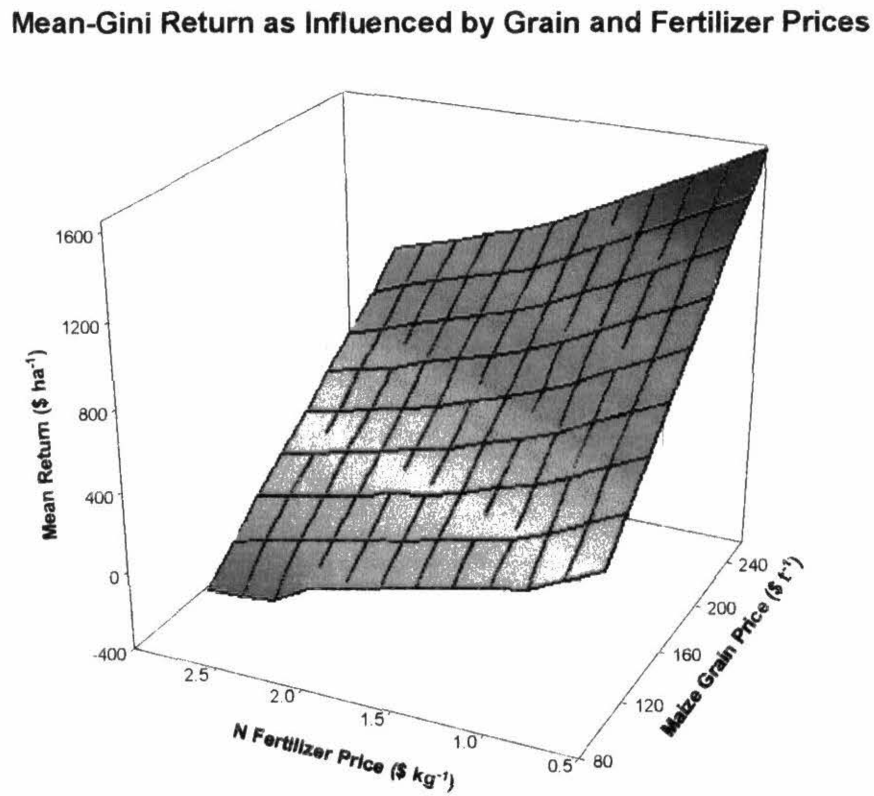


Figure 12. Mean grain yield response to applied N at Koukombo (a) and Davié (d) as simulated by CERES-Maize and three quadrant figure approach using grain yield-N uptake relationship (c) and apparent recovery of 35%. The simulated mean-variance effect is shown in (b).



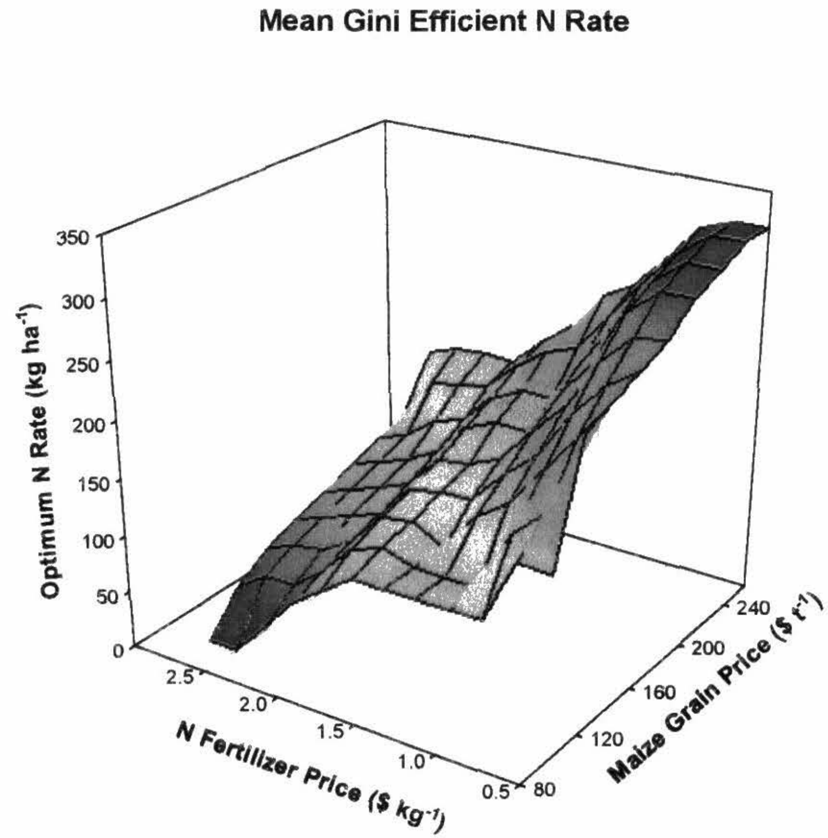


Figure 13: Mean Gini monetory return and mean Gini efficient N rate as influenced by fertilizer costs and grain prices

The N uptake versus grain yield relationship generally holds true for a genotype across varying management conditions. The simulated N uptake-grain yield results (Fig. 12c) were used with the three quadrant figure approach (van Keulen, 1982) to derive a new grain yield response to N application with apparent recoveries of about 35% (Fig. 12a). At the reduced fertilizer recoveries the mean-Gini efficient N rate was 155 kg N ha^{-1} and mean monetary returns were \$566 ha^{-1}.

For Davié, the mean grain yield response ranged from 2.3 to 5.2 t ha^{-1} across the N rates as presented in Figure 12d. The simulated apparent recoveries of applied N at Davié also ranged from 40%-60% across the N rates. From 0 to 60 kg N ha^{-1} rates, large increases in mean monetary returns occurred but the variance also increased. Davié had both lower mean returns and lower risk compared to Koukombo (Fig. 12b). The mean-Gini efficient N rate was 60 kg N ha^{-1} at Davié with mean monetary returns of \$388 ha^{-1}. However, at the lower apparent fertilizer recovery of 35% (Fig. 12d), the mean-Gini efficient N rate was 40-80 kg N ha^{-1} and mean monetary returns were about \$340 ha^{-1}.

A common conclusion from both the sites is that moderate additions of N fertilizer tend not only to increase net returns but also decrease risk associated with year-to-year variability in weather and prices. Based on the mean-Gini stochastic dominance approach, the recommended fertilizer N rates for Koukombo and Davié were 110 and 60 kg N ha^{-1}. At lower rates of fertilizer recovery (apparent recovery of 35%), the mean-Gini efficient N rates for Koukombo increased to 155 kg N ha^{-1}; however, at Davié the N rates remained at about 60 kg N ha^{-1}. The above economic analysis was based on subsidized fertilizer prices (Table 6). The fertilizer prices without subsidy would have resulted in lower fertilizer recommendation rates. The fluctuations in weather and grain prices resulted in high variance in relation to the mean monetary returns (Fig 12b), hence it is not surprising that the fertilizer application rates are low in SSA. The large dependence of mean monetary returns or N optimum rates to fertilizer cost, and grain prices is evident from Figure 13.

OUTPUT 5: Greater Institutional Capacity for Combating Nutrient Depletion through Training of Scientists in the Use of Decision Support Systems and Information Exchange

Output 5.1 Field Training on Systems-Based Research and Minimum Data Set

Training at field level on design of process-oriented field trials, on data collection and field observations were conducted at Sekou and Cotonou in Benin, December 3-4, 1998 and at Zaria, Nigeria during July 16-21, 1999. Such training will continue through the 1999 and 2000 cropping seasons.

Output 5.2 Training on Use and Understanding of Decision Support Systems

Training and confidence-building in the principles of systems oriented research was achieved by simplified presentation of relationships in the models and the emphasis on the use of simulation models as one of many tools available for analyses and extrapolation of field results. The 12 scientists from EPHTA benchmark areas participated in a "International Training Program on Use of Computer Simulation Models for Crop Growth, Soil Water Balance and Soil and Plant Nutrient Dynamics", from 9-14 February 1998 at IFDC-Africa in Lomé, Togo.

Output 5.3 Training on Use and Interpretation of Simulated Results

Principles and assumptions used in models, and analysis and interpretation of simulated results have been discussed in the following workshops and meetings:

i. CNDC Workplan meeting, 1-8 February, 1999, Lomé, Togo
ii. CNDC Review meeting, 29 November-2 December, 1998, Cotonou, Benin
iii. Training workshop on Database Management and Analyses of Field Data for Statistical and Simulation Modeling, IFDC-Africa, Lomé, Togo, 7-14 February, 1999
iv. CNDC Review meeting, 15-22 July, 1999, Institute of Agricultural Research, Zaria, Nigeria
v. Training meeting on DSSAT, IFDC-Africa, Lomé, Togo, 6-10, September, 1999

Output 5.4 Information Exchange

Dr. Victor O. Chude, Institute of Agricultural Research, ABU, Zaria, Nigeria represented the CNDC West African Savannas at the OSWU Consortium meeting, Sadoré, Niger from 28 April – 1 May, 1998

Drs. V. O. Chude and A.H. Roy participated in SWNM Pre-Brasilia MTM at CIAT, Cali, Colombia from 20-22 May, 1998.

P. Dejean was sponsored by IDRC to attend the Conference on Building the Information Community in Africa (BICA), Pretoria, South Africa from 22-25 February, 1999. IFDC through its CNDC and Ecoregional effort hopes to organize Internet training on agricultural accessibility for researchers, extensionists, and NGOs in West Africa.

P. Dejean also attended the training on Systems analysis and Simulation of Rice Production and Rice-Weed Interactions organized by WARDA.

U. Singh presented a paper on CDNC at the 2nd International Conference on Multiple Objective Decision Support System, 1-8 August, 1999, Brisbane, Australia.

6: Reports and Publication

Chude, V. O., H. Breman, and U. Singh. 1998. Combating Nutrient Depletion Consortium (CNDC): goals, objectives and activities. In: N. van Duivendoon, M. Pala, and C.L. Bielders (eds.) Efficient Soil Water Use – the Key to Sustainable Agricultural Development in WANA and SSA. Proceedings of an International Workshop, Sadoré, Niger, 28 April –1 May, 1998.

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IFDC. 1998a. Workplan for CNDC-SWNM Project on Combating Nutrient Depletion: Application of Decision Support Systems for Nutrient Replenishment and Integrated Nutrient Management. 1998-2000. 27 pages.
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Singh, U., H. van Reuler, P. Dejean, K. Aihou and V. Chude. 1999. Using Decision Support Systems to Stimulate Resource Conserving Practices. Multi-Objective Decision Support System Conference, Brisbane Australia, 1-6 August, 1999.

Other Relevant Publications

Henao, Julio and Carlos Baanante. 1999. Estimating Rates of Nutrient Depletion in Soils of Agricultural Lands of Africa. IFDC, Muscle Shoals, Alabama, USA. 76 pages.
Henao, Julio and Carlos Baanante. 1999. An Evaluation of Strategies to Use Indigenous and Imported Sources of Phosphorus to Improve Soil Fertility and Land Productivity in Mali. IFDC, Muscle Shoals, Alabama, USA. 75 pages.

7: Inter-Consortium Collaboration

In collaboration with the Optimizing Soil Water Use (OSWU) Consortium, CNDC is preparing a project proposal on, "Contributing Towards Utilization of Resources Effectively (CURE) in sub-Saharan Africa." Water, nutrients, and water x nutrient interactions are the key factors responsible for low yields in sub-Saharan Africa.

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Combating Nutrient Depletion Consortium - East Africa Highlands

Introduction

A workshop was held 11-16 February 1996 at CMRT, Egerton University to launch the Combating Nutrient Depletion (CND) theme of the Soil, Water, and Nutrient Management Program (SWNMP) of the CGIAR. The meeting at Egerton, convened by Tropical Soil Biology and Fertility Programme (TSBF), brought together partners from national institutions of the countries participating in the African Highlands Program, Ethiopia, Kenya, Madagascar, and Uganda as well as international centers collaborating in the region, and expertise from outside the region. The project is a joint action of the African Highlands Initiative (AHI) and the Soil Water and Nutrient Management Programme (SWNMP) of the CGIAR. The project is implemented by a consortium of national, regional and international agencies with a wide range of expertise and experience in nutrient management research, farmer participatory research, agricultural problem-solving and development actions. The project is coordinated by TSBF on behalf of the SWNMP and represented within AHI through the technical support group.

The rationale for conducting the CND theme in the East African Highlands is stated below.

1. Nutrient depletion is a reversible constraint to African Highland Agriculture because diverse nutrient resources are available but are currently under-utilized. These resources include commercial fertilizers, agro-mineral deposits, agro-industrial by-products, and locally produced and available organic materials.

2. Nutrient recapitalization has become an emerging priority in the African Highlands based upon increasing recognition that soils in smallholder agriculture are a crucial but poorly-protected resource. The underlying principle of nutrient recapitalization is the enhancement of long-term food security by offsetting nutrient losses suffered by smallholders.

3. In most cases, the nutrients that are constraining to smallholder agriculture have been, or are being identified. The most frequent, but by no means only, limiting nutrients are nitrogen and phosphorus.

4. Nutrient depletion can lead to irreversible consequences such as soil erosion and biodiversity losses and thus has off-site as well as on-site environmental impacts. Nutrient and soil losses result in sedimentation within watersheds, eutrophication and pollution of waters, and biodiversity losses.

5. Income generation by smallholders, and subsequent investment in soil amendments, are essential components to combatting soil depletion.

6. Nutrient access operates at the national level and is policy-driven while nutrient availability operates at local levels and is strongly influenced by farmer opportunities and decision-making.

7. Improvements in both nutrient access and availability require innovative solutions achieving nutrient recapitalization, better fertilizer distribution and marketing and refinements in farmer participatory techniques.

8. Farmer participatory methods, whereby scientists and farmers work closely together to identify and resolve soil nutrient deficiencies, are not widely available and are a necessary component of nutrient replenishment efforts.

9. A comparative advantage of the AHI/SWNM Consortium is its ability to develop mechanisms that rebuild and maintain soil fertility on depleted lands including improved nutrient acquisition and management strategies as well as innovative policy initiatives.

The following agreed upon set of objectives and outputs were developed at the workshop.

The objective of the CND – East Africa Consortium are:

1. Integrating nutrient management practices that redress nutrient imbalances and environmental degradation.

2. Enabling policies for combatting nutrient depletion.

3. Assisting farmers to adopt improved nutrient management practices.

Outputs for the East African Highlands

Output 1. Increased institutional capacity for participatory diagnosis, development, and dissemination of improved nutrient management practices.

Output 2. Resource management domains indentified and characterized.

Output 3. Tested guidelines for soil recapitalization of nitrogen and phosphorus in degraded soils resulting from smallholder farming systems.

Output 4. Recommendations for optimizing combinations of organic-inorganic inputs and their management.

-Output 5. Improved farming systems for greater nutrient use efficiency.

Output 6. Guidelines for adaptable land use strategies which integrate agricultural and environmental concerns based on land use indicators of sustainability.

Output 7. Policy recommendations for combating nutrient deletion.

Output 8. Research findings and recommendations disseminated and stakeholders trained. Since the inception of CND- East Africa considerable progress has been made toward the stated outputs. This report provides an update on the status of the different outputs and activities. Some of those activities have been led by other programs involved with AHI; these activities and the lead institutions will be mentioned here but no report on the activities. Detailed reports of the activities funded by the SWNM consortium and led by TSBF and its collaborators are included.

Activities of CND-East Africa have been funded through various funding sources: SWNMP, AHI, and individual donors. Funds obtained through SWNMP and AHI are used synergistically to achieve regional and generic outputs. The Nutrient Depletion Theme is addressed primarily through the AHI benchmark sites. In this approach, strategic research is concentrated in a few sites that are representative of larger recommendation domains. Further networked activities bring in additional sites when necessary to cover a wider range in farming systems and soil types. Several integrated activities, including strategic and adaptive research and extension and dissmenation are conducted at those sites.

Output 1. Increased institutional capacity for participatory diagnosis, development, and dissemination of improved nutrient management practices.

Activities: These activities have become a major focus of research within the AHI program. Training courses have been funded by AHI and held on Participatory Agroecosystem Management at all of the AHI sites. SWNM-CND activities have been developed to complement and strengthen the participatory approach. BMZ has recently funded a project, Improving integrated nutrient management strategies in small scale farms in Africa, that focuses on adapting integrated nutrient management practices for farmers, dissemination and training. These activities will be conducted with CIAT, NARES, NGOs, and farmers in W. Kenya, E. Uganda, and N. Tanzania.

1.1 Evaluate and enhance participatory research methods as they relate to smallholder nutrient management with respect to farmer adoption and diffusion (Participatory Diagnosis and Dissemination - PDD) of acceptable solutions. Special attention will be paid to gender issues as they relate to participatory research.

1.2 Training of farmers, extension workers, and researchers in participatory diagnosis, planning, testing, implementation, and evaluation of on-farm nutrient replenishment trials.

Output 2. Resource management domains identified and characterized.

Activities:

2.1 Conduct participatory diagnosis in supplement to that of the African Highland Initiative benchmark (or other) sites that is designed to generate specific information on fertility management. The diagnosis include: current fertility conditions, current practices and recommendation for fertility management, extent and major pathway of nutrient depletion, and identification of farmer groups with these constraints and opportunities.

These activities have been funded directly by AHI and realized principally through the national participants at the AHI benchmark sites.

2.2 Identify and characterize the currently available and under-exploited soil amendments which provide sources of plant nutrients including agro-minerals, fertilizers, aro-industrial wastes, crop residues, tree biomass and livestock manures.

TSBF has led the activity on the characterization of the organic resources as sources of nutrients. This activity has been conducted by a project funded by DFID to the SWNM consortium and has resulted in the compilation of this information into the Organic Resource Database. A summary of this activity follows:

The Organic Resource Database

Robert Delve, Catherine Gachengo, Cheryl Palm, Georg Cadisch, and Ken Giller

The Organic Resource Database, introduced in the 1996 TSBF report, has become a reality. The orginial intent for ORD was to provide researchers with information on the macronutrient, lignin and polyphenolic contents from a variety of organic resources found in the tropics. Those chemical parameters help to define the resource quality of the material and determine in part the nutrient release patterns and decomposition rates of the materials. The Organic Resource Database (ORD) was developed as a joint project between Wye College University of London and TSBF as a catalogue of standardized characterization of plant resource. The information contained in ORD has moved beyond just plant resource quality parameters and now also contains information on nitrogen release rates, decomposition, digestibility in ruminants for many materials. The soil and climate properties from where the material was collected is also available in some cases.

Contents of the Organic Resource Database

At present the ORD contains data on quality parameters of over 1700 records covering at least 32 families. Of the plant materials, over 1000 records are legumes. One third of the records are results of analysis done in the Soil Chemistry laboratory at KARI-Muguga while the rest are from the literature. More recently data from AfNet, SoilFertNet and The Legume Screening Network East and Southern Africa and from CIAT in Latin America have been added to the database.

The database has been written in Microsoft Access, a specialized database program. The ORD has been designed for easy entry, storage, searching and analyzing of data. Queries are used to search data stored in the database. They may be used to obtain averages, variances, count, sums etc. of data contained in tables. A new user manual and tutorial has been produced to guide people through the database, the stages of data entry, data searches using queries and how to produce reports.

Uses of the Organic Resource Database

ORD can be used by researchers for a variety of purposes: 1) examining the range in resource quality parameters of a single species within a site and among sites, 2) relating resource quality parameters to soil properties, 3) identifing links between decompositon and disgestibility, and 4) selecting materials with specified resource quality parameters. Using queries users can search the database, for example, for the chemical characteristics of a range of organic resources (Table 1). Queries can also be used to select materials that fall into the various categories of the TSBF Decision Tree for Organic Matter Management for Nitrogen. A subset of the materials that fall into the high quality category of materials that have %N >2.5, %lignin<15, and polyphenol < 4% and that can be incorporated directly into the soil are presented in Table 2.

Distribution of the Organic Resource Database

Wye College has agreed to host the Organic Resource Database webpage, available at http://www.wye.ac.uk/BioSciences/soil/ . Initially this is designed to provide information about the database and its content and to allow people to download the database from the internet. A password is required to download the ORD allowing a register of users to be compiled. Catherine Gachengo is responsible for distributing the password and developing the list of people that have acquired ORD. In future it is hoped to be able to offer the database on-line, allowing data searches etc through the internet. Researchers can also add data to ORD by requesting the data form from TSBF. The form is then sent to TSBF for entry into ORD. ORD will be up-dated quarterly.

Requests for information from the database are continually received by TSBF. These requests are generally for information on the quality characteristics of specific plants and the range of values observed for given parameters. The information requested is used both for selection of materials for experiments and for use in publications. Requests come from scientists and extension workers from national and international institutions and NGOs.

A project funded by DFID, Confronting soil erosion and nutrient depletion in the humid/subhumid tropics, supports research in Uganda to further develop and distribute the Organic Resource Database, develop decision support systems for the combined use of organic and inorganic nutrient sources, and test the ORD and decision support systems with farmers. This project includes collaborative activities in W. Africa with IFDC, Latin America with CIAT, and Southeast Asia with IBSRAM.

Table 1: Average values for various organic resources in the Organic Resource Database

Organic Resource	Material analysed	% Nitrogen	% Phosphorus	% Lignin	% Polyphenol
Calliandra calothyrsus	leaf	3.4	0.15	17.6	9.88
	litter	1.6	0.05	22.6	9.24
Canavalia ensiformis	leaf	3.3	0.16	5.5	2.24
	litter	2.0	0.09	9.3	0.93
Tephrosia vogelii	leaf	2.9	0.18	8.0	5.18
	litter	1.4	0.07	23.1	1.12
Leucaena diversifolia	leaf	3.9	0.25	10.4	5.44
	litter	1.8	0.08	27.8	1.01
Zea mays	leaf	1.3	0.15	13.1	0.71
	stover	0.8	0.06	7.9	0.86
Cattle manure	-	1.1	0.09	13.3	-

Table 2: Leaves of plant materials suitable as a source of N for direct incorporation into the soil

Plant name	% N	% Lignin	% Polyphenol
Acanthus eminens	*3.25*	*8.45*	*3.38*
Cajanus cajan	3.73	12.59	3.52
Croton macrostachys	3.12	11.08	2.34
Dolichos lablab	4.11	7.20	1.67
Gliricidia sepium	3.60	11.38	2.13
Leucaena diversifolia	3.81	8.86	1.50
Mucuna pruriens	4.06	11.74	2.93
Senna spectablis	3.68	9.96	3.38
Vitis vinifera	3.34	5.43	2.65

ICRAF has led the activity on the characterization of agro-minerals – primarily locally available rock P sources, with their own funding, supplemented by small amounts of SWNM consortium funds.

Output 3. Tested guidelines for soil recapitalization of nitrogen and phosphorus in degraded soils resulting from smallholder farming systems.

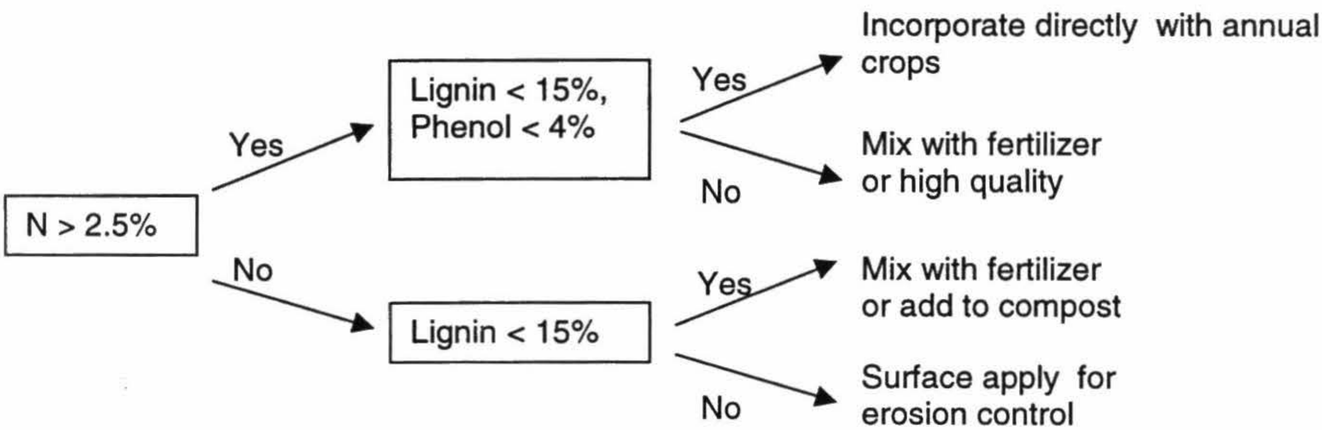
Activities:

3. 1 Develop a decision support tool for use by farmers and extensionists in the selection of nitrogen and phosphorus resources as soil amendments.

A decision support tool for the selection and management of N sources has been developed by TSBF as shown in Figure 1. It is a heirarchical decision tree with the resource parameters of N content, lignin, and polyphenolic content. This decision tree can be linked to the ORD for selecting materials for different soil management practices – it will be tested with farmers through SWNM projects funded by DFID for Uganda and BMZ for AHI sites in Kenya, Uganda and Tanzania.

This decision tree has also been translated into a farmer-friendly version that relates N content of the material to its color, the lignin content to the toughness of the leaf, and the polyphenol content to the astringent taste of the material. This version has been published into a regional extension manual.

Figure 1: TSBF biomass transfer decision tree



3.2. Develop and compare options for improving phosphorus and nitrogen stocks in different soils based on soil requirements, resource availability, costs and farmer acceptance of specific soil management technologies.

These activities will be conducted under the recently awarded BMZ project to CIAT and TSBF, Improving integrated nutrient management strategies in small scale farms in Africa. Several soil management options developed by the NARES and IARCs have been identified for broader testing and comparing on farmers fields. These options including organic and inorganic nutrient sources (tithonia and cattle manure as the organic resources); legume cover crops; and short term leguminous tree fallows. These options will be assessed according to farmers perceptions and criteria as well as convential economic assessments. These activities will be conducted with CIAT, NARES, NGOs, and farmers in W. Kenya, E. Uganda, and N. Tanzania.

Output 4. Recommendations for optimizing combinations of organic-inorganic inputs and their management.

Activities:

4.1. Determine the effects of organic and inorganic additions on soil nutrient pools and plant nutrient availability on a representative range of soil types.

This activity has been a major focus for CND-East Africa. Network protocols have been developed on combing organic and inorganic nutrient sources under the following titles:

Nitrogen 1: A. Nitrogen fertilizer equivalencies based on organic input quality, B. Optimal combinations of organic and inorganic N sources.

Nitrogen 2: Overcoming the negative effects of low quality organic inputs.

Nitrogen 3: Determining the *in situ* fertilizer equivalency values of best bet leguminous technologies.

Phosphorus 1: Optimal combinations of organic and inorganic P sources.

Phosphorus 4: Residual effects following different rates of P application.

These protocols were published and distributed widely among all the SWNM consortia and other related networks in Southern Africa. The research has been conducted as a series of network trials that have been conducted in a variety of locations in the AHI benchmark sites and a few additional sites that increase the range in soil and climate conditions in which the experiments are tested; the sites and collaborators are listed in Table 4. Reports on the progress of a few of these experiments are reported here. The other trials have recently been installed and no results are yet available.

Table 4. *Summary of network experimental sites and collaborators.*

Experiment N1: A) Nitrogen Fertilizer Equivalencies Based on Organic Input Quality and B) Optimal Combinations of Organic and Inorganic N Sources

Location/ Collaborator	Date commenced	Organic materials	Status
Tanga, Tanzania S. Marandu S. Ikerra	Long rains 1998	Sesbania, maize stover, Neem	1 application, 1 residual, New site started
Njoro, Kenya N. Mungai	May 1999	Leucaena, Calliandra	First crop
Maseno Kenya P. Mutuo	Long rains 1998	Senna, Calliandra, Tithonia	One season
Madagascar R. Rabeson	March 1998	Tephrosia	
Chitedze, Malawi S. Snapp	March/April 1998	Cajanus (litter), Neem, maize stover	1 application, residual
Chilanga, Zambia M. Mwale	March/April 1998	Sesbania	1 application, New site

Experiment N3: Determining the in-situ Fertlizer Equivalency values of best-bet leguminous technologies

Tanga, Tanzania A. Marandu, S. Ikkera	Long rains 1999		Establishment
Magoye,Zambia M. Mwale	March/April 1999	Velvet beans	Establishment
Chitedze, Malawi R. Gilbert	November, 1998	Soyabean, Groundnut, Pigeon pea, Tephrosia, Mucuna	Finishing first season

Experiment P1: Maintenance of soil P with small applications of organic and inorganic sources

Kawanda, Uganda K. Kayuki	**Long rains 1998**	Tithonia, Lantana	2 applications, on first residual
Maseno, Kenya G. Nziguheba,	Short rains 1997	Tithonia	2 applications, 2 residuals
Kakamega, Kenya J. Ojiem	Long rains 1997	FYM	3 applications, 1 residual

Experiment P4: Maintenance of soil P with small applications of organic and inorganic sources

Maseno, Kenya P. Mutuo	**Long rains 1998**	1 application, harvested for 2nd residual (2 sites)
Embu, Kenya F. Kihanda	Long rains 1998	1 application

Nitrogen 1: A. Nitrogen fertilizer equivalencies based on organic input quality.

Network trial results from East and Southern Africa: Season 1

Mutuo P., Marandu A.E., Rabeson R., Mwale M., Snapp S., and Palm C.

Given the high cost and the uncertain availability of inorganic fertilizers in much of Africa, the goal should be to provide as much of the nutrients as possible through organic materials, making up the shortfall of the limiting nutrients through inorganic fertilizers. Numerous field trials indicate both added benefits and disadvantages of combining nutrient sources yet there are no predictive guidelines for the management or organics, such as those that exist for inorganic fertilizers. A set of hypotheses has been placed into a decision tree for selecting organic materials for soil N management based on their quality (Figure 1). From this decision tree we would predict that organic materials with N content above 2.5%, lignin less than 15% and polyphenol contents less than 4% would be suitable as replacements for mineral N fertilizer.

A network trial was designed to test this hypothesis and to determine the fertilizer equivalency values of organic resources based on their resource quality. The trial was conducted in W. Kenya, Tanzania, and Madagascar in East Africa as part of the SWNM-AHI ecoregional program and in Zambia and Malawi in Southern Africa as part of the SoilFertNet and IFAD projects.

Network trial protocol

The basic design of the trial includes a N response curve (treatments 1-5) and then two treatments comparing equal amounts of N added as an inorganic source (treatment 6) or an organic source (treatment 7) (Table 1). The organic materials used at the different sites varied widely in their resource quality parameters (Table 2) and could therefore be used to also test the decision tree (Figure XX). Organic materials were broadcast and incorporated into the top 0.15 m soil prior to planting, while the urea was applied according to the normal practice (split application). Organic materials also supply K and P which might affect yields, and so as to avoid this confounding effect both nutrients were applied in all plots in non-limiting quantities, usually 100 kg ha^{-1}.

Fertilizer equivalencies (FE) of organic materials were obtained by comparing the yield from the organic materials to that of the N response curve (Figure 1). In order to compare the FE of organic materials between sites and where amounts of N applied were different the fertilizer equivalency, FE (%) values were then calculated as:

$$FE\,(\%) = \frac{X*100}{N\ \text{applied}}$$

Where N applied = actul amount of N applied

For example, a %FE of 100 means that the organic source is equally effectvie to that of the inorganic and a FE = 80% means the organic material gives a yield 80% that of the inorganic N applied.

RESULTS: Nitrogen fertilizer equivalency values of organic inputs

The FEs of the different organic materials used at all sites ranged from 16% for neem to 139% for senna (Table 3). The organic materials, which performed more than or comparably to inorganic N fertilizer in increasing maize yield were tephrosia, tithonia and senna. This can be attributed to the high N levels of these organic materials (%N • 3.5). Although tephrosia has a slightly higher level of lignin (17.7%) above the predicted critical value of 15%, its good performance together with tithonia and senna would classify them as high quality organic materials that can be recommended for direct application as N sources.

Despite the high N content (3.8%) of calliandra the FE was low (36%), mostly likely due to the high polyphenol content which was more than double the critical value. Similarly, sesbania in Zambia had a FE of 39% despite its high N content (5.0%) probably due to the higher level of polyphenol (5.1%) as compared to the critical level of 4.0%. Pigeon pea litter and neem leaves, both with N contents about 2.8% had FEs of 33% and 16%, respectively. The fairly poor performance of these organic materials in increasing maize yield could be attributed to the high amounts of lignin in pigeon pea (19.2%), and polyphenols in neem (4.6%). The management recommendation that is suggested for these materials is to mix with N fertilizer or high quality organic material. The indication from these results is that the critical level of lignin in organic materials is likely to be between 18 and 19%.

The maize yields following application of maize stover in Malawi and Tanzania were lower than the control plots (no inputs). The poor performance of maize stover could be attributed solely to the low N content (1.0 to 1.3%). This finding agrees with the hypothesis that nitrogen concentration in tissue of about 2.2% is the critical value for the transition from net immobilization to net mineralization. The management recommendation for such a material is to mix with N fertilizer or to add to compost.

In order to find out the effect of increasing the amount of N in an organic material above the critical value on its percent FE, the percent FEs of organic materials with %N • 2.5 were plotted against their N content (Figure 2). A linear relationship was observed between the percent fertilizer equivalency and N content ($r = 0.86$, $P = 0.01$). This linear function indicates that with increase of 0.1% N in the tissue of the plant material, there is an 8% increase in the fertilizer value. From the estimator line, the critical level of N content of organic materials for net immobilization or net mineralization to occur was 2.4% (Figure 3). This critical value of N content obtained from this study is close to that suggested in the decision tree. The linear plot in Figure 2 excluded the %FE values for calliandra and maize stover because they were consider to be in different quality categories.

The way forward

On the basis of the first season results from several sites we can tentatively say the decision tree for N management is useful. However, we need more trials testing more materials and through several seasons to confirm these early findings. The residual effects of the organic materials must also be explored and compared to that of inorganic N sources.

Table 1: Basic structure of basic treatments used in the N fertilizer equivalency trial.

Treatment	N source	
	% of N added as inorganic	% of N added as organic
1	0	0
2	30 kg N ha^{-1}	0
3	60 kg N ha^{-1}	0
4	90 kg N ha^{-1}	0
5	120 kg N ha^{-1}	0
6	100%	0
7	0	100%

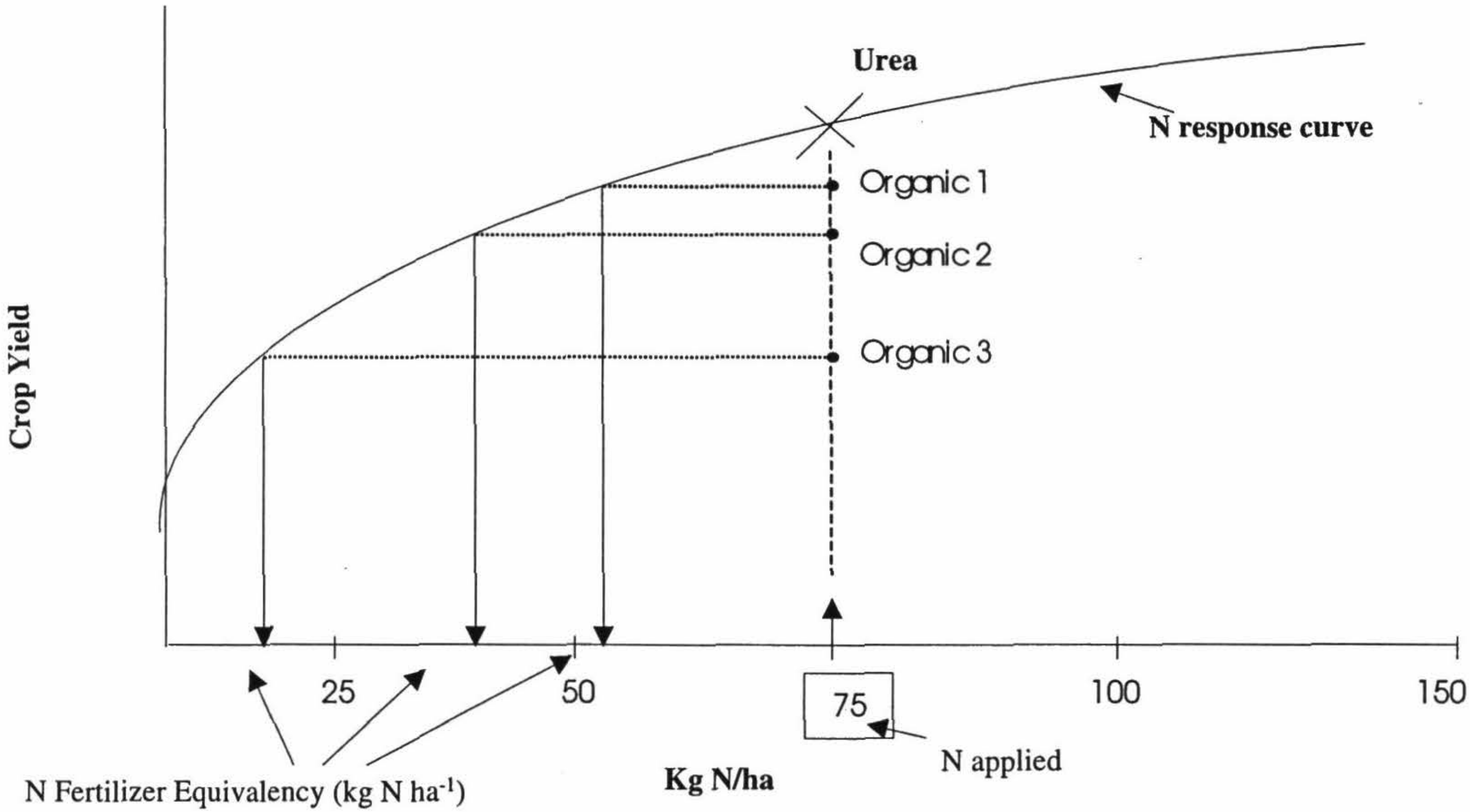
Table 2: Characterization for %N, P, lignin and polyphenols of the organic materials used for the trial.

		%			
Site	Organic material	N	P	Lignin	Polyphenol
Kenya	Tithonia	3.5	0.35	5.2	2.5
	Senna	3.7	0.21	10.7	3.4
	Calliandra	3.8	0.15	14.4	9.9
Tanzania	Sesbania	3.5	0.17	4.7	4.3
	Maize stover	1.3	0.07	7.2	1.3
	Sesbania stem	1.7	0.12	13.8	2.2
	Neem	2.9	0.15	18.0	4.6
Madagascar	Tephrosia	4.0	0.38	17.7	3.7
Zambia	Sesbania	5.0	0.26	8.0	5.1
Malawi	Pigeon pea	2.8	-	19.2	3.1
	Maize stover	1.0	-	-	-

Table 3: Percent fertilizer equivalencies of the different organic inputs used at all sites.

Site	Organic material	% N in material	Fertilizer equivalency (%)
Kenya	Senna	3.7	139
Tanzania	Sesbania	3.5	<100
Madagascar	Tephrosia	4.0	93
Kenya	Tithonia	3.5	87
Zambia	Sesbania	5.0	39
Kenya	Calliandra	3.8	36
Malawi	Pigeon pea	2.8	33
Tanzania	Neem	2.9	16
Tanzania	Maize stover	1.3	0
Malawi	Maize stover	1.0	<0

Figure 1: Determining fertilizer equivalency values



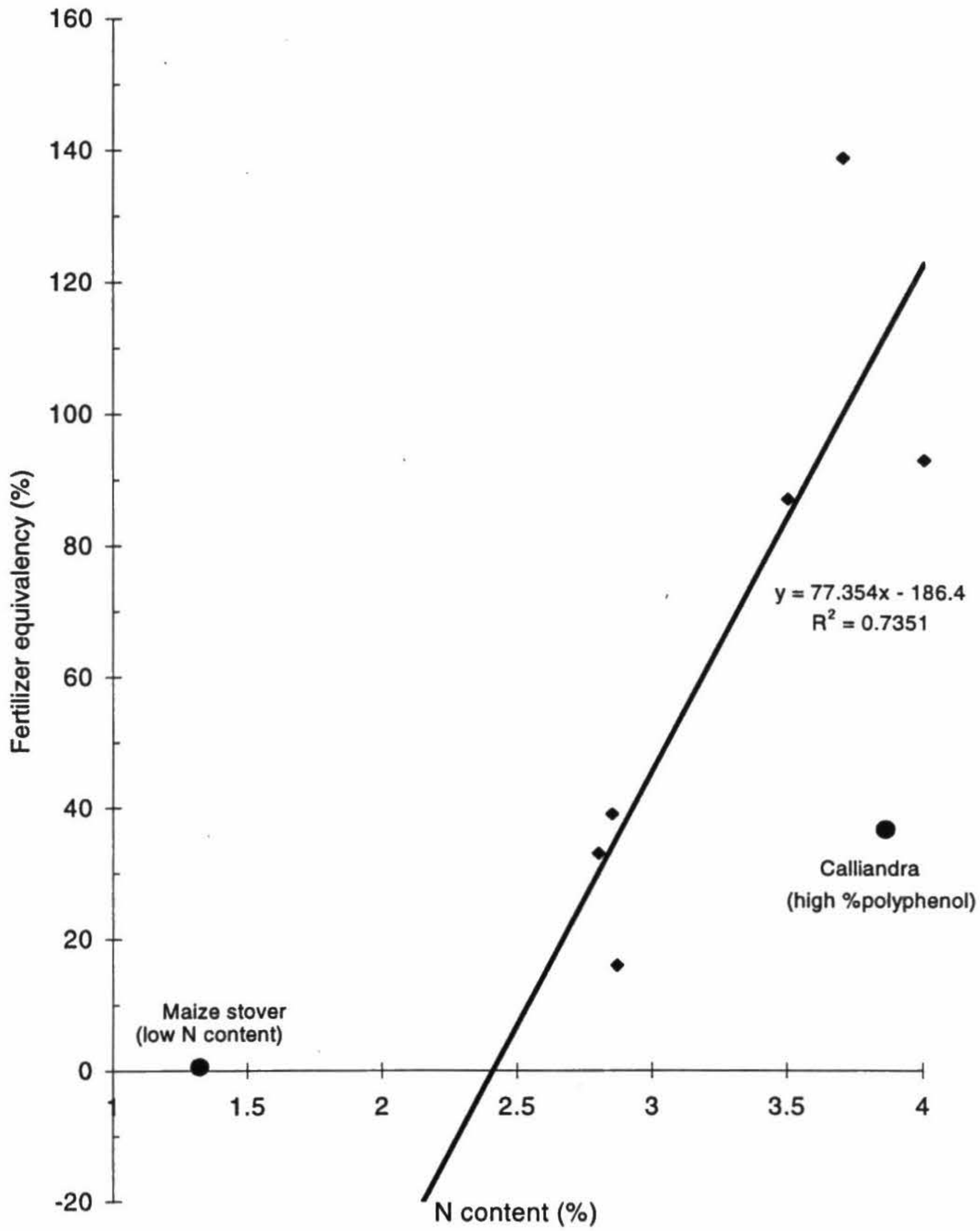


Figure 2: The relationship between percent fertilizer eqivalencies and N content of organic materials. (Regression line excludes calliandra and maize stover)

Nitrogen Mineralization of organic materials of differing quality in a Rhodic Ferralsol in Tanzania.

Marandu, A.E, S.T.Ikerra, M.C. Kalumuna, R.H Assenga, and P.K. Mutuo

Decomposition of organic materials and nutrient release patterns are determined by climatic, edaphic and resource quality factors. Time and again, N release patterns have been related to the resource quality or the chemical characteristics of organic materials, with N content and C-to-N ratio of the materials serving as the most robust indices. This study was done in Tanga, Tanzania to determine N release patterns of *Sesbania sesban* and *Azadirachta indica* (neem) leaves, and maize stover. Nitrogen from the organic materials was added at 75 kg N ha^{-1} in a field trial. The nutrient contents and chemical characteristics of these materials are presented in Table 4.

Table 4: Nutrient contents and chemical characteristics of these materials used

		·········· % ··········		
Organic material	**N**	P	Lignin	Polyphenol
Sesbania	3.5	0.17	4.7	4.3
Neem	2.9	0.15	18.0	4.6
Maize stover	1.3	0.07	7.2	1.3

In all treatments NH_4-N decreased in the first 35 days after application of materials (Figure 3a). The decrease in NH_4 can be attributed to nitrification process in aerobic soil conditions, which is evidenced by an initial increase in nitrate-N (Figure 3b). At day 35 after organic additions, nitrate-N was higher with sesbania compared to other treatments, while nitrate levels in the stover and neem treatments were slightly lower compared to the control (Figure 1b). This indicates that there was net N release with application of sesbania while there was partial immobilization with application of stover and neem.

From 35 to 84 days after treatment application, ammonium remained constant for maize stover, neem and control treatments. Accumulation of ammonium with sesbania between day 56 to 70 could be attributed partly to microbial biomass which likely build up following high N release earlier and partly from mineralization of the slow decomposing fractions of the sesbania. The sharp decline in nitrate 35 and 56 days can be attributed to heavy rains which occurred during this period causing much leaching of nitrate, in addition to N uptake by maize crop. Nitrate levels start increasing after 56 days following application of neem leaves. The implication from this is that net mineralization starts to occur after 2 months following the breakdown of the highly lignified material, hence releasing the constituent N.

It is notable that all the N from sesbania is released fast (in about one and half months), which is associated to its high N content and low concentrations of lignin and polyphenols. The partial N immobilization resulting from high lignin levels in neem and immobilization up to three months by low N content maize stover, is a clear indication that N release from organic materials is highly dependent on the N content and chemical characteristics.

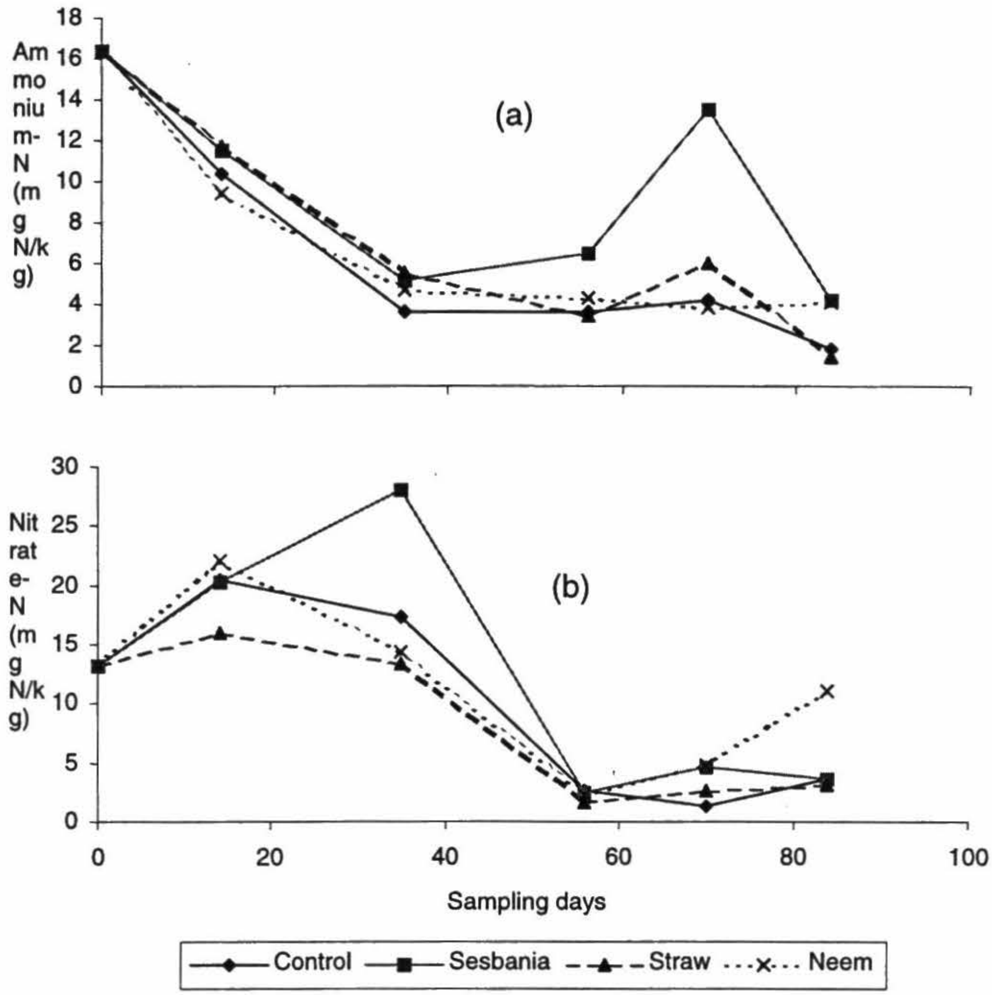


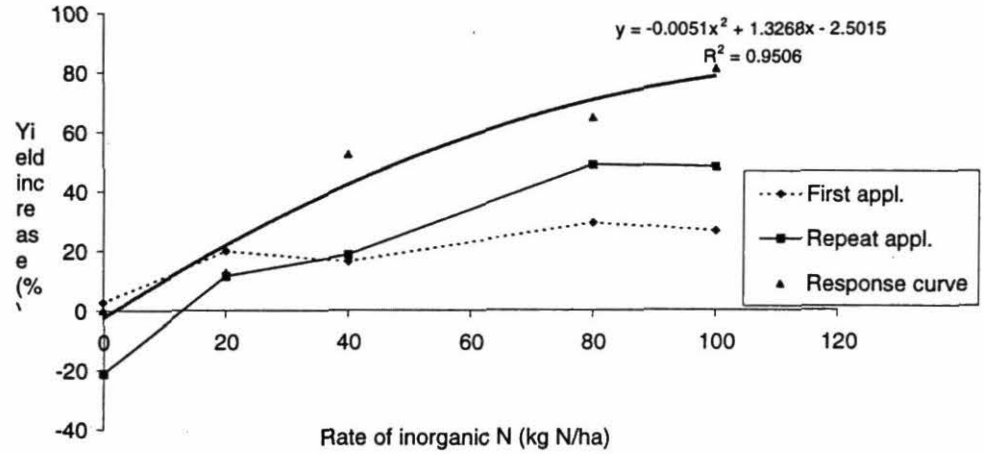
Figure 3: Levels of (a) ammonium-N and (b) nitrate-N following organic amendments

N2: Overcoming negative effects of low quality organic inputs.
K. Kaizzi, Kabale Uganda

Low quality organic inputs can often results in decreased crop yields caused by immobilization of N. These same organic materials however are essential for maintaining and building soil organic matter and will in the longer term increase soil N availability. These negative effects might be overcome by small applications of mineral N fertilizer yet there are not yet recommendation on how much is needed to result in postive crop yields.

In Kabale Uganda this experiment was installed by combining 2 tonnes of maize stover with increasing amounts on N fertilizer. The results were compared to an N response curve with no maize stover added. The treatments were applied for two seasons. Figure 4 indicates that indeed the maize stover application resulted in reduced yields of 80% for the first crop – no matter the amount of N added. For the second crop the decrease in yield was still apparent for N levels of 20 kg N and less but at higher levels the yield reductions were decreased to 40 or 50 % indicating that the N added the previous season was being remobilized. The longer term benefits in terms of soil N build up are obvious but the shorter term economic implications in terms of decreased yields would be difficult to justify in the smaller holder sections. Alternative uses of maize stover such as for fodder or composting would be recommended, as indicated by the TSBF N decision tree.

Figure 4: Relative yield increases with application of maize stover (2 t/ha) in combination with inorganic N in Kabale, Uganda



Phosphorus 1: Optimal combinations of organic and inorganic P sources.

Effects of combining organic and inorganic P sources on maize grain yield in western Kenya

Ojiem J.O., S.E. Carter, C.A. Palm, M.O. Odendo, E. Okwuosa

There is an indisputable need to correct deficiency of soil P western Kenya. Recent work has shown success in improving the effectiveness of organic manures to supply plant-available P, by mixing them with inorganic P fertilizers. This study was conducted on-station and on-farm between March to August 1997, to test the effects of combining farmyard manure and inorganic P fertilizer on maize yield. The on-farm trials were established in three locations in Kabras division on a total of 21 farms. Various proportions of organic and inorganic P sources were applied to supply a total of 30 kg P

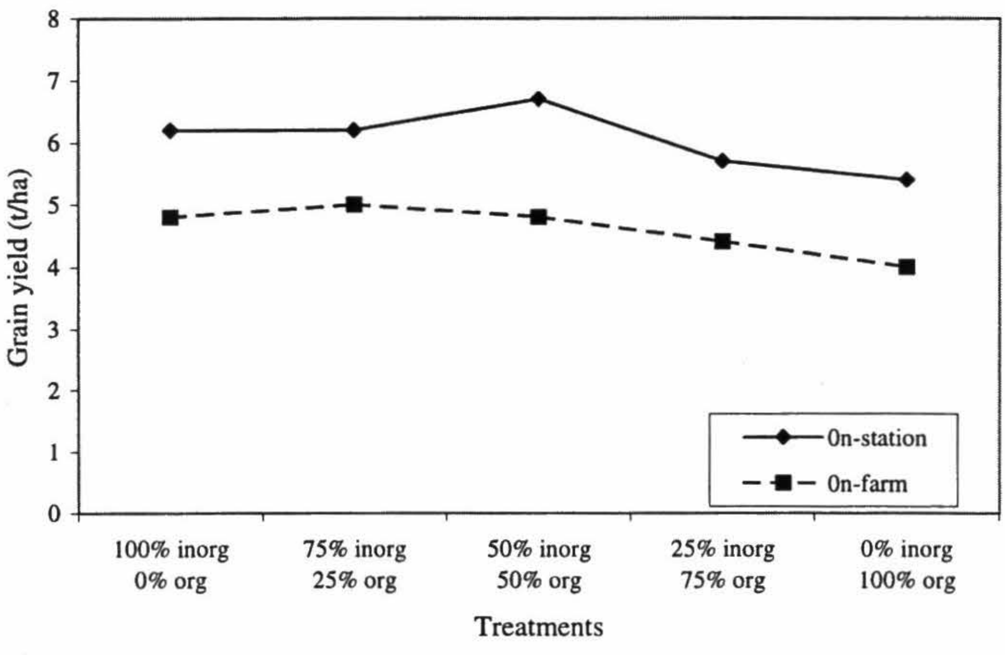
ha^{-1} to all treatments, except the no-input control. To eliminate confounding effects of N and K deficiencies, 100 kg N ha^{-1} and 135 kg K ha^{-1} were applied to all plots.

In the on-station trial, application of P increased maize grain yields by at least 2 t ha^{-1} above the control. The combination of P fertilizer with farmyard manure in different proportions did not result to yield differences, shown by zero slope of a fitted regression curve. Yield following sole addition of farmyard manure was equivalent to those from both the inorganic P fertilizer, and the organic-inorganic combinations (Figure 5). Although highest yields were obtained with the 50%+50% organic and inorganic P sources, there were no significant synergistic effects in combining farmyard manure and P fertilizer.

Maize yield significantly increased by at least 1 t ha^{-1} with addition of P in the on-farm trials. Generally, yields were lower by at least 1 t ha^{-1} for the on-farm trials, as compared to yields obtained from on-station (Figure 5). Regression analysis to determine yield response to organic and inorganic P combinations showed a similar trend to that of on-station data. However, the on-farm data showed high variability between replicates (farms), likely resulting from differences in soil chemical and physical properties, and management practices.

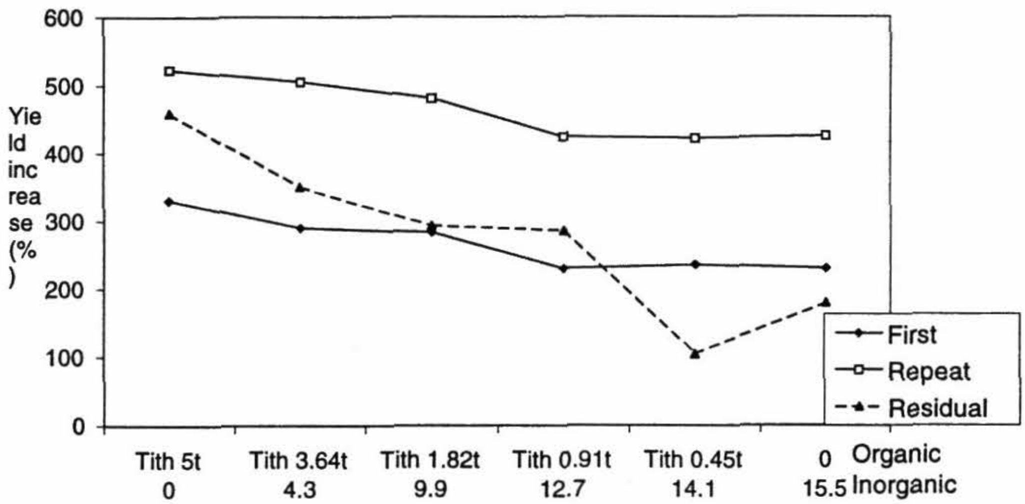
Given the high costs of inorganic fertilizers, scarce availability of organic resources in the area and low P content of these organics, the implication from these results is that farmers can use cattle manure to replace P or to combined organic-inorganic P sources to minimize the amounts of mineral fertilizer purchased.

Figure 5: Mean maize grain yield response to P sources in western Kenya



A continuation of the on-station trial with a second application of the treatments show the same trend as the first application with a slight advantage shown for the organic treatment (Figure 6). However a subsequent crop with no application of treatments indicated a dramatic residual effect of the manure treatment – the residual effect decreasing dramatically as the proportion of manure decreased. The previous applications of manure could have resulted in a decrease in the P-fixation capacity of the soil. Such results strongly advocate the advantages of integrated nutrient management not only in the short term but more importantly in the longer term.

Figure 6: Grain yield increases for two applications of combined organic (tithonia) and inorganic P sources and a residual crop in western Kenya



4.2 Establish guidelines on which materials are best composted and how the composting process should be managed.

There are no current or planned activities on composting.

Output 5. Improved farming systems for greater nutrient use efficiency.

Activities:

5.1 Identify farming systems components that capture deep soil nutrients that would otherwise be unavailable to field crops.

This activity has been led by ICRAF through its own funding sources.

5.2 Explore the better use of symbiotic nitrogen-fixing species within smallholder farming systems.

Network trials have been developed to explore various temporal and spatial niches in which to locate legume cover crops on farm. These trials are beginning in March 1999. ICRAF has led the activities with legume trees and shrubs.

Output 6. Guidelines for adaptable land use strategies which integrate agricultural and environmental concerns based on land use indicators of sustainability.

Activities:
These activities have not yet been planned, nor are funds available.

6.1 Synthesize available information on agricultural-environmental interactions in the African Highlands.

6.2 Determine off-site environmental impacts resulting from nutrient loss.

Output 7. Policy recommendations for combating nutrient deletion.

Activities:
These activities will not be handled directly by SWNM. IFPRI does have a BMZ project that will address policy issues relevant to soil fertility management in Uganda. SWNM will benefit from such activities and there are plans for joint activities with IFPRI in one site in Uganda

7.1 Analyze the effect of past market liberalization and infrastructure development on fertilizer prices, availability and use and their resulting impact on soil nutrient management.

7.2 Assess the potential impacts of community-level actions and consider enabling policies such as informal credit, extension alternatives, property rights and the local regulation of land use.

7.3 Develop models at farm to landscape scales to assess the impacts of technology and policy changes on nutrient recapitalization and use efficiency, soil and water quality, productivity, profitability and farmer welfare.

Output 8. Research findings and recommendations disseminated and stakeholders trained.

Activities:

8.1 Develop decision support systems for participatory research and technology diffusion based on existing soil nutrient models, that incorporate farmer priorities and socio-economic conditions.

TSBF has recently received a grant from ACIAR, Integrated nutrient management in tropical cropping systems: Improved capabilities in modeling and recommendations that begins in 1999. This project will bring together soil scientists specializing in N and P dynamics from Africa, Latin America and Southeast Asia to work with modelers, particular with the APSIM model, to improve the capabilities for modeling integrated nutrient management. The model incorporates an economic assessment of various N and P nutrient management strategies and can serve as a first case for narrowing the options with which to work with which categories of farmers.

8.2 Training through models and decision support systems of agricultural extensionist and researchers, policy researchers in the implications of nutrient depletion and nutrient management at farm and landscape scales.
This activity will develop as activities 3.1 and 8.1 proceed.

8.3 Conduct a policy forum to disseminate research findings and recommendations for policy interventions.

Not yet planned.

8.4 Implementation of various dissemination techniques including land management manuals targeted to extensionists, local NGOs and subsequent study of their effectiveness.

Will be developed as soil management options are tested and evaluated with farmers.

Combating Nutrient Depletion Consortium -The economic assessment of soil nutrient depletion (IBSRAM)

Soil fertility depletion is seen as the most important process in the land degradation equation, and as the main biophysical limiting factor for increasing per capita food production in the majority of African small farms.

While there is much literature on soil degradation in general and soil erosion in particular, there is very little literature on the economic assessment of nutrient depletion, especially beyond erosion. In a joint approach with CIAT and TSBF, IBSRAM took over the initiative to develop a framework for the economic assessment of soil erosion and nutrient depletion. This is part of a DFID-funded initiative within the Soil, Water, and Nutrient Management (SWNM) programme. In a first step, a review on the economic assessment of soil erosion was prepared and published in the IBSRAM series Issues in Sustainable Land Management (No. 2). A forthcoming follow-up publication has been prepared by IBSRAM's African office, and will focus on different approaches to cost nutrient depletion using in most cases subSaharan Africa (SSA) as an example, as nowhere else is nutrient depletion better demonstrated and of more serious concern in view of food insecurity.

A central part of the study was the analysis of relations between nutrient depletion and population density as well as economic growth. A corresponding paper with a new estimation of the costs of nutrient depletion in SSA will be published in the forthcoming proceedings of the Second International Land Degradation Conference, that took place in Khon Kaen, Thailand, in January 1999. Some of the highlights of the findings are presented here.

Box 2: Nutrient depletion

Nutrient depletion or nutrient mining means net loss of plant nutrients from the soil or production system due to a negative balance between nutrient inputs and outputs. Typical processes of nutrient depletion are nutrient removal through harvest, leaching, denitrification, fire, soil erosion, and runoff. Nutrient inputs are caused by, for example, fertilization, atmospheric nitrogen fixation or dry and wet deposition. Thus, the soil nutrient balance is used as a tool to assess soil nutrient depletion, not the depleting processes alone.

Data from 37 countries in SSA show a close relationship between nutrient depletion and land pressure indicators (Figures 1 and 2) and thus confirm one of the main assumptions of the well known downward spiral to the poverty trap, i.e. increasing soil degradation through reduced fallow periods under growing demographic pressure. The most affected countries, such as Burundi, Rwanda, Kenya, or Lesotho have high altitudes, which, traditionally, have been densely populated because of a healthy and mild climate and sufficient rains. Not considered in Figure 1 were two outliers: Mauritius with the highest population density but little nutrient mining due to heavy fertilization, and Malawi with the highest nutrient losses (mostly erosion) but moderate population density. The data also show that with decreasing ability to fallow (i.e. increasing cropping intensity) there is increasing nutrient depletion in SSA (Figure 2). We find that N, P, and K losses are very high in countries with less than 50% of farm land under fallow and moderate if 60% or more of the farm land is under fallow. However, upscaling of nutrient in- and outflows through data aggregation is still an insecure exercise, and these thresholds are certainly not suited for application at lower scales with increasing biophysical and socioeconomic variability. On the other hand, they are useful to guide policy and decision making for the larger picture.

Approaches for the economic analysis of nutrient balances that combine biophysical and economic information vary between participatory action research and relatively sophisticated computer models that can consider soil organic matter dynamics and flows between different nutrient fractions. In most cases, the monetary value of nutrient mining is assessed with the productivity loss approach (PLA) or replacement cost approach (RCA). While the PLA has more advantages with regard to the assessment of one depletion process and its yield function, the RCA appears easier to apply to the nutrient balance model and the more complex assessment of nutrient depletion. Being aware of the weaknesses of the economic-environmental valuation techniques, the different approaches provide useful information on the costs of resource depletion to decision-makers. Of more significance for the farmer are, however, cost assessments at the farm level that consider criteria in a farmer's decision making to be labour prices and opportunity costs.

Taking a recent IBSRAM fertilizer retail price survey in SSA as an example, the replacement costs of nutrient mining were calculated on the basis of the nutrient balance model adjusted for nutrient availability but not for fertilizer efficiency. It showed that in certain countries, such as Rwanda, Tanzania, Mozambique, and Niger, nutrient depletion accounts for 12% or more of the agricultural GDP, indicating nutrient mining as a significant basis of economic growth (Table 1). Table 1 also shows that for the whole of SSA, nutrient mining accounts for about 7% of the subcontinental AGDP. Thus, the annual share of the average subSaharan farmer in the nutrient deficit is about US$32.

These figures are based on a wide range of assumptions mostly due to the aggregation of nutrient depletion data (see above). Though these estimates are certainly crude (cf. Bojö, 1996), they represent the best information available from a single source per data set (FAO, 1986; Stoorvogel and Smaling, 1990), and thus have the advantage of being a "Global Tool" by using a uniform estimation method for all countries. The often requested adjustment for nutrient availability in the nutrient balance affects mostly erosion with relatively low amounts of available nutrients among the total amount considered in the nutrient balance. Thus, countries with high nutrient depletion rates through erosion, such as Malawi, are not automatically countries with high nutrient depletion costs.

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Table 1. SSA nations grouped according to nutrient depletion in percent of the agricultural gross domestic product (AGDP).

Countries	% of AGDP
Benin, Botswana, Cameroon, C.A.R., Dem. Rep. Congo, Rep. Congo, Gabon, Ghana, Guinea, Kenya, Mauritania, Mauritius, Senegal, Sierra Leone, Swaziland, Zambia, Zimbabwe	≤ 5
Angola, Burkina Faso, Burundi, Chad, Côte d'Ivoire, Ethiopia, Lesotho, Madagascar, Malawi, Mali, Nigeria, Senegal, Togo, Uganda	6 - 11
Mozambique, Niger, Rwanda, Tanzania	>11
SSA (average)	7

Drechsel and Gyiele (In prep.), Drechsel and Penning de Vries (In prep.)

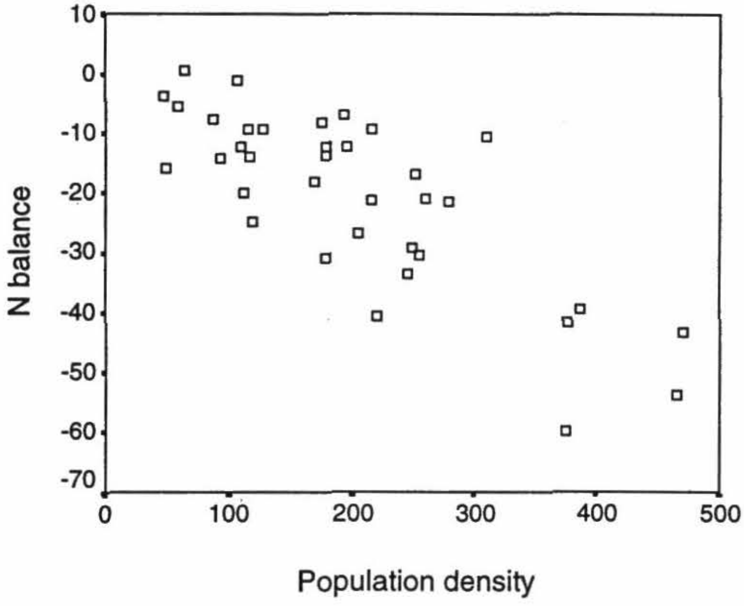

Figure 1: Increasing nutrient depletion with increasing population density. Population density refers to the total national population per square km annual and permanent cropland; annual N balance is in kg ha^{-1}. Data of 36 SSA countries from FAO (1986) and Stoorvogel and Smaling (1990). Source: Drechsel and Penning de Vries (2000).

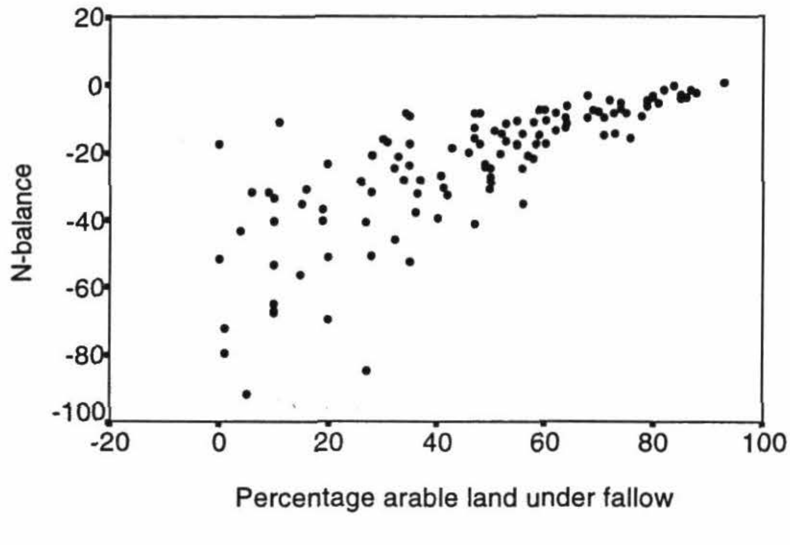

Figure 2. Relation between N balance (kg ha^{-1} y^{-1}) as calculated by Stoorvogel and Smaling (1990) and the percentage of arable land under fallow in SSA. We observe very high N depletion rates (>40 kg ha^{-1} y^{-1}) in areas with less than 50% of arable land under fallow. Data bases are the different FAO Land/Water classes per country in SSA (n=115). The relation is not influenced by N input during fallowing. Source: Drechsel and Penning de Vries (In prep.)

Progress towards achieving milestones of the Managing Soil Erosion *Consortium* (MSEC): Building the foundations for participatory research in catchment management

The Management of Soil Erosion Consortium (MSEC) is a catchment-based research programme on land management for erosion-prone areas in the humid and subhumid tropics of Asia. As one of the four consortia established through the soil, water, and nutrient management (SWNM) initiative of the CGIAR, MSEC uses an integrated, interdisciplinary, participatory, and community-based approach that involves all land users and stakeholders at a catchment scale. It focuses on the on- and off-site impacts of soil erosion and integrates biophysical and socioeconomic sciences to generate hard data and identify practical solutions that are acceptable to the various users of the land.

The approval of the technical assistance grant from the Asian Development Bank (ADB-RETA 5803) late in 1998 has provided the momentum for laying the groundwork for the implementation of this innovative approach to soil erosion research. The provision of funding for the project "Catchment Approach to Managing Soil Erosion in Asia", has meant more thorough characterization, manpower training for national partners, and distribution of the needed equipment and instrumentation for calibration and monitoring. In addition, the formation of the country teams and the discussion of the collaboration mechanism within and among the participating countries were intensified.

Intensifying catchment selection and inventories

The representative catchments in India, Indonesia, Laos, Nepal, Philippines, Thailand, and Vietnam have been selected. The catchments range from 120 to 264 ha in area with three or four microcatchments involving different land uses. All catchments (except in India) have more than 30% slope (Table 1). In the case of Sri Lanka, the country team has just been identified and is now evaluating the site for MSEC. A more complete description of the profiles of the representative catchments is planned in a publication to be produced later by MSEC. An example of a detailed soil map of the site in Laos is shown in Figure 1.

More detailed surveys and evaluations of the biophysical and socioeconomic conditions have been completed for the catchment sites in Nepal, Philippines, Thailand, and Vietnam. These are now documented by IBSRAM in Issues in Sustainable Land Management No. 6. The document highlights the evaluation of the indigenous land-use systems and management, and assessment of existing policies, programmes, and institutional arrangements relevant to natural resources management. Issues in Sustainable Land Management No. 3 documents indigenous technical knowledge for land management in India, Indonesia, Laos, Nepal, Philippines, Thailand, and Vietnam.

Table 1. Catchment sites in MSEC collaborating countries.

Country	*Province*	*Catchment name*	Latitude	Longitude	Catchment size (ha)	Catchment Slope (%)
India	Lateri/Bhopal	Lalatola	23° N	77° 30' E	200	<5
Indonesia	Semarang/ Central Java	Kali Garang	07° 20' S	110° E	230	30-50
Laos	Luang Prabang	Ban Lak Sip	19°51' 10" N	102° 10' 45" E	80	70-80
Nepal	Kathmandu	Dee Khola	27° N	85° E	264	40-60
Philippines	Bukidnon/ Mindanao	Mapawa	08° 02' 50" N	124° 56' 35" E	105	40-50
Sri Lanka	To be identified	-			-	-
Thailand	Phrae	Yom/Ma Nai	18° 13' 20" N	100° 23' 40" E	100	60
	Nan	Khun Sathan/Huai Som	18° 18' 10" N	100° 29' 20" E	120	40
Vietnam	Hoa Binh	Dong Cao	20° 57' 40" N	105° 29' 10" E	150	60

Providing instruments and structures

Calibration and monitoring of the selected catchments needs measuring structures and equipment that are also provided by the project. Equipment such as automatic weather stations, automatic water level recorders, staff gauges, rain gauges, notebook computers, and other accessories have been purchased and provided to Indonesia, Laos, Philippines, Thailand, and Vietnam (Table 2). Additional equipment was provided by Institut Recherche pour le Développement (IRD, formerly ORSTOM) for water current measurement.

Table 2. Equipment purchased and distributed to Indonesia, Laos, Philippines, Thailand, and Vietnam for the MSEC project.

Equipment	Country (purchased/company)	Number of units purchased
Automatic weather station ENERCO 407	France/CIMEL	6
Automatic water level recorder	France/OTT	26
Laptop computer	Thailand/Toshiba	5
Staff gauge	Thailand/Chaw Rakanagang	80
Rainfall collector	Thailand	75
Graduated rainfall jar	France/National Meteorology	20

Funds have also been provided for the construction of field structures for hydrological and soil erosion measurements. Currently, a number of weirs have been constructed in Laos, Philippines, and Vietnam and catchment calibration has been started.

Training on participatory approaches and catchment research

Three training workshops were conducted to prepare the national partners in the implementation of the MSEC project (Table 3). A training workshop on "Project Management and Participatory Approaches, Monitoring and Analysis" was held from 4-13 October 1998 in Phrae, Thailand. The training aimed to: (i) enhance the ability of participants to plan, implement, monitor and evaluate the MSEC project in a participatory manner; (ii) develop teamwork among participants; and (iii) strengthen the capacity of participants for analyzing, interpreting, linking, integrating, and scaling up different kinds of data and information and then using them for managing the project. Ten project coordinators or project leaders from Indonesia, Laos, Nepal, Philippines, Sri Lanka, Thailand, and Vietnam attended the first two days that focused on project planning and management. They were later joined by 20 other participants representing biophysical and socioeconomic disciplines.

Based on the principles and steps for project management, the participants developed project planning matrixes by country following a logical framework. The matrixes identified the goals, objectives, expected results and outputs, and the activities to evolve with the outputs. Several techniques were discussed to characterize the land and land users through a participatory approach. In characterizing the land, the groups dealt with topics such as seasonal calendars, transects, village maps, and time trends/historical profiles. Livelihood analyses, institutional linkages, mobility maps, and needs' assessment were carried out to characterize the land users. A project proposal for the village following the steps on project formulation and a logical framework were also prepared using the data gathered from the community, focusing on an assessment of needs and resources.

The training workshop on "Catchment Research: Biophysical Processes, Instrumentation, Data Collection, Analysis and Interpretation" was conducted from 25 March to 10 April 1999 at Phrae and Bangkok, Thailand. Thirteen participants from Indonesia, Laos, Philippines, Thailand, and Vietnam attended. The training aimed to (i) familiarize the participants with instrumentation requirements and identify common and standard data sets for the MSEC project; (ii) enhance the capability of the participants in data collection, assembly, analysis, and interpretation; and (iii) enhance the capacity of participants in linking, integrating, and scaling up various data and information for managing the project. The training programme included lectures and field exercises on hydrology, agronomy, soils, and nutrient and water fluxes. The final week was a hands-on training on hydrological analysis using computers. Experts from IRD, University of Bayreuth, KKU, ICRISAT, and IBSRAM served as resource persons. The participants were asked to design their catchments specifying the location of the measuring devices and the dimensions of the hydrological structures. These were followed up on during the country visits conducted later.

Table 3. Training workshops conducted by MSEC for the national partners.

Training workshop	Date/ Venue	Facilitators/ resource persons	*Participants*
Project Management	5-6 October 1998/Phrae, Thailand	C. Niamskul/IBSRAM; A. Maglinao/PCARRD	10 MSEC project coordinators/leaders from Indonesia (2), Laos (1), Nepal (1), Philippines (2), Sri Lanka (1), Thailand (2), and Vietnam (1)
Participatory Approaches, Monitoring and Analysis	7-13 October 1998/Phrae, Thailand	A. Maglinao/PCARRD; H.D. Bechstedt/IBSRAM; J.P.Bricquet/IBSRAM; S. Chandrapatya/IBSRAM; G. Duckitt/NGO-Thailand; and L. Cerna/NGO-Philippines	20 biophysical scientists and socioeconomists from Indonesia (3), Laos (2), Nepal (2), Philippines (2), Sri Lanka (1), Thailand (7), and Vietnam (3)
Biophysical Processes, Design, Data Collection, Analysis, Monitoring, and Interpretation	25 March to 10 April 1999/Phrae and Bangkok, Thailand	B. Thebe/IRD; J.P. Bricquet/IBSRAM; S. Ruaysoongnern/KKU; A. Moeller/Bayreuth U.; S. Virmani/ICRISAT; J. de Rouw/IRD; C. Dieulin/IRD; A. Maglinao/IBSRAM; A. Sajjapongse/IBSRAM; H.D. Bechstedt/IBSRAM	13 soil scientists and hydrologists from Indonesia (2), Laos (1), Philippines (2), Thailand (6), and Vietnam (2)

Collaborating for strategic and adaptive research

Our partnership with IARCs, ARIs, and universities has proved useful in bringing additional inputs for conducting strategic and adaptive research. The IBSRAM-ICRISAT collaboration now implements an interinstitutional NARES-driven programme for strategic research and on-farm validation of technologies to address the sustainability of agricultural production in India, Thailand, and Vietnam. SEARCA, ACIAR, and ICRAF complement the MSEC project in the Philippines through their work on modelling and evaluation of technology adoption. IRD has proposed to assess the influence of the rapid change of cropping systems on water erosion on scales ranging from the plot level to small catchments in Laos, Thailand, and Vietnam.

In collaboration with universities and funding agencies, a number of graduate students have worked on topics relevant to the activities of MSEC. The University of Bayreuth supports a PhD student to work on nutrient dynamics under different land uses in the catchment site in Thailand (Khun Sathan). The objective is to evaluate the impact of land use on nutrient concentrations in soil solution (on-site effect) and in-stream outflow (the off-site effect) of catchments that are used differently. The University of the Philippines (UPLB) at Los Baños and ICRAF have chosen the catchment site in the Philippines to test and validate models for catchment management through their support of two (one MSc and one PhD) graduate students. More recently, three students from the Asian Institute of Technology (AIT) have expressed interest in modelling work in Thailand. The University of Wolverhampton in the UK has likewise initiated discussion on possible collaboration in improving the productivity and sustainability of cropping systems on the sloping lands of South China and Thailand.

Sharing and disseminating information

On 19 November 1998, the MSEC programme was presented during the project holders' meeting in Lantapan, Bukidnon, Philippines. Representatives from UPLB, SEARCA, ICRAF, PCARRD, BSWM, DA, DENR, SANREM and the local government of Lantapan attended the consultation and discussed the complementation of projects conducted at the site. It was agreed that SANREM would focus on policy, SEARCA/ACIAR on technology adoption, ICRAF/UPLB on modelling, and MSEC on soil erosion and hydrology. As an initial joint activity, the projects agreed to prepare a protocol for data sharing and management.

From 17-20 January 1999, the project accomplishments for 1998 and plans for 1999 were presented and discussed during the IBSRAM Internal Programme Review (IPR) in Cha-Am, Thailand. All senior staff and three members of the IBSRAM Board of Trustees attended. The interrelationships among IBSRAM projects were emphasized with MSEC as the focal point. MSEC plans for 1999 were approved with minor suggestions and modifications.

ADB, IBSRAM, and ICRISAT conducted a joint planning meeting from 1-3 February 1999 in Bangkok, Thailand to identify collaborative work in India, Thailand, and Vietnam. The progress and plans of MSEC were presented and discussed *vis à vis* the plans of the ICRISAT project, also funded by ADB. Twenty-five participants from India, Thailand, Vietnam, the USA, ADB, ICRISAT, and IBSRAM attended the meeting.

Other related conferences and symposia participated in by IBSRAM staff also served as a venue for information dissemination through posters and distribution of MSEC information materials. These included (i) symposium on "Floods from Average to Extreme: Rainfall, Infiltration, Runoff, and Movement", from 10 to 11 March 1999 in Lyon, France; (ii) First Asia-Pacific Conference and Exhibition on "Ground and Water Bioengineering for Erosion Control and Slope Stabilization", from 19-21 April 1999 in Manila, Philippines; (iii) methodology workshop on "Environmental Services and Land Use Change: Bridging the Gap between Policy and Research in Southeast Asia", from 31 May to 2 June 1999 in Chiang Mai, Thailand; and (iv) IBSRAM's international forum on "Our Land: A Precious National Resource", on 14 July 1999 in Bangkok, Thailand.

The plan for an MSEC Newsletter was discussed with the NARES' representatives who agreed that each collaborating country will designate from the national team a regular contributor to the publication. Meanwhile, information from the project has been disseminated regularly through "News from MSEC", which is a regular column in the *IBSRAM Newsletter*.

The documentation of the Phrae training course on project management and participatory approaches has been finished and incorporated in *IBSRAM Training Manual on Participatory Research and Technology Development for Sustainable Land Management* (Global Tool Kit No. 3). The MSEC brochure was also printed and made available to concerned parties.

Table 4. Consortium partners and potential research activities in the MSEC collaborating countries.

Country	National partners	International centres and institutions	Proposed research activities
India	CRIDA, BAIF, IISS	IRD, ICRISAT	Hydrological studies; farming systems; off-site impact
Indonesia	CSAR, BAPEDA, BPTP, CSES	CIRAD, IRD	Agronomy; hydrological studies; institutional arrangements
Laos	SSLCC	IRD, ICRAF, NORAGRIC	Hydrological studies; nutrient dynamics
Nepal	NARC	ICIMOD, Bayreuth U., IRD, IFPRI	Farming systems; nutrient dynamics; hydrological studies; institutional aspects
Philippines	PCARRD, CMU, BSWM DA, DENR, SANREM, UPLB, local government	ICRAF, IRD, SEARCA, ACIAR	Hydrological studies; institutional arrangements; policy studies; off-site impact; farmers' adoption; modelling
Sri Lanka	MFE, Dept of Irrigation, UWP	IWMI	Farming systems; nutrient dynamics
Thailand	RFD, DLD	ICRISAT, IRD, AIT, Bayreuth U.	Farming systems; off-site impact; nutrient dynamics and pollutants; hydrological studies; remote sensing
Vietnam	NISF, NEU	ICRISAT, CIRAD, IRD, IFPRI, IRRI	Farming systems; hydrological studies; institutional arrangements

Operationalizing the mechanism for governance

During the consortium assembly in Cebu City, Philippines, a steering committee (SC) was recommended to provide policy guidelines for and direction of the implementation of the consortium. An *ad hoc* committee, composed of all NARES was created which continued until 1997. In 1998, during the assembly in Hanoi, Vietnam, the SC was reconstituted to limit the membership to five NARES, but adding four members from IARCs/ARIs, one NGO representative, and one IBSRAM representative. Chairing the committee is the representative from Nepal with representatives from Indonesia, Nepal, Thailand, Sri Lanka, and Vietnam, ICRISAT, ICRAF, IRD, the University of Bayreuth and IBSRAM as members. Serving as the secretary and nonvoting member is the MSEC coordinator who was appointed by IBSRAM recently.

In addition to the consortium level committee, the assembly also ratified the creation of the NARES committee. Its functions are: (i) Identify and recommend R&D needs of the consortium; (ii) prioritize activities of the consortium; and, (iii) develop new proposals for recommendation to the SC. The group of IARCs/ARIs also formed a similar committee. At the national level, national committees and research teams likewise exist. Table 4 shows the consortium partners and potential research activities in the MSEC collaborating countries. The organization of these committees and teams is expected to enhance the participatory, interdisciplinary and interinstitutional mechanism that the consortium is implementing. Generally, this arrangement is committed through formal agreements signed between and among institutions. The MOUs for the implementation of consortium activities in different countries have already been formalized for Indonesia, Laos, Nepal, Philippines, Thailand and Vietnam. The arrangement with India is via an MOU between ICRISAT and IBSRAM.

Participatory review and planning: The 4th MSEC assembly

The next assembly of the consortium partners has been organized by IBSRAM and PCARRD and is scheduled for 24- 29 October 1999 in Cagayan de Oro City, Philippines. About 40 representatives from the NARES, IARCs, ARIs, NGOs and the local government are expected to participate in the assembly to review the progress of the consortium during the past year and plan its activities in the coming year. While reviewing the progress of the work in eight participating countries, a special focus will be given to the use of the interdisciplinary, interinstitutional and participatory framework in research and development for catchment management.

Progress towards achieving milestones of the Optimizing Soil Water Use Consortium (OSWU):

1. Project overview

Goal, objective and expected outputs

The long-term goal of OSWU is defined as: ***Sustainable and profitable agricultural production in dry areas based upon the optimal use of the restricted available water at different scales.***

The overall objective of the project is: *to develop and promote adoption of integrated land management strategies and techniques that capture and retain rainwater with crop husbandry techniques that maximize productive transpiration and minimize evaporative and drainage losses, within water-efficient, productive and sustainable cropping systems.*

Specific objectives for research

- *Adaptive and participatory*: Land-surface and soil/crop husbandry practices developed and under test on farmers' fields that optimize output per unit of available water within sustainable production systems that match climate characteristics (especially patterns of rainfall and evaporative demand) and production and livelihood aspirations at household, community and national level, integrating
  - ◊ the management of land surfaces to optimize the retention of rainwater;
  - ◊ the management of cropped soils and crops to minimize losses of water to deep drainage, surface evaporation and weed transpiration;
  - ◊ choices of crops (and cultivars), crop and fallow sequences, and cropping practices to optimize the efficiency of soil water use in the production of economic yield.
- *Applied and generic:* Research activities established at selected locations to study key problems of soil-water-plant processes general to dry-area cropping systems.

Specific objectives for strategic and development activities

- Spatially-referenced data bases at national and regional levels, developed from research and development experience and from national statistics and environmental information; and appropriate data handling and modelling systems with which to use them.
- Increased capacity **in national agricultural research and extension systems** (NARES) to identify and advise on appropriate management systems for enhanced water-use efficiency in dry-area cropping sequences, based upon relevant research and development experience, at national and international level, and supported by access to spatially referenced information on the biophysical environment, farming systems, production practices and relevant research and development experience.

- Increased opportunity to communicate new insights and successful techniques among national researchers in dry-area agriculture.
- Enhanced human skills and practical knowledge, within national and regional research, development and extension institutions, and at farm level.
- Guidelines for national and regional policies to promote efficient and acceptable water-use management techniques within the development of dry-area agriculture.

The keyword in the OSWU Consortium is partnership towards the long-term goal. On one hand, through a multi-institutional research approach, in which the national agricultural research systems (NARS), international agricultural research centers (IARCs), non-governmental organizations (NGOs) and advanced research institutions (ARIs) are partners in one program; and on the other hand, through the participation of local (farming) communities. Research and extension teams will work in a participatory way with local people, in order to fully incorporate their perceptions of the problems, their indigenous knowledge, and their production objectives and priorities, with a view to develop and test the potential improvements together with them. To optimize efficiency of use of limited physical and human resources, linkages to ongoing activities will be sought whenever possible. Particular attention will be given to sites already supporting research and develop-ment activities on soil and fertility management, crop rotation, water-harvesting and/or supplemental irrigation within existing projects, national and international, within watershed and community contexts.

The general products to be delivered (SWNMI, 1996) include:

- Updated knowledge base and problem appraisal for crop water use efficiency in dry areas;
- Techniques for soil surface management that increase the availability of water to crops through improved interception and infiltration of rainwater;
- Enhanced uptake and use of soil water through improved crops, crop husbandry and cropping systems;
- Spatial extrapolation of site-specific findings on optimizing soil water use;
- Enhanced human skills and policy guidelines.

Target agro-ecological zones, production systems, groups and scales

OSWU focuses on two broad target agro-ecological zones and their associated production systems:

WANA: Systems of dryland annual cropping, based mainly on winter cereals (barley and wheat), that occupy most of the arable land between the 150 and 400 mm isohyets, including locally important areas in which rainfall is supplemented by groundwater or surface water.

SSA: Systems of dryland annual cropping, based on summer cereals (barley, wheat, millet, sorghum and maize), that lie mainly between the 250 and 800 mm isohyets, including systems in which water harvesting is used to concentrate sparse rainfall onto cropped land.

These two agro-ecological zones have the following bio-physical and socio-economic conditions in common: *(i)* a low, unreliable single-season rainfall regime with a large variability in both time and space requiring particular focus on soil-moisture storage and water-use efficiency, *(ii)* low soil fertility, *(iii)* surface crusting and restricted infiltration, and *(iv)* a low purchase power of farmers (high poverty level).

The predominant focus of OSWU is on rainfed farming, and - to a lesser extent - also on cropping systems using supplemental irrigation, which have many important issues related to water-use efficiency in common with rainfed farming systems. Commonalities in production systems of the two agro-ecological target zones include a predominance of traditional small-farmer enterprises (except for South Africa) and a strong interdependence between crop and livestock production (sheep and goats in WANA; cattle, sheep and goats in SSA) that grows more important with increasing aridity of the environment. Subsistence farming is widespread; but also commercial production and market opportunities are important in both SSA and WANA, as is the use of animals and, particularly, tractors for tillage (except in West Africa) and local transport.

The target groups of OSWU are small-holder and commercial farmers as well as rural communities (villages). Besides farmers and communities, other land users, NARS, extension workers, NGOs, Decision and Policy makers will also be the user of the outputs of the OSWU consortium activities. As a consequence, OSWU will carry out research and development activities at scales up to the watershed level. The watershed approach should not be an objective as such, but should derive in a logical way from the definition of the objectives. The scale of approach comes with the implementation of the work. Taking into consideration the goal and also the unique features of OSWU, the consortium will focus on optimizing soil water use through on-farm and farmer participatory research at field and watershed (community) level.

Across all research venues, encouragement will be given to recognition of the occurrence of problems at different scales, the inter-relation of those different scales, and the selection of scale-related research designs. Research teams in different countries will be encouraged to focus on different problems, *optimizing the compa-rative advantage of each institution* to maximize the coverage and complementarity across OSWU as a whole. Data exchange, and more general interaction, between field teams and information-support groups will be an important integrating process. A major aim will be to build up national awareness of scale linkages and national capabilities to analyze and generalize field research data through spatially referenced information systems and well-focused modeling tools.

Wherever appropriate, linkages will be established (particularly in data exchange) to other initiatives, consortia and projects promoting research and development activities involving land and water use in dry-area agriculture.

In summary, the OSWU Consortium tries to take into account economic (growth, efficiency), social (equity, poverty reduction) and ecological (natural resource management) objectives of development.

Uniqueness of OSWU

Like most other SWNMP consortia, OSWU takes an integrated and participatory research and systems approach, includes different levels of scale (i.e. farmer and community/watershed), capitalizes on existing knowledge, works with development projects, and uses different models. The uniqueness of OSWU, however, lies in the following:

- Water is the cross-cutting issue among five different agro-ecological regions (WANA: North African and West Asia, and SSA: West, East, and Southern Africa) which allows exchange of experience and generation of new solutions for resource poor farmers in regions where water is the most scarce natural resource;
- Emphasis is on optimizing the water balance at the farmer and community (watershed) level to increase water availability for intensified and increased agricultural production;
- Increase the awareness of farmers on the environmental issues related to optimizing soil water use (i.e. biological, physical and chemical soil degradation);
- OSWU puts particular emphasis on rainfed crop production (in contrast to other similar programs such as On-farm Water Harvesting Consortium);
- The different level of the member countries NARS' capacities allows the less developed to profit from and capitalize on the experience of more advanced NARS;
- Standardization of documentation to facilitate exchange and achieve comprehensive coverage of the subject;
- Linkages and collaboration among different organizations and institutions working in the domain.

Milestones

1996: Planning workshop at ICARDA headquarters in Syria in February 1996, funded by the SWNM Initiative (SWNMI).
1997: OSWU Steering Committee meeting.
1998: Workshops on the 'state of the art review of OSWU related research'.
Development of a climate, soil and land utilization database to elaborate a common methodology.
1999: Workshop on the impact of OSWU related research and the use of information tools.

Start of on-station and on-farm research identified and prioritized based on national review and impact papers.

2000: Implementation of project proposals with expected outputs on guidelines for optimizing soil water use. Researchers trained in the use of crop simulation models.

2001: Cadre of local researchers, farmers and community groups, extension workers trained in development of local solutions to OSWU constraints.

Linkages with other consortia and networks

One important objective of the OSWU consortium is to render research in its domain as efficient and effective as possible. Therefore, emphasis is laid on exchange of information and experiences - both within the Consortium and with other organizations and institutions - in order to avoid duplication of research and render efforts complementary. Close collaboration among the member countries in relevant topics, and exchange of planning and progress reports facilitate achieving this objective. In addition, linkages with other organizations and institutions working in related fields allow capitalizing from each other's experiences and the development of complementary projects. Some of the linkages outlined below are already put into action and collaboration is effective, while others are still in preparation.

Within SWNMP, the consortium closest to OSWU is Combating Nutrient Depletion Consortium (CNDC) because of its rainfall and target area (i.e. the humid and sub-humid tropics of sub-Saharan Africa). It has been stressed in various chapters of the workshops proceedings (van Duivenbooden et al., 1999) that nutrient depletion has associated negative consequences for water use efficiency. Initial steps have been set to start joint experiments in 2000 (pending funding).

The Managing Soil Erosion Consortium (MREC) has its mandate preliminary in Asia (focus on Thailand, Indonesia, and the Philippines) with much higher rainfall, so that links will therefore relate mainly to methodological issues.
Links with Managing Acid Soils (MAS) Consortium will be limited, because of the much more acid nature of the soils and the eco-regional zone which is the hillside, savanna and forest margin agro-ecosystems of Latin America. However, this consortium started recently activities in Africa.

In most countries, OSWU members have links to specific projects dealing with similar problems of water management (e.g. CRISP in Mali, and PGRN in West Africa), especially in the fields of rainwater use and conservation, variety selection according to climatic constraints, and soil and water conservation. Results of the OSWU Consortium will also be of importance to the Convention to Combat Desertification, especially in the formulation of sustainable farming systems.

In the WANA region, links with the On-Farm Water Harvesting (OFWH) Consortium will comprise mainly water harvesting techniques and their development, dissemination, and impact. Close cooperation exists between the OSWU co-convenor and the OFWH Coordinator to avoid duplication and to ensure that complementary research will be carried out.

In SSA, links and exchanges with the Desert Margins Program (DMP) are plausible, especially in the field of soil water conservation technologies. Currently, countries in which both projects are active include Burkina Faso, Kenya, Mali, Niger, and South Africa, but current research activities are completely different. The OSWU co-convenor and the DMP Coordinator cooperate closely to ensure that research will be complementary. In East and southern Africa, another potentially important link could be with the ASARECA network on Soil and Water Management (SWM-Net). Currently, overlapping countries include Kenya, Zimbabwe, and South Africa. In West Africa, a potential link could also be established with the Consortium for Sustainable Use of Inland Valleys (IVC), with OSWU focussing on the upland part of the watershed. Current overlapping countries include Burkina Faso and Mali. At the same spatial scale, collaboration with IWMI in sub-Saharan Africa could be useful (e.g. also on supplemental irrigation). IWMI works currently in the OSWU member countries South Africa and Kenya. If financial means permit, inviting countries that have experience in watershed management may also be an option.

So far, links with projects and consortia acting mainly in developing countries are mentioned. Linkages with Advanced Research Institutes (ARIs) in the developed world are also envisaged (e.g. Institute of Hydrology, UK). In the USA, for instance, farmers too need to increase water use efficiency, as was recently underscored.

The WOCAT Training Workshops in Niamey (May 1999, co-sponsored by OSWU) and Aleppo (June 1999) have revealed a great opportunity for linking OSWU to WOCAT. OSWU members from Burkina Faso and Niger, ICARDA, and ICRISAT participated. The OSWU convenors will, in collaboration with WOCAT resource persons, stimulate the use of the WOCAT approach within the consortium, especially to monitor implementation of developed technologies in the various countries.

In summary, OSWU is an open-structured consortium, and linkages with partners will be determined by demand and supply from the participating partners on the basis of commonly-set goals that increase alignment and research efficiency.

2. Project work breakdown structure

It was unanimously expressed that the OSWU Consortium should not be doing 'old wine in new bottles' research, and it should not be a network on a theme that links national research programs. The list of potential research subjects, as developed during the 1996-Aleppo meeting, is no longer the only basis for further development of OSWU's research agenda. Instead, the National Review and Impact Papers on the optimization of soil water use are used to identify existing research gaps and priorities. Hence, project outputs and activities in the general OSWU Consortium proposal have been re-formulated and re-fined (compared to the proposal submitted to TAC) and are given in Table 1. The activities will be implemented according to the funding level.

Table 1. Proposed outputs and activities of OSWU Consortium.

Outputs		Activities
A. For Research		
A1	Appraisals of climate, farming systems and farm-level constraints, from technical and farmer points of view, with particular reference to water-use efficiency in selected target areas.	A.1.1. Review of secondary information and local professional expertise. A.1.2. Data analysis to provide information on seasonal patterns of precipitation (amounts and intensities) and evaporative demand. A.1.3. Participatory rural appraisal (followed, where necessary, by more detailed survey and/or on-farm monitoring) to detail modes of water capture and utilization, and associated (socio-economic) problems and success of improved OSWU technologies.
A2	On-station tested techniques for arable land management (and data quantifying them), compatible with local rainfall patterns, farming systems and household constraints, that improve interception and retention of rainwater.	A.2.1. Investigations of soil infiltration characteristics and surface crust formation in relation to soil type, rainfall characteristics and land utilization history. A.2.2. Adaptation and testing of techniques (e.g. tillage, chemical amendments, plant cover, mulching, residue management) to control soil surface crusting and promote infiltration. A.2.3. Adaptation and on-farm testing of in-field water harvesting systems to improve rainwater use efficiency.
A3	On-Station tested production practices for individual crops	A.3.1. Comparison of crop varieties with different morphological and phenological characteristics with respect to water-use efficiency. A.3.2. Evaluation of the effects of plant density, geometry and row orientation on water balance components. A.3.3. Evaluation of appropriate weed control techniques.
A4	Sustainable on-farm-tested management practices that maximize the productivity of the farming systems per unit of available water.	A.4.1. Farmer participatory identification and testing of integrated land management interventions at field and watershed level to improve the well-being of rural house-holds by means of a more efficient use of available water resources. A.4.2. On-farm quantification of the agronomic, socio-economic and environmental impact of existing and improved water, soil and crop management technologies on the overall efficiency of water use at farm and community level.

A5	General principles of optimal soil water use in dry-area cropping systems, integrating the best practices.	A.5.1. Analysis, interpretation and integration of biophysical and socio-economic data outputs (A.1-4; e.g. using Bayesian Belief Networks). A.5.2. Use of data outputs from A.1-4 to adapt and validate available models of soil-crop-water management. A.5.3. Linkage of validated models to selected environmental data bases to quantify local yield potentials and identify mechanisms underlying major yield gaps, and test spatial extrapolation of site-specific plot results.
B. For strategic and developmental activities		
B1	Publication of national- and regional-level reviews and detailed research results in the OSWU domain.	B.1.1. Inventory, analysis, and synthesis of available information of past and ongoing research and development of initiatives directed at optimizing soil water use in dry-area arable cropping systems. B.1.2. Exchange of results obtained within OSWU with other SWNMP and other relevant consortia (e.g. CNDC, DMP, On-farm Water Harvesting Consortium)
B2	Accessible sets of spatially referenced data for dry arable farming areas.	B.2.1. Data acquisition and data-base building.
B3	Staff of research, development and extension institutions with a) enhanced understanding of OSWU techniques, and b) enhanced capability to work together to identify and transfer the most locally appropriate techniques to farmers.	B.3.1. Involvement of technical and socioeconomic scientists and extension specialists in farmer-participatory research activities. B.3.2. Workshops (at Project, regional and national levels). B.3.3. Formal technical training courses.
B4	Dry-area farmers using locally appropriate techniques of land, soil and crop management for efficient soil water use for sustainable and profitable agricultural production.	B.4.1. Farmer-participatory research and development activities. B.4.2. Farmers support through formal extension activities and, where necessary, the recommendation of appropriate policy measures to support the adoption of improved techniques.
B5	Reliable guidelines on efficient and acceptable water-use management techniques for the	B.5.1. Involvement of policy-unit staff in field-level problem identification and research planning. B.5.2. Joint seminars between research and policy/planning staff to review research results

	development of dry-area agriculture available to, and accepted by, relevant government planners and policy-makers.	and their implications. B.5.3. Publication (workshop proceedings, final project report, and recommendations).

3. Project log-frame

Summary	Indicators	Means of verification	Important assumptions
Goal: Sustainable and profitable agricultural production in dry areas based upon the optimal use of the restricted available water at different scales.	Agricultural production increased in benchmark sites. Farmer's income increased on the basis of each mm of rain water and supplemental surface or underground water combined with more effective land management.	Agricultural census data, Human welfare statistics	Farmers have means and are willing to undertake proposed actions
Purpose: The integration of land management techniques that capture and retain rain- water with crop husbandry techniques that maximize productive transpiration and minimize evaporative and drainage losses, within water-efficient, productive and sustainable cropping systems, to improve the productivity of the cropping systems and welfare of farmers in WANA and SSA.	20% of farmers in target areas adopt at least one new OSWU technique through individual and community-based actions from plot to watershed scales. Information on OSWU technologies published in linkage with other SWNM consortia.	Surveys of land use practices. Lists of publications, web pages. Bulletins and brochures.	Policy environment is favorable for the adoption of improved OSWU technologies. Farmers are reached through NARES and IARCs. NARES have the means to develop and disseminate technologies and information.

Outputs			For Outputs A and B:
A. for Research			
A1. Appraisals of climate, farming systems and farm-level constraints, from technical and farmer points of view, with particular reference to water-use efficiency in selected target areas.	Problems of farmers, other land users and communities with respect to OSWU identified for the new technology development.	Publications in international journals, Annual reports.	External funding levels are maintained, Benchmark sites established and maintained with partners, Community-based groups continue with their own resources, Institutions within the consortium maintain their matching support for the OSWU program, Critical and skilled manpower maintained at NARES, GIS facilities established and maintained, Policy and decision-makers are open to dialogue with OSWU program.
A2. On-station tested techniques for arable land management (and data quantifying them), compatible with local rainfall patterns, farming systems and household constraints, that improve interception and retention of rainwater.	One or two new or improved OSWU technologies developed for testing on a watershed scales in farmers' fields.	Publications in international journals, Annual reports.	
A3. On-Station tested production practices for individual crops	At least one new or improved production practices adopted by the farmers for common crops.	Publications in international journals, Annual reports.	
A4. Sustainable on-farm-tested management practices that maximize the productivity of the farming systems per unit of available water.	At least one or two OSWU technologies adopted by farmers and communities.	Publications in international journals, Annual reports, Newsletters, bulletins.	
A5. General principles of optimal soil water use in dry-area cropping systems, integrating the best practices.	Integrated approach for OSWU technologies developed and adopted by NARS scientists.	Publications in international journals, Annual reports, Manuals.	
B. for Strategic & Development activities			
B1. Publication of national- and regional-level reviews and detailed research results in the OSWU domain.	Workshops and surveys conducted at national and regional levels.	Publications in Workshop Proceedings, Annual reports, Referee	
	Data bases of climate,		

B2. Accessible sets of spatially referenced data for dry arable farming areas.	soil and land use in GIS systems established and mapped.	Journals. Published databases, Maps of soils, climate and research outputs.	
B3. Staff of research, development and extension institutions with a) enhanced understanding of OSWU techniques, and b) enhanced capability to work together to identify and transfer the most locally appropriate techniques to farmers.	Sufficient amount of relevant staff of national programs trained for OSWU technologies and the dissemination of the techniques to farmers with a team approach in interdisciplinary or multi-disciplinary way.	Number of training courses, field visits, Numbers of personnel trained, Institutional reports.	
B4. Dry-area farmers using locally appropriate techniques of land, soil and crop management for efficient soil water use for sustainable and profitable agricultural production.	Sufficient amount of farmers and other land users trained and adopted OSWU technologies.	Numbers of farmers and other land users participated in on-farm testing and field days and trained.	
B5. Reliable guidelines on efficient and acceptable water-use management techniques for the development of dry-area agriculture available to, and accepted by, relevant government planners and policy-makers.	Awareness of OSWU technologies created and guidelines and decision support systems developed.	Newsletters and bulletins, Policy guidelines document.	
Activities:			For Activities A and B: Appropriate mix of inter-disciplinary scientists maintained, Continued accessibility to benchmark sites, Farmers maintain their interest in experiments
A.1.1. Review of secondary information and local professional expertise.	Review information published through workshop proceedings.	Workshop proceedings, annual reports, publications	
A.1.2. Data analysis to pro-vide information on seasonal patterns of precipitation (amounts and intensities) and evaporative demand.	Climate data analysis developed and published.	Reports and Maps.	
	Technical and socio-economic problems and	Survey reports, Annual reports,	

A.1.3. Participatory rural appraisal (followed, where necessary, by more detailed survey and/or on-farm monitoring) to detail modes of water capture and utilization, and associated (socio-economic) problems and success of improved OSWU technologies.	solutions to them identified, the related database developed and published.	Newsletters, bulletins.	on their farms, Critical mass of trained staff available in NARES.
A.2.1. Investigations of soil infiltration characteristics and surface crust formation in relation to soil type, rainfall characteristics and land utilization history.	Number of trials established. Soils and land utilization is fully characterized for OSWU related matters and database developed and published.	Annual reports, Soil and Land use maps	
A.2.2. Adaptation and testing of techniques (e.g. tillage, chemical amendments, plant cover, mulching, residue management) to control soil surface crusting and promote infiltration.	The soil management techniques for optimization of soil water use adopted by sufficient amounts of farmers and other land users.	Numbers of farmers adopted soil management techniques, Annual reports, Publications.	
A.2.3. Adaptation and on-farm testing of in-field water harvesting systems to improve rainwater use efficiency.	In-field water harvesting technologies adopted by sufficient amount of farmers and other land users.	Numbers of farmers adopted water harvesting techniques, Annual reports, Publications. Annual reports, Publications.	
A.3.1. Comparison of crop varieties with different morphological and pheno-logical characteristics with respect to water-use efficiency.	Number of trials established. Improved crop varieties with maximum water use efficiency developed and transferred to farmers.	Annual reports, Publications.	
A.3.2. Evaluation of the effects of plant density, geo-metry and row orientation on water balance components.	Number of trials established. Best crop geometry identified and disseminated to farmers.	Annual reports, Publications.	
A.3.3. Evaluation of	Proper weed control techni-ques for optimum soil water use by crops	Numbers of farmers	

appropriate weed control techniques.	identified and transferred to farmers.	participated, Survey results on Farmers' welfare.
A.4.1. Farmer participatory identification and testing of integrated land management interventions at field and watershed level to improve the well-being of rural house-holds by means of a more efficient use of available water resources.	Sufficient amount farmers participated in testing the integrated management techniques and their welfare improved.	Annual reports, Publications.
A.4.2. On-farm quantifica-tion of the agronomic, socio-economic and environmental impact of existing and improved water, soil and crop management technolo-gies on the overall efficiency of water use at farm and community level.	Impact of the new or improved OSWU technologies quantified.	Annual reports, Publications.
A.5.1. Analysis, inter-pretation and integration of biophysical and socio-economic data outputs	Methodology for integration of technical and socio-economic parameters developed.	Annual reports, Cropping systems models and com-puter programs in use, Publications.
A.5.2. Use of data outputs from A.1-4 to adapt and validate available models of soil-crop-water management	Suitable soil-crop-water management models tested, validated and adapted.	Yield gap maps, Drought indexes maps, Water use maps, Annual reports, Publications.
A.5.3. Linkage of validated models to selected environmental data bases to quantify local yield potentials and identify mechanisms underlying major yield gaps, and test spatial extrapolation of site-	Site-specific results extrapolated spatially and mapped for OSWU related outputs.	Database reports, Annual reports, Publications.
	Past and ongoing research and	

specific plot results.	development activities in relation to OSWU monitored and assessed.	Annual reports, Newsletters.
B.1.1. Inventory, analysis, and synthesis of available information of past and on-going research and develop-ment of initiatives directed at optimizing soil water use in dry-area arable cropping systems.	Linkage with other relevant consortia developed, results exchanged and duplications avoided.	Computer programs, Annual reports.
B.1.2. Exchange of results obtained within OSWU with other SWNMP and other relevant consortia (e.g. CNDC, DMP, OWHC)	Data-base for OSWU related research and development established.	Numbers of researchers and extension specialists participated.
B.2.1. Data acquisition and data-base building.	Number of multi-disciplinary teams conducting OSWU participatory research.	Lists of workshop, Numbers of staff participated, Proceedings, reports.
B.3.1. Involvement of tech-nical and socio-economic scientists and extension specialists in participatory research activities.	Number of workshops conducted.	Numbers of trainees, Theses published.
B.3.2. Workshops (at project, regional and national levels).	Number of training courses held.	Survey reports, List of farmers.
B.3.3. Formal technical training courses.	Number of farmers participated in watershed research and development.	Lists of farmers, Survey reports, Extension bulletins.
B.4.1. Farmer-participatory research and development activities.	Number of farmers participated in demonstrations.	
B.4.2. Farmers support through formal extension activities and, where necessary, the recommendation of appropriate policy measures to support the	Appropriate policy measures recommended.	Lists of policy makers participated, Number of field visits,
	Number of policy makers participated in field-level	Lists of meetings/ seminars, Reports and

adoption of improved techniques.	studies.	publications.
B.5.1. Involvement of policy-unit staff in field-level problem identification and research planning.	Number of meetings and seminars held with policy makers.	List of publications, annual reports and proceedings.
B.5.2. Joint seminars between research and policy/planning staff to review research results and their implications.	Workshop proceedings and number of research results published.	
B.5.3. Publication (workshop proceedings, final Project report/ recommendations).		

4. Highlights

The OSWU consortium activities are now - much more than in the past - based on specific needs and information gaps identified through the national review papers (detailed current knowledge and knowledge gaps, and identified priority areas for action), assisted by input from other members and invited external soil-water specialists during a workshop in 1998 in Niger. The proceedings of this workshop have been combined with those of the workshop on Impact of OSWU related research and need for information tools in this domain which was held in 1999 in Jordan (van Duivenbooden *et al.*, 1999).

OSWU finds itself in a web of linkages with various consortia, networks, and institutions. They include, for instance, another SWNMP consortium (CNDC), the Desert Margins Program (DMP) in SSA, the Water Husbandry Program in WANA, and WOCAT. Through effective collaboration with the coordinators of these consortia etc., duplication of efforts is avoided and complementary research is planned and achieved.

Based on the needs of the various OSWU members, on-station and on-farm research has started in 1999 within the framework of the overall OSWU program, laying emphasis on avoiding repetitions or duplications. The approach taken by the Consortium caused some delay in starting field research (in comparison to other SWNMP consortia), but given the complexity of the five agro-ecological zones occurring in the mandate area of OSWU and the risk of creating old-wine-in-new bottles (as expressed by TAC), this seems justified in the long run. In addition, by putting the focus on impact created within the NARS of the member countries, an increased awareness of the importance of such impact assessments was achieved. In the near future, the impact assessment of research and technologies aiming at optimized soil water use will thus play a major role in the OSWU activities. Using the WOCAT-tools will facilitate these impact assessments.

The consortium's chances of attracting sufficient funding to support an integrated program of field research across all participating countries have improved by elucidating the uniqueness of OSWU and giving clearer focus. Through the progress made (as elaborated in the following section), OSWU has built its research agenda on the basis of actual needs of its members and target groups. The importance of the SWNMP need to be further put in place by using standardized methods, global testing of products, and establishment and/or strengthening of long-term study sites. A meeting with stake-holders planned for 2000 will also help in further improving the integration of the four SWNMP consortia.

5. Progress Report on achievements

Below are given the major achievements for the period 1998-1999. To better understand the approach OSWU has taken to come to these achievements, the chronology of events is presented.

1996: The first OSWU activity, funded by the SWNM Initiative (SWNMI), was a planning workshop at ICARDA headquarters in Syria in February 1996. Eleven countries from WANA and SSA as well as from ICRISAT Sahelian Center and ICARDA were represented. The research proposal generated by this meeting was reviewed by the steering committee of SWNMI and incorporated in the full SWNMI proposal submitted in March 1996 to the Technical Advisory Committee (TAC) of the CGIAR (SWNMI, 1996), and subsequently approved. Following a delay occasioned by uncertainties over funding, and departure of initiators from ICRISAT and ICARDA, OSWU was revived by ICRISAT and ICARDA in January 1997. Today, OSWU includes the following countries: Burkina Faso, Egypt, Iran, Jordan, Kenya, Mali, Morocco, Niger, South Africa, Syria, Turkey, and Zimbabwe.

1997: The next OSWU activity was the OSWU Steering Committee meeting in Morocco in May 1997. It made two decisions:

1. To utilize existing consortium funds (obtained through the SWNM Program) to: *(i)* commission at the national level, full-scale review reports of past research on soil water and related issues and also the impact of that research on farm-level practices, and *(ii)* hold a workshop early in 1998 on the outcomes of these studies to define the state-of-the-art in soil water studies in the dry areas of the WANA and SSA regions and set priorities on the basis of these outcomes before initiating new field studies.
2. To seek substantial additional funding to enable new field studies and associated support activities, to be conducted at national level among consortium members.

Although no funds were made available to the NARS out of available OSWU funds, the NARS continued research that fits within the overall goal and objective of OSWU. The outputs of that work were included in the national review papers.

1998: On the basis of the Morocco meeting, the OSWU Consortium conducted a workshop in Sadoré, Niger (April 26 - May 1), with the objectives to:

1. find ways and means for demonstrating the greatest possible coherence and complementarity in OSWU's project goal and objectives, and re-distillate outputs and activities;
2. place greater justification and clearer targeting of activities on the basis of the needs and strengths of each member country (detailed current knowledge and knowledge gaps, and identified priority areas for action as distilled from the national review papers) with input from invited external soil-water specialists;
3. clarify the consortium's knowledge base and priority areas, and identify the complementarities and synergisms across countries and regions;
4. emphasize the linkages with other SWNMP consortia, Desert Margins Program in Sub-Saharan Africa and the On-farm Water Husbandry Program in WANA;
5. improve the consortium's chances of attracting sufficient funding to support an integrated program of field research across all participating countries;
6. align the activities in such a way that research efficiency is increased.

Furthermore, OSWU was represented during the world soil congress in Montpellier, France with the paper on Optimizing Soil Water Use in Dry-area Farming Systems of Sub-Saharan Africa and the West Asia/North Africa Region.

In addition, OSWU developed a climate, soil and land utilization databases in a case study at ICARDA, in order to elaborate a methodology to be utilized by all the members as needed.

1999: During the 1998 Workshop and the subsequent interactions related to the proceedings among convenors and member countries, it became clear that the material presented in the national review papers was very valuable, but that one important issue had not been tackled: What was the *impact* of all that work on optimizing soil water use? Impact of research on natural resources management (NRM) issues such as water-use efficiency is more difficult to measure than that on commodity improvement, primarily because the NRM-technologies are knowledge-intensive and improvements usually occur in small increments. Nevertheless, the rate of adoption of OSWU technologies could be a measure of this impact. Further, it was felt that the OSWU Consortium should make better use of modern information tools available among the members and/or to be developed, to better identify and facilitate the transfer (in a participatory way) of technologies to similar agro-ecological areas with similar socio-economic conditions. In the light of these observations, another Workshop was held (9-13 May) in Amman, Jordan with the following objectives:

1. Identify and discuss the impact of past and present research in the domain of optimizing soil water use on farmers (poverty, food security, income), resources, science and capacity building of NARS.

2. Illustrate the use of information tools and technologies in the OSWU member countries, and discuss further needs for modern technologies in order to increase efficiency and impact of OSWU related research.

OSWU also co-financed the WOCAT/ICRISAT/OSWU/INSAH training workshop on the use of the WOCAT (World Overview of Conservation Approaches and Technologies) in Niger (Sadore, Niger, 2-7 May 1999).

Technical discussions on country presentations in the 1998 Workshop in Niamey

The various presentations (the abstracts are given in Annex 1) laid open how different the bio-physical and socio-economic conditions in the 12 member countries are. Against this background, it is almost impossible to capture all details of the discussions during the workshop. Therefore, some highlights are presented here:

- Soil water storage is influenced by the water holding capacity of any given soil (varying from less than 0.1 to more than 100 mm depending on the rooting zone) and that we can do little about it (hydro-fixing chemicals excluded). However, the role of roots in water capture has often been ignored. The consideration should be on root density and not depth.
- Minimizing evaporation in farmers fields is imperative because water lost through evaporation is completely lost ('actual losses' versus 'paper losses'; the latter being recuperated in the water balance at the watershed level).
- Supplemental irrigation (i.e. the addition of small amounts of water to essentially rain-fed crops during times when rainfall fails to provide sufficient moisture for normal plant growth in order to improve and stabilize yields) is an important technology in WANA, but seems to have less possibilities in SSA. Success depends, in addition to plasticity of crop, also on the biophysical conditions.
- "Water productivity" and "water use efficiency" can be used both, but in situations where water is recycled, productivity becomes more appropriate.
- OSWU should do 'in-situ' research, rather than 'in-vitro', i.e. more development oriented applied, adaptive, and participatory research.
- Simulation models can be an important tool to identify knowledge gaps and research needs, to develop technologies, and for mapping of outputs of technologies in combination with GIS. However, this modeling should be done in a farmer participatory way (e.g. inputs and outputs should be measurable by or in collaboration with farmers), and the model should be not too complicated and farmers perceptions should be utilized wherever possible.
- Regarding socio-economics issues, it was again acknowledged that most of research technologies are not being adopted by farmers. The 'normal' thinking is to do research on 'why the farmers are not doing what we want them to do?', but the opposite direction was put forward: 'Research the reasons why technologies are adopted'. Evaluating constraints suggests that farmers do not adopt OSWU technologies because there are constraints. This is not always the case. Farmer beliefs and perceptions are different to those of researchers.

- Permanent water points (e.g. drilled holes) could increase the (financial) output of farmers; or in other words, add significantly value to the agricultural systems. Growing vegetables (e.g. with a mulch of stones) could be such an activity.
- Two problems associated with integrated water management are reconciliation of decision-making at local and regional levels, and the interaction between researchers and users of technologies. This re-iterates the need for a multi-scale and participatory research approach of the OSWU Consortium. Roles should be assigned to different stakeholders (farmers, community, etc.) for watershed level research.
- Results obtained at the field-level should now be further elaborated and extrapolated to larger areas (e.g. village- or watershed-level) with similar agro-ecological conditions.

In addition to research issues related specifically to the OSWU Consortium, the following methodological issues were identified which are cross-cutting among various projects and programs (e.g. eco-regional projects, such as Desert Margins Program, and Water Husbandry Program):

- improvement of run-off modules or routines in crop simulation models. Since run-off depends largely on the intensity of the rainfall, and intensity is only measured at a very low number of meteorological stations, alternative ways on estimating the parameter are required.
- ways to integrate disciplines through a modeling approach based on Bayesian Belief Networks.

Impact assessment during the 1999 workshop in Amman

From the presentations (the abstracts are presented in Annex 1) it became clear that - in contrast to irrigated agriculture - no formal assessments on the impact of OSWU related research have been performed in any of the OSWU member countries. The "impacts" that have been presented were mainly based on observations at the farmers' level, or on specific case studies. It was also stressed that impact not only relates to yields in farmers' fields or adoption rates of certain technologies, but also to the effects of such an adoption on the farmers' conditions and overall economy, to human resource development, capacity building, institutional strengthening etc.

While the effect of participatory on-farm research is still not high in terms of technology adoption, there are countries where the farmers themselves showed their strong interest in adopting the technology (e.g. farmers in Burkina Faso adopting stone bunds), but again often no data are available on the number of farms or area covered. It is therefore essential that quantitative studies on the impact of OSWU related research will be performed in all member countries. As a first step, each member country could select one specific project, for which the impact of optimizing soil water use would be analyzed. This will also bring a further integration of disciplines in the OSWU Consortium.

Information tools analyzed in the 1999 Workshop in Amman

The presentations on information tools (integrated in those on impact, see Annex 1) clearly showed the importance of these technologies in the OSWU member countries. According to the working group, no differences exists in the level of sophistication of models among the member countries. However, some countries (e.g. South Africa and Morocco) are more advanced in using models and GIS for formulating recommendations for farmers and identification of new research.

The presentations revealed, however, also the lack of co-ordination between institutions using crop simulation models or different decision support systems in each country. Although standardization of software may help to resolve this problem, different groups do need different models or databases because of differences in required outputs. OSWU members are identifying their own objectives for database and model use according to their specific needs, and databases and models already available and used. Nevertheless, it was stated that commonly defined minimum datasets are important to allow for exchange of modeling experiences and extrapolation to similar regions. Hence, with regard to experiments, it was recommended to collect all parameters necessary for modeling. Joint modeling activities could serve the focus of new modeling efforts in the domain of optimizing soil water use (e.g. to explain the yield-gap between farmer's and simulated rainfed potential yield). The need for validated models with both nutrient (nitrogen and phosphorus) and water balance subroutines was again underlined.

In the working group, also the need for training in the use of crop simulation models and of information tools at different levels of scales was highlighted. To increase knowledge on crop simulation modeling, training workshops in crop simulation models (CROPSYST and APSIM) are envisaged.

Project proposals

During the Steering Committee Meeting in 1999, funds were allocated (as detailed in Annex 2) to the following projects:

- Linking of existing databases: During the workshop in Amman, the absence of comprehensive and openly accessible databases was considered a major limiting factor in increasing impact of past research. The proposed activity entails linking of existing databases to increase transparency on existing data and experience and to avoid duplication of efforts (it is not to fill in/populate the databases), which will also allow better impact assessment and use of simulation models and GIS to extrapolate results to larger areas. It will be carried out tentatively in Burkina Faso, Egypt, Iran and South Africa for 1 year first. Backstopping to Burkina Faso and Iran will be provided by South Africa, Egypt and/or convenors. The original proposal for the development of a database as developed by South Africa and Egypt was considered too large to be funded with existing OSWU funds; OSWU will seek other funding sources to finance this project proposal.

- 'In-field water harvesting techniques: the way to increase yields in water scarce areas': The existing joint project proposal developed by South Africa and Jordan was adapted with a 1.5 year phase to quantify soil evaporation (representing the major water loss). The entire project proposal - considered too large to be funded with existing OSWU funds - has been approved by the Steering Committee and will be submitted separately to donors.
- No-till and change of rotation: On the basis of the national review carried out in Turkey, no-till and change of rotation seems a promising alternative management strategy for larger parts of the country. Linking field work with use of crop simulation models should enable identification of target zones and impact assessment at later stages. OSWU's contribution to the total project will be 50% of total costs for the four year period.
- Optimizing soil water use through changing cropping systems: the proposal submitted to OSWU fits in the national strategy of Morocco and Niger. Funds are used to complement existing work as well as to initiate new work. Work in Morocco will be carried out by INRA-Settat and in Niger by INRAN and ICRISAT.
- Training of scientists in information tools: The need was expressed by NARS participants to have more training in the domain of crop simulation models, database development and management. Proposed activities include training workshops in crop simulation modeling (CropSyst for WANA and APSIM for SSA; their performance to be compared at a later stage) and in the use of the WOCAT database. OSWU co-sponsored already the WOCAT training course in Niamey.
- Impact assessment: The 1999 workshop results indicate that there is promising information available. However, the workshop has also revealed that no proper (formal) studies on the impact of research on optimization of soil water use have been performed in any country. Therefore, funds will be allocated to carry this out within a two-year period. This will then also be the topic of the workshop in 2001, linked to the Steering Committee Meeting.

The general OSWU project proposal (OSWU Consortium, 1998) will be further improved with inputs from the various country reviews to highlight aspects in one of the five agro-ecological zones within OSWU. This improved proposal will then be submitted to various donors.

Other OSWU Related Research work funded by other sources

DFID supported ICARDA's Agronomic management of cropping systems project for its objective of 'sustain-able and resource-efficient crop rotations that optimize production and maintain the productive potential of the soil' with the output: Management principles for choice of crop, crop rotation, input use and husbandry practice, in respect of rotational output, resource-use efficiency and long-term soil and crop productivity trends. With respect to this project, there have been follow-up of long-term trials of cooperating countries such as Egypt, Jordan and Iran for resource use efficiency, water in particular. Summary of the work is given in Annex 3.

At ICRISAT, related work has also been carried out since the start of OSWU in Africa as well as in India. Examples are development of simulation models, decision support systems, and effects of tillage. This research has been funded by various donors. It goes beyond the scope of this report to report on all those activities. Some publications are listed in the following section.

Finally, it is repeated that OSWU related research has been carried out by NARS, funded by their governments and, sometimes, other sources of funding. A selected number of publications is listed in the following section.

6. Updated list of selected refereed and other publications of OSWU members

2000

Christiansen, S., M. Bounejmate, F. Bahhady, E. Thomson, B. Mawlawi, and M. Singh. 2000. On-farm trials with forage legume/barley compared to fallow/barley rotations and continuous barley in northwest Syria. (Paper accepted in Experimental Agriculture).

Pala, M., H. Harris, J. Ryan, R. Makboul, and S. Dozom. 2000. Tillage Systems and stubble management in a Mediterranean-type environment. (accepted by Experimental Agriculture)

1999

Eberbach, P., and M. Pala. 1999.. The influence of row spacing on the partitioning of evapotranspiration into evaporation and transpiration under winter grown wheat in Northern Syria. Paper for presentation in International Conference for Combating Desertification, 22-27 August, 1999, Cairo, Egypt.

Sivakumar, M.V.K. and S.A. Salaam, 1999. Effect of year and fertilizer on water-use efficiency of pearl millet (*Pennisetum glaucum*) in Niger. J. of Agric. Sci (Cambridge) 132: 139-148.

Somi, G., and A. Abdul Aal. 1999. Surface water resources management using runoff harvesting and spreading techniques in the Syria steppe (1995-1998 seasons). Syrian Ministry of Agriculture and Agrarian Reform, Department of Water Management / IDRC / UNDP. Damascus. 34pp.

van Duivenbooden, N., M. Pala, C. Studer and C.L. Bielders (Eds), 1999. Efficient soil water use: the key to sustainable crop production in the dry areas of West Asia, North and sub-Saharan Africa. Proceedings of the 1998 (Niger) and 1999 (Jordan) Workshops of the Optimizing Soil Water USE (OSWU) Consortium. Aleppo, Syria: ICARDA, and Patancheru, India: ICRISAT (in press).

Zhang, H., M. Pala, T. Oweis, and H. Harris. 1999. Water use and water-use efficiency of chickpea and lentil in a Mediterranean environment (accepted in Australian Journal of Agricultural Research)

1998

Bationo, A., C.L. Bielders, N. van Duivenbooden, A.C. Buerkert and F. Seyni, 1998. The management of nutrients and water in the West African semi-arid tropics. In: Management of nutrients and water in rainfed arid and semi-arid areas. Proc. Consultants meeting, Vienna 26-29 May 1997. IAEA-TECDOC-1026, IAEA, Vienna, pp. 15-36.

Batchelor,C.H. and J.D. Cain. 1998. Application of belief networks to water management studies. Agric. Water Management 40: 51-57.

Bennie, A.T.P., M.G. Strydom, and H.S. Vrey 1998. [The application of computer models for agricultural water management on ecotope level] [Afr]. pp. 42-45 *in:* Report No. 625/1/98. Water Research Commission, Pretoria.

Botha, J.J. and M. Hensley 1998. [Quantification of the stress curve for wheat on a Hebron/Bainsvlei ecotope] [Afr]. pp. 27 *in:* Abstracts of Combined Congress of the SSSSA and the S.A. Soc. for Crop Prod., Alpine Heath, KwaZulu-Natal, 20-22 January 1998.

Jones, M., M. Pala, N. van Duivenbooden and M.D. Doumbia 1998. Optimizing soil water use in dry-area farming systems of sub-Saharan Africa and the West Asia/North Africa region. In: CD-Rom Proceedings of 16th World Congress of Soil Science, 20-26 August 1998, Montpellier. ISSS/AFES, Montpellier.

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Maatman, A., H. Sawadogo, C. Schweigman, and A. Ouedraogo 1998. Application of zaï and rock bunds in the north-west region of Burkina Faso: study of its impact on household level by using a stochatic linear programming model. Netherlands Journal Agricultural Science 46: 123-136.

Nyagumbo, I. 1998. Effects of tillage systems on soil physical properties with special reference to infiltration, bulk density and organic carbon. African Crop Science Conference Proceedings 3: 359-368.

Ouattara, B., M.P. Sédogo, A. Assa, F. Lompo and K Ouattara 1998. Modifications de la porosité du sol après trente trois années de labour d'enfouissement de fumier au Burkina Faso. Cahiers Agricole 7: 9-14.

Oweis, T., M. Pala, and J. Ryan. 1998. Stabilizing rainfed wheat yields with supplemental irrigation and nitro-gen in a Mediterranean Climate. Agron. Jour. 90: 672-681.

Rao, K.P.C., Steenhuis, T.S., Cogle, A.L., Srinivasan, S.T., Yule, D.F., and Smith, G.D. 1998. Rainfall infil-tration and runoff from an alfisol in semi-arid tropical India. II. tilled systems. Soil and Tillage Research. 48: 61-69.

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Piara Singh, Monteith, J.L., Lee, K.K., Rego, T.J., and Wani, S.P., 1998. Response to fertilizer nitrogen and water of post-rainy season sorghum on vertisol. 2. Biomass and water extraction. Journal of Agricultural Science 131: 429-438.

Shetty, S.V.R., N. van Duivenbooden, A. Bationo and M.V.K. Sivakumar, 1998. Stratégies agronomiques pour l'intensification des systèmes de production au Sahel. pp. 727-745 *in:* H. Breman & K. Sissoko (Eds), L'intensification agricole au Sahel: mythe ou réalité? Paris, France: Karthala.

van Duivenbooden, N. and C.L. Bielders, 1998. Crop growth simulation modelling as part of a methodology to improve natural resource management in semi-arid West Africa. In: G.E. Okwach & M.M. Siambi (Eds), Agricultural resource management for sustainable cropping in semi-arid eastern Africa. Proceedings of the first review workshop of the CARMASAK project, 27-29 May 1997, Machakos, Kenya. CARMASAK Proceedings No 1. KARI/NDRFRC, Katumani, pp. 180-189.

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1997

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7. List of donors

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Annex 1.

Abstracts in the proceedings of the 1998 and 1999 workshops

National review papers

Efficient soil water use in rainfed agriculture in Egypt – a review: Rainfed agriculture in Egypt occupies about 2-3% of agricultural land. It mainly concentrates in North West Coastal Zone (northern area of Matrouh Governorate). Land use is entirely dependent on rainfall and cultivation depends on various forms of water harvesting. Appropriate water harvesting and methods and soil conservation techniques are badly needed to optimize soil water use. Watershed management is badly needed in the area, as there is no experience or studies dealing with this issue. There is a potentiality to double the current barley production, in average and better rainfall years, by improving barley production technology. On the other hand, fruit crops could be increased 2– 3 times the current level through improved plant management such as fertilization, tillage practices, proper pruning, and integrated pest management as well as the introduction of better varieties. Although this may not appear significant in relation to the total agricultural land, it is important to local communities and economies. Better management of resources would contribute to the conservation of natural resources and better sustain the livelihood of local communities. The later are important objectives of Egypt's Environmental Action plan (*A.T.A. Moustafa and N.M. El-Mowelhi*)

National review on optimizing soil water use in Iran: Sustainable agriculture is commonly defined as the average level of output over an indefinitely long period without depleting the renewable resources on which it depends. Iran's greatest present and future need for water is to irrigate crops required to reach self sufficiency in agriculture being one of the nations priority goals. In this report several documents pertaining land and water use at the national level are reviewed. The emphasis is on identifying the urgent need of vast dry-land areas of the country with respect to climate, and soil, water and crop management practices. Since efficient use of water and soils is a basic concept to the survival of the increasing population, methods of optimizing utilization of soil and water resources are reviewed. Priorities and suggestions are given for maintaining such sustainable levels of their uses. The role of supplemental irrigation in increasing the yield in arid and semi-arid areas and ways of enhancing the soil and water conservation and production measures are discussed (*E. Pazira and K. Sadeghzadeh*).

Review paper on optimizing soil water use research in Jordan: Jordan is dominated by arid climate; 91% of the country receiving less than 200 mm of annual rainfall. Rainfed farming systems depend on a delicate balance between crops, livestock, fruit trees, rangeland, and fallow land. Cultivated rainfed areas cover about 5.5% of the total land (0.5 Million ha), and are primarily used for producing field crops (wheat, barley and summer vegetables). Jordan suffers from severe water shortage since the 1960's, limiting the development of agricultural production in irrigated and rainfed areas. Rapid population growth (3.4%) exerts great pressure on the limited natural resources; most of these resources are already utilized, and their productivity has started to decline. Agricultural research and extension in the past 45 years has focused on improving the productivity of farming systems in both rainfed and irrigated agricultural lands. To optimize the use of limited rainfall in rainfed agriculture, activities mainly related to amending crop rotations, tillage practices, fertilizer rates and application, weed control, and to promoting improved varieties, water harvesting techniques, and supplemental irrigation. Past research activities and results in the domain of optimizing soil water use are reviewed, and priority research goals for the future identified (*A. Taimeh, A. Al-Nabi Fardous and A. Al-Shrouf*).

Optimizing soil water use in the semi-arid areas of Kenya: a review: The paper describes the salient features of crop production systems in the semi-arid areas of Kenya in relation to climate, water resources, soils, crops and their management practices, and socioeconomic conditions. The paper also summarizes past research findings on factors affecting the efficiency of soil water use, such as rainwater capture and infiltration, soil evaporation, weed transpiration, plant spacing and population, time of planting, and application of fertilizers and manure. These findings are then interpreted and conclusions drawn on major forms of water loss, occurrence of wide differences between actual and potential yields, and farming systems and socioeconomic factors affecting the efficiency of soil water use and the adoption of improved techniques. The paper concludes with a list of priority issues for further research (*J K Itabari*).

Optimizing soil water use in Mali: a review: Soil constraints to crop productions in Mali are dominated by water and nutrient-related constraints. Mali receives annually from less than 200 to 1,300 mm of rainfall in addition to water sources of the Niger and Senegal rivers. In general, 36% of the soils are affected by serious nutrient limitations while 84% of the soils have water related constraints. Traditional practices and improved technologies available to alleviate the above constraints and to optimize soil water use include better soil surface management through tillage, water capture and infiltration techniques, addition of soil amendments, and use of cropping strategies such as species combinations and varietal choices. A major gap to increase production and obtain sustainable cropping systems is the absence of transfer and adoption of available technologies to optimize soil water use. A second critical gap is the limitation of the efficient use of soil water by nutrient stress, especially P deficiency. Two research priorities are identified. First to define technologies to "reroute" via transpiration the amount of rainfall (at least 30%) lost by evaporation from the soil. Secondly, to find ways to relate the optimization of soil water use to economic growth, environmental issues, health and population growth, and poverty alleviation (*M.D. Doumbia*).

Optimizing soil water use research in deficient water environments of Morocco, the state of the art: Arid and semi arid regions of Morocco face severe water deficits. Average annual rainfall is limited and highly erratic in amount as well as in distribution. The traditional dry farming techniques used are not well adapted. They usually cause waste of scare soil water and make crop production risky in these regions. Research has been conducted to address production constraints and improve production and soil water use. Different sources of information were used to assess research findings regarding the optimization of soil water use in dryland agriculture. Technologies that have been developed are related to crop, soil, and nutrient management, and supplemental irrigation. These technologies showed the potential of improving soil water use under deficient conditions of Morocco, but some issues are still to be investigated. This paper discusses past and current research and illustrates some of the prospects and future research (*M. Boutfirass, M. El Gharous, M. ElMourid, and M. Karrou*).

Optimizing soil water use in Niger: research, develop-ment, and perspectives: Research on optimal water use in Niger has been carried out since the seventies on various themes, including physical and hydrodynamic soil characterization, crop water use, water conservation techniques, and water use efficiency improvement. Results indicate that soils used for rainfed crop production have in general low water holding capacity and are therefore subject to deep drainage beyond the rooting depth in years of adequate rainfall (P > ~300 mm). Runoff and water erosion are common as a result of high rainfall intensity and the occasional occurrence of a thin surface crust. Soil evaporation is a major component of the water balance as a result of low planting densities (sparse canopy). Water storage in the sandy soils during the 8 to 9 month-long dry season is inefficient and therefore technology development has been geared towards a more efficient use of soil moisture during the growing season. Technical options for improving water use efficiency include the use of short-cycle varieties, improved residue and surface management practices, intercropping, and soil fertility improvement (*M. Amadou, M. Gandah, C.L. Bielders and N. van Duivenbooden*).

A review on the optimization of soil water use in the dry crop production areas of South Africa: The wide variation in its natural agricultural resources makes South Africa a country of great diversity. It is exemplified in the rainfall and production potential maps presented, and also by the wide variety of crops grown and production techniques employed. The latter range from advanced technology to traditional subsistence procedures. Of the total area, less than 14% is arable and less than 4% of high potential, with rainfall the main limiting factor. Maize and wheat are the main cereal crops. Results are presented of extensive on-station and on-farm research to quantify water losses by evaporation, run-off and deep drainage, and on measures to minimize these losses such as mulching, soil surface modification and planting patterns. Success depends on correct technique/soil type matching. Increased soil water storage through fallowing, improved infiltration and water harvesting have received some attention. Research needs include studies about the simultaneous optimization of soil water and nutrient use, water harvesting, and mulching to reduce evaporation losses. A crop growth simulation model, with a rainfall intensity subroutine, and which has proved reliable for different soil-climate-crop combina-tions in dry areas is needed to extrapolate research results and make long-term yield predictions to quantify productivity and facilitate matching of farmer needs and farm size (*D.J. Beukes, A.T.P. Bennie and M. Hensley*).

Review paper on optimizing soil water use in the Syrian Arab Republic: Syria has annual rainfall between 200 and 600 mm. The variable and often chronic deficiency of rainfall is coupled with widespread nutrient deficiencies and improper soil and crop management which results in low water use efficiency (WUE), and eventually lower crop yields as well as poor animal production. About 6 million ha are suitable for cropping. Only about 20% of the cultivable land is under irrigation, the remainder being used byrain-fed farming systems. Wheat and barley are the major rainfed field crops followed by lentil, chickpea and forage crops. Since the limiting factor in agricultural production is water, most of the research has been directed to improve water use efficiency through crop improvement and soil and crop management, the main emphasis being onfactors affecting the proportion of available water transpired by crops. Major focus was given to tillage practices and residue management; crop rotations; selecting varieties with rapid early growth, deep roots and early maturity; early sowing and optimum plant population; application of fertilizer; weed control; supplemental irrigation and water harvesting. Two crop simulation models have been tested under Syrian conditions and worked well for northwestern region, but need to be validated for other regions to extrapolate research findings to larger areas, in order to support sound decision-making in prioritization of research and development. Future research should aim at filling the knowledge gap for the drier areas of the country, particularly with respect to supplemental irrigation, water harvesting, minimum tillage, and the transfer of promising soil and crop management practices together with improved crop varieties to farmers for optimal use of the limited water resources (*A. Jumaa, G. Al-Tibi, M. Naji and M. Pala*).

Optimizing soil water use in wheat production systems in dryland areas of Turkey: Semi-arid areas in Turkey covers about 55% of the country and are found mainly in the Central Anatolian Plateau. Main crop production systems are fallow/wheat and legume/wheat. Wheat is generally subject to droughts, which severely affect the yields. Research on soil moisture use in fallow-wheat systems started in 1930's. Its focus was on water perception and conservation techniques, and detailed research on rainfall perception let to practices, which have been adopted by most of the plateau farmers. In 1980's research focussed on the replacement of fallow in the rotation systems by a crop. In most areas, fallow can be best replaced in terms of yield by forage crops, while economically by edible legumes. Characterisation of other areas will identify fallow or continuous cropping target areas, and extrapolation of research results to these areas. Regarding technologies, the importance of terracing in moisture conservation increases with the degree of slope and the occurrence of erosive rainfall. Contour tillage and sowing were found effective only on steep slopes. Future research is needed on supplemental irrigation in order to increase water use efficiencies of wheat and barley varieties especially developed for irrigation (*M. Avci*).

Optimizing soil water use in Zimbabwe: Zimbabwe has been classified into five Natural Regions (NRs) based on rainfall amount and variability. The dry area production systems or semi-arid environments in Zimbabwe, refer to areas classified as NRs III, IV and V. The three NRs constitute about 83% of the country. Rainfall onset and length of growing period are unpredictable and highly variable, thus making crop production in the semi-arid areas risky and unstable. However, crop production by small scale farmers in these areas continue to depend on the limited rainfall and its success depends on using management techniques that conserve and increase the total soil water available to crops. This document is a review of past and current research on soil water use efficiency and ways to improve it in low-rainfall dryland production systems. Gaps in the research of optimizing soil water use are identified (e.g. crop water use and crop water use efficiency) and suggestions for further research presented (*J. Mzezewa, J. Gotosa, and Z. Shamhudzarira*).

Expert opinions, case studies and linkages

Development of water management technologies for rainfed crops in Burkina Faso: This chapter briefly reviews the main characteristics of the physical environment that determine the water supply of rainfed crops as well as their consequences for the production systems in Burkina Faso. Developed water management techniques relate to techniques for soil preparation at the scale of a field (plowing, earthing-up, tied ridging, weeding, zaï etc.) and to anti-erosion devices at the scale of a village or watershed. There exist no blue print of techniques to save water at the field level. Each one needs to be adapted to the particular pedo-climatic and socio-economic conditions of the land user. Generated technology can often be combined as soil preparation techniques determined by on the established objectives. Techniques combating erosion, starting with rock bunds and contour earthen bunds for community application are widespread in the center and north of the country. Along with techniques of zaï, half moons, etc., they are used to rehabilitate degraded soils. Finally, the runoff water collection system for complimentary irrigation appears at this time to be the surest means to secure agricultural production under the harsh climatic conditions ((*B. Ouattara, V. Hien and F. Lompo).*

Optimizing soil water use from a watershed perspective: Sustainable and profitable agricultural development in dryland areas requires technologies and practices that make efficient and productive use of water resources and enabling environments that encourage adoption of these technologies. There is a wide range of technologies that can be used by farmers to make more efficient and productive use of soil water at the field and farm scales. However, it is argued in this paper that consideration should be given to the impact that these technologies may have at the watershed scale. In particular, it is argued that water that is considered as being lost at the field and farm scales can have important uses and value elsewhere in a watershed. Hence, improving the efficiency of water use in one part of a watershed can have important equity implications by reducing water availability to other potential users. Many institutions and international agencies are showing considerable interest in inte-grated watershed management (IWM) as a practical means of improving the management of water resources, reducing environmental degradation and promoting sustainable agricultural development. This paper outlines some of the main components of IWM and discusses how it might be used in dryland areas to design and implement programmes that lead improved utilisation of soil water at the watershed scale. Recommendations are made for IWM-related research that could be undertaken by the OSWU Consortium. In particular, the case is argued for using interdisciplinary modelling techniques that make use of belief and decision networks (*C. Batchelor*)

Cropping systems and crop complementarity in dryland agriculture: Dryland agriculture under rainfed conditions is found mainly in Africa, the Middle East, Asia and Latin America. In the harsh environment of Sub-Saharan Africa (SSA) and West Asia and North Africa (WANA), the factor which ultimately limits the crop yield is the availability of water. A variable supply of water due to seasonal differences in precipitation leads to equally variable crop yields. However, research has shown that good soil and crop management practices can considerably increase the efficiency with which the limited amount of water available from precipitation is used. That is, more production per unit area can be gained from each mm of precipitation if crops are well established and adequately fertilized, weeds are controlled, and appropriate crop rotations are used. These activities should also be considered together with the proper management of the soil if production is to be sustained and resources to be conserved in the long term. Both will be responsible for higher production with improved water use efficiency. WANA production systems are dominated by cereals, primarily wheat and barley in wetter and drier areas, respectively, in rotation with mainly food legumes such as chickpea and lentil, which occupy, however, only 10-15% of the area planted to cereals. Fallows are inefficient in storing sufficient amount of water. Continuous cereal cropping is becoming the main production system, but is found to be unsustainable. Crop production takes place under limited, variable and chronically deficient precipitation. Precipitation occurs mainly during winter months, so that crops must often rely on stored soil moisture when they are growing most rapidly in spring months. Soils of the region are predominantly calcareous, frequently phosphate deficient with variable depth and texture determining the maximum amount of water that can be stored and hence the effective length of the growing season. SSA production systems are generally characterized by cereal/legume mixed cropping dominated by maize, millet, sorghum and wheat. The major constraints to production are low soil fertility, insecure rainfall, low productive genotypes, and lack of appropriate institutional support. The soils are structurally weak, are easily compacted, have low water holding capacities, and are susceptible to both water and wind erosion. Soil management with conventional tillage systems appears suitable. Several improved genotypes, which are both stress tolerant and tailor well under more productive cropping systems have also been identified (*M. Pala, N. van Duivenbooden, C. Studer, and C.L. Bielders*).

Combating Nutrient Depletion Consortium (CNDC): goals, objectives and activities: The Combating Nutrient Depletion Consortium (CNDC) is, like OSWU, part of the Soil Water Nutrient Management Program. Its goal and objectives, as well as its methodology and activities are being presented. Collaboration with OSWU will make sense as sharing the experiences and building knowledge blocks interactively, and avoiding duplication wherever possible although the climatic conditions are different (*V.O. Chude, H. Breman, and U. Singh*).

Impact of OSWU related research and the use of information tools

Use of decision support tools in and impact of optimizing soil water use research in Burkina Faso: A literature review has been carried out in order to evaluate the impact of research related to the optimization of soil water use in agriculture in Burkina Faso, as well as to assess current knowledge, the use and future perspectives of database management and decision support tools. It appears that the impact of rainwater management technologies on the livelihood of producers and on the environment is largely dependent upon the prevailing agro-ecological conditions. For instance, soil and water conservation technologies that make use of indigenous know-how in the more arid areas result mostly in socio-environmental benefits for the producers rather than in economic benefits. On the other hand, the use of soil tillage for more efficient rainfall water use, which is largely dependent upon the purchasing power of farmers, is more frequent in the cotton-belt of the country where this practice generates substantial financial benefits. Existing management tools for this type of technical information for a more efficient decision support are very diverse and have been developed only recently. Since the 80's, there has been a real tendency for a more specific use of such tools by national research institutions as well as some NGOs and international organizations. Climate simulation models have been the most used for making predictions related to agricultural production. However, the need to have access to such tools in other areas as well is pressing and is most often linked to the development of geographical information systems *(B. Ouattara, S. Youl and J.B. Saré).*

Impact from optimizing soil water use research, and the need for new information tools and methodologies in Egypt: Integrated research activities in the domain of optimizing soil water use is badly needed in the area of rainfed agriculture in Egypt. Using DSS, models, GIS and databases are essential and of most importance to plan and implement any developmental activities. Assessing the impact of past research is essential to decide the needed future plans and activities in the domain of optimizing soil water use *(A.T.A. Moustafa).*

Impact of optimizing soil water use research in Iran: A major challenge to development of agriculture in Iran is shortage of water, because more than 90% of the total area of the country receives an insufficient amount of rainfall. Issues related to soil erosion, soil salinity, and sodicity are the second major problem in many parts of the country. In view of the ever increasing population and the higher demand for food supply, the much needed increase in crop production can be met by improving the productivity of available crop lands. This, in turn, implies the urgent need for proper management and utilization of the soil and water resources of the country without waste. To achieve proper soil and water conservation, engineering techniques such as moisture conservation, water resources management, erosion control, drainage, flood control, and irrigation have to be improved. In this paper, present status of soil and water resources of Iran with respect to resources potentiality and the relevant limitations are discussed. Further, impact of optimizing soil and water use on success of development programs is outlined, and it is concluded that an international forum like the Optimizing Soil Water Use (OSWU) Consortium can have a positive effect on solving the regional and domestic problems of the member countries (*E. Pazira*).

Impact of research on soil water use in Jordan: The management of Jordan's limited resources, which necessitates a long term effort in order to be properly addressed, requires the development of a national agricultural research strategy which would help the national agricultural research system prioritize its research and technology transfer programs in such a way to best utilize the agricultural research resources of the country. The limited availability of water, as well as the deterioration of the quality of the water available for agriculture are major constraints impeding the intensification of agriculture in Jordan. The prospects are for a decrease in water availability for agriculture in the future. Therefore, ways must be found to improve water efficiency and maintain its quality. These include the use of more water efficient crops, reduction of losses in transmission and distribution, and employment of farm management methods to include all the factors which will result in optimum water use efficiency (*A.Al-Nabi. Fardous, and A Al-Shrouf*).

Soil water use research impact and use of decision support systems in dryland agriculture of Morocco: The Aridoculture Center has been working on soil water use since its creation in the early eighties. After 16 years, it has regenerated knowledge and developed methods and technologies relevant to the constraints of fragile dryland farming systems of Morocco. Most of the technologies were taken to the farmers, within a farming system participatory approach, either as single technologies or as a package to technologies. All the technolo-gies tested on the farmer's fields showed a positive impact on the production trend in all regions. Some of them are discussed in this chapter and quantitative indicators of the impact are given. However, impact assessment and evaluation for most of these technologies is still needed. Development of sustainable agricultural systems requires access to better information. Elaboration of databases and decision support systems is one of the research priorities of the center. Therefore, many surveys have been done and data related to climate, farming systems, crop production, socio-economics are compiled. Moreover, some models have been validated and adapted to Moroccan conditions. However, this can only be just a beginning for the construction of databases with dependable data and that are better integrated (*M. Boutfirass, M. El Gharous and A. Ait Lhaj*).

Impact of soil water optimization research and need for new information tools and methodologies in Niger: Soil water research and applied technologies have been carried out in two separate ways in Niger. Few of the results obtained by national and international organisations have found applications in farmer's fields. At the same time, agricultural development projects, in need of proven technologies, have adapted and used several water conservation techniques without sufficient expertise to measure real impacts. This background pleas in favour of the development of information tools and new methodologies capable of gathering available field data and using it in models and

GIS for a broad transfer of knowledge (*M. Gandah, M. Amadou, N. Van Duivenbooden, and C. Bielders*).

Impact from optimizing soil water use research, and the need for using new information tools and methodologies in South Africa: Research in the domain of optimizing soil water use has been carried out since the seventies with a fair adoption rate among farmers of the results. Case studies in the summer rainfall areas indicate yield increases of 5-46% for maize and wheat because of implementing reduced tillage and residue mulching technologies. A wide spectrum of models, GIS, and databases are currently in use. Empirical rate of return studies have been done on various horticultural, field crop and livestock enterprises, while the environmental impact of some research programs have been qualitatively evaluated. Impact studies have also been conducted on the economic efficiency of water use for irrigation. However, there is an urgent need for formal impact assessment studies on the numerous research efforts regarding the optimization of water use in drylands. An integrated research approach should be pursued to simultaneously optimize soil water and nutrient use by crops in dry areas for greater efficiency and sustainability (*D.J. Beukes C.N. Marasas, A.T.P. Bennie and M. Hensley*).

Impact from optimizing soil water use research, and the need for using new information tools and methodologies in Syria: Farming in dry areas is associated with high risk both in terms of year to year fluctuation in yield, and long-term decline in productivity from the degradation of the resource base. Research results clearly indicated that there is a great potential in increasing food and feed production to meet the demand while conserving water resources and improving soil productive capacity through improved soil and crop management practices in rainfed regions of the country. However, experimental results obtained either from the stations or farmers' fields yet to be transferred to farmers in wider areas. This is the most important area that Syrian government has placed a special emphasis in the last decade. Most of the research findings were tested through improved variety trials for evaluation and release, through participatory on-farm trials or through demonstrations in farmers' fields by extension agent. As a result of these efforts, yield increases from 1 to 2 t ha^{-1} have been observed in the last decade following adoption of certain soil and crop management practices under rainfed conditions. These practices include more timely cultivation, earlier planting, increased planter use compared with broadcast method, improved fertilizer use in drier areas and in particular the application of P on barley, and pest control practices related to diseases, insects and weeds. Major yield increases have been observed by introducing supplemental irrigation into winter crops, and into wheat in particular. A GIS unit was established in 1993 within the framework of a development planning project to assist in the preparation of an agro-ecological assessment of agricultural potential and the quantitative analysis of some of the most pressing problems in Syria, i.e., soil degradation and water resources deficiency. Therefore, soil databases were stored in digital format, processed, analyzed and outputs were given to the decision makers to be used for prioritization of agricultural research and development projects (*G. Al-Tibi, B. Katalan, M. Naji, B. Akkad, and M. Pala*).

Impact of water use efficiency research and OSWU, and use of information tools and methodologies in Turkey: In the last 50 years, improved crop husbandry practices and crop varieties increased wheat yields 3-fold, from 0.8 to 2.4 t ha^{-1}. In this success, the techniques developed for water conservation and efficient water use played major role. Activities for optimum use of soil water dominated the research programs of the NARES and contributed much to their scientific development and capacity building. The OSWU Consortium enabled the process to retrospect the past developments in this domain, and elucidated future research needs. Besides conventional, the use of new intelligent tools and satellite based information systems has been increasing. In spite of this, these activities seem to be uncoordinated and discrete; therefore, they need a certain reorganization and transformation into large-scale projects *(M. Avci).*

Impact from optimizing soil water use research and the need for using new information tools and methodologies in Zimbabwe: Considerable research in optimizing soil water in the semi-arid environments has been documented. However, the impact of such research on the livelihoods of the poor rural communities and on research institutions has not been widely reported. This chapter reports some of these impacts. The state of research information record keeping in the country is assessed to determine whether modern information tools and methodologies can be used to increase research efficiency. The role of the OSWU consortium and its activities in spearheading research in optimizing soil water use is outlined *(J. Mzezewa and J. Gotosa).*

Preliminary analysis of potential impact of OSWU Consortium on improved agricultural production in dryland areas using a Bayesian Belief network approach: In a working group during the 1998 workshop, Bayesian belief networks were used to assess the potential impact of OSWU activities. A simple belief network was developed to assess the potential impact of OSWU over the next five years. Preliminary analysis shows that, if OSWU takes a multidisciplinary approach, the potential impact of agricultural production could be significant in areas of high demand for OSWU technologies that also have significant scope for yield improvement. A more complex belief network was constructed and this will be developed and used in the next few months as an OSWU activity (*C. Batchelor, A.T.P. Bennie, and M. Avci*).

ANNEX 2.

Tentative budget of OSWU for the period 1999-2002

	Country	Projects Total	no of chapters	amount	1999	2000	2001	2002
	WANNA			Egypt	Dbase		5.0	Jordan
	WH			10.0	5.0			Iran
	DBase			5.0				Morocco
	Soil/crop			7.5	7.5	7.5		Syria*
	Rotation			8.0	3.5	3.5		Turkey
	No-till			7.5	7.5	7.5	7.5	**92.5**
						SSA		
				B.Faso	DBase			5.0
Kenya				5.0	5.0	5.0		
Mali				5.0	5.0	5.0		
Niger				5.0	5.0	5.0		
S. Africa	WH			10.0	5.0			
S. Africa	Dbase			5.0				
Zimbabwe*	WH			5.0	5.0	5.0		**85.0**
GENERAL								
Review				11	2.5	27.5		
impact studies				12	5	30.0		30.0
Communication/office			12	0.25	3.0	3.0	3.0	3.0
Seminar on review			12	0.25	3.0			
Bayesian BN			3		3	9.0		
WUE training workshops				5.0				
Workshops	Amman			20.0				
	Cropsyst			15.0				
	APSIM				10.0			
	WOCAT in SSA			2.5				
SC Meetings				15.0	15.0	15.0		
Traveling:	convenors			15.0	10.0	10.0	10.0	
	SA/Egypt			2.5				
Publication + shipment				10.0			10.0	
Miscelleaneous					10.0	10.0	10.0	10.0
	316.5							
TOTAL				**230.5**	**116.5**	**76.5**	**70.5**	**494.0**

Annex 3.

Details of OSWU related research work funded by other sources

Egypt

Long-term trials based on different agroecologies of Egypt as well as neighbouring farmers? fields which are under monitoring by the project have been visited for a week. The resource-management program initiated some years ago in Egypt, collaborative between ICARDA and a group of national research institutions, provides an early example of the new research paradigm in action: Program activities began with a preparatory phase, comprising inventory studies, rapid rural appraisal and multi-disciplinary surveys, and the knowledge gained was used in the planning of two closely related research activities, long-term agronomic trials (LTT) and long-term farm monitoring (LTM). The long-term trials (with such experimental variables as water quantity, water quality, nutrient input and crop rotation) have been established at sites representing the old irrigated lands, the areas newly reclaimed from desert, and the rainfed agricultural areas; and each trial is complemented by extensive long-term monitoring in villages close to the experimental site, recording farmers? perspectives, farming practices and the condition of their soils and crops, with the aim of identifying over time sustainable and non-sustainable practices and the social and economic factors that underlie them. The complementarity of LTT and LTM activities within an integrated, multidisciplinary approach provides a new research model for the identification of sustainable, intensive production systems that has wider application in other agro-environments.

Jordan

The Project of Tillage, Residue and Nitrogen Management in Crop Rotations conducted in collaboration with National Center Agricultural Research and Technology Transfer (NCARTT) and University of Jordan (UOJ). The project has been established to study the different systems of crop residue management under three tillage methods which are conventional deep moldboard plowing, deep chisel (modification to deep plowing) and minimum tillage by ducks-foot cultivation (conservation tillage) combined with different rates of nitrogen application on wheat crop in wheat-lentil or wheat-vetch two course rotations or wheat-lentol-melon three course rotation in different agroecological zones of Jordan and their effects on systems productivity and on soil physical and chemical properties and **crop water use efficiencies**.

The project is jointly implemented by NCARTT and University of Jordan since 1990. Three graduate students completed their MSc. degree with thesis research related to tillage, residue and nitrogen management.

The initial results of crop data showed that wheat grain yield significantly varied in each location and rotation depending on the seasonal climatic conditions. Tillage systems had significantly affected the wheat yield, however, it interacted with residue management to some extent. Chisel use before the rainfall appeared to be the worst one, but ducks-foot cultivation as a minimum tillage used after the initial rainfall seemed to be, if not better, as good as moldboard plowing which has been used before rainfall.

Conservation practice by ducks-foot cultivator which is easily available for farmers has a promising future in sustainable production systems affecting soil aggregate stability positively. It was better in moisture retention than moldboard and chisel. Conservation tillage has also a lower energy requirement and reduced time for tillage. However, at some stage of crop production within a common crop rotations moldboard has to be used especially for growing summer crops such as melon.

Residue management did not show any clear effect on wheat yield for the first five year. However, yield trends showed that grazing stubble in summer and incorporating the remainder late in the season was better than the early incorporation of the stubble without grazing. However, long-term effects of residue management on soil quality parameters still the aim of the project.

Nitrogen application increased mean wheat yield significantly almost in every ecological zone as independent of tillage and residue management, but year. So, this may give an opportunity to farmers to modify nitrogen application in late winter and early spring according to seasonal conditions for sustainable production.

Iran

The dryland research program was initiated 4 years ago on the Studies on fallow replacement by legumes and oilseed crops in fallow-cereal rotation in the dry areas of Iran a) to investigate the effect of introducing annual food and feed legumes and oilseed crops into the fallow-wheat rotation on the productivity, b) to study the effect of introduction of above mentioned crops on soil organic matter and nitrogen content, eventually soil quality c) To quantify biological nitrogen fixation by legumes and determine their contribution to the nitrogen nutrition of cereals, d) To assess the profitability of crop sequences compared with fallow-cereal rotation in a farming system context in relation to **precipitation use efficiency** to increase the productivity of rain water by improved soil and crop management practices. Initial results show that fallow replacement is feasible with other crops, legumes in particular for a more productive and sustainable system.